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(54) **ORGANOMETALLIC COMPOUND,
ORGANIC LIGHT EMITTING DEVICE, AND
COMPOSITION FOR DIAGNOSING
INCLUDING ORGANOMETALLIC
COMPOUND**

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(57) **ABSTRACT**

An organometallic compound represented by Formula 1:

$M(L_1)(L_2)$

Formula 1

wherein, in Formula 1, M, L₁, and L₂ are the same as
described in the specification.

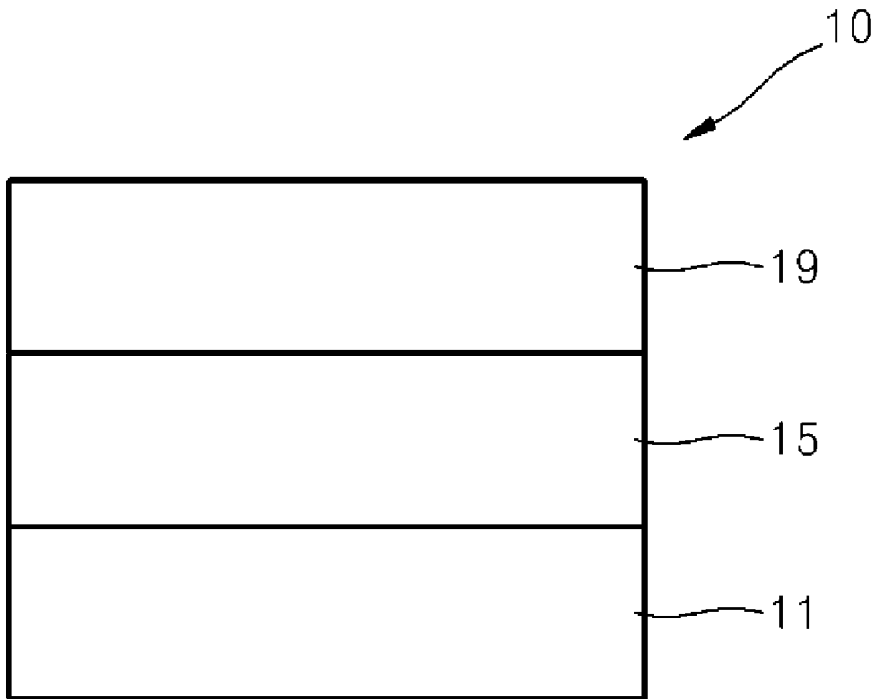
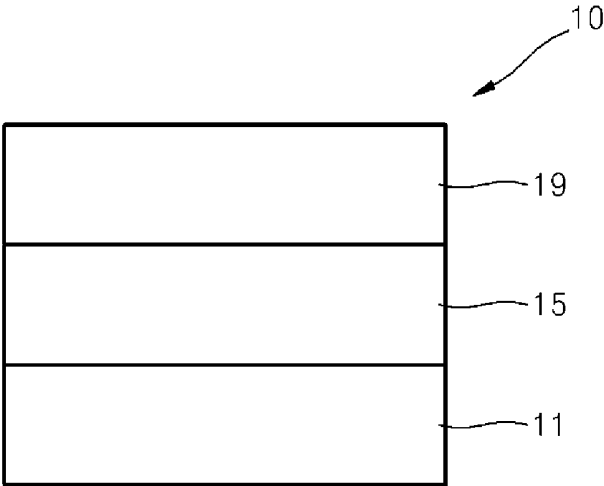


FIG. 1



**ORGANOMETALLIC COMPOUND,
ORGANIC LIGHT EMITTING DEVICE, AND
COMPOSITION FOR DIAGNOSING
INCLUDING ORGANOMETALLIC
COMPOUND**

CROSS-REFERENCE TO RELATED
APPLICATION

[0001] This application claims priority to Korean Patent Application No. 10-2016-0015675, filed on Feb. 11, 2016 in the Korean Intellectual Property Office, and all the benefits accruing therefrom under 35 U.S.C. §119, the content of which is incorporated herein in its entirety by reference.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates to an organometallic compound, an organic light-emitting device including the organometallic compound, and a composition for diagnosing including the organometallic compound.

[0004] 2. Description of the Related Art

[0005] Organic light-emitting devices (OLEDs) are self-emission devices, which have wide viewing angles, exhibit excellent driving voltage and response speed characteristics, and produce full-color images.

[0006] In an example, an organic light-emitting device includes an anode, a cathode, and an organic layer that is disposed between the anode and the cathode, wherein the organic layer includes an emission layer. A hole transport region may be disposed between the anode and the emission layer, and an electron transport region may be disposed between the emission layer and the cathode. Holes provided from the anode may move toward the emission layer through the hole transport region, and electrons provided from the cathode may move toward the emission layer through the electron transport region. The holes and the electrons recombine in the emission layer to produce excitons. These excitons transit from an excited state to a ground state, thereby generating light.

[0007] Further, light-emitting compounds, e.g., phosphorescent emitting compounds, can also be used in monitoring, sensing, or detecting of biological materials including a variety of cells and proteins.

[0008] Various types of organic light emitting devices are known. However, there still remains a need in OLEDs having low driving voltage, high efficiency, high brightness, and long lifespan.

SUMMARY

[0009] Provided are an organometallic compound, an organic light-emitting device including the organometallic compound, and a composition for diagnosing the organometallic compound.

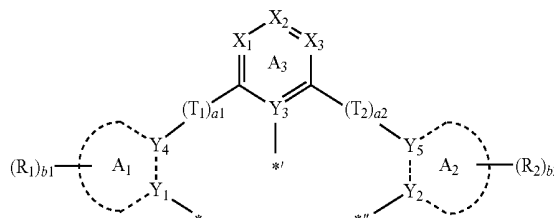
[0010] Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

[0011] According to an aspect of an embodiment, an organometallic compound is represented by Formula 1:



Formula 1

Formula 2



[0012] wherein, in Formulae 1 and 2,

[0013] M may be beryllium, magnesium, aluminum, calcium, titanium, manganese, cobalt, copper, zinc, gallium, germanium, zirconium, ruthenium, rhodium, palladium, silver, rhenium, gold, or platinum,

[0014] L₁ may be selected from tridentate ligands represented by Formula 2,

[0015] L₂ may be selected from monodentate organic ligands,

[0016] *, *, and *' in Formula 2 may each indicate a binding site to M in Formula 1,

[0017] Y₁ to Y₃ may each be nitrogen,

[0018] Y₄ and Y₅ may each be carbon,

[0019] Y₁ may be bound to Y₄ via a single or double bond, Y₂ may be bound to Y₅ via a single or double bond,

[0020] provided that one selected from a bond between Y₁ and M, a bond between Y₂ and M, and a bond between ligand L₂ and M may be a coordinate bond, while the rest are each a covalent bond,

[0021] a bond between Y₃ and M may be a coordinate bond,

[0022] ring A₁ may be a 5-membered ring including at least one nitrogen as a ring-forming atom,

[0023] ring A₂ may be a 6-membered ring including at least one nitrogen as a ring-forming atom,

[0024] X₁ may be N or C(R₅), X₂ may be N or C(R₄), X₃ may be N or C(R₅), at least two selected from R₃ to R₅ may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group,

[0025] T₁ may be a group selected from a single bond, *—O—*, *—S—*, *—C(R₆)(R₇)—*, *—C(R₆)=*, *—C(R₆)—*, *—C(R₆)=C(R₇)—*, *—C(=O)—*, *—C(=S)—*, *—C=C—*, *—N(R₆)—*, Si(R₆)(R₇)—*, and *—P(R₆)(R₇)—*, wherein * and *' in each of the foregoing groups independently indicate a binding site to a neighboring atom,

[0026] T₂ may be a group selected from *—O—*, *—S—*, *—C(R₆)(R₇)—*, *—C(R₆)=*, *—C(R₆)—*, *—C(R₆)=C(R₇)—*, *—C(=O)—*, *—C(=S)—*, *—C=C—*, *—N(R₆)—*, *—Si(R₆)(R₇)—*, and *—P(R₆)(R₇)—*, wherein * and *' in each of the foregoing groups independently indicate a binding site to a neighboring atom,

[0027] R₆ and R₇ may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group,

[0028] a1 and a2 may be each independently an integer selected from 1 to 3,

[0029] R_1 to R_7 may be each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, —SF₅, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C₁-C₆₀ alkyl group, a substituted or unsubstituted C₂-C₆₀ alkenyl group, a substituted or unsubstituted C₂-C₆₀ alkynyl group, a substituted or unsubstituted C₁-C₆₀ alkoxy group, a substituted or unsubstituted C₃-C₁₀ cycloalkyl group, a substituted or unsubstituted C₁-C₁₀ heterocycloalkyl group, a substituted or unsubstituted C₃-C₁₀ cycloalkenyl group, a substituted or unsubstituted C₁-C₁₀ heterocycloalkenyl group, a substituted or unsubstituted C₆-C₆₀ aryl group, a substituted or unsubstituted C₆-C₆₀ aryloxy group, a substituted or unsubstituted C₆-C₆₀ arylthio group, a substituted or unsubstituted C₁-C₆₀ heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), and —P(=O)(Q₈)(Q₉).

[0030] b_1 and b_2 may be each independently an integer selected from 0 to 3, and when b_1 is 2 or greater, groups R_1 may be identical to or different from each other, and when b_2 is 2 or greater, groups R_2 may be identical to or different from each other.

[0031] two of the b_1 number of groups R_1 may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group.

[0032] two of the b_2 number of groups R_2 may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group.

[0033] at least one of substituents of the substituted C₅-C₃₀ carbocyclic group, substituted C₂-C₃₀ heterocyclic group, substituted C₁-C₆₀ alkyl group, substituted C₂-C₆₀ alkenyl group, substituted C₂-C₆₀ alkynyl group, substituted C₁-C₆₀ alkoxy group, substituted C₃-C₁₀ cycloalkyl group, substituted C₁-C₁₀ heterocycloalkyl group, substituted C₃-C₁₀ cycloalkenyl group, substituted C₁-C₁₀ heterocycloalkenyl group, substituted C₆-C₆₀ aryl group, substituted C₆-C₆₀ aryloxy group, substituted C₆-C₆₀ arylthio group, substituted C₁-C₆₀ heteroaryl group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0034] deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group;

[0035] a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric

acid group or a salt thereof, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —N(Q₁₁)(Q₁₂), —Si(Q₁₃)(Q₁₄)(Q₁₅), —B(Q₁₆)(Q₁₇), and —P(=O)(Q₁₈)(Q₁₉);

[0036] a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0037] a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —N(Q₂₁)(Q₂₂), —Si(Q₂₃)(Q₂₄)(Q₂₅), —B(Q₂₆)(Q₂₇), and —P(=O)(Q₂₈)(Q₂₉); and

[0038] —N(Q₃₁)(Q₃₂), —Si(Q₃₃)(Q₃₄)(Q₃₅), —B(Q₃₆)(Q₃₇), and —P(=O)(Q₃₈)(Q₃₉).

[0039] wherein Q₁ to Q₉, Q₁₁ to Q₁₉, Q₂₁ to Q₂₉, and Q₃₁ to Q₃₉ may be each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryl group substituted with at least one selected from a C₁-C₆₀ alkyl group and a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

[0040] According to an aspect of another embodiment, an organic light-emitting device includes:

[0041] a first electrode;

[0042] a second electrode; and

[0043] an organic layer disposed between the first electrode and the second electrode, wherein the organic layer includes an emission layer and at least one organometallic compound described above.

[0044] In the emission layer, the organometallic compound may serve as a dopant.

[0045] According to an aspect of another embodiment, there is provided a composition for diagnosing that includes at least one organometallic compound represented by Formula 1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

[0047] FIG. 1 is a schematic cross-sectional view of an organic light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0048] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items. Expressions such as “at least one of,” when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0049] It will be understood that when an element is referred to as being “on” another element, it can be directly in contact with the other element or intervening elements may be present therebetween. In contrast, when an element is referred to as being “directly on” another element, there are no intervening elements present.

[0050] It will be understood that, although the terms first, second, third etc. may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the present embodiments.

[0051] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0052] The term “or” means “and/or.” It will be further understood that the terms “comprises” and/or “comprising,” or “includes” and/or “including” when used in this specification, specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or groups thereof.

[0053] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this general inventive concept belongs. It will

be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0054] Exemplary embodiments are described herein with reference to cross section illustrations that are schematic illustrations of idealized embodiments. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments described herein should not be construed as limited to the particular shapes of regions as illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, a region illustrated or described as flat may, typically, have rough and/or nonlinear features. Moreover, sharp angles that are illustrated may be rounded. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region and are not intended to limit the scope of the present claims.

[0055] “About” or “approximately” as used herein is inclusive of the stated value and means within an acceptable range of deviation for the particular value as determined by one of ordinary skill in the art, considering the measurement in question and the error associated with measurement of the particular quantity (i.e., the limitations of the measurement system). For example, “about” can mean within one or more standard deviations, or within $\pm 30\%$, 20% , 10% , 5% of the stated value.

[0056] An organometallic compound is represented by Formula 1:

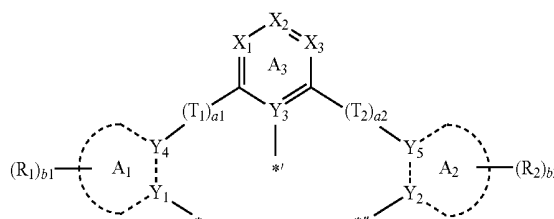


[0057] wherein, in Formula 1, M may be beryllium, magnesium, aluminum, calcium, titanium, manganese, cobalt, copper, zinc, gallium, germanium, zirconium, ruthenium, rhodium, palladium, silver, rhenium, gold, or platinum (Pt). For example, in Formula 1,

[0058] M may be platinum (Pt).

[0059] L_1 in Formula 1 may be selected from tridentate ligands represented by Formula 2, L_2 may be selected from monodentate organic ligands, and *, **, and *** in Formula 2 each indicate a binding site to M in Formula 1.

Formula 2



[0060] wherein, in Formula 2, Y_1 to Y_3 may each be nitrogen (N), Y_4 and Y_5 may each be carbon (C), a bond between Y_1 and Y_4 may be a single bond or double bond, and a bond between Y_2 and Y_5 may be a single bond or a double bond.

[0061] In Formula 2,

[0062] a bond between Y_1 and M and a bond between ligand L_2 and M may each be a covalent bond, and a bond between Y_3 and M and a bond between Y_2 and M may each be a coordinate bond,

[0063] a bond between Y_1 and M and a bond between Y_2 and M may each be a covalent bond, and a bond between Y_3 and M and a bond between ligand L_2 and M may each be a coordinate bond, or

[0064] a bond between Y_2 and M and a bond between ligand L_2 and M may each be a covalent bond, and a bond between Y_1 and M and a bond between Y_3 and M may each be a coordinate bond.

[0065] Thus, the organometallic compound represented by Formula 1 may be electrically neutral, non-ionic compound having no charge.

[0066] Ring A_1 in Formula 2 may be a 5-membered ring including at least one nitrogen as a ring-forming atom, and ring A_2 may be a 6-membered ring including at least one nitrogen as a ring-forming atom.

[0067] According to an embodiment, ring A_1 in Formula 2 may be a 5-membered ring including at least two nitrogens as ring-forming atoms, but embodiments are not limited thereto.

[0068] In various embodiments, ring A_1 in Formula 2 may be selected from a pyrrole ring, a pyrazole ring, an imidazole ring, a triazole ring, a tetrazole ring, an oxazole ring, an isoxazole ring, a thiazole ring, an isothiazole ring, an oxadiazole ring, thiadiazole ring, a benzopyrazole ring, and a benzoimidazole ring.

[0069] According to some embodiments, ring A_1 in Formula 2 may be selected from a pyrazole ring, an imidazole ring, a triazole ring, a tetrazole ring, an oxadiazole ring, a thiadiazole ring, a benzopyrazole ring, and a benzoimidazole ring.

[0070] According to some embodiments, ring A_2 may be selected from a pyridine ring, a pyrimidine ring, a pyrazine ring, a pyridazine ring, a triazine ring, a quinoline ring, an isoquinoline ring, a quinoxaline ring, a quinazoline ring, and a phenanthroline ring.

[0071] According to some embodiments, in Formula 2, ring A_1 may be selected from a pyrazole ring, an imidazole ring, a triazole ring, a benzopyrazole ring, and a benzoimidazole ring, and ring A_2 may be selected from a pyridine ring, a pyrimidine ring, a quinoline ring, an isoquinoline ring, a quinoxaline ring, and a quinazoline ring, but embodiments are not limited thereto.

[0072] In Formula 2, X_1 may be N or $C(R_3)$, X_2 may be N or $C(R_4)$, and X_3 may be N or $C(R_5)$, wherein at least two of R_3 to R_5 may optionally be bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group (e.g., a substituted or unsubstituted pentadiene group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted adamantane group, a substituted or unsubstituted benzene group, a substituted or unsubstituted pyridine group, a substituted or unsubstituted pyrimidine group, a substituted or unsubstituted pyrazine group, a substituted or unsubstituted pyridazine group, a substituted or unsubstituted naphthalene group, a substituted or unsubstituted anthracene group, a substituted or unsubstituted tetracene group, a substituted or unsubstituted phenanthrene group, a substituted or unsubstituted dihydronaphthalene group, a substituted or unsubstituted phenalene group, a substituted

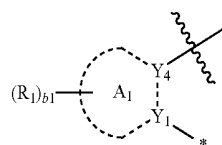
or unsubstituted benzothiophene group, a substituted or unsubstituted benzofuran group, a substituted or unsubstituted indene group, or a substituted or unsubstituted indole group).

[0073] Ring A_3 in Formula 2 may include one or two nitrogens as ring-forming atoms.

[0074] In Formula 2, T_1 may be a group selected from a single bond, $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-C(R_6)=*$, $*=C(R_6)-*$, $*-C(R_6)=C(R_7)-*$, $*-C(=O)-*$, $*-C(=S)-*$, $*-C=C-*$, $*-N(R_6)-*$, $*-Si(R_6)(R_7)-*$, and $*-P(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom, and T_2 may be a group selected from $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-C(R_6)=*$, $*=C(R_6)-*$, $*-C(R_6)=C(R_7)-*$, $*-C(=O)-*$, $*-C(=S)-*$, $*-C=C-*$, $*-N(R_6)-*$, $*-Si(R_6)(R_7)-*$, and $*-P(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom, wherein R_6 and R_7 may optionally be bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group (e.g., a substituted or unsubstituted cyclopropane group, a substituted or unsubstituted cyclobutane group, a substituted or unsubstituted cyclopentane group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted benzene group, or a substituted or unsubstituted naphthalene group). R_6 and R_7 are as provided herein.

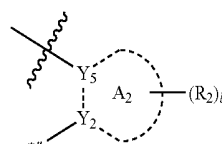
[0075] a_1 and a_2 in Formula 1 may be each independently an integer selected from 1 to 3. a_1 indicates the number of groups T_1 , and when a_1 is 2 or greater, groups T_1 may be identical to or different from each other, and a_2 indicates the number of groups T_2 , and when a_2 is 2 or greater, groups T_2 may be identical to or different from each other. For example, a_1 and a_2 may be each independently 1 or 2.

[0076] A moiety in Formula 2 represented by

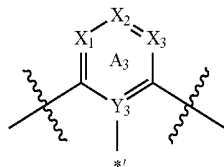


may be represented by one of Formulae 3-1 to 3-25, 3-31 to 3-74, and 3-81 to 3-92,

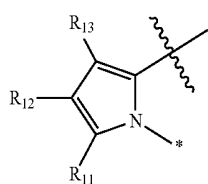
[0077] a moiety in Formula 2 represented by



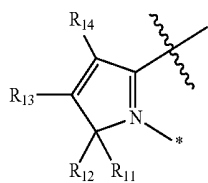
may be represented by one of Formulae 4-1 to 4-53, and a moiety in Formula 2 represented by



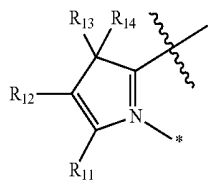
may be represented by one of Formulae 5-1 to 5-48:



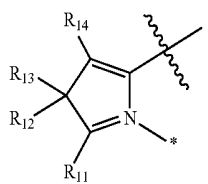
Formula 3-1



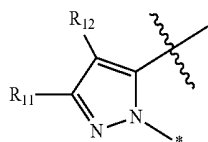
Formula 3-2



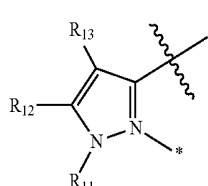
Formula 3-3



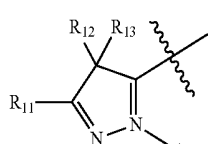
Formula 3-4



Formula 3-5

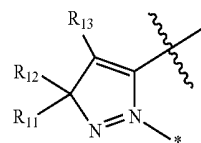


Formula 3-6

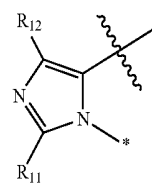


Formula 3-7

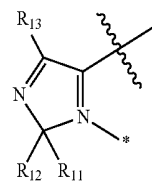
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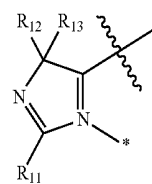
Formula 3-8



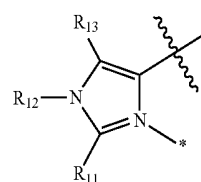
Formula 3-9



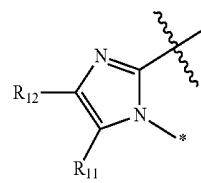
Formula 3-10



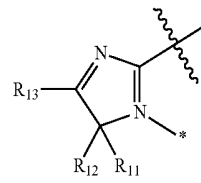
Formula 3-11



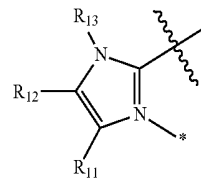
Formula 3-12



Formula 3-13

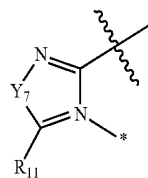
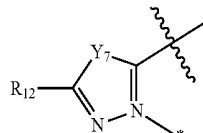
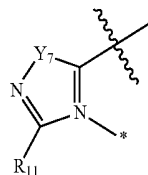
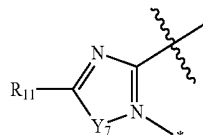
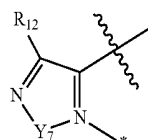
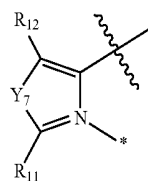
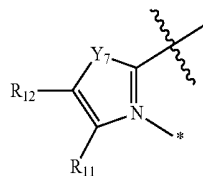
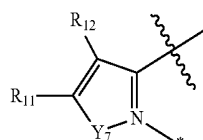
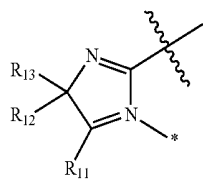


Formula 3-14



Formula 3-15

-continued



Formula 3-16

Formula 3-17

Formula 3-18

Formula 3-19

Formula 3-20

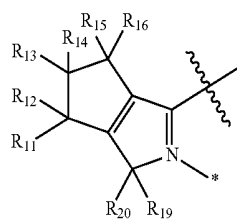
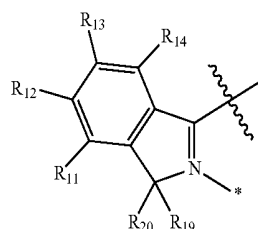
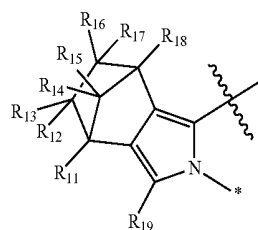
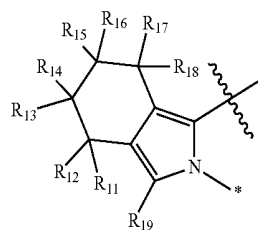
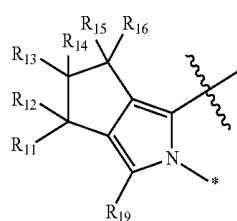
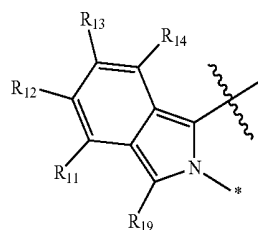
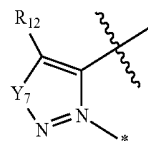
Formula 3-21

Formula 3-22

Formula 3-23

Formula 3-24

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Formula 3-25

Formula 3-31

Formula 3-32

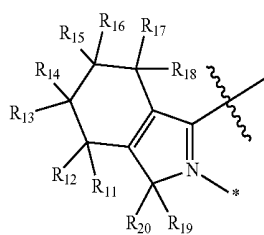
Formula 3-33

Formula 3-34

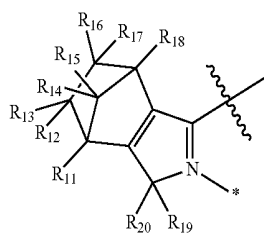
Formula 3-35

Formula 3-36

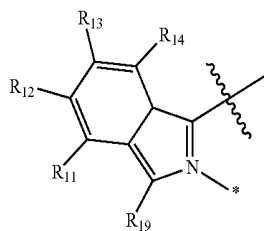
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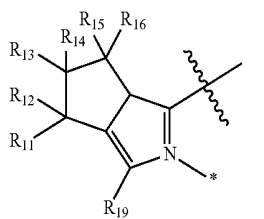
Formula 3-37



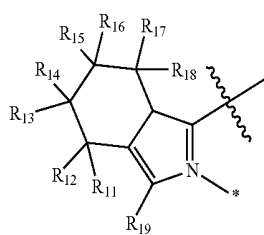
Formula 3-38



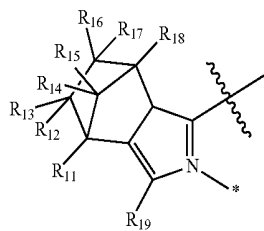
Formula 3-39



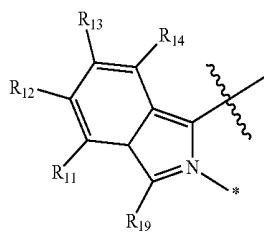
Formula 3-40



Formula 3-41

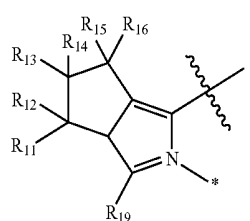


Formula 3-42

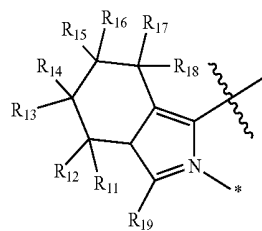


Formula 3-43

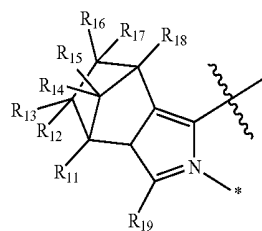
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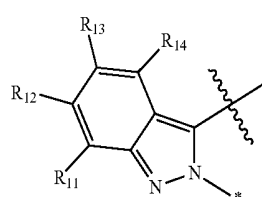
Formula 3-44



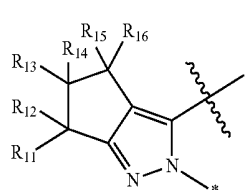
Formula 3-45



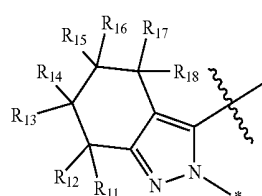
Formula 3-46



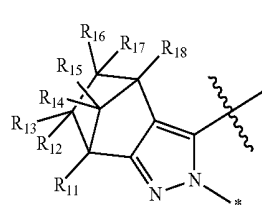
Formula 3-47



Formula 3-48

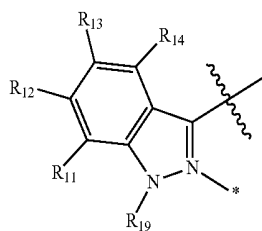


Formula 3-49

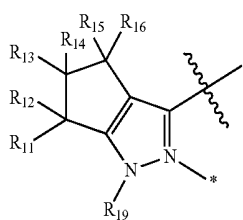


Formula 3-50

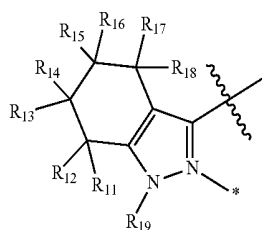
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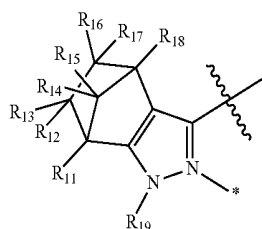
Formula 3-51



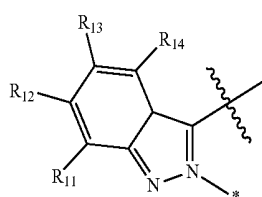
Formula 3-52



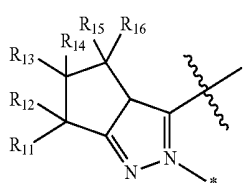
Formula 3-53



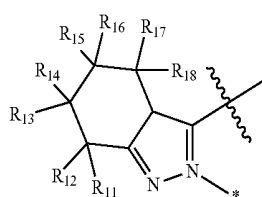
Formula 3-54



Formula 3-55

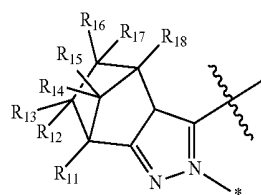


Formula 3-56

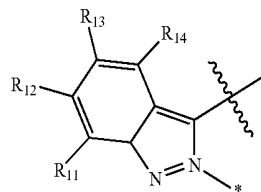


Formula 3-57

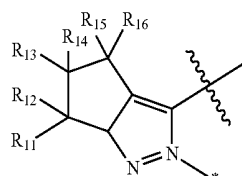
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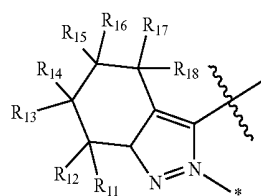
Formula 3-58



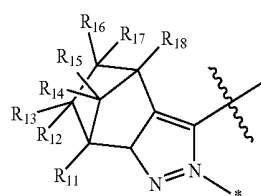
Formula 3-59



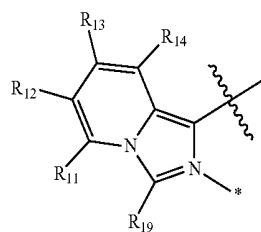
Formula 3-60



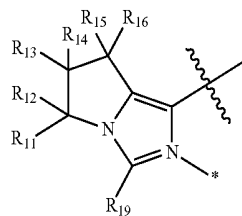
Formula 3-61



Formula 3-62

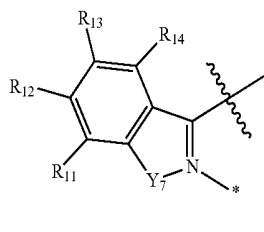
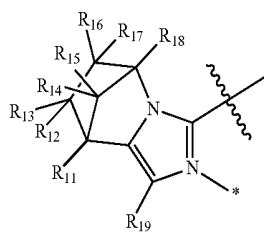
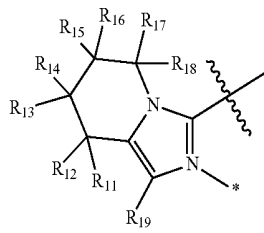
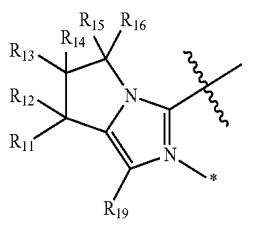
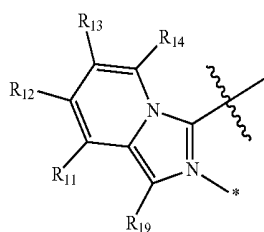
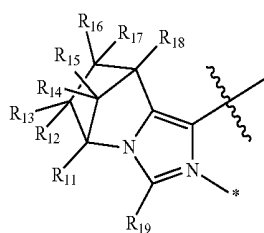
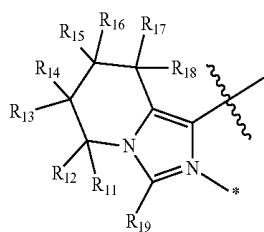


Formula 3-63



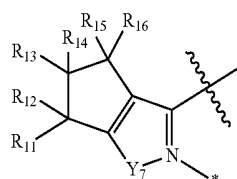
Formula 3-64

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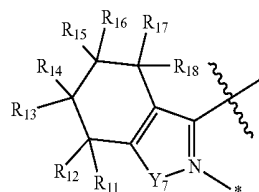
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Formula 3-65



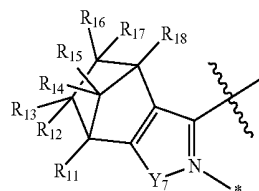
Formula 3-72

Formula 3-66



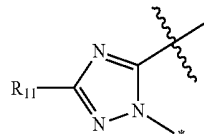
Formula 3-73

Formula 3-67



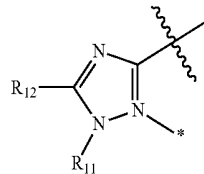
Formula 3-74

Formula 3-68



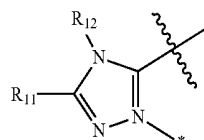
Formula 3-81

Formula 3-69



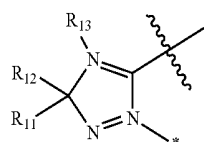
Formula 3-82

Formula 3-70



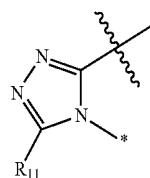
Formula 3-83

Formula 3-71

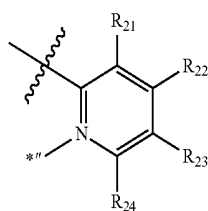
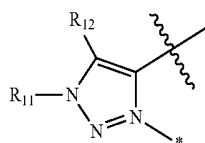
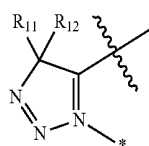
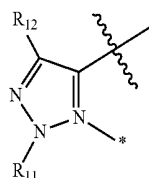
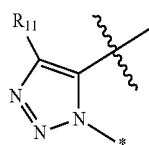
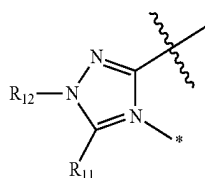
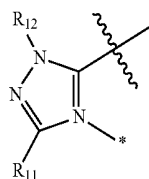
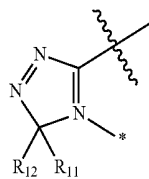


Formula 3-84

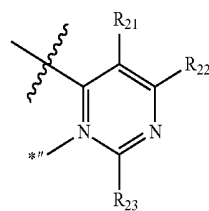
Formula 3-85



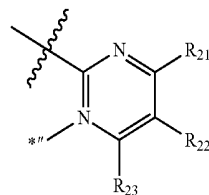
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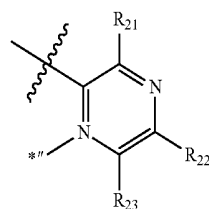
Formula 3-86



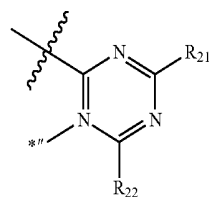
Formula 3-87



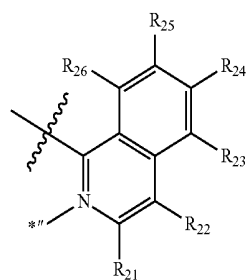
Formula 3-88



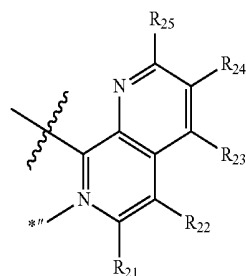
Formula 3-89



Formula 3-90

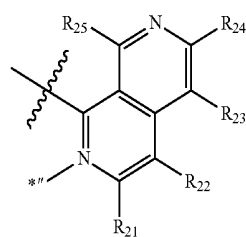


Formula 3-91



Formula 3-92

Formula 4-1



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Formula 4-2

Formula 4-3

Formula 4-4

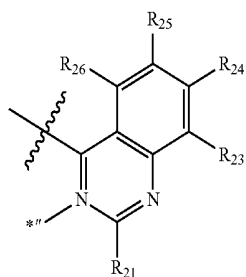
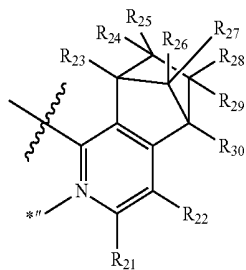
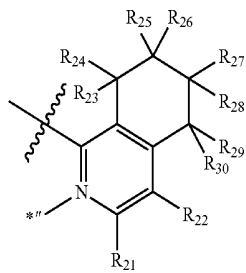
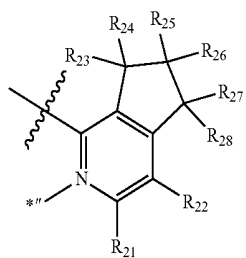
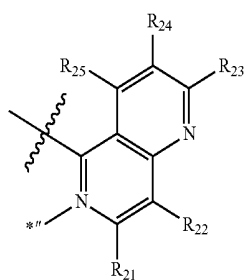
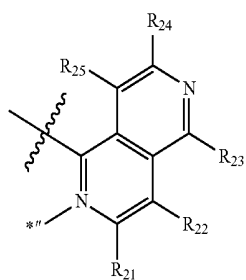
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Formula 4-6

Formula 4-7

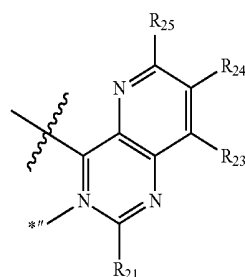
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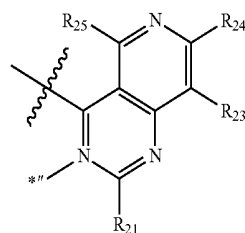


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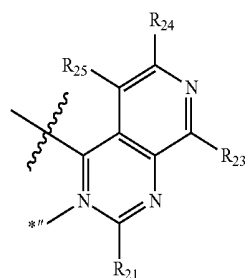
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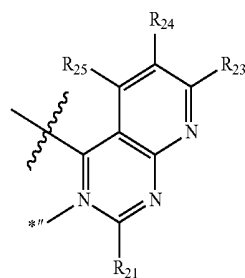
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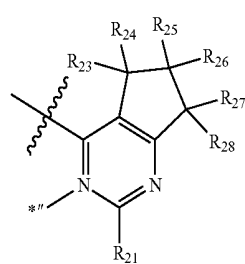
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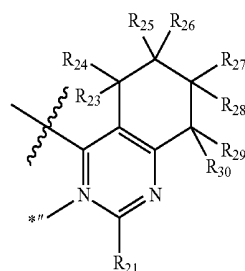
Formula 4-12



Formula 4-13



Formula 4-14



Formula 4-15

Formula 4-16

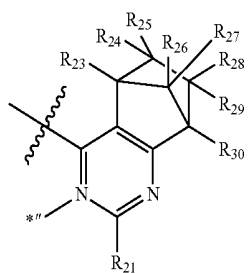
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Formula 4-18

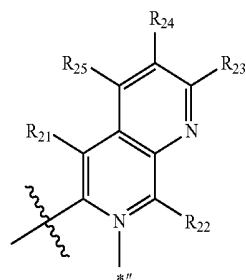
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Formula 4-20

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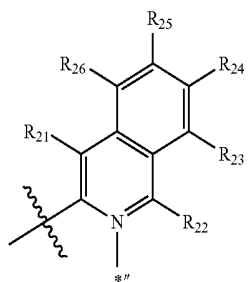


Formula 4-21

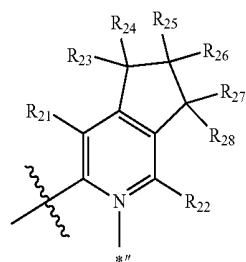


Formula 4-26

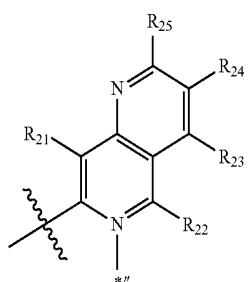
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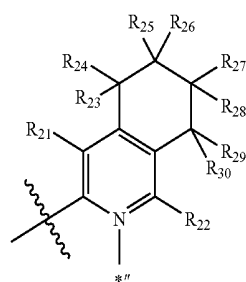
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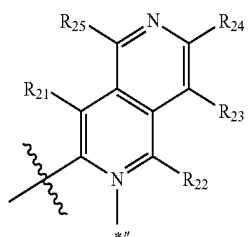
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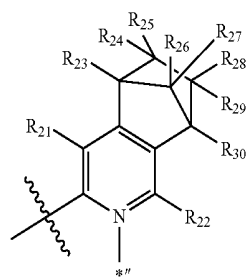
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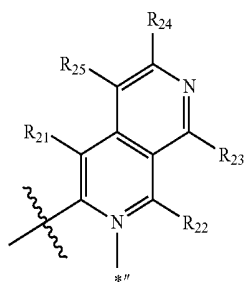
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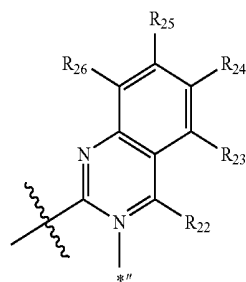
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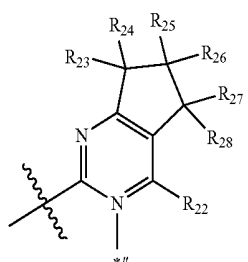
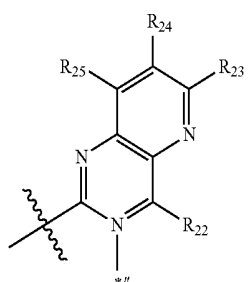
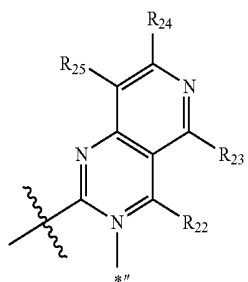
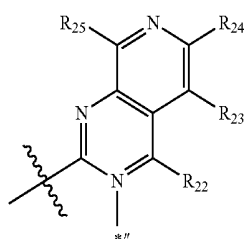
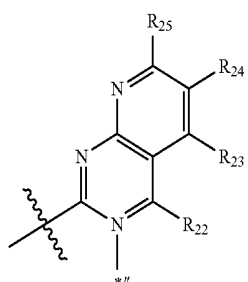
Formula 4-25



Formula 4-30

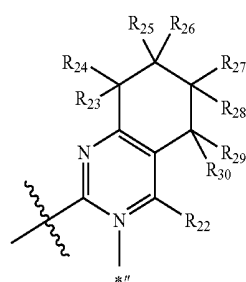


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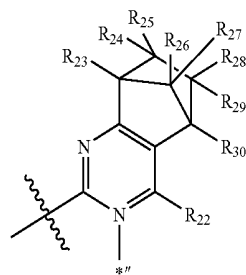
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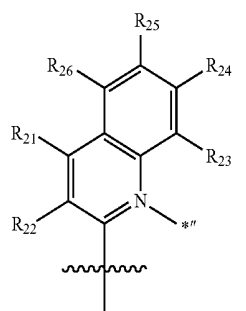
Formula 4-36

Formula 4-32



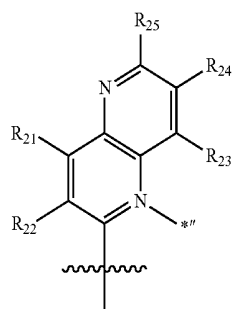
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Formula 4-33



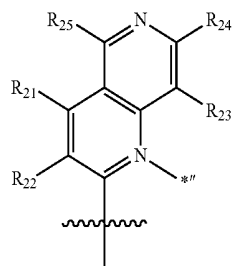
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Formula 4-34



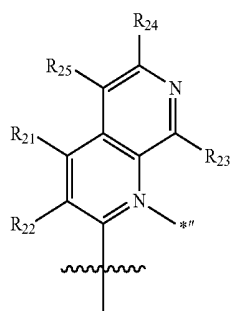
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Formula 4-35



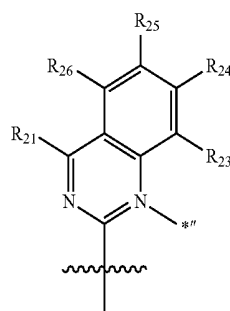
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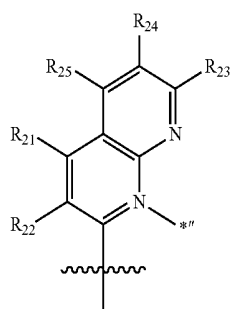


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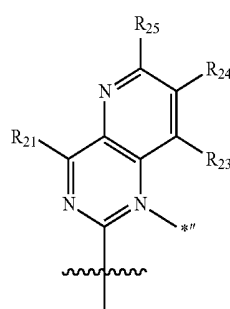
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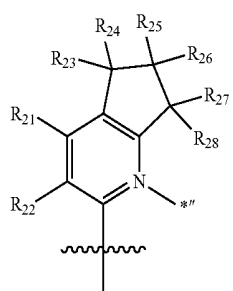
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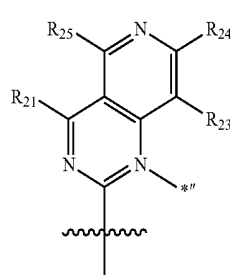
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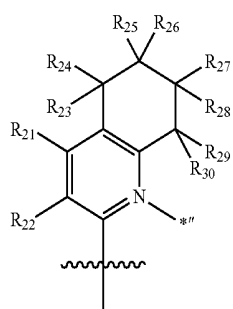
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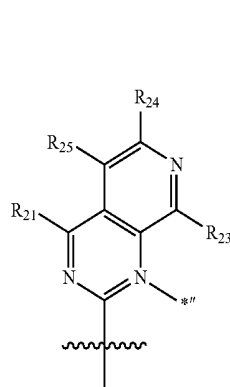
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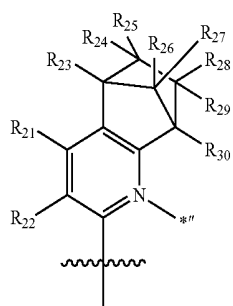
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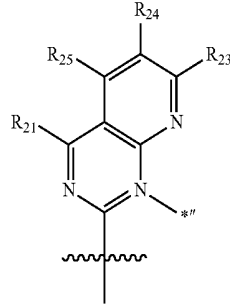
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Formula 4-49

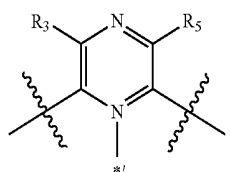
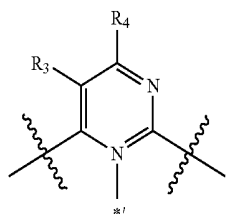
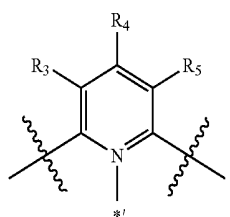
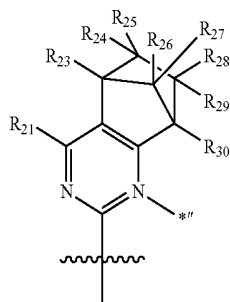
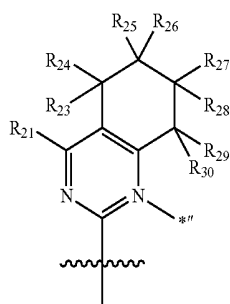
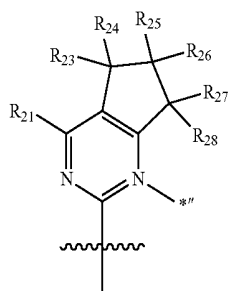


Formula 4-45



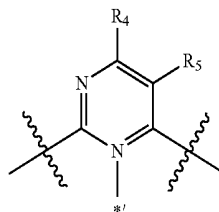
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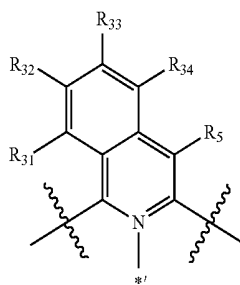
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Formula 4-51



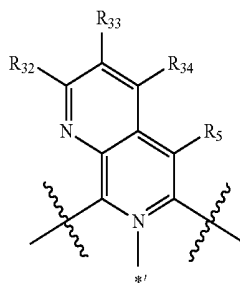
Formula 5-4

Formula 4-52



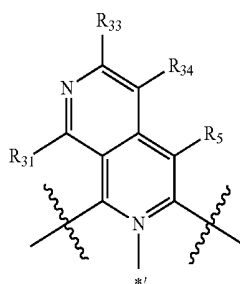
Formula 5-5

Formula 4-53



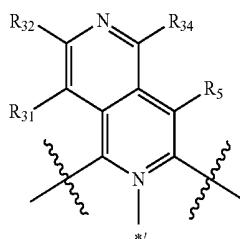
Formula 5-6

Formula 5-1



Formula 5-7

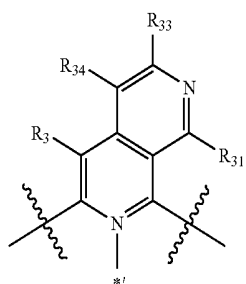
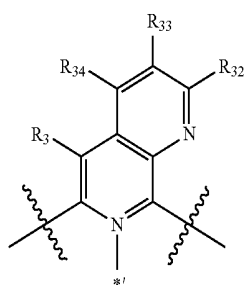
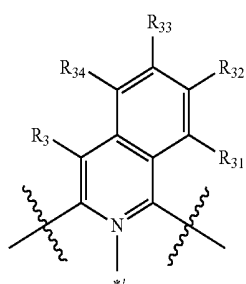
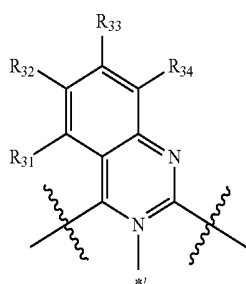
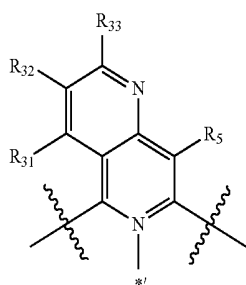
Formula 5-2



Formula 5-8

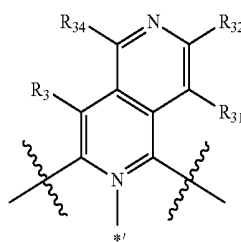
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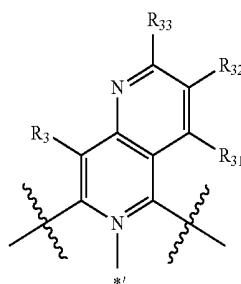
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Formula 5-9



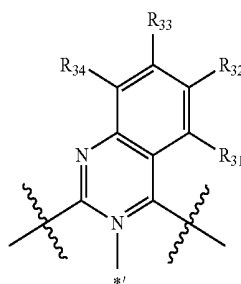
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Formula 5-10



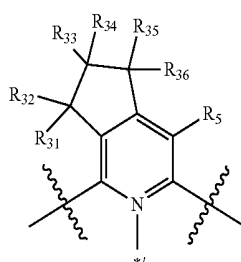
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Formula 5-11



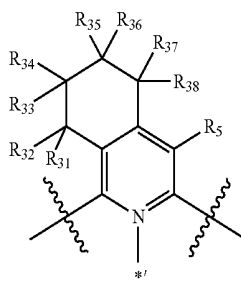
Formula 5-16

Formula 5-12



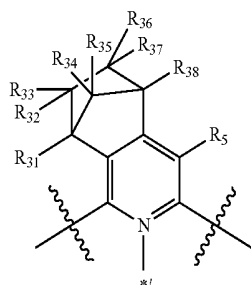
Formula 5-17

Formula 5-13



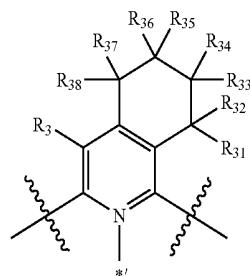
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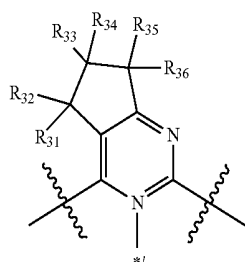


Formula 5-19

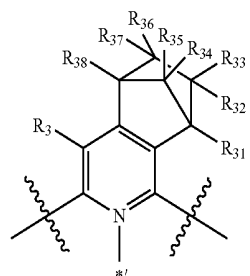
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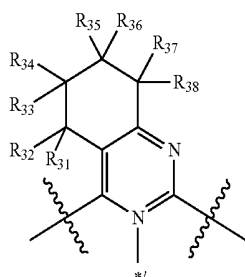
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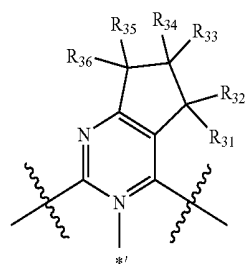
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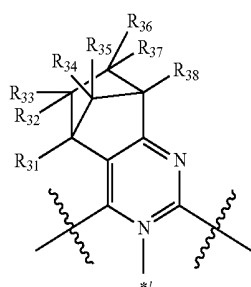
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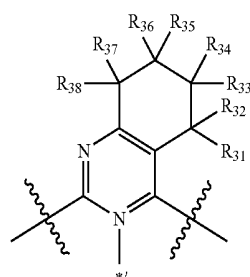
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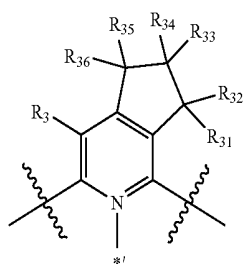
Formula 5-26



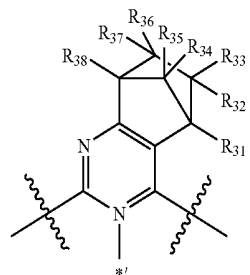
Formula 5-22



Formula 5-27

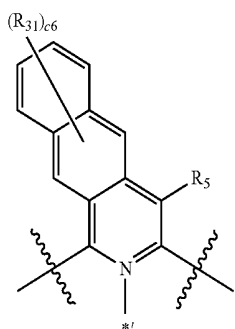


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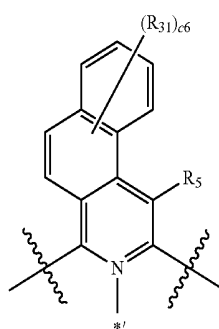
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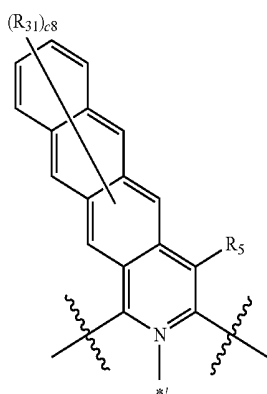


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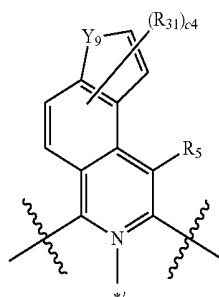
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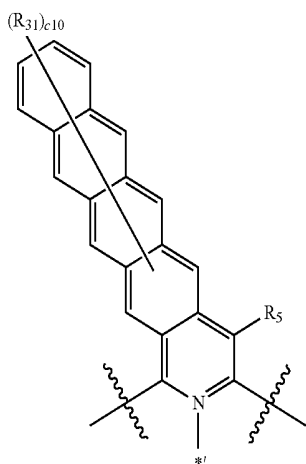
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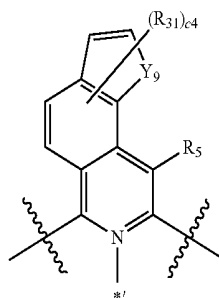
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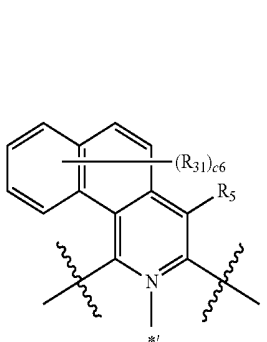
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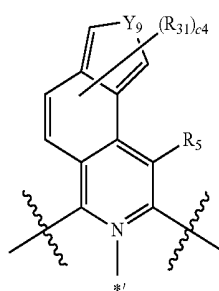
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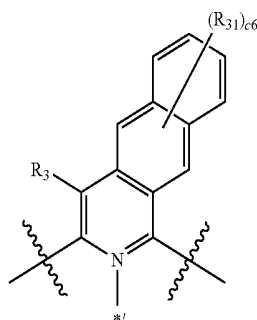
Formula 5-35



Formula 5-32

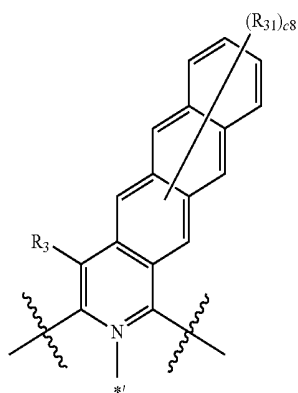


Formula 5-36



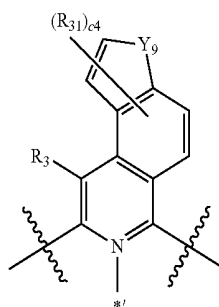
Formula 5-37

-continued



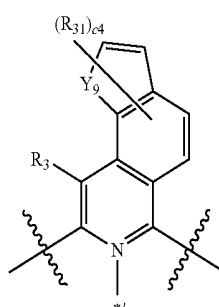
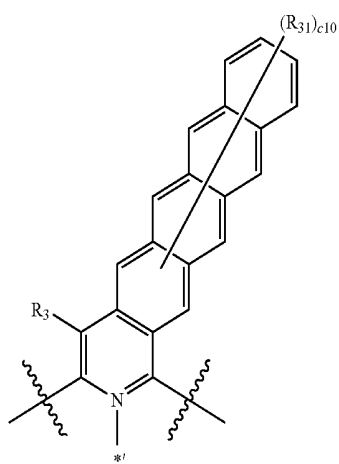
Formula 5-38

-continued



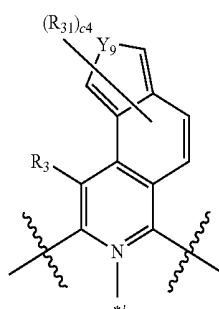
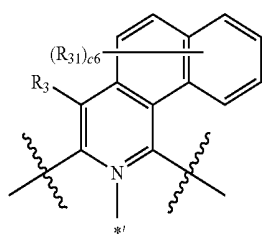
Formula 5-42

Formula 5-39



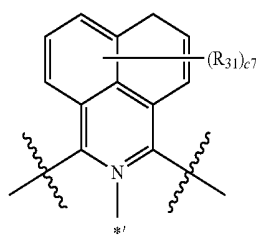
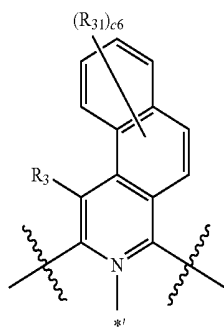
Formula 5-43

Formula 5-40



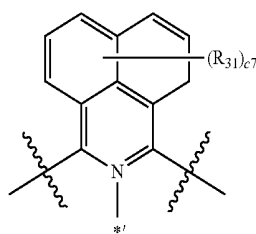
Formula 5-44

Formula 5-41

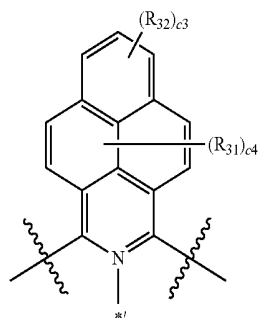


Formula 5-45

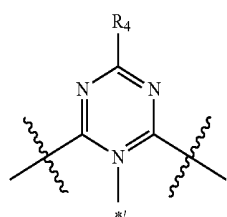
Formula 5-46



-continued



Formula 5-47



Formula 5-48

[0078] wherein, in Formulae 3-1 to 3-25, 3-31 to 3-74, 3-81 to 3-92, 4-1 to 4-53, and 5-1 to 5-48,

[0079] Y_7 and Y_8 may be each independently O or S,

[0080] Y_9 may be O, S, or $N(R_{39})$,

[0081] R_3 to R_5 may be the same as those described herein,

[0082] R_{11} to R_{20} may be each independently the same as R_1 described herein,

[0083] R_{21} to R_{30} may be each independently the same as R_2 described herein,

[0084] R_{31} to R_{39} may be each independently the same as R_3 described herein,

[0085] c_3 may be an integer selected from 0 to 3,

[0086] c_4 may be an integer selected from 0 to 4,

[0087] c_6 may be an integer selected from 0 to 6,

[0088] c_7 may be an integer selected from 0 to 7,

[0089] c_8 may be an integer selected from 0 to 8,

[0090] c_{10} may be an integer selected from 0 to 10, and

[0091] *, **, and *** may each indicate a binding site to M in Formula 1.

[0092] R_3 to R_5 and R_{11} to R_{39} in Formulae 3-1 to 3-25, 3-31 to 3-74, 3-81 to 3-92, 4-1 to 4-53, and 5-1 to 5-48 are as provided herein.

[0093] R_1 to R_7 and R_{11} to R_{39} may be each independently selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-SF_5$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1 - C_{60} alkyl group, a substituted or unsubstituted C_2 - C_{60} alkenyl group, a substituted or unsubstituted C_2 - C_{60} alkynyl group, a substituted or unsubstituted C_1 - C_{60} alkoxy group, a substituted or unsubstituted C_3 - C_{10} cycloalkyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3 - C_{10} cycloalkenyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6 - C_{60} aryl group, a substituted or unsubstituted C_6 - C_{60} aryloxy group, a substituted or unsubstituted C_6 - C_{60} arylthio group, a substituted or unsubstituted C_1 - C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic

group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_1)(Q_2)$, $-Si(Q_3)(Q_4)(Q_5)$, $-B(Q_6)(Q_7)$, and $-P(=O)(Q_8)(Q_9)$.

[0094] According to an embodiment, R_1 to R_7 and R_{11} to R_{39} may be each independently selected from

[0095] hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, $-SF_5$, a C_1 - C_{20} alkyl group, and a C_1 - C_{20} alkoxy group;

[0096] a C_1 - C_{20} alkyl group and a C_1 - C_{20} alkoxy group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1 - C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

[0097] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group;

[0098] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimida-

zoyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazoyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group; and

[0099] —N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), and —P(=O)(Q₈)(Q₉),

[0100] wherein Q₁ to Q₉ may be each independently selected from

[0101] —CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDCH₃, —CHDCH₂H, —CHDCH₂H, —CHDCH₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

[0102] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

[0103] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group.

[0104] In some embodiments, R₁ to R₇ and R₁₁ to R₃₉ may be each independently selected from

[0105] hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl

group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

[0106] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0107] —N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), and —P(=O)(Q₈)(Q₉),

[0108] wherein Q₁ to Q₉ may be each independently selected from

[0109] —CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDCH₃, —CHDCH₂H, —CHDCH₂H, —CHDCH₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

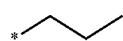
[0110] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group.

[0111] In some embodiments, R₁ to R₇ and R₁₁ to R₃₉ may be each independently selected from hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, —CH₃, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, groups rep-

resented by Formulae 9-1 to 9-19, groups represented by Formulae 10-1 to 10-38, and $-\text{Si}(\text{Q}_3)(\text{Q}_4)(\text{Q}_5)$, but embodiments are not limited thereto:



Formula 9-1



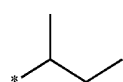
Formula 9-2



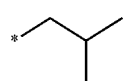
Formula 9-3



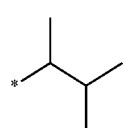
Formula 9-4



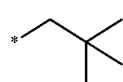
Formula 9-5



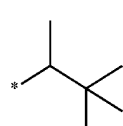
Formula 9-6



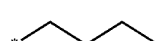
Formula 9-7



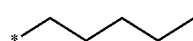
Formula 9-8



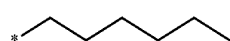
Formula 9-9



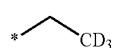
Formula 9-10



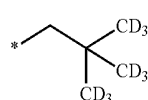
Formula 9-11



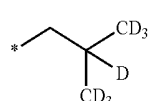
Formula 9-12



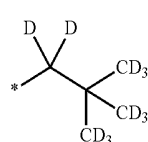
Formula 9-13



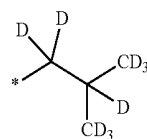
Formula 9-14



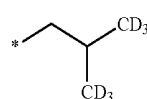
Formula 9-15



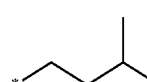
Formula 9-16



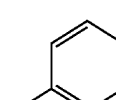
Formula 9-17



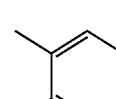
Formula 9-18



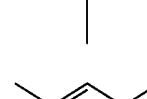
Formula 9-19



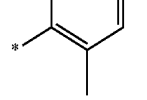
Formula 10-1



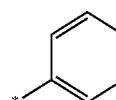
Formula 10-2



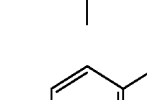
Formula 10-3



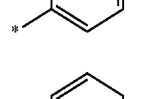
Formula 10-4



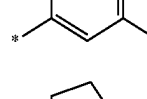
Formula 10-5



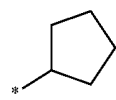
Formula 10-6



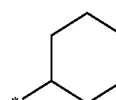
Formula 10-7



Formula 10-8

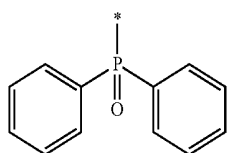
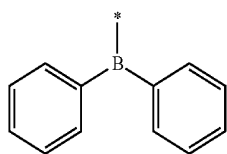
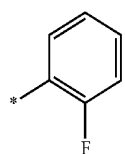
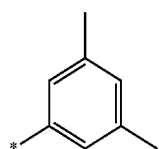
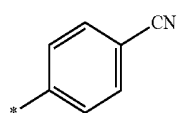
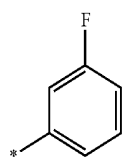
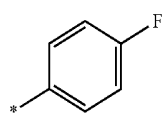
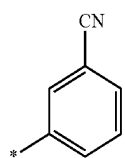
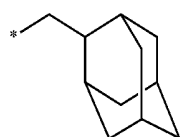
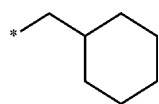
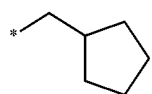


Formula 10-9



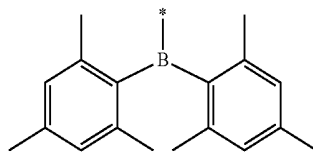
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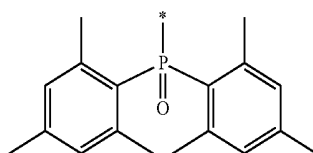
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Formula 10-10

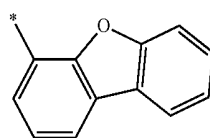


Formula 10-11

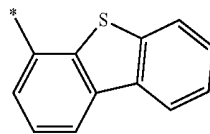
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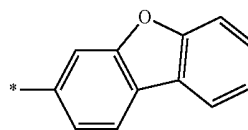
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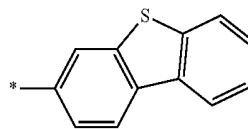
Formula 10-14



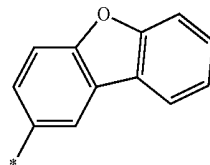
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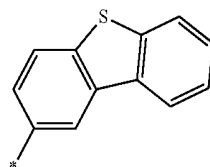
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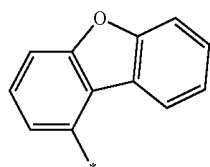
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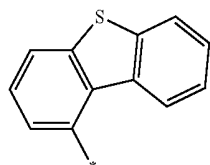
Formula 10-18



Formula 10-19



Formula 10-20



Formula 10-21

Formula 10-22

Formula 10-23

Formula 10-24

Formula 10-25

Formula 10-26

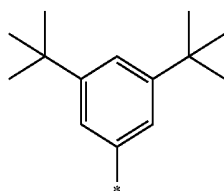
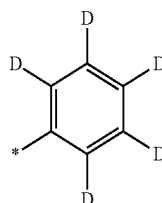
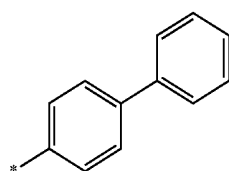
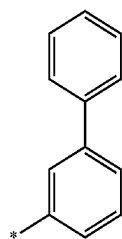
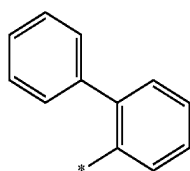
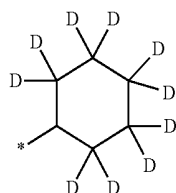
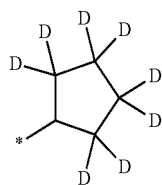
Formula 10-27

Formula 10-28

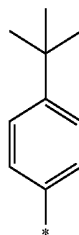
Formula 10-29

Formula 10-30

-continued



Formula 10-31



Formula 10-32

Formula 10-33

Formula 10-34

Formula 10-35

Formula 10-36

Formula 10-37

-continued

Formula 10-38

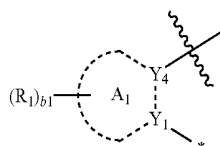
[0112] wherein, in Formulae 9-1 to 9-19 and 10-1 to 10-38, * indicates a binding site to an adjacent atom.

[0113] In Formula 2, b1 and b2 may be each independently an integer selected from 0 to 3, and when b1 is 2 or greater, groups R₁ may be identical to or different from each other, and when b2 is 2 or greater, groups R₂ may be identical to or different from each other.

[0114] In Formula 2, two of the b1 number of groups R₁ may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group (e.g., a substituted or unsubstituted cyclopentane group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted adamantane group, a substituted or unsubstituted benzene group, a substituted or unsubstituted pyridine group, a substituted or unsubstituted pyrimidine group, a substituted or unsubstituted pyrazine group, a substituted or unsubstituted pyridazine group, or a substituted or unsubstituted naphthalene group).

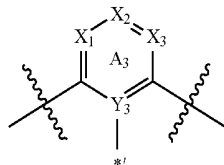
[0115] In Formula 2, two of the b2 number of groups R₂ may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group (e.g., a substituted or unsubstituted cyclopentane group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted adamantane group, a substituted or unsubstituted benzene group, a substituted or unsubstituted pyridine group, a substituted or unsubstituted pyrimidine group, a substituted or unsubstituted pyrazine group, a substituted or unsubstituted pyridazine group, or a substituted or unsubstituted naphthalene group).

[0116] According to an embodiment, a moiety represented by



in Formula 2 may be represented by one of Formulae 3-1, 3-5, 3-9, 3-13, 3-31 to 3-34, 3-47 to 3-50, 3-81, 3-85, and 3-89, but embodiments are not limited thereto.

[0117] In various embodiments, a moiety represented by



in Formula 2 may be represented by one of Formulae 5-1 to 5-28, 5-29, and 5-45, but embodiments are not limited thereto.

[0118] In some embodiments, in Formula 2,

[0119] T_2 may be a group selected from $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-N(R_6)-*$, and $*-Si(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom, and

[0120] R_6 and R_7 may optionally be bound to each other via a first linking group,

[0121] wherein the first linking group may be selected from

[0122] a single bond, a C_1-C_3 alkylene group, and a C_2-C_3 alkenylene group;

[0123] a C_1-C_3 alkylene group and a C_2-C_3 alkenylene group, each substituted with at least one selected from deuterium, a cyano group, C_1-C_{10} alkyl group, C_1-C_{10} alkoxy group, a phenyl group, and a biphenyl group, and

[0124] a_2 may be 1.

[0125] In some embodiments, in Formula 2,

[0126] T_1 may be a single bond,

[0127] T_2 may be a group selected from $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-N(R_6)-*$, and $*-Si(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom,

[0128] R_6 to R_7 may be each independently selected from

[0129] hydrogen, deuterium, a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, and a biphenyl group; and

[0130] a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, and a biphenyl group, each substituted with at least one selected from deuterium, a cyano group, a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, and a phenyl group,

[0131] wherein R_6 and R_7 may optionally be bound to each other via a single bond, and

[0132] a_1 may be 1.

[0133] According to some embodiments, L_1 in Formula 1 may be selected from ligands represented by Formula 2-1:

[0134] wherein, in Formula 2-1,

[0135] T_1 , T_2 , a_1 , a_2 , X_1 to X_3 , $*$, $*$, and $*$ are the same as those described herein,

[0136] X_{11} may be C or N(R_{11a}), X_{12} may be C or N(R_{12a}), X_{13} may be C or N(R_{13a}), X_{21} may be C or N(R_{21a}), X_{22} may be C or N(R_{22a}), X_{23} may be C or N(R_{23a}), X_{24} may be C or N(R_{24a}),

[0137] R_{11a} to R_{13a} are each the same as described herein in connection with R_1 ,

[0138] R_{21a} to R_{24a} are each the same as described herein in connection with R_2 ,

[0139] at least two of R_{11a} to R_{13a} may optionally be bound to each other to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{30} heterocyclic group (e.g., a substituted or unsubstituted cyclopentane group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted adamantane group, a substituted or unsubstituted benzene group, a substituted or unsubstituted pyridine group, a substituted or unsubstituted pyrimidine group, a substituted or unsubstituted pyrazine group, a substituted or unsubstituted pyridazine group, or a substituted or unsubstituted naphthalene group), and

[0140] at least two of R_{21a} to R_{24a} may optionally be bound to each other to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{30} heterocyclic group (e.g., a substituted or unsubstituted cyclopentane group, a substituted or unsubstituted cyclohexane group, a substituted or unsubstituted adamantane group, a substituted or unsubstituted benzene group, a substituted or unsubstituted pyridine group, a substituted or unsubstituted pyrimidine group, a substituted or unsubstituted pyrazine group, a substituted or unsubstituted pyridazine group, or a substituted or unsubstituted naphthalene group).

[0141] According to an embodiment, in Formula 2-1, a) two of R_{11a} to R_{13a} or b) two of R_{21a} to R_{24a} may optionally be bound to each other to form one selected from

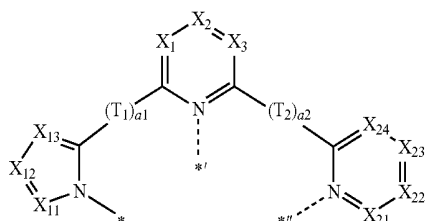
[0142] a cyclopentane group, a cyclohexane group, an adamantane group, a norbornane group, a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a pyrene group, and a chrysene group; and

[0143] a cyclopentane group, a cyclohexane group, an adamantane group, a norbornane group, a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a pyrene group, and a chrysene group, each substituted with at least one selected from deuterium, $-F$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

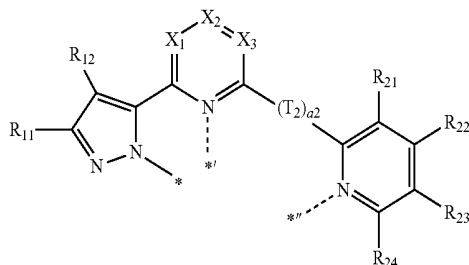
[0144] but embodiments are not limited thereto.

[0145] According to some embodiments, L_1 in Formula 1 may be selected from ligands represented by one of Formulae 2A to 2C:

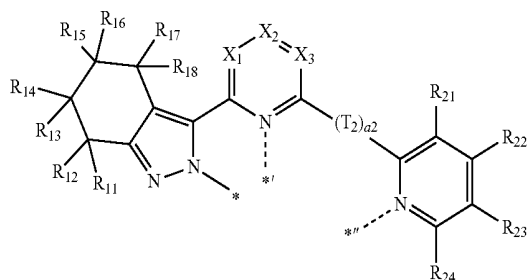
Formula 2-1



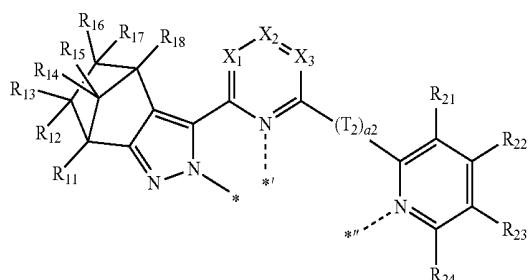
Formula 2A



Formula 2B



Formula 2C



[0146] wherein, in Formulae 2A to 2C,

[0147] T_2 , a_2 , X_1 to X_3 , *, **, and ** are the same as those described herein,

[0148] R_{11} to R_{18} are each the same as described herein in connection with R_1 ,

[0149] R_{21} to R_{24} are each the same as described herein in connection with R_2 , and at least two of R_{21} to R_{24} may optionally be bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group.

[0150] L_2 in Formula 1 may be selected from ligands represented by Formula 6-1:



Formula 6-1

[0151] wherein, in Formula 6-1,

[0152] T_3 may be a group selected from a single bond, $*-O-*$, $*-S-*$, $*-C(R_{62})(R_{63})-*$, $*-C(R_{62})=*$, $*=C(R_{62})-*$, $*-C(R_{62})=C(R_{63})-*$, $*-C(=O)-*$, $*-C(=S)-*$, $*-C=C-*$, and $*-N(R_{62})-*$, wherein * and * in each of the foregoing groups independently indicate a binding site to a neighboring atom,

[0153] a_3 may be an integer selected from 1 to 5,

[0154] R_{61} may be selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-SF_5$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or

unsubstituted C_1 - C_{60} alkyl group, a substituted or unsubstituted C_2 - C_{60} alkenyl group, a substituted or unsubstituted C_2 - C_{60} alkynyl group, a substituted or unsubstituted C_1 - C_{60} alkoxy group, a substituted or unsubstituted C_3 - C_{10} cycloalkyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3 - C_{10} cycloalkenyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6 - C_{60} aryl group, a substituted or unsubstituted C_6 - C_{60} aryloxy group, a substituted or unsubstituted C_1 - C_{60} arylthio group, a substituted or unsubstituted C_1 - C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_1)(Q_2)$, $-Si(Q_3)(Q_4)(Q_5)$, $-B(Q_6)(Q_7)$, $-P(=O)(Q_8)(Q_9)$, and $P(Q_{41})(Q_{42})(Q_{43})$,

[0155] wherein Q_1 to Q_6 and Q_{41} to Q_{43} may be each independently selected from

[0156] $-CH_3$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CH_2CH_3$, $-CH_2CD_3$, $-CH_2CD_2H$, $-CH_2CDH_2$, $-CHDCH_3$, $-CHDCH_2H$, $-CHDCHD_2$, $-CHDCHD_3$, $-CD_2CD_3$, $-CD_2CD_2H$, and $-CD_2CDH_2$;

[0157] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

[0158] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C_1 - C_{10} alkyl group, and a phenyl group,

[0159] R_{62} to R_{63} may be each independently selected from

[0160] hydrogen, deuterium, $-F$, a cyano group, a nitro group, $-SF_5$, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuran group, and a dibenzothiofenyl group; and

[0161] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a

tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

[0162] R₆₂ and R₆₃ may optionally be bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group, and

[0163] * in Formula 1 indicates a binding site to M.

[0164] In some embodiments, R₆₁ may be selected from

[0165] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, —SF₅, a C₁-C₂₀ alkyl group, and a C₁-C₂₀ alkoxy group;

[0166] a C₁-C₂₀ alkyl group and a C₁-C₂₀ alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₁₀ alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

[0167] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group;

[0168] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group; and

[0169] —N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), —P(=O)(Q₈)(Q₉), and P(Q₄₁)(Q₄₂)(Q₄₃),

[0170] wherein Q₁ to Q₉ and Q₄₁ to Q₄₃ may be each independently selected from

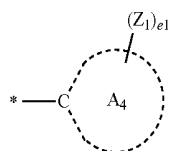
[0171] —CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDCH₃,

—CHDCD₂H, —CHDCDH₂, —CHDCD₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

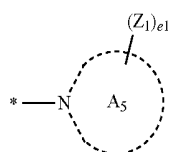
[0172] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

[0173] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group, but embodiments are not limited thereto.

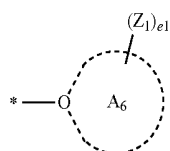
[0174] According to an embodiment, L₂ in Formula 1 may be selected from ligands represented by one of Formulae 12-2 to 12-5, but embodiments are not limited thereto:



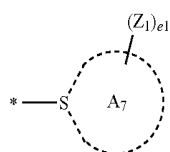
Formula 12-2



Formula 12-3



Formula 12-4



Formula 12-5

[0175] wherein, in Formulae 12-2 to 12-5,

[0176] ring A₄ may be selected from a cyclopentene ring, a cyclohexene ring, a cycloheptene ring, a benzene ring, an indene ring, a naphthalene ring, an azulene ring, a heptalene ring, an indacene ring, acenaphthylene ring, a fluorene ring, a spiro-bifluorene ring, a benzofluorene ring, a dibenzofluorene ring, a phenalene ring, a phenanthrene ring, an anthracene ring, a fluoranthene ring, a triphenylene ring, a pyrene ring, a chrysene ring, a naphthacene ring, a picene ring, a perylene ring, a pentacene ring, a hexacene ring, a pentalene ring, a rubicene ring, a coronene ring, an ovalene ring, a pyrrole ring, a thiophene ring, a furan ring, an imidazole ring, a pyrazole ring, a thiazole ring, an isothiazole ring, an oxazole ring, an isoxazole ring, a pyridine ring, a pyrazine ring, a pyrimidine ring, a pyridazine ring, an iso-indole ring, an indole ring, indazole ring, a purine ring, a quinoline ring, an isoquinoline ring, a benzoquinoline ring, a quinoxaline ring, a quinazoline ring, a cinnoline ring, a naphthyridine ring, a carbazole ring, a phenanthroline ring, a benzoimida-

zole ring, a benzofuran ring, a benzothiophene ring, a benzothiazole ring, an iso-benzothiazole ring, a benzoxazole ring, an isobenzoxazole ring, a triazole ring, a tetrazole ring, an oxadiazole ring, a thiadiazole ring, a triazine ring, a dibenzofuran ring, a dibenzothiophene ring, a benzocarbazole ring, a dibenzocarbazole ring, an imidazopyridine ring, and an imidazopyrimidine ring,

[0177] ring A₅ may be selected from a pyrrole ring, an imidazole ring, a pyrazole ring, a thiazole ring, an isothiazole ring, an oxazole ring, an isoxazole ring, a pyridine ring, a pyrazine ring, a pyrimidine ring, a pyridazine ring, an iso-indole ring, an indole ring, an indazole ring, a purine ring, a quinoline ring, an isoquinoline ring, a benzoquinoline ring, a quinoxaline ring, a quinazoline ring, a cinnoline ring, a naphthyridine ring, a carbazole ring, a phenanthroline ring, a benzoimidazole ring, a benzofuran ring, a benzothiazole ring, an iso-benzothiazole ring, a benzoxazole ring, an isobenzoxazole ring, a triazole ring, a tetrazole ring, an oxadiazole ring, a thiadiazole ring, a triazine ring, a benzocarbazole ring, a dibenzocarbazole ring, an imidazopyridine ring, and an imidazopyrimidine ring,

[0178] ring A₆ may be selected from a furan ring, an oxazole ring, an isoxazole ring, a benzofuran ring, a benzoxazole ring, an isobenzoxazole ring, an oxadiazole ring, and a dibenzofuran ring,

[0179] ring A₇ may be selected from a thiophene ring, a thiazole ring, an isothiazole ring, a benzothiophene ring, a benzothiazole ring, an iso-benzothiazole ring, a thiadiazole ring, and a dibenzothiophene ring,

[0180] Z₁ may be each independently selected from

[0181] hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofurananyl group, and a dibenzothiophenyl group;

[0182] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a

norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, $-F$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a cyano group, a nitro group, a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0183] $-N(Q_{31})(Q_{32})$, $-Si(Q_{33})(Q_{34})(Q_{35})$, $-B(Q_{36})(Q_{37})$, and $-P(=O)(Q_{38})(Q_{39})$,

[0184] wherein Q_{31} to Q_{39} may be each independently selected from

[0185] $-CH_3$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CH_2CH_3$, $-CH_2CD_3$, $-CH_2CD_2H$, $-CH_2CDH_2$, $-CHDC_3$, $-CHDCD_2H$, $-CHDCDH_2$, $-CHDCD_3$, $-CD_2CD_3$, $-CD_2CD_2H$, and $-CD_2CDH_2$;

[0186] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

[0187] an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C_1 - C_{10} alkyl group, and a phenyl group,

[0188] two of groups Z_1 may optionally be bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group,

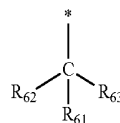
[0189] e1 may be an integer selected from 0 to 8, and

[0190] * in Formula 1 indicates a binding site to M.

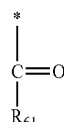
[0191] In some embodiments, L_2 in Formula 1 may be selected from ligands represented by one of Formulae 13-1 to 13-49 and 14-1 to 14-28, but embodiments are not limited thereto:

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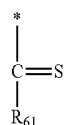
Formula 13-4



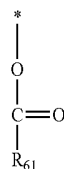
Formula 13-5



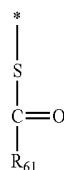
Formula 13-6



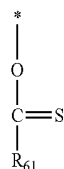
Formula 13-7



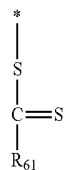
Formula 13-8



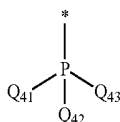
Formula 13-9



Formula 13-10

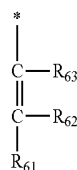


Formula 13-1



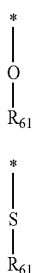
Formula 13-11

Formula 13-2

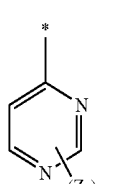
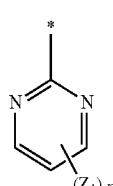
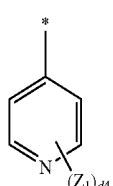
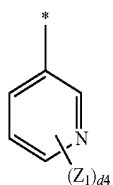
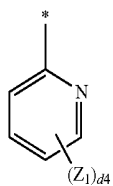
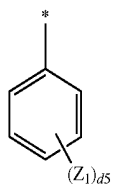


Formula 13-12

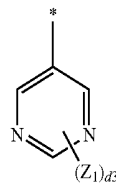
Formula 13-3



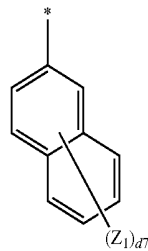
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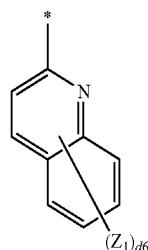
Formula 13-13



Formula 13-14

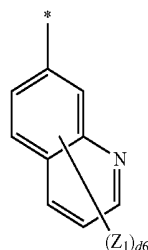


Formula 13-15



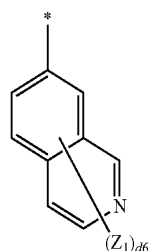
Formula 13-16

Formula 13-17

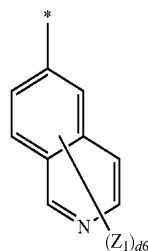


Formula 13-18

Formula 13-19



Formula 13-20



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Formula 13-21

Formula 13-22

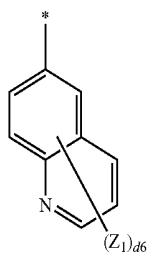
Formula 13-23

Formula 13-24

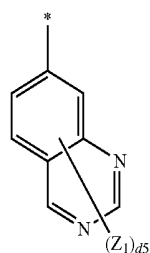
Formula 13-25

Formula 13-26

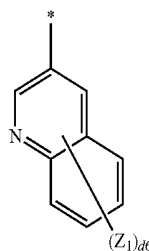
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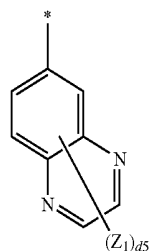
Formula 13-27



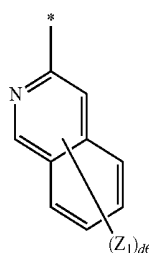
Formula 13-33



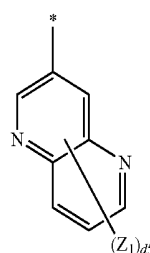
Formula 13-28



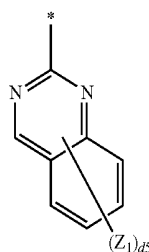
Formula 13-34



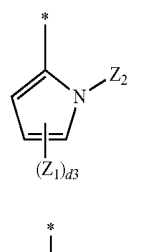
Formula 13-29



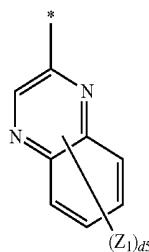
Formula 13-35



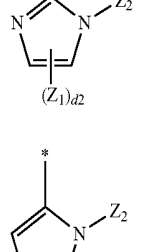
Formula 13-30



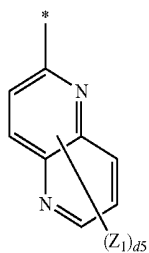
Formula 13-36



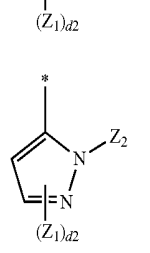
Formula 13-31



Formula 13-37



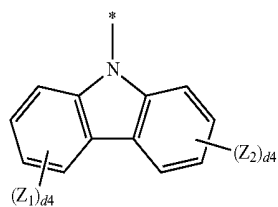
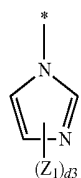
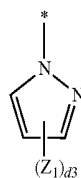
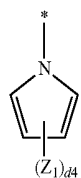
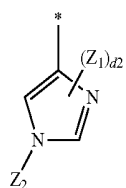
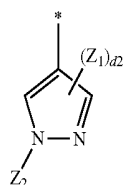
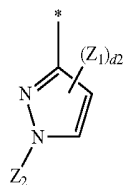
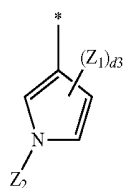
Formula 13-32



Formula 13-38

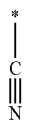
Formula 13-39

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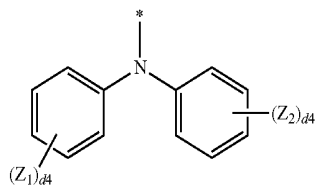


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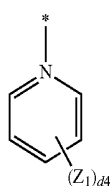
Formula 13-40



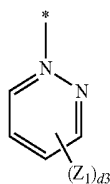
Formula 13-41



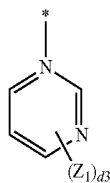
Formula 13-42



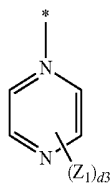
Formula 13-43



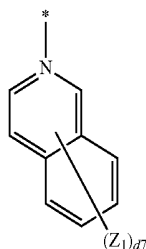
Formula 13-44



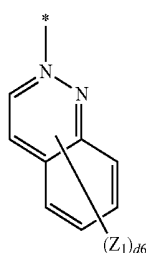
Formula 13-45



Formula 13-46



Formula 13-47



Formula 13-48

Formula 13-49

Formula 14-1

Formula 14-2

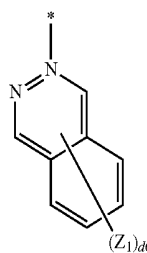
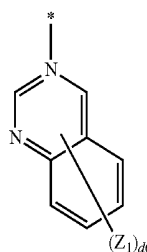
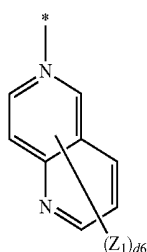
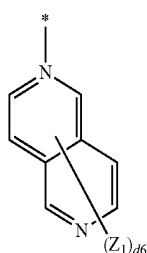
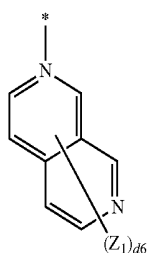
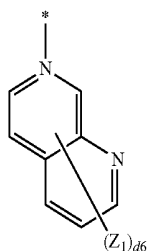
Formula 14-3

Formula 14-4

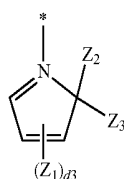
Formula 14-5

Formula 14-6

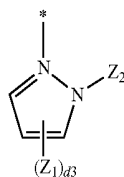
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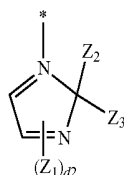
Formula 14-7



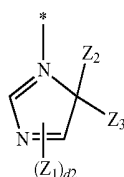
Formula 14-8



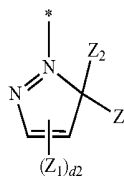
Formula 14-9



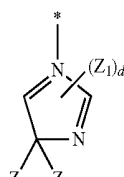
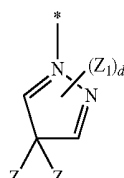
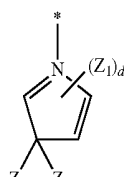
Formula 14-10



Formula 14-11



Formula 14-12



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Formula 14-13

Formula 14-14

Formula 14-15

Formula 14-16

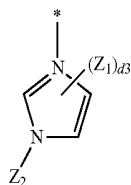
Formula 14-17

Formula 14-18

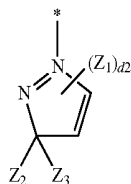
Formula 14-19

Formula 14-20

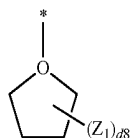
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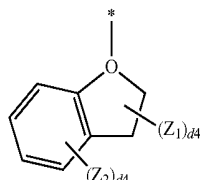
Formula 14-21



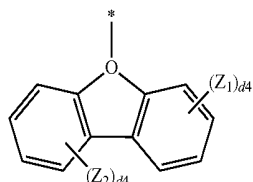
Formula 14-22



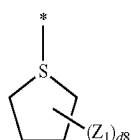
Formula 14-23



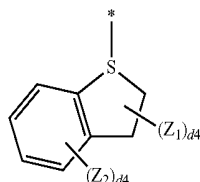
Formula 14-24



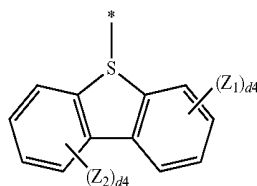
Formula 14-25



Formula 14-26



Formula 14-27



Formula 14-28

[0192] wherein, in Formulae 13-1 to 13-49 and 14-1 to 14-28,

[0193] R_{61} may be the same as described herein,

[0194] Z_1 may be the same as described herein, Z_2 and Z_3 may be each independently the same as described herein in connection with Z_1 ,

[0195] d_2 may be an integer selected from 1 and 2,

[0196] d_3 may be an integer selected from 1 to 3,

[0197] d_4 may be an integer selected from 1 to 4,

[0198] d_5 may be an integer selected from 1 to 5,

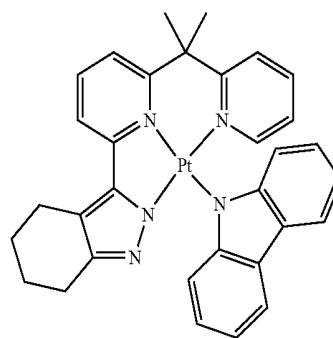
[0199] d_6 may be an integer selected from 1 to 6,

[0200] d_7 may be an integer selected from 1 to 7,

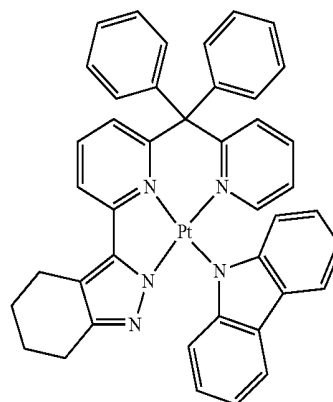
[0201] d_8 may be an integer selected from 1 to 8, and

[0202] * in Formula 1 indicates a binding site to M.

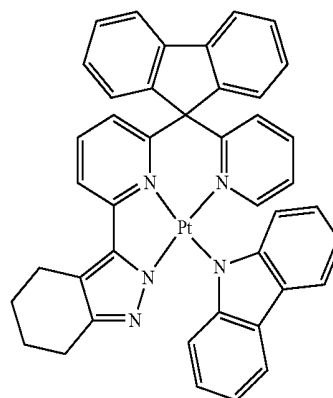
[0203] The organometallic compound represented by Formula 1 may be one of Compounds 1 to 180, but embodiments are not limited thereto:



1

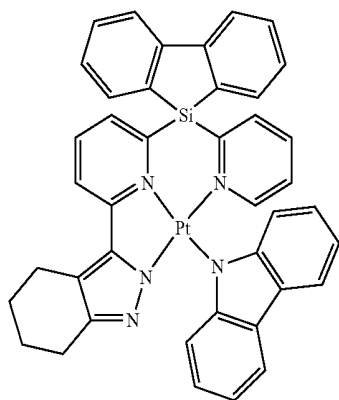


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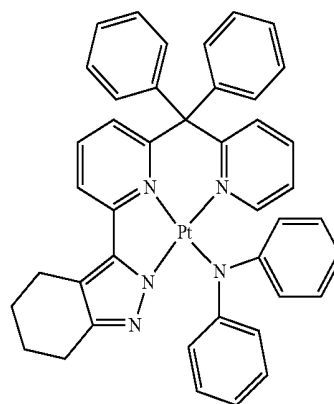
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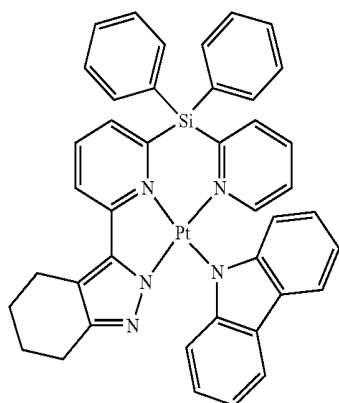


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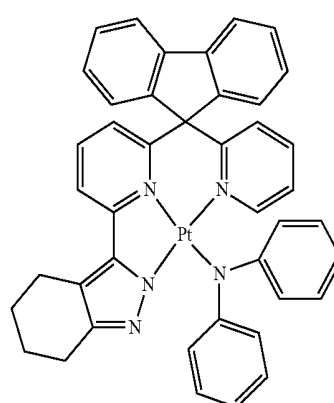
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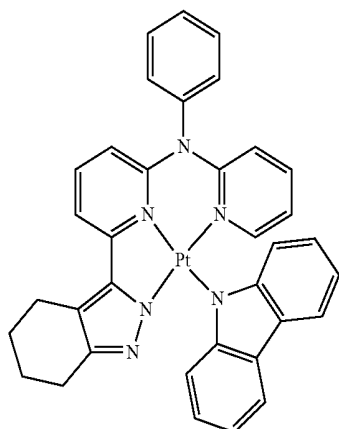
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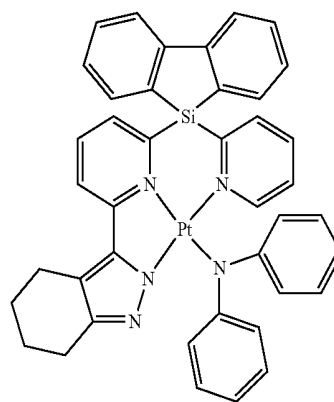
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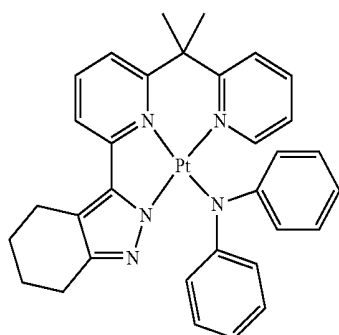
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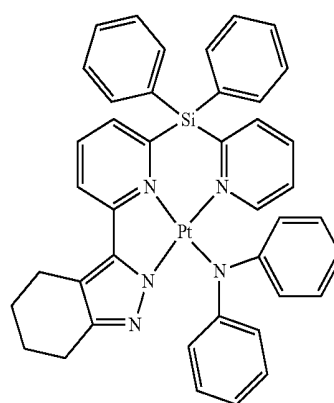
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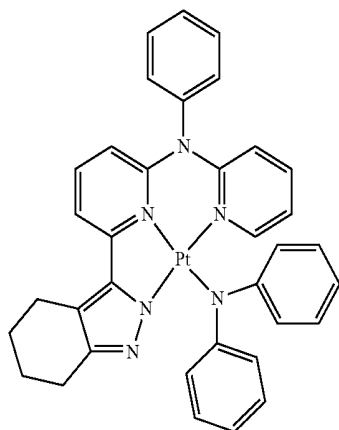


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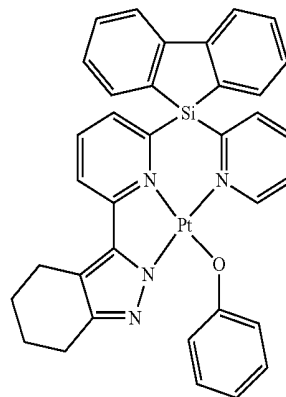
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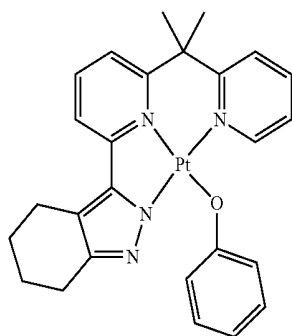


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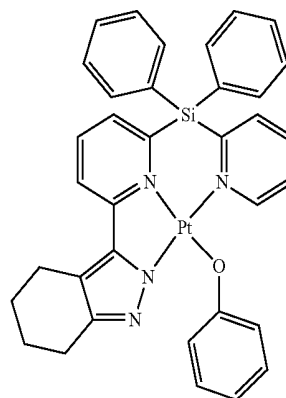
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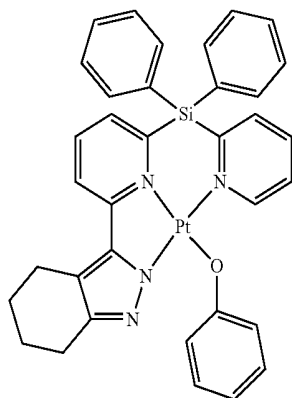
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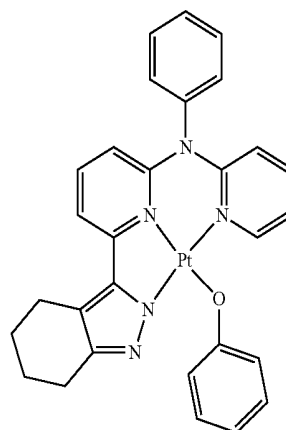
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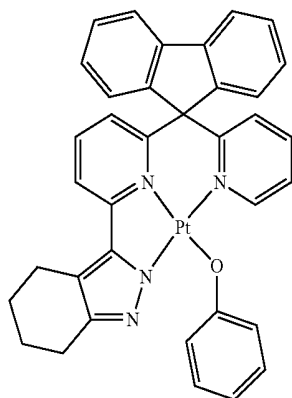
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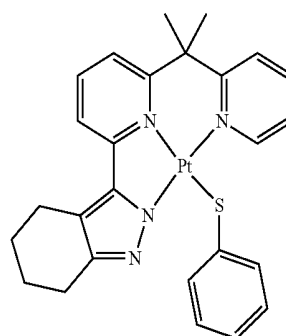
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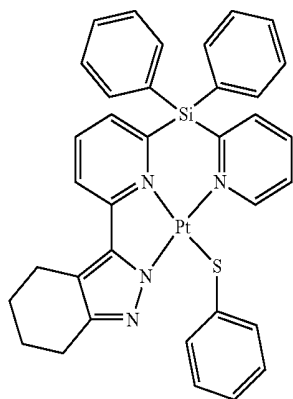
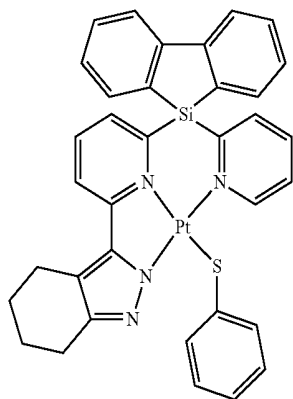
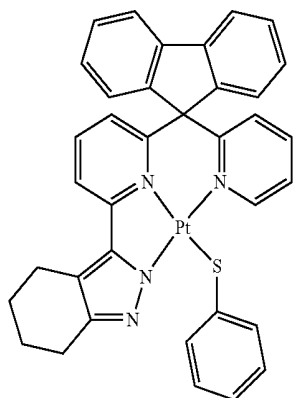
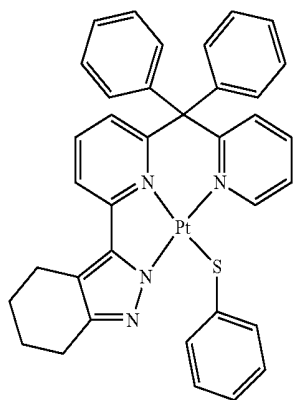


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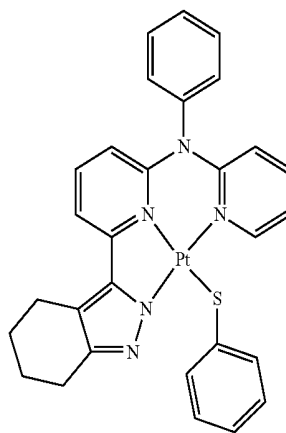
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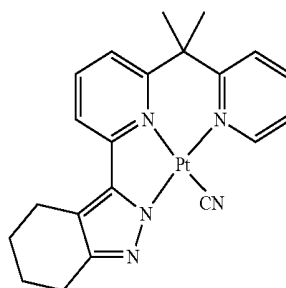
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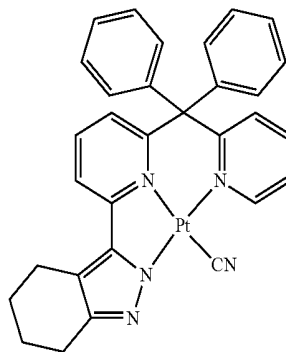
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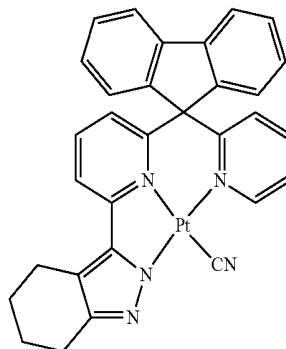
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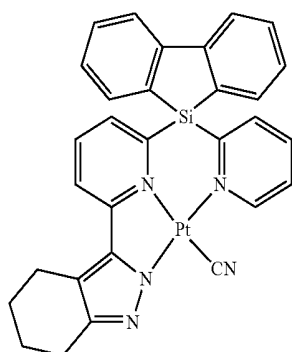


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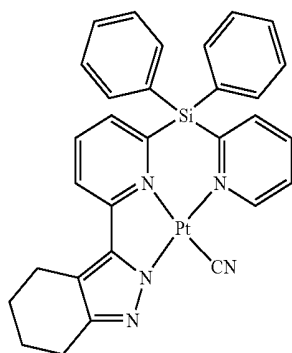
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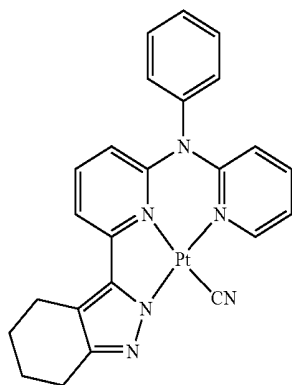
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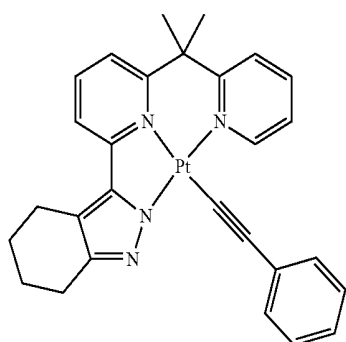
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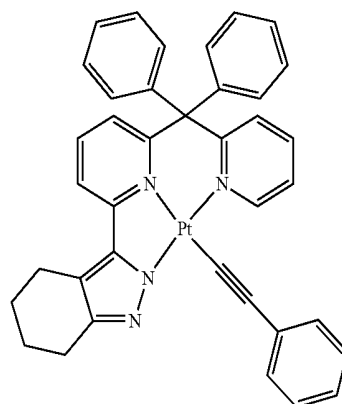


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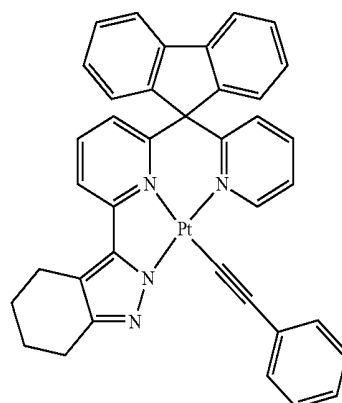


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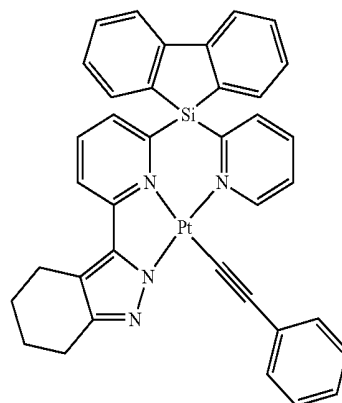
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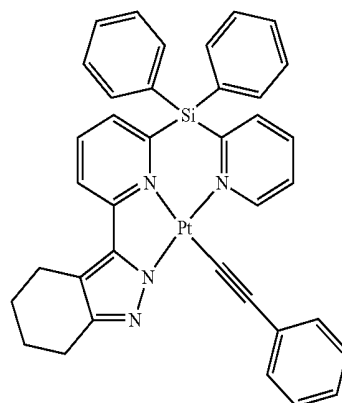
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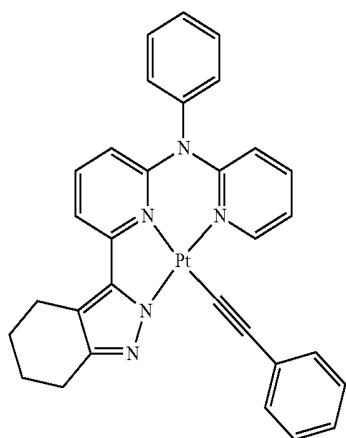


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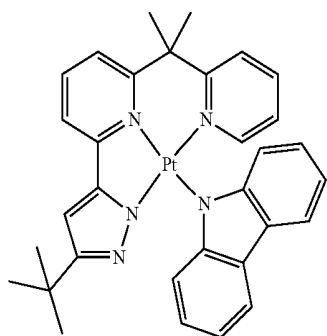


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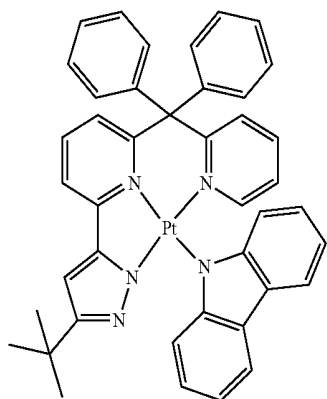
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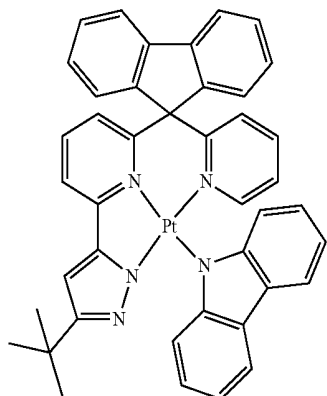
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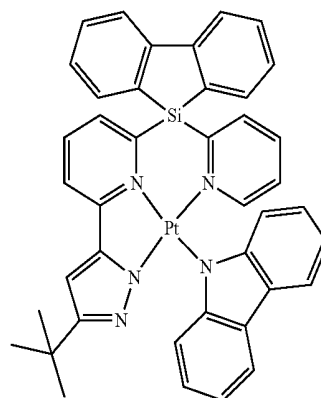


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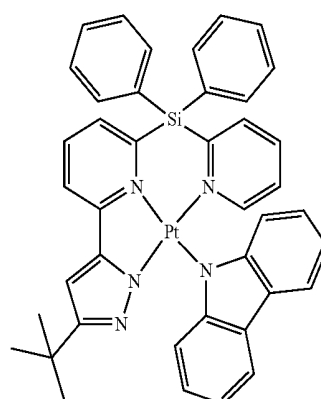


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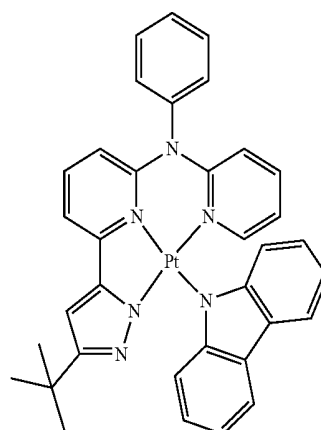
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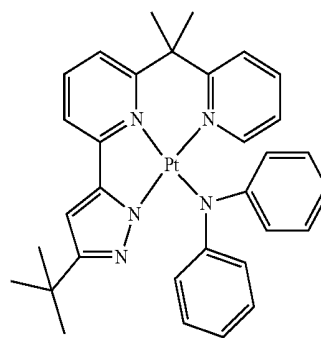
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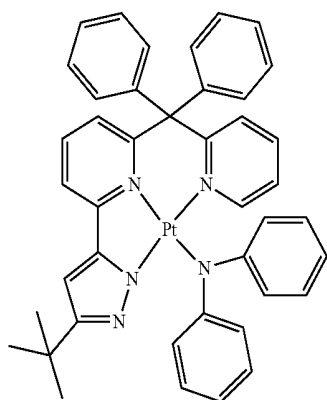


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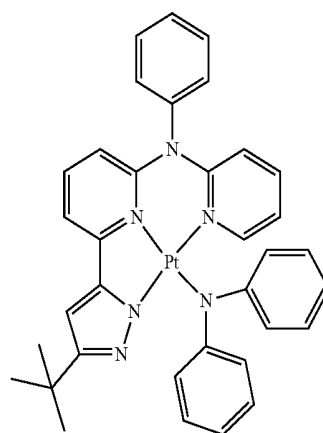
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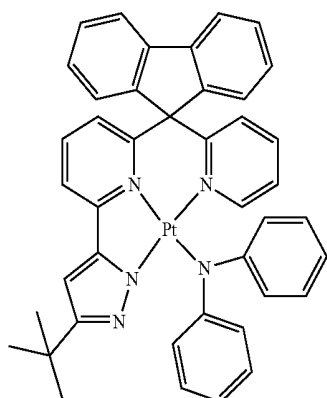
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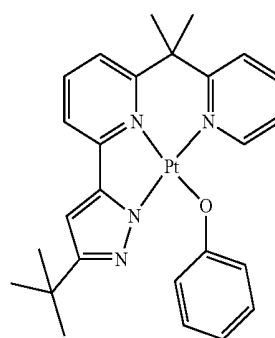


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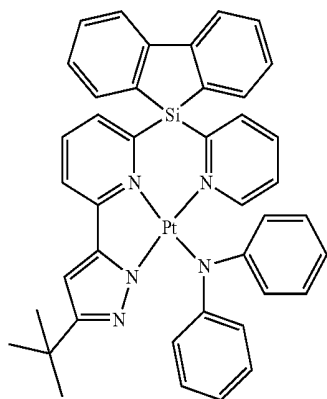


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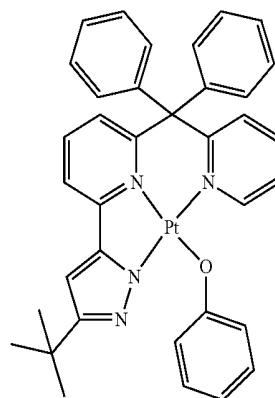


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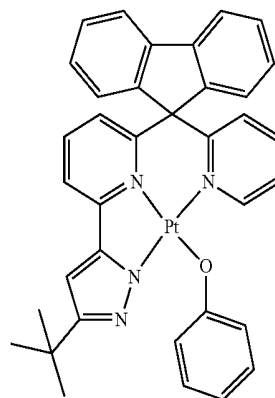
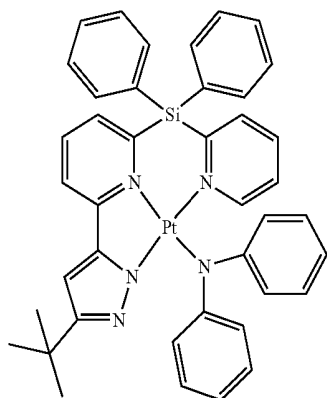
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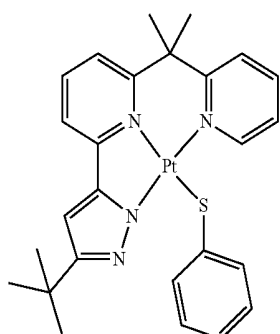
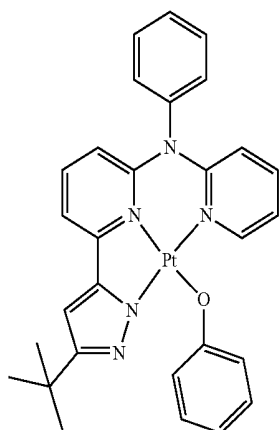
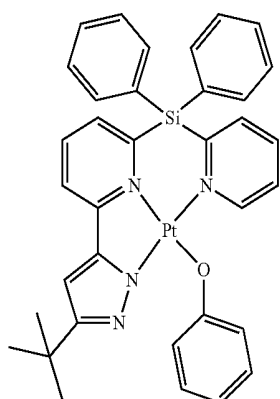
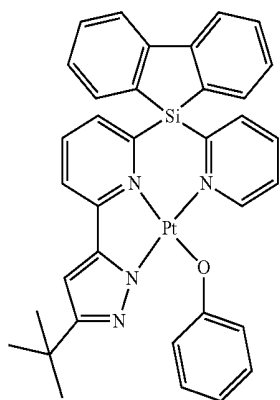
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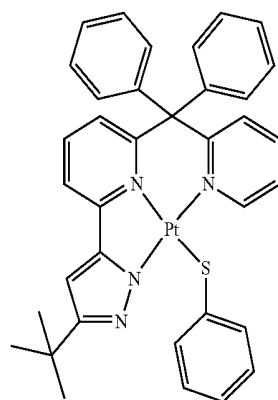


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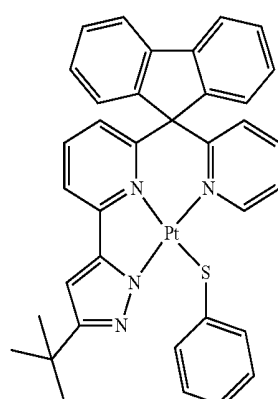
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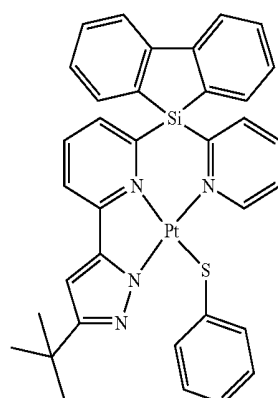
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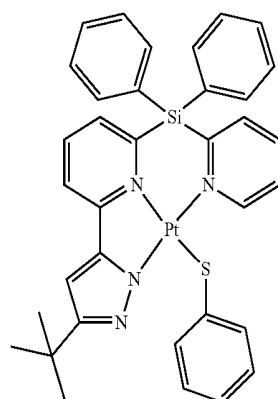
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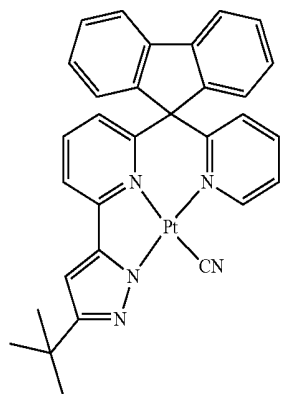
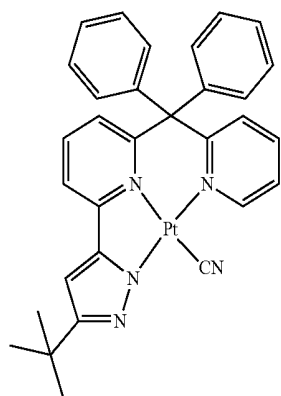
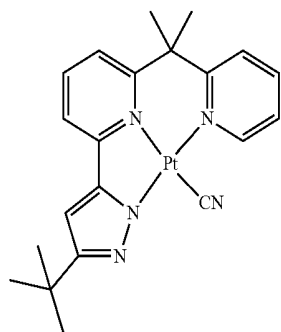
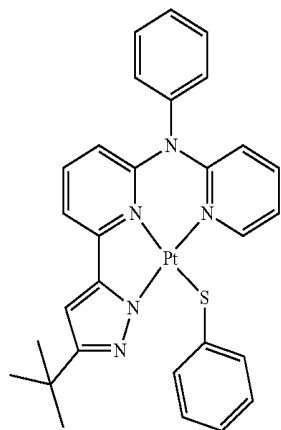
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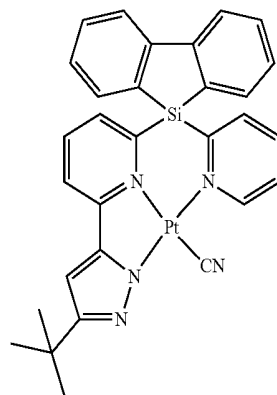
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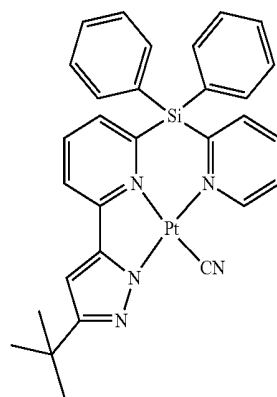
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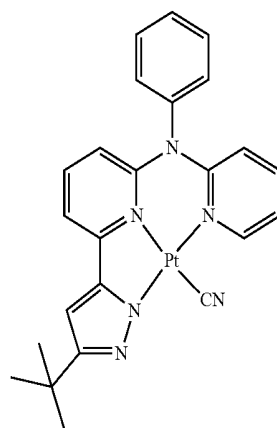
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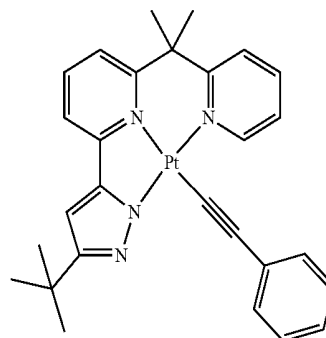
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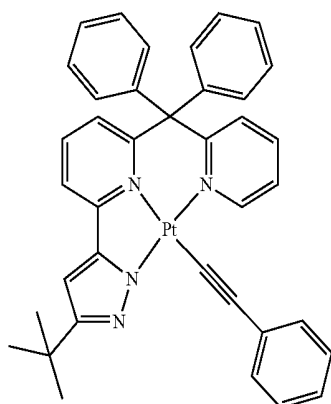
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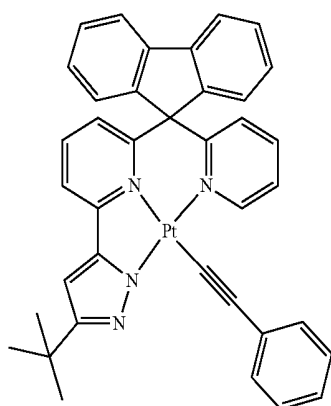


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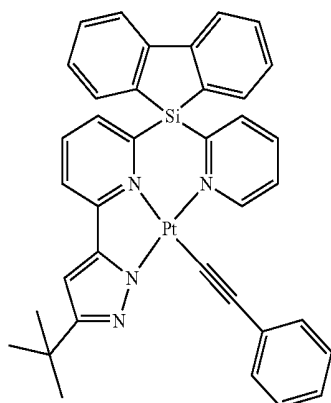
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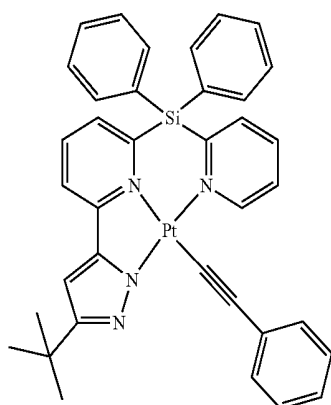
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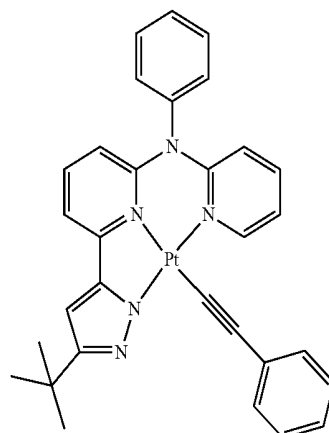


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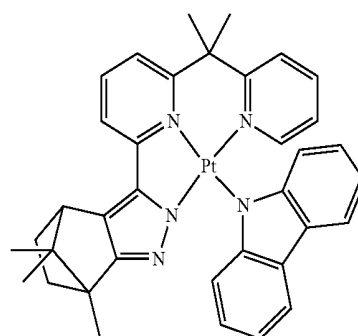


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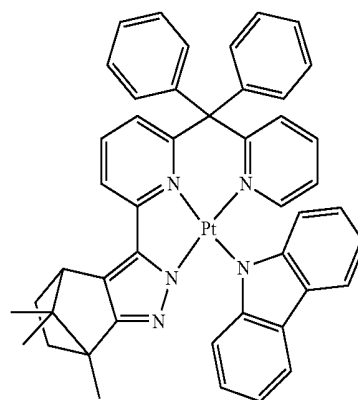
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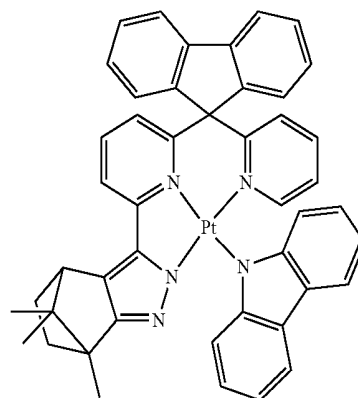
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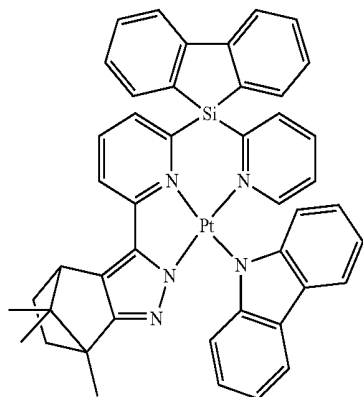


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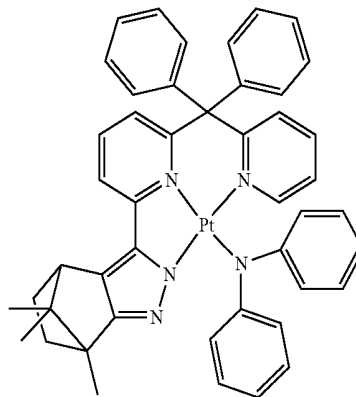
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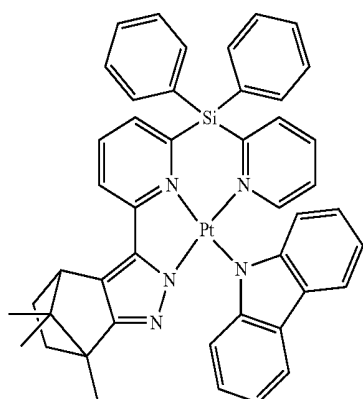


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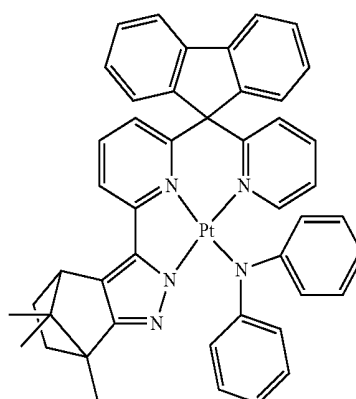
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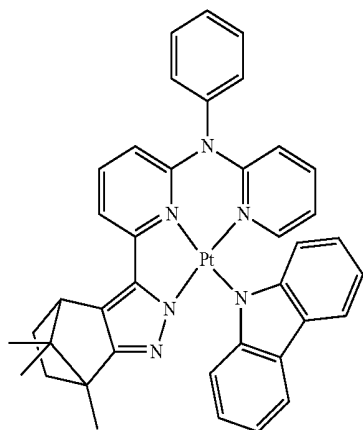
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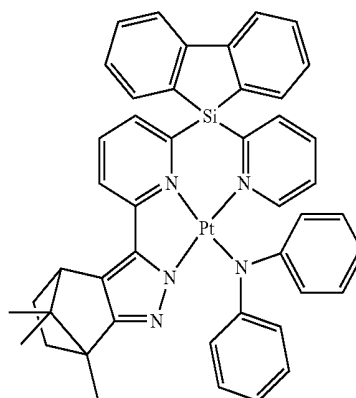
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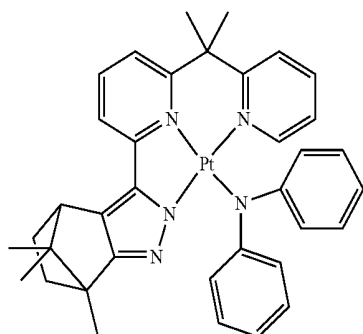
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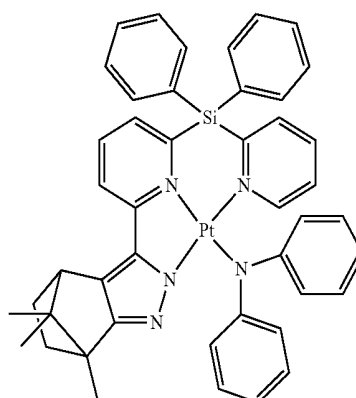
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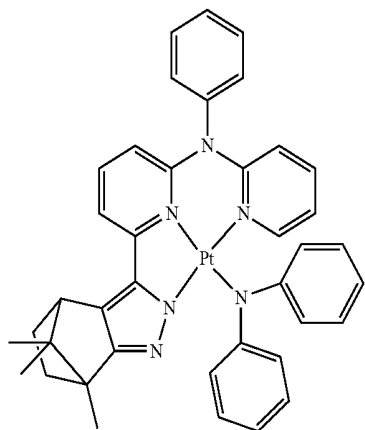


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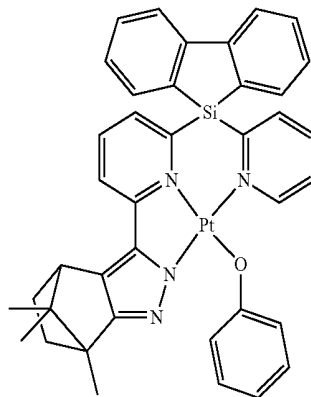
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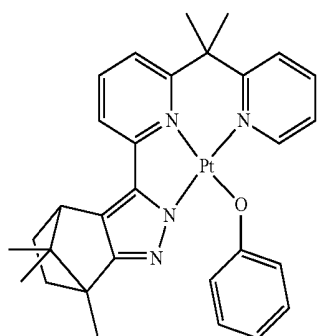


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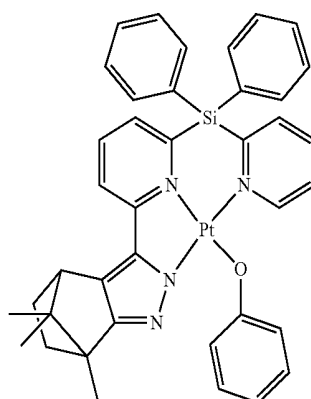
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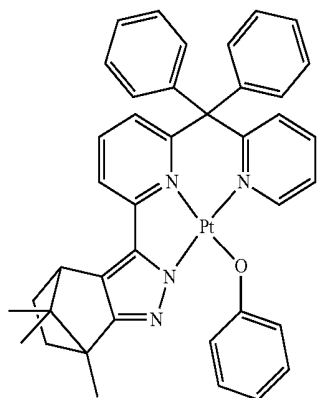
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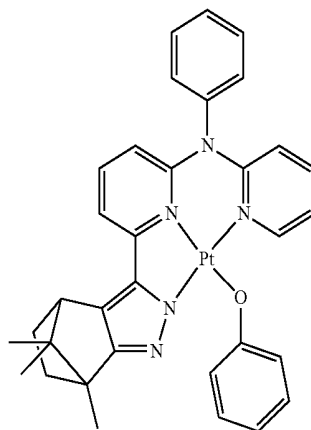
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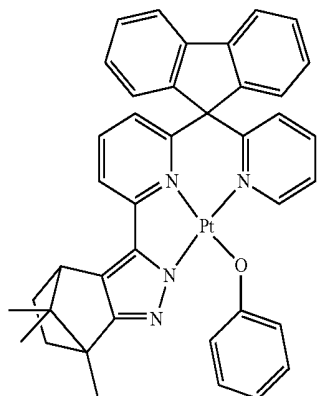
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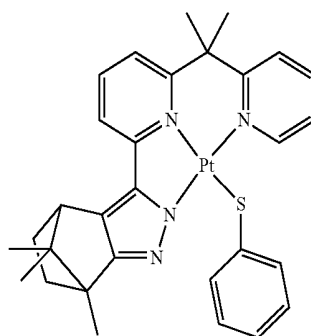
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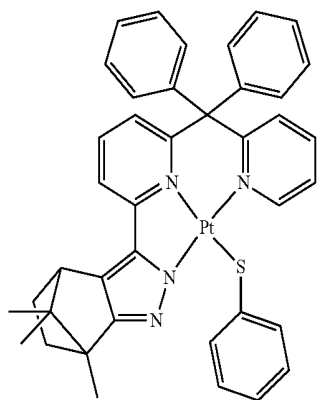


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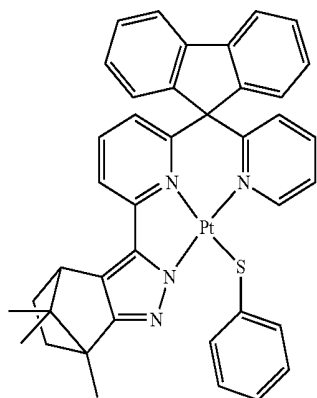


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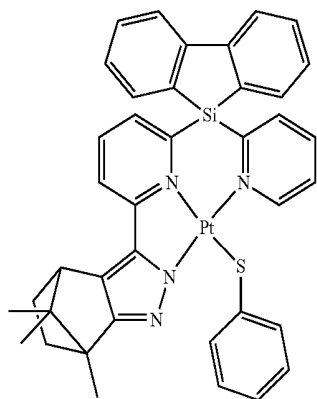
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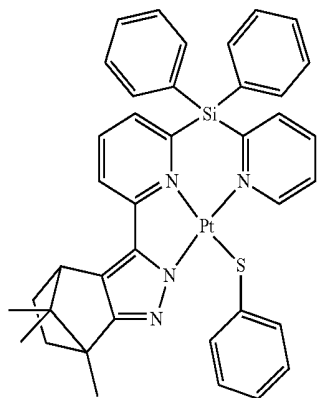
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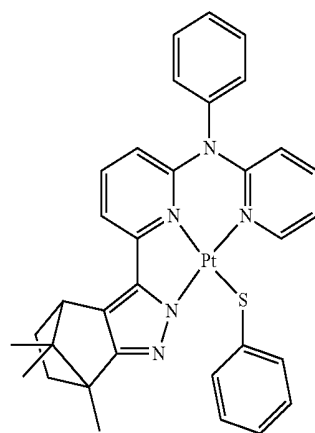


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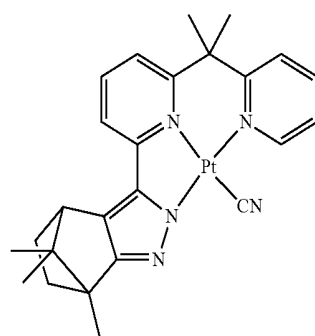


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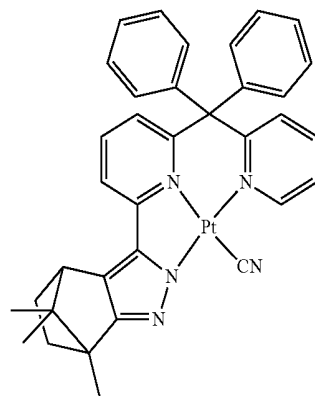
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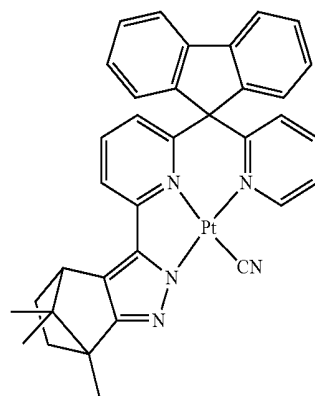
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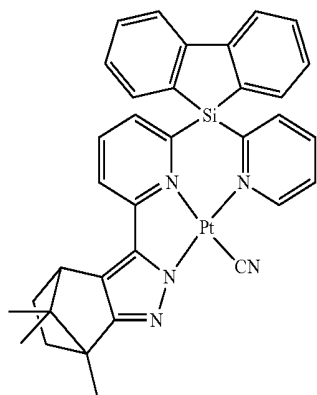


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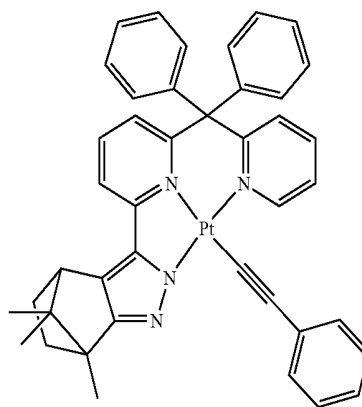
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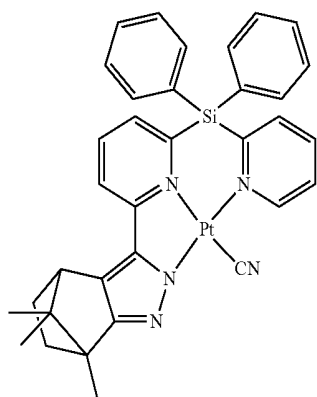


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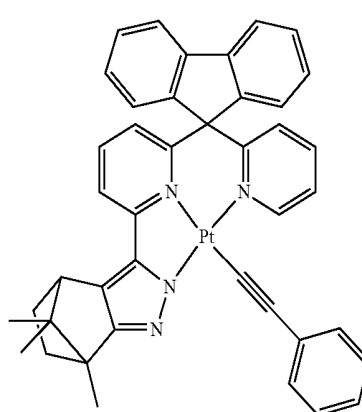
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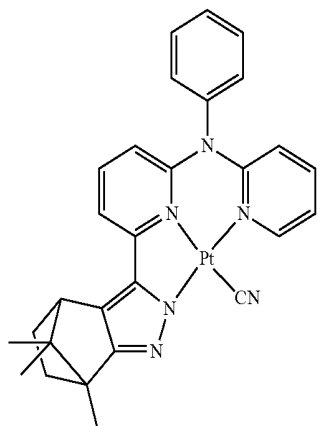
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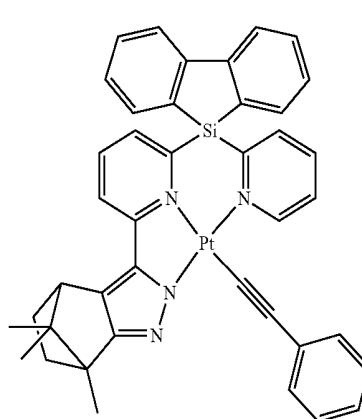
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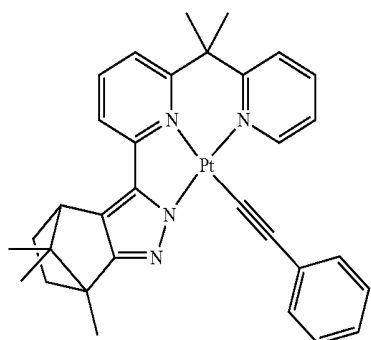
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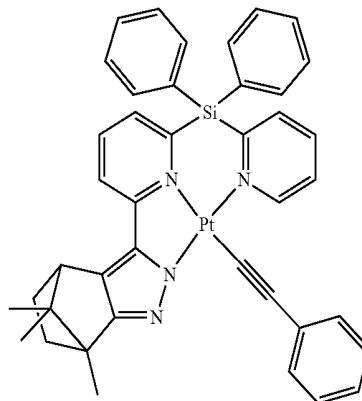
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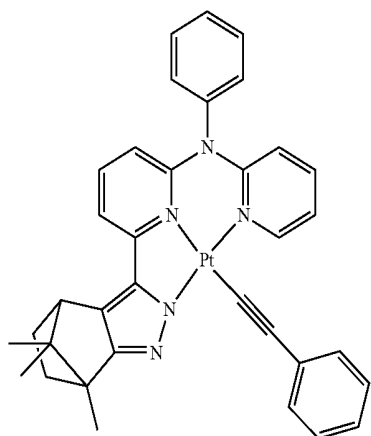


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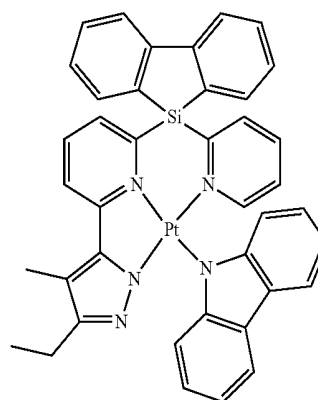
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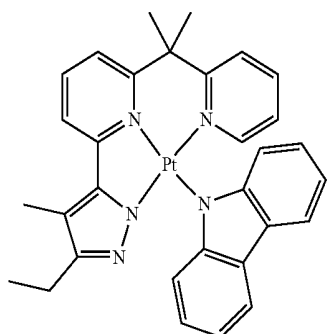


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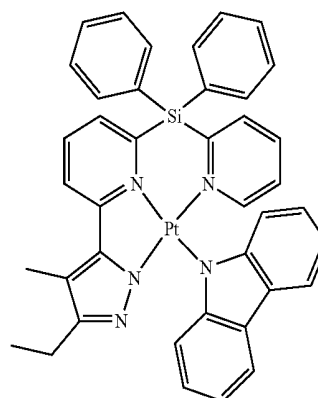
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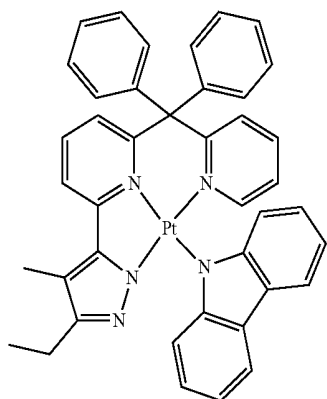
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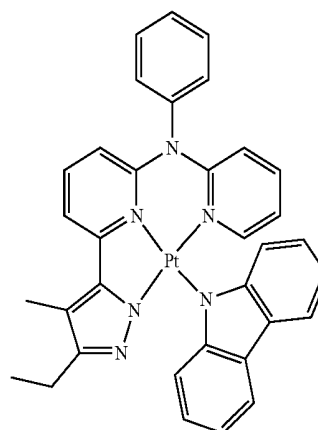
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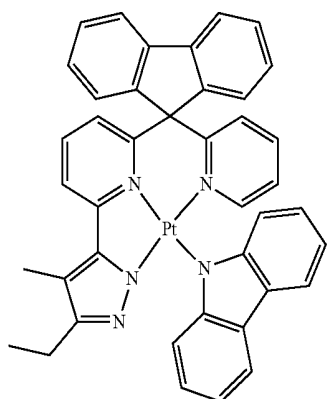
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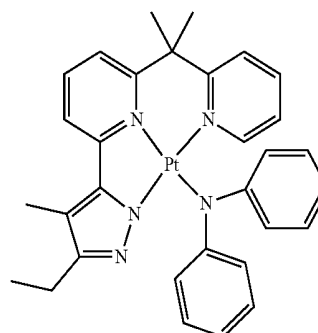
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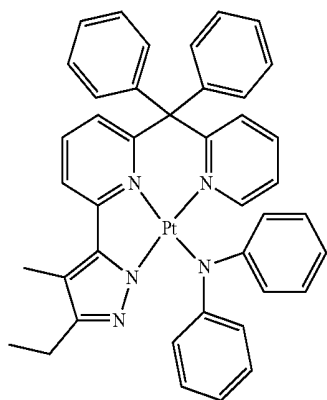


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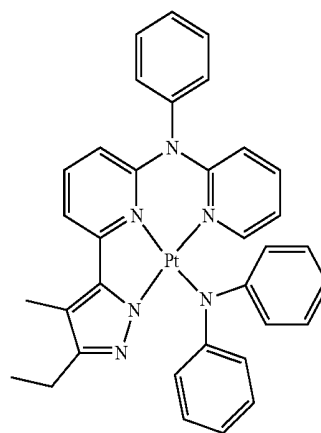
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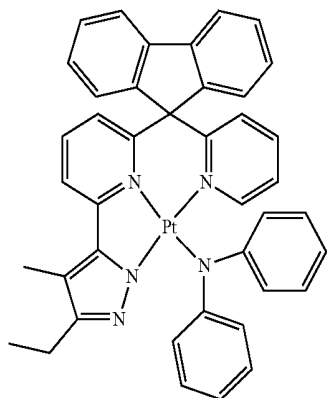
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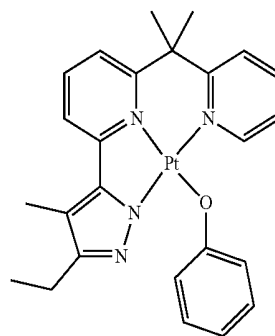


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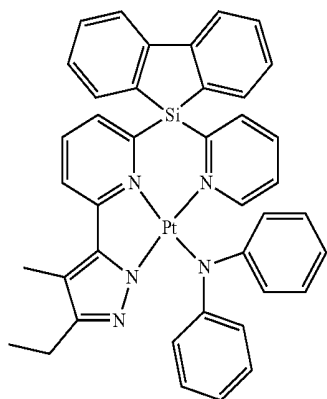


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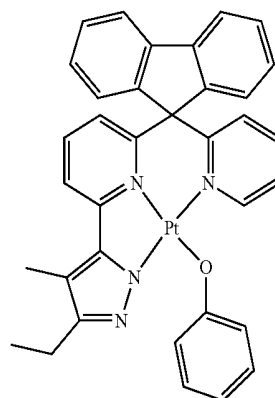
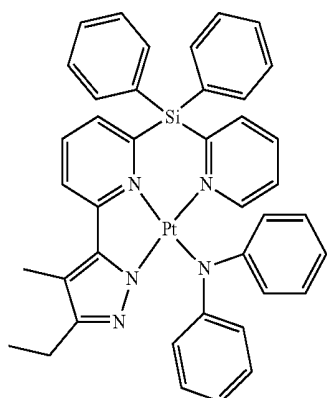
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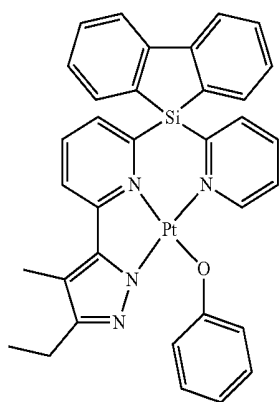


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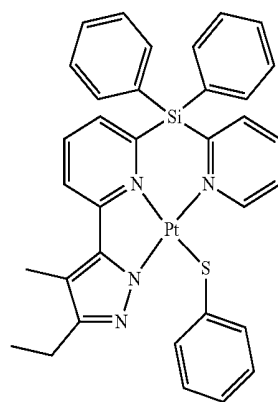


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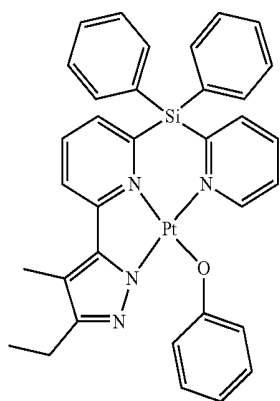


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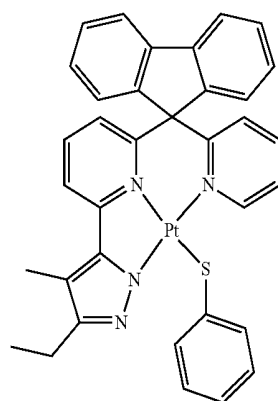
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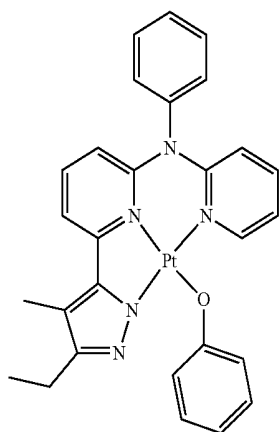
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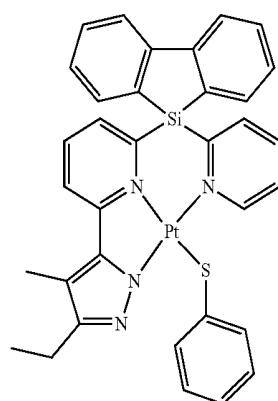
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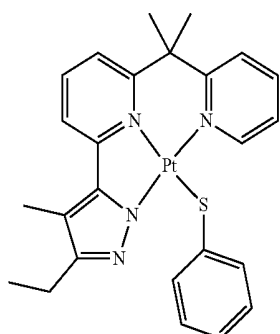
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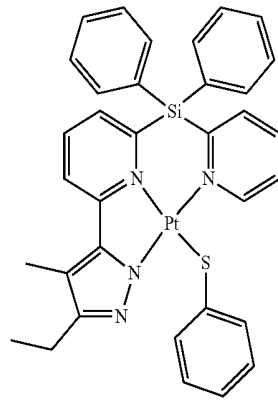
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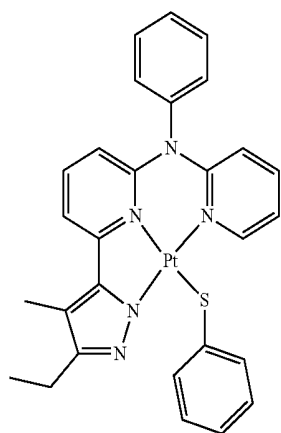


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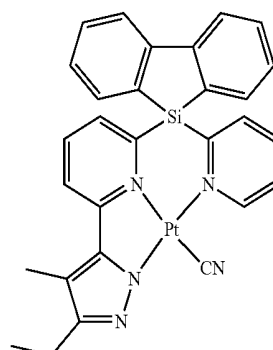
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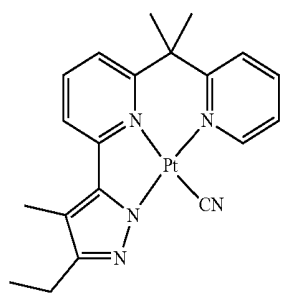


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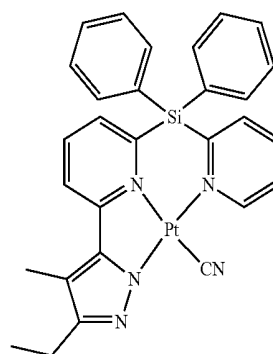
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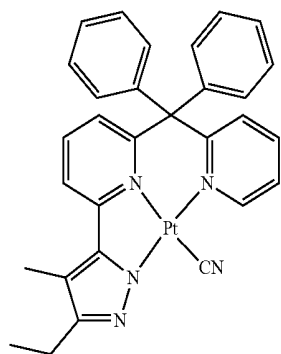
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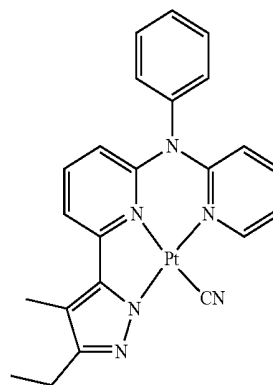
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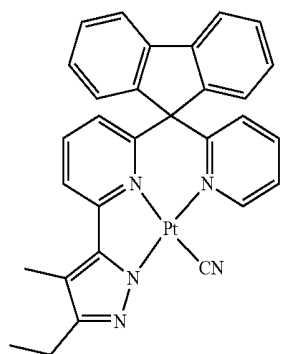
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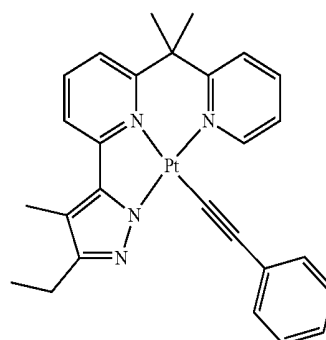
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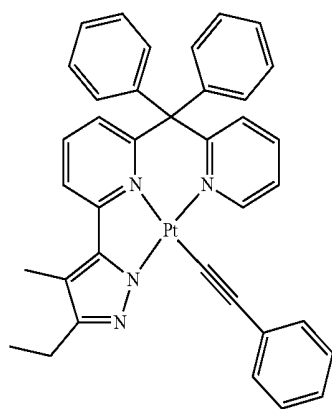


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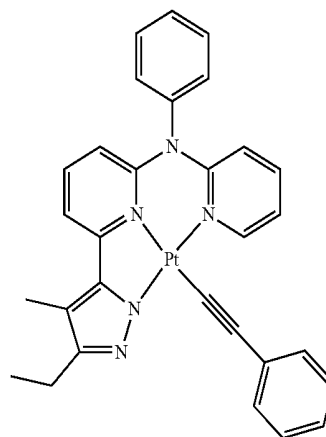
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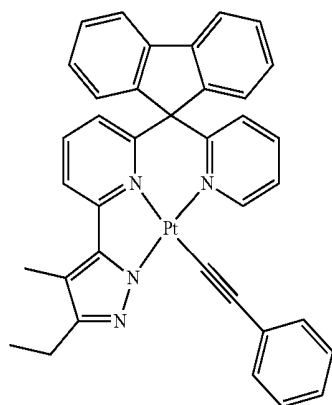


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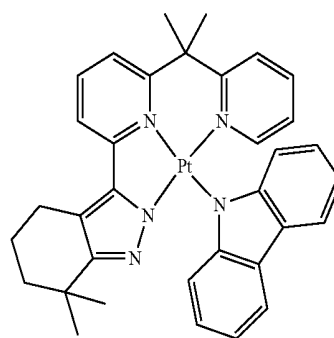
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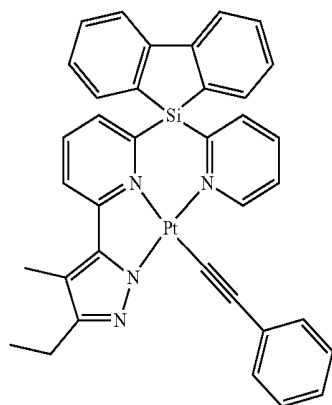
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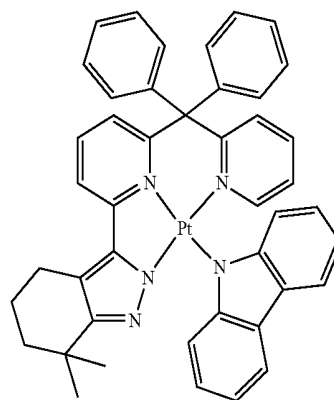
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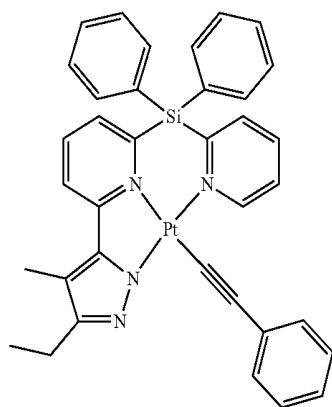
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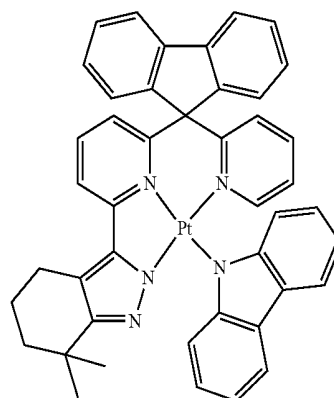
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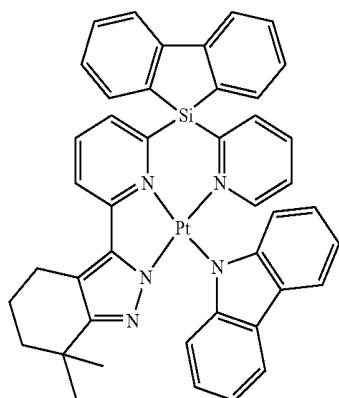


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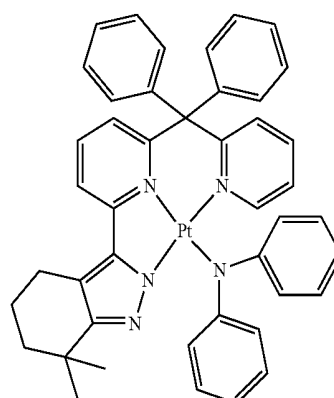
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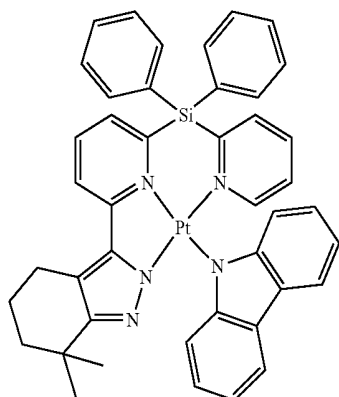


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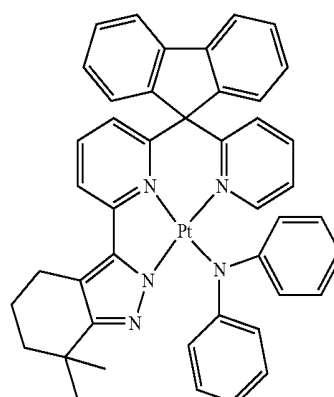
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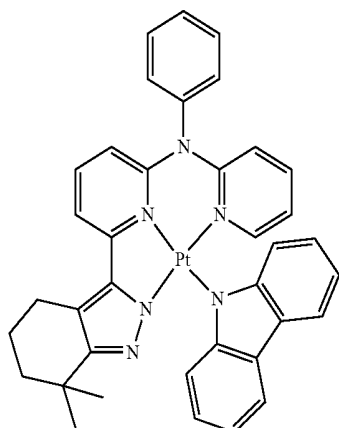
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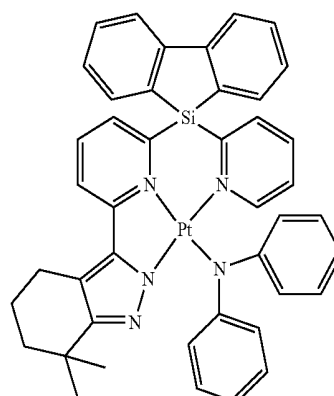
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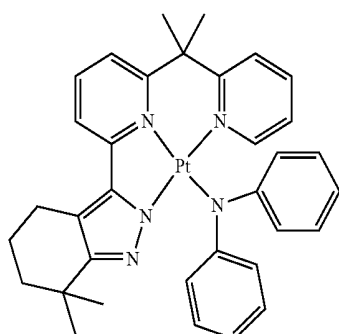
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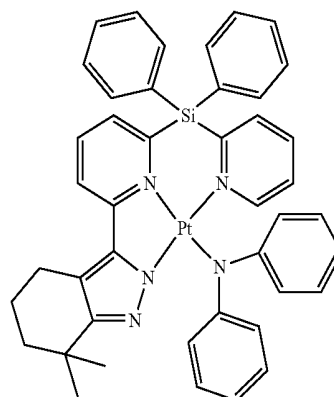
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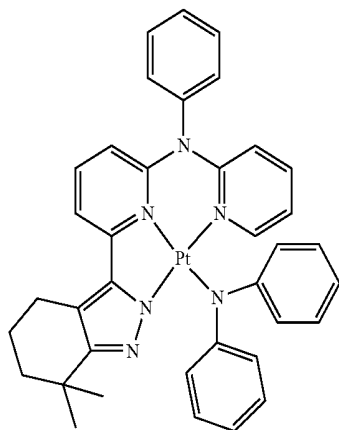


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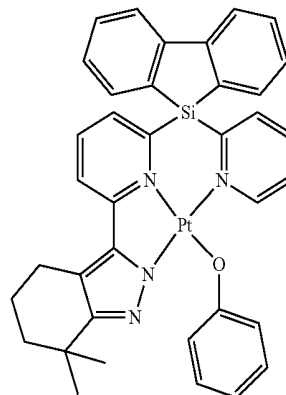
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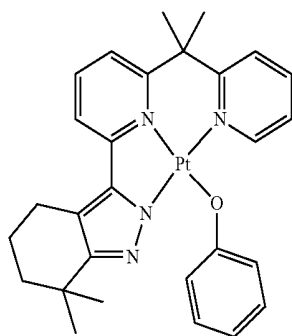


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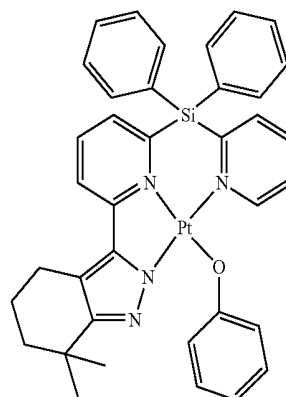
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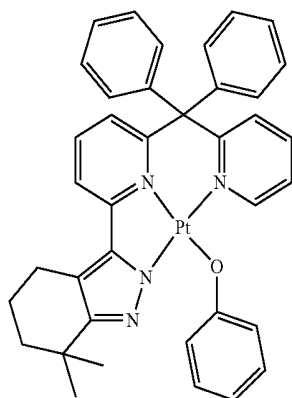
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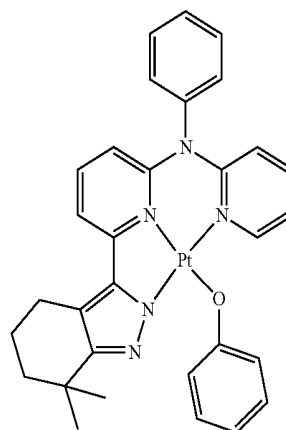
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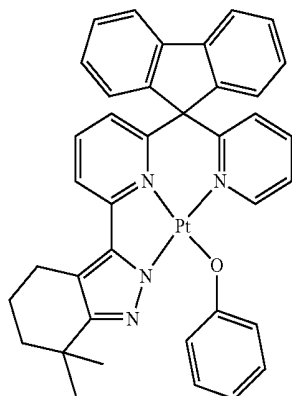
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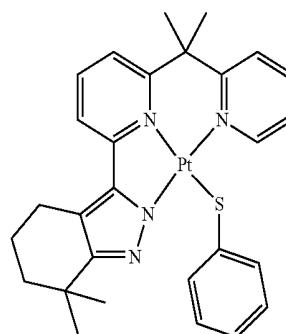
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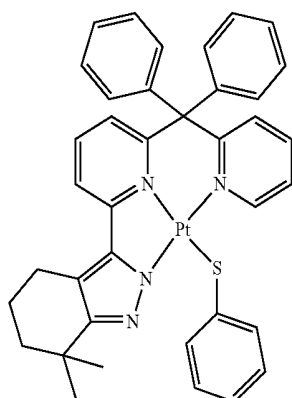


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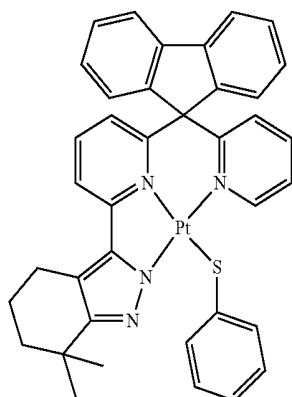


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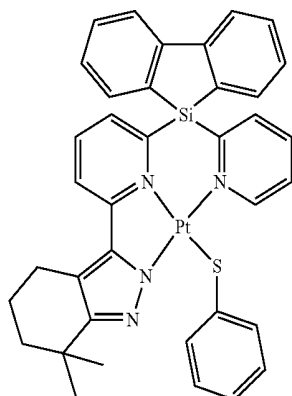
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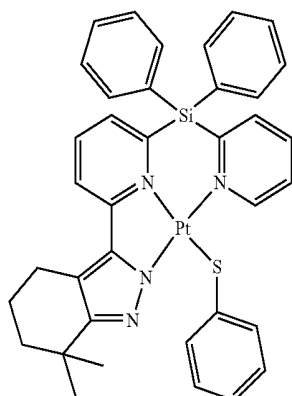
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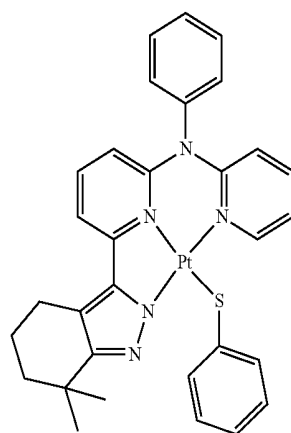


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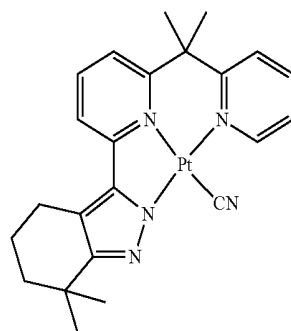


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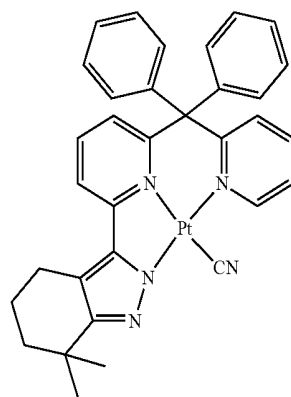
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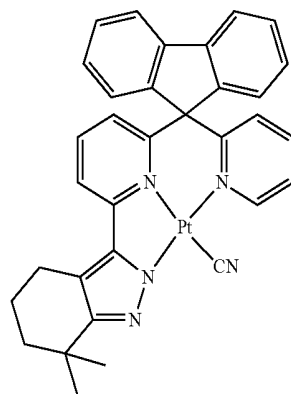
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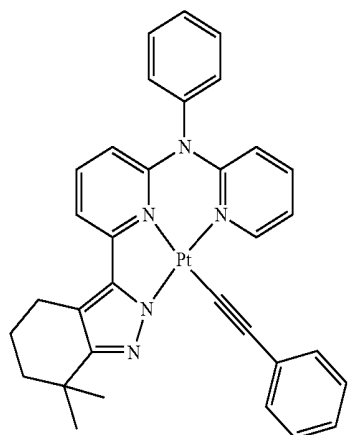


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[0204] Ligand L_1 in the organometallic compound represented by Formula 1 may be selected from ligands represented by Formula 2, provided that T_2 in Formula 2 is not a single bond. Hence, the organometallic compound represented by Formula 1 may emit light of a relatively short wavelength and have the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) energy levels that are suitable in migration of charges. Therefore, the quality of an electron device, e.g., an organic light-emitting device that includes the organometallic compound may be excellent.

[0205] In addition, Y_1 , Y_2 , and Y_3 in Formula 2 are each nitrogen. Thus, the organometallic compound represented by Formula 1 may provide excellent emission efficiency, which lead to improved emission efficiency of an electron device, e.g., an organic light-emitting device, including the organometallic compound.

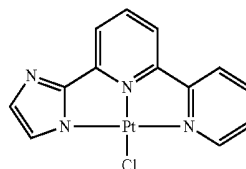
[0206] For example, the HOMO, LUMO, singlet (S_1), and triplet (T_1) energy levels of the organometallic compounds above and Compounds A and B were evaluated by using Gaussian according to a density functional theory (DFT) method (structure optimization is performed at a degree of B3LYP, and 6-31G(d,p)). The results thereof are shown in Table 1.

TABLE 1

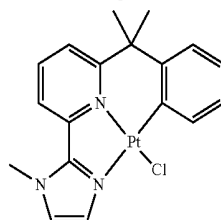
Compound No.	HOMO (eV)	LUMO (eV)	S_1 energy level (eV)	T_1 energy level (eV)
33	-4.864	-1.722	2.557	2.445
34	-4.902	-1.913	2.423	2.32
69	-4.920	-1.766	2.568	2.454
70	-4.960	-1.954	2.438	2.337
105	-4.850	-1.712	2.554	2.450
106	-4.876	-1.904	2.406	2.314
108	-4.772	-1.688	3.084	2.518
141	-4.872	-1.728	2.559	2.443
142	-4.906	-1.922	2.419	2.317
177	-4.897	-1.731	2.581	2.456
178	-4.922	-1.924	2.431	2.330

TABLE 1-continued

Compound No.	HOMO (eV)	LUMO (eV)	S_1 energy level (eV)	T_1 energy level (eV)
A	-5.488	-2.800	2.103	1.809
B	-5.094	-2.236	2.166	2.035



Compound A



Compound B

[0207] Referring to the results of Table 1, the organometallic compound of Formula 1 was found to have suitable electric characteristics as a dopant for use in an electron device, e.g., an organic light-emitting device.

[0208] Synthesis methods of the organometallic compound represented by Formula 1 may be recognizable by one of ordinary skill in the art by referring to Synthesis Examples provided below.

[0209] The organometallic compound represented by Formula 1 is suitable for use in an organic layer of an organic light-emitting device, for example, for use as a dopant in an emission layer of the organic layer. Thus, another aspect provides an organic light-emitting device that includes:

[0210] a first electrode;

[0211] a second electrode; and

[0212] an organic layer that is disposed between the first electrode and the second electrode,

[0213] wherein the organic layer includes an emission layer and at least one organometallic compound represented by Formula 1.

[0214] The organic light-emitting device may have, due to the inclusion of an organic layer including the organometallic compound represented by Formula 1, low driving voltage, high efficiency, high power, high quantum efficiency, long lifespan, and excellent color coordination.

[0215] The organometallic compound of Formula 1 may be used between a pair of electrodes of an organic light-emitting device. For example, the organometallic compound represented by Formula 1 may be included in the emission layer. In this regard, the organometallic compound may act as a dopant, and the emission layer may further include a host (that is, an amount of the organometallic compound represented by Formula 1 may be less than an amount of the host).

[0216] The expression that "(an organic layer) includes at least one of organometallic compounds" used herein may refer to an embodiment in which "(an organic layer) includes identical organometallic compounds represented by For-

mula 1” and to an embodiment in which “(an organic layer) includes two or more different organometallic compounds represented by Formula 1”.

[0217] For example, the organic layer may include only Compound 1 as the organometallic compound. In this regard, Compound 1 may be included only in the emission layer of the organic light-emitting device. In various embodiments, the organic layer may include, as the organometallic compound, Compound 1 and Compound 2. In this regard, Compound 1 and Compound 2 may be included in an identical layer (for example, Compound 1 and Compound 2 both may be in an emission layer).

[0218] The first electrode may be an anode, which is a hole injection electrode, and the second electrode may be a cathode, which is an electron injection electrode; or the first electrode may be a cathode, which is an electron injection electrode, and the second electrode may be an anode, which is a hole injection electrode.

[0219] For example, in the organic light-emitting device, the first electrode may be an anode, the second electrode may be a cathode, and the organic layer may further include a hole transport region disposed between the first electrode and the emission layer and an electron transport region disposed between the emission layer and the second electrode, wherein the hole transport region may include a hole injection layer, a hole transport layer, an electron blocking layer, or any combinations thereof, and the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combinations thereof.

[0220] The term “organic layer” as used herein refers to a single layer and/or a plurality of layers disposed between the first electrode and the second electrode of the organic light-emitting device. The “organic layer” may include, in addition to an organic compound, an organometallic complex including metal.

[0221] FIG. 1 is a schematic view of an organic light-emitting device 10 according to an embodiment. Hereinafter, the structure of an organic light-emitting device according to an embodiment and a method of manufacturing an organic light-emitting device, according to an embodiment, will be described in connection with FIG. 1. The organic light-emitting device 10 includes a first electrode 11, an organic layer 15, and a second electrode 19, which are sequentially stacked in this stated order.

[0222] A substrate may be additionally disposed under the first electrode 11 or above the second electrode 19. For use as the substrate, any substrate that is used in general organic light-emitting devices may be used, and the substrate may be a glass substrate or a transparent plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and water-resistance.

[0223] The first electrode 11 may be formed by vacuum depositing or sputtering a material for forming the first electrode 11 on the substrate. The first electrode 11 may be an anode. The material for forming the first electrode 11 may be selected from materials with a high work function to facilitate hole injection. The first electrode 11 may be a reflective electrode, a semi-transmissive electrode, or a

transmissive electrode. The material for forming the first electrode 11 may be an indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), or zinc oxide (ZnO). In various embodiments, the material for forming the first electrode 11 may be metal, such as magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), or magnesium-silver (Mg—Ag).

[0224] The first electrode 11 may have a single-layered structure or a multi-layered structure including two or more layers. For example, the first electrode 11 may have a three-layered structure of ITO/Ag/ITO, but the structure of the first electrode 11 is not limited thereto.

[0225] The organic layer 15 is disposed on the first electrode 11.

[0226] The organic layer 15 may include a hole transport region, an emission layer, and an electron transport region.

[0227] The hole transport region may be disposed between the first electrode 11 and the emission layer.

[0228] The hole transport region may include at least one selected from a hole injection layer, a hole transport layer, an electron blocking layer, and a buffer layer.

[0229] The hole transport region may include only either a hole injection layer or a hole transport layer. In various embodiments, the hole transport region may have a structure of hole injection layer/hole transport layer or hole injection layer/hole transport layer/electron blocking layer, which are sequentially stacked in this stated order from the first electrode 11.

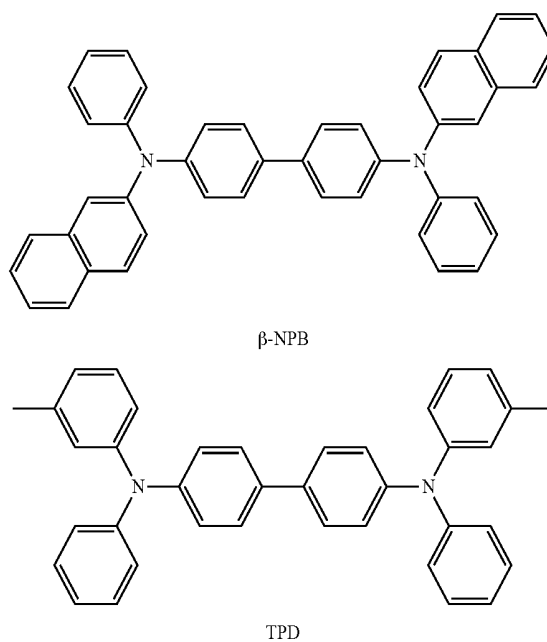
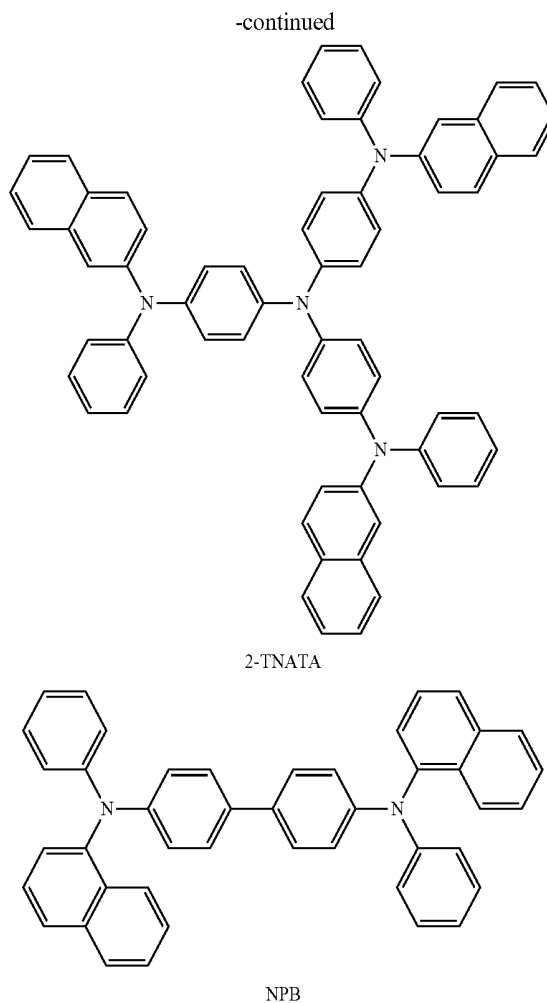
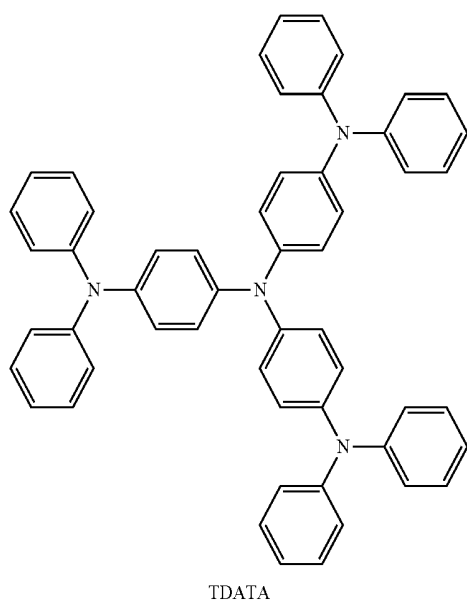
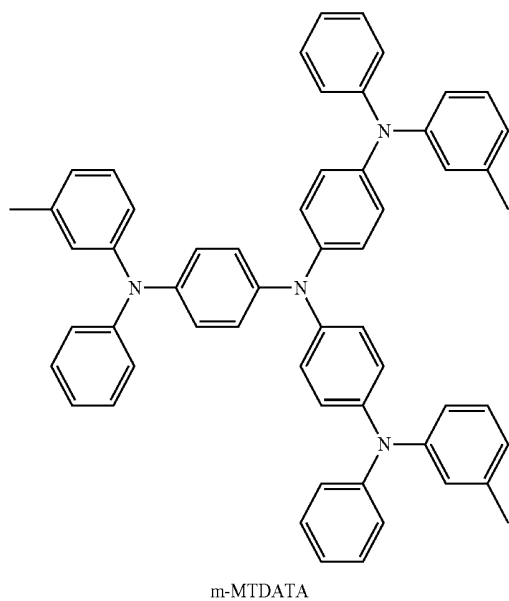
[0230] When the hole transport region includes a hole injection layer, the hole injection layer may be formed on the first electrode 11 by using one or more suitable methods, for example, vacuum deposition, spin coating, casting, and/or Langmuir-Blodgett (LB) deposition.

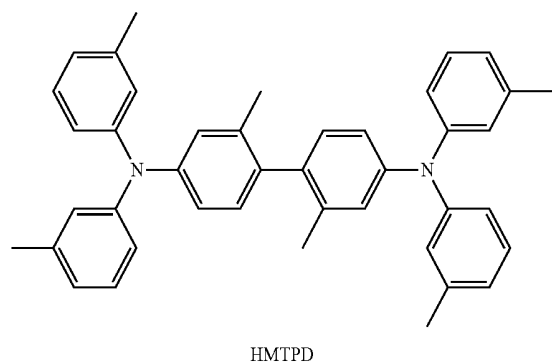
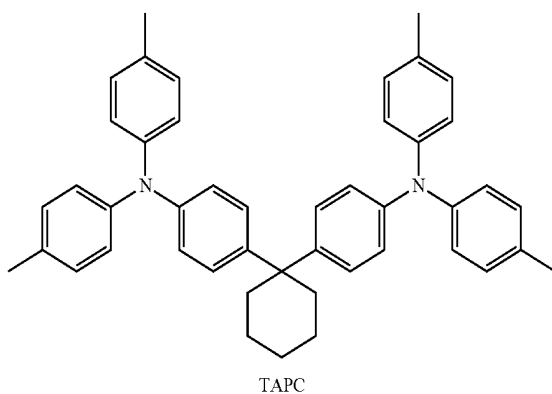
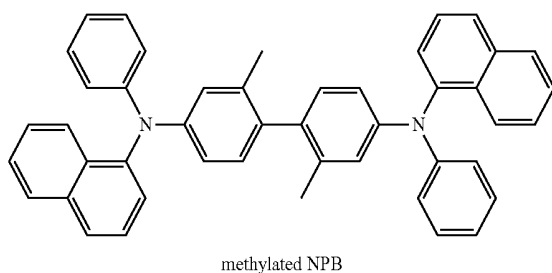
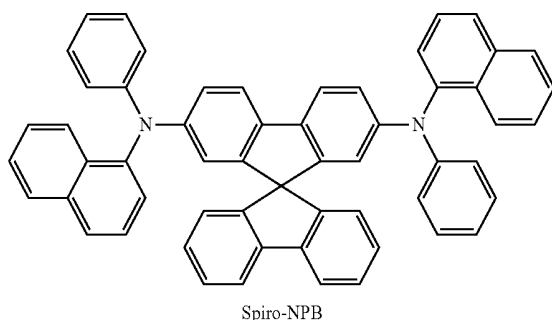
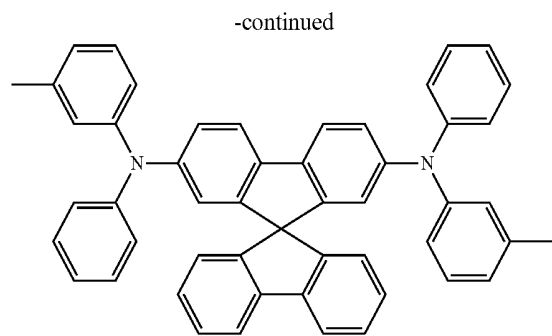
[0231] When a hole injection layer is formed by vacuum deposition, the deposition conditions may vary according to a material that is used to form the hole injection layer, and the structure and thermal characteristics of the hole injection layer. For example, the deposition conditions may include a deposition temperature of about 100 to about 500° C., a vacuum pressure of about 10^{-8} to about 10^{-3} torr, and a deposition rate of about 0.01 to about 100 Angstroms per second ($\text{\AA}/\text{sec}$). However, the deposition conditions are not limited thereto.

[0232] When the hole injection layer is formed using spin coating, coating conditions may vary according to the material used to form the hole injection layer, and the structure and thermal properties of the hole injection layer. For example, a coating speed may be from about 2,000 revolutions per minute (rpm) to about 5,000 rpm, and a temperature at which a heat treatment is performed to remove a solvent after coating may be from about 80° C. to about 200° C. However, the coating conditions are not limited thereto.

[0233] Conditions for forming a hole transport layer and an electron blocking layer may be understood by referring to conditions for forming the hole injection layer.

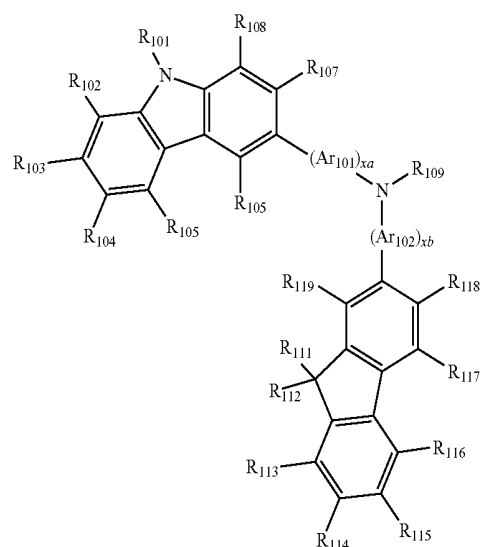
[0234] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB, β -NPB, TPD, Spiro-TPD, Spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4''-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzene sulfonic acid (Pani/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (Pani/CSA), polyaniline/poly(4-styrenesulfonate) (Pani/PSS), a compound represented by Formula 201 below, and a compound represented by Formula 202 below:



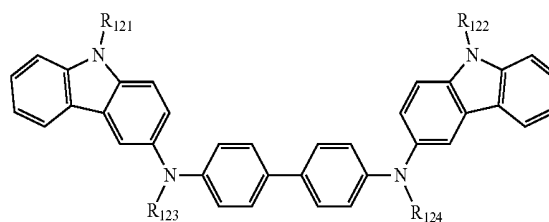


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Formula 201



Formula 202



[0235] wherein in Formula 201, Ar₁₀₁ and Ar₁₀₂ may be each independently selected from

[0236] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an acenaphthylene group, a fluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthrenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, and a pentacenylene group; and

[0237] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an acenaphthylene group, a fluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthrenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, and a pentacenylene group, each substituted with at least one selected from a deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₃-C₁₀ cycloalkenyl

group, a C₁-C₁₀ heterocycloalkyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

[0238] In Formula 201, xa and xb may be each independently an integer selected from 0 to 5. Alternatively, xa and xb may be each independently an integer selected from 0, 1, and 2. In some embodiments, xa may be 1 and xb may be 0, but embodiments are not limited thereto.

[0239] R₁₀₁ to R₁₀₈, R₁₁₁ to R₁₁₉, and R₁₂₁ to R₁₂₄ in Formulae 201 and 202 may be each independently selected from

[0240] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₁₀ alkyl group (e.g., a methyl group, an ethyl group, a propyl group, a butyl group, pentyl group, or a hexyl group), and a C₁-C₁₀ alkoxy group (e.g., a methoxy group, an ethoxy group, a propoxy group, a butoxy group, or a pentoxy group);

[0241] a C₁-C₁₀ alkyl group and a C₁-C₁₀ alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, and a phosphoric acid group or a salt thereof;

[0242] a phenyl group, a naphthyl group, an anthracenyl group, a fluorenyl group, and a pyrenyl group; and

[0243] a phenyl group, a naphthyl group, an anthracenyl group, a fluorenyl group, and a pyrenyl group, each substituted with at least one selected from a deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₁₀ alkyl group, and a C₁-C₁₀ alkoxy group, but embodiments are not limited thereto.

[0244] R₁₀₉ in Formula 201 may be selected from

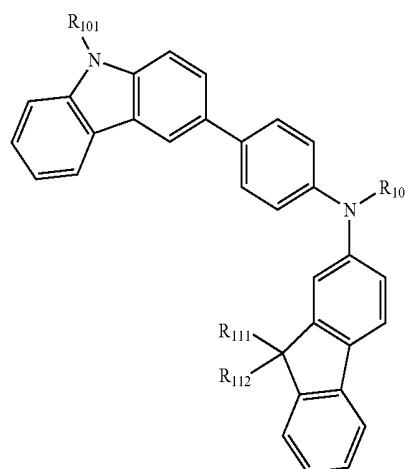
[0245] a phenyl group, a naphthyl group, an anthracenyl group, and a pyridinyl group; and

[0246] a phenyl group, a naphthyl group, an anthracenyl group and a pyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt

thereof, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a naphthyl group, an anthracenyl group, and a pyridinyl group.

[0247] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A, but embodiments are not limited thereto:

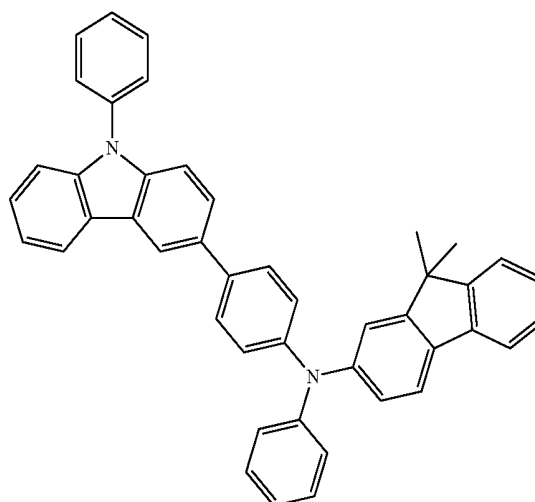
Formula 201A



[0248] R₁₀₁, R₁₁₁, R₁₁₂, and R₁₀₉ in Formula 201A may be the same as those described herein.

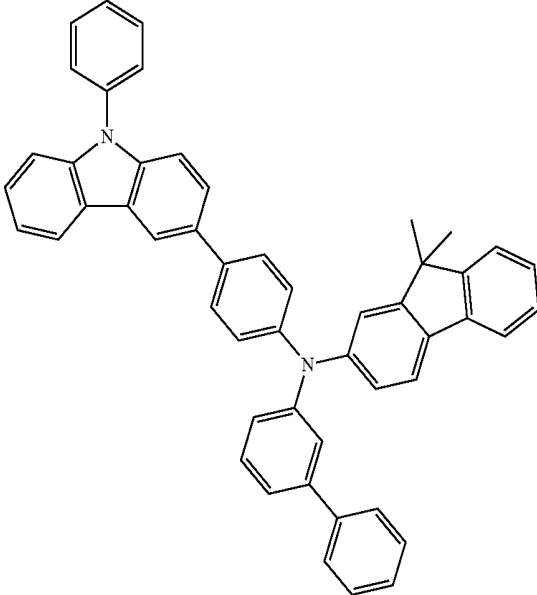
[0249] For example, the compound represented by Formula 201 and the compound represented by Formula 202 may include Compounds HT1 to HT20, but embodiments are not limited thereto:

HT1



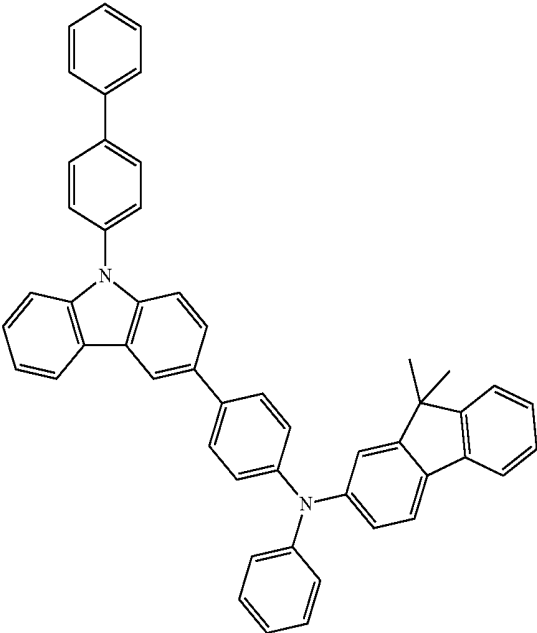
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HT2

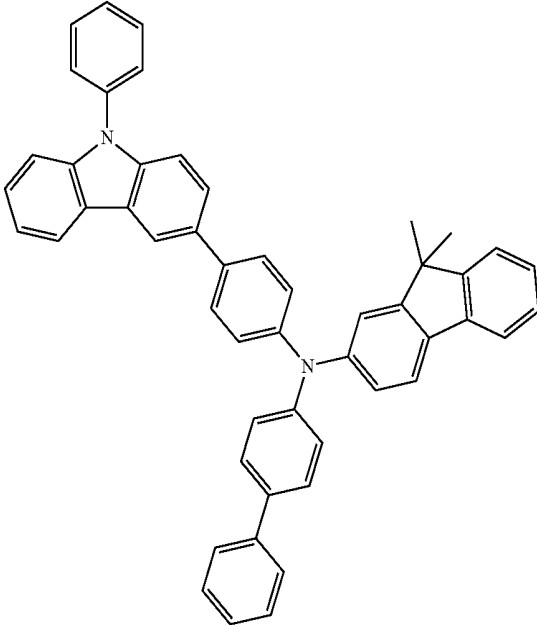


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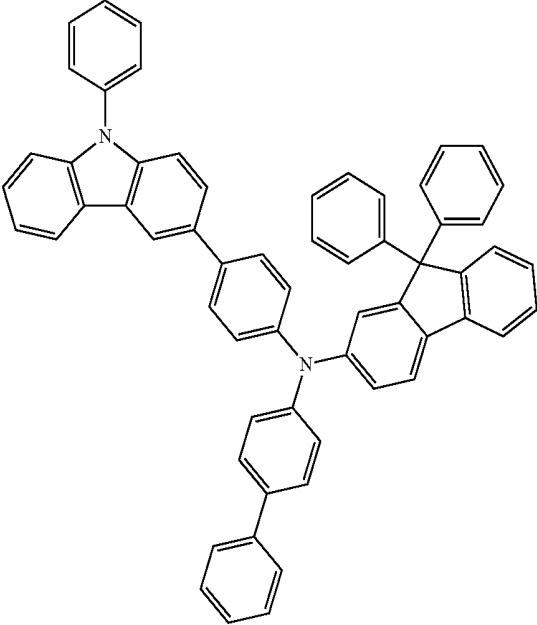
HT4



HT3

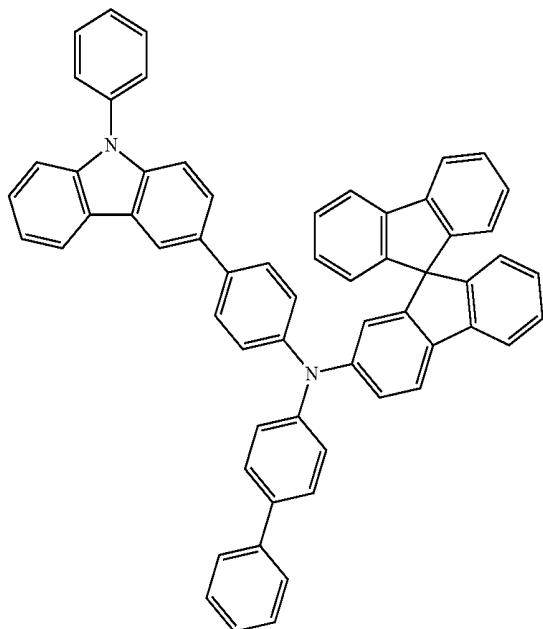


HT5



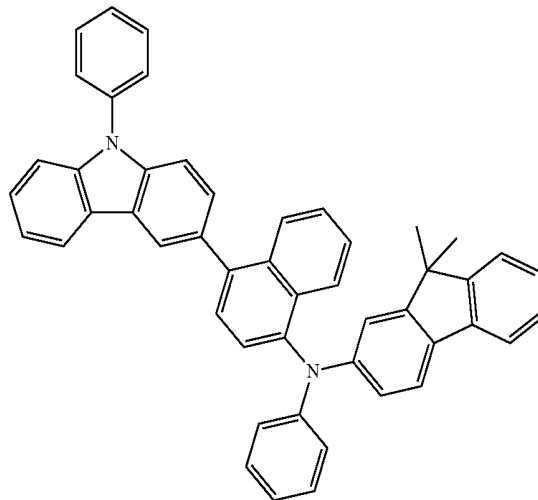
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HT6



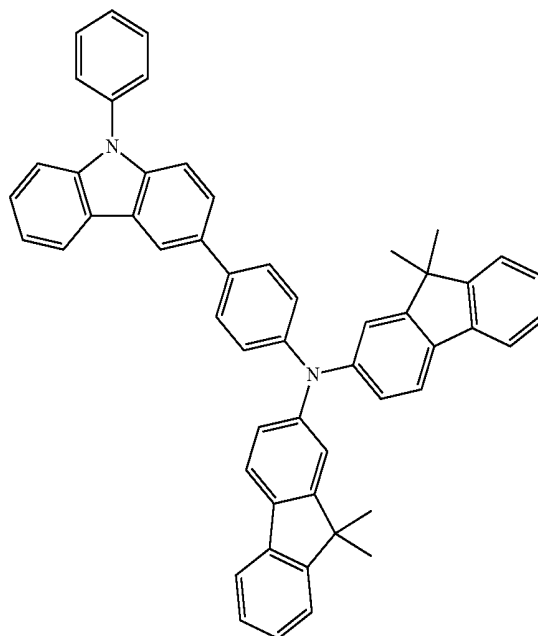
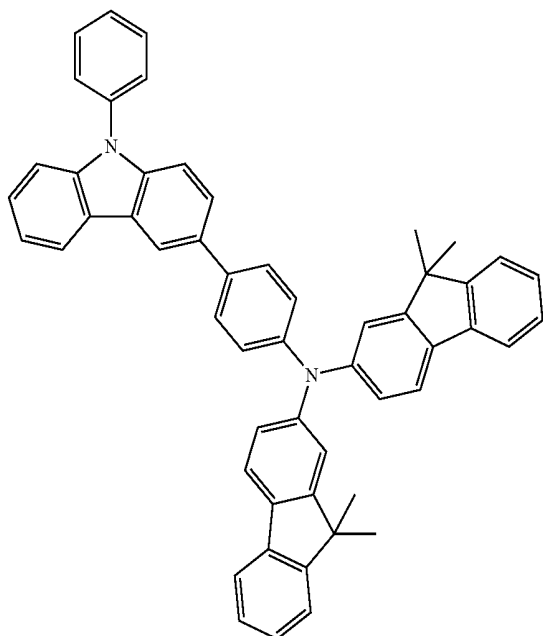
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HT8



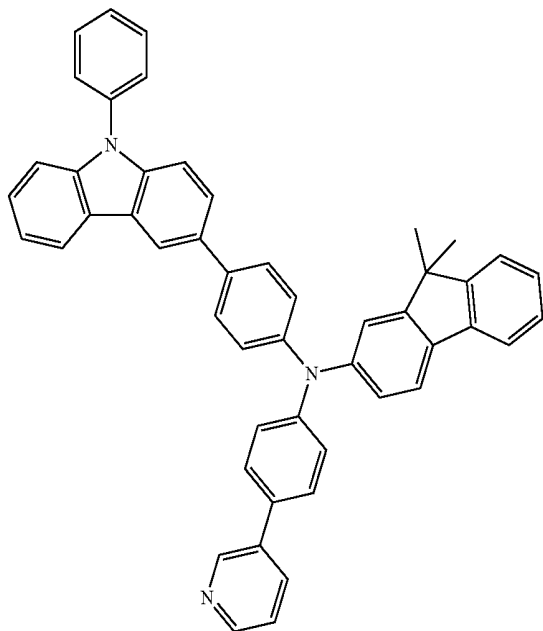
HT9

HT7



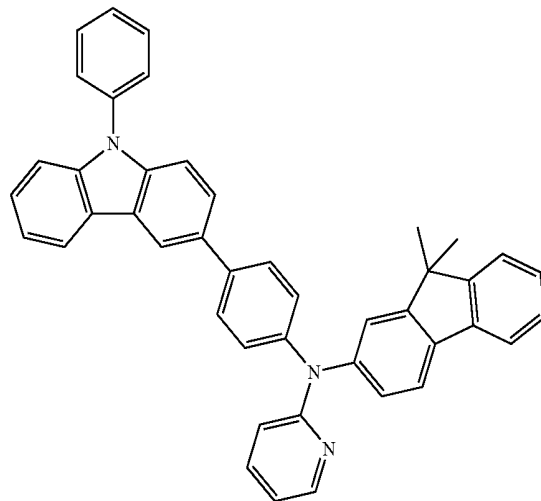
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HT10

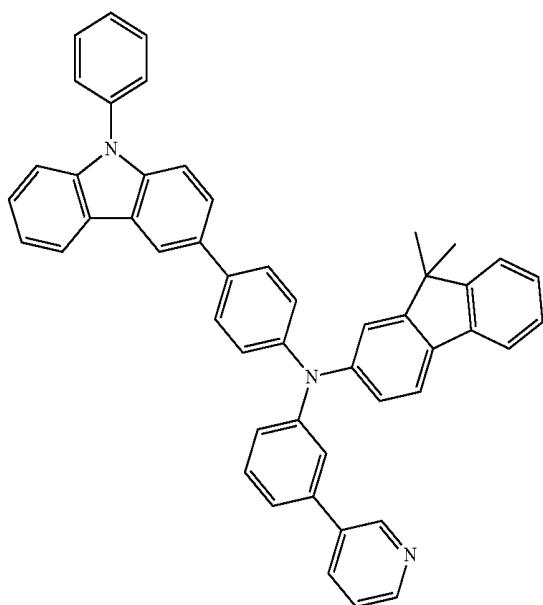


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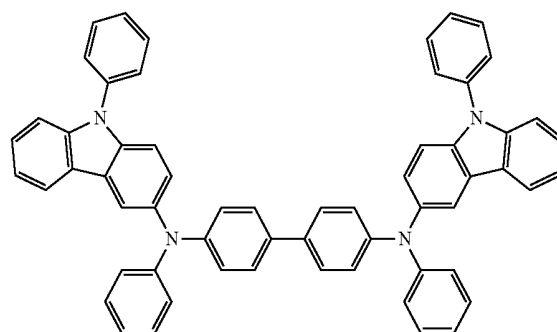
HT12



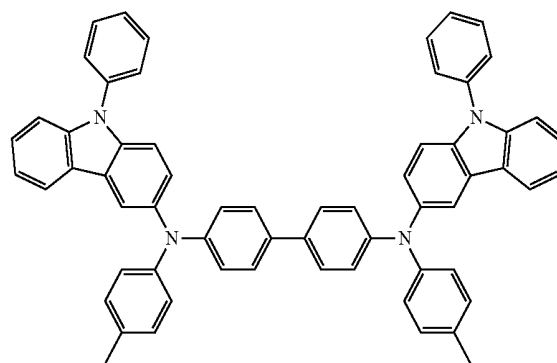
HT11



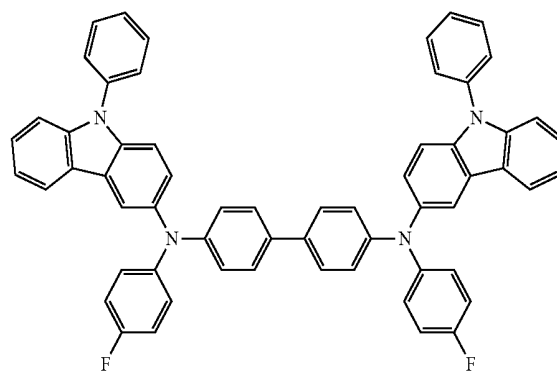
HT13



HT14

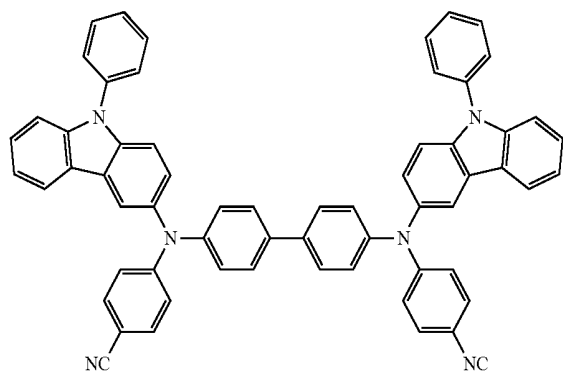


HT15

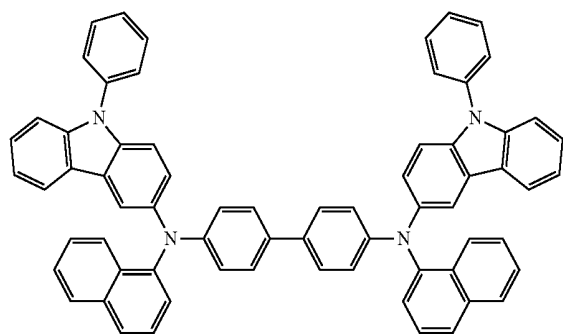


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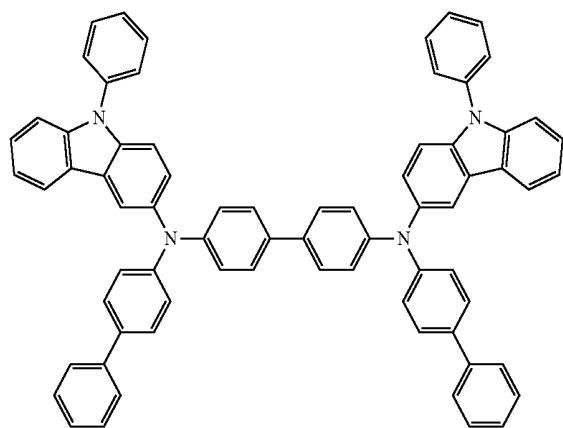
HT16



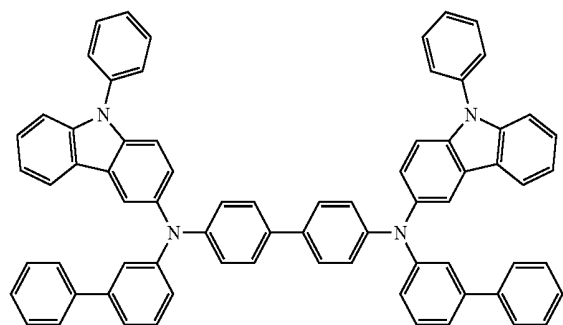
HT17



HT18

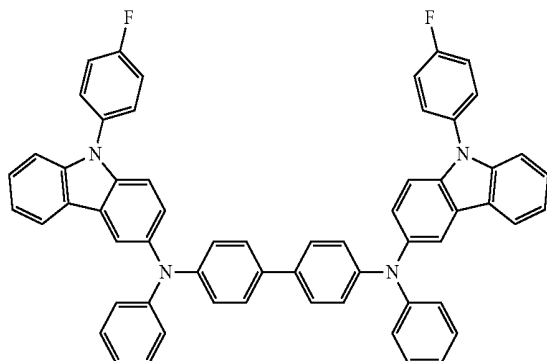


HT19



-continued

HT20

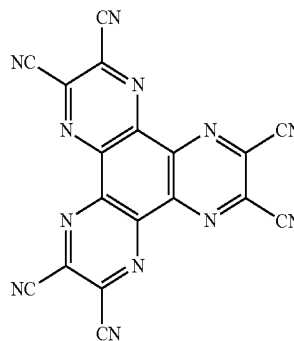


[0250] A thickness of the hole transport region may be in a range of about 100 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å. When the hole transport region includes at least one of a hole injection layer and a hole transport layer, a thickness of the hole injection layer may be in a range of about 100 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å, and a thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, for example about, 100 Å to about 1,500 Å. While not wishing to be bound by theory, it is understood that when the thickness values of the hole transport region, the hole injection layer and the hole transporting layer are within these ranges, satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

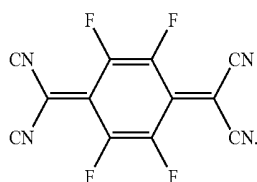
[0251] The hole transport region may further include, in addition to these materials, a charge-generation material for the improvement of conductive properties. The charge-generation material may be homogeneously or non-homogeneously dispersed in the hole transport region.

[0252] The charge-generation material may be, for example, a p-dopant. The p-dopant may be one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments are not limited thereto. Non-limiting examples of the p-dopant are a quinone derivative, such as tetracyanoquinonedimethane (TCNQ) or 2,3,5,6-tetrafluoro-tetracyano-1,4-benzoquinonedimethane (F4-TCNQ); a metal oxide, such as a tungsten oxide or a molybdenum oxide; and a cyano group-containing compound, such as Compound HT-D1 below, but are not limited thereto:

Compound HT-D1



-continued



F4-TCNQ

[0253] The hole transport region may include a buffer layer.

[0254] Also, the buffer layer may compensate for an optical resonance distance according to a wavelength of light emitted from the emission layer, and thus, efficiency of a formed organic light-emitting device may be improved.

[0255] Then, an emission layer may be formed on the hole transport region by vacuum deposition, spin coating, casting, LB deposition, or the like. When the emission layer is formed by vacuum deposition or spin coating, the deposition or coating conditions may be similar to those applied to form the hole injection layer although the deposition or coating conditions may vary according to the material that is used to form the emission layer.

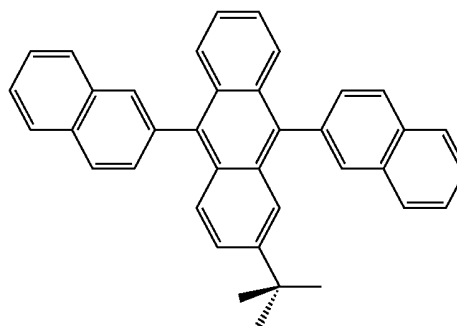
[0256] Meanwhile, when the hole transport region includes an electron blocking layer, a material for the electron blocking layer may be selected from materials for the hole transport region described above and materials for a host to be explained later.

[0257] However, the material for the electron blocking layer is not limited thereto. For example, when the hole transport region includes an electron blocking layer, a material for the electron blocking layer may be mCP, which will be explained later.

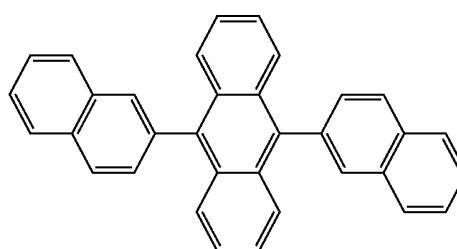
[0258] The emission layer may include a host and a dopant, and the dopant may include the organometallic compound represented by Formula 1.

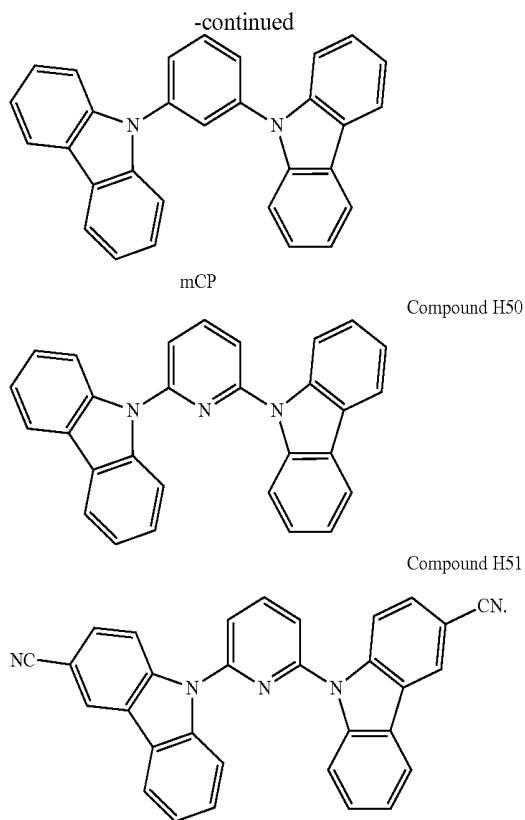
[0259] The host may include at least one selected from TPBi, TBADN, ADN (also referred to as "DNA"), CBP, CDBP, TCP, mCP, Compound H50, and Compound H51:

-continued



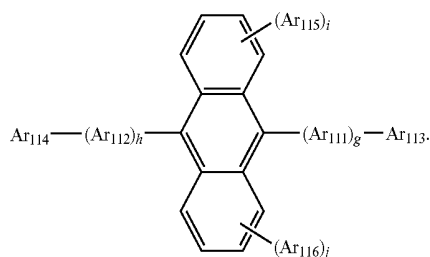
TBADN





[0260] In some embodiments, the host may further include a compound represented by Formula 301:

Formula 301



[0261] wherein, in Formula 301, Ar_{111} and Ar_{112} may be each independently selected from

[0262] a phenylene group, a naphthylene group, a phenanthrenylene group, and a pyrenylene group; and

[0263] a phenyl group, a phenylene group substituted with at least one selected from a naphthyl group and an anthracenyl group, a naphthylene group, a phenanthrenylene group, and a pyrenylene group.

[0264] Ar_{113} to Ar_{116} in Formula 301 may be each independently selected from

[0265] a C_1 - C_{10} alkyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, and a pyrenyl group; and

[0266] a phenyl group, a phenyl group substituted with at least one selected from a naphthyl group and an anthracenyl group, a naphthyl group, a phenanthrenyl group, and a pyrenyl group.

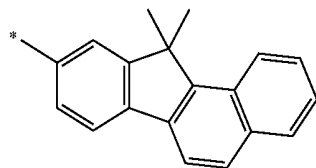
[0267] g , h , i , and j in Formula 301 may be each independently an integer selected from 0 to 4, for example, 0, 1, or 2.

[0268] Ar_{113} to Ar_{116} in Formula 301 may be each independently selected from

[0269] a C_1 - C_{10} alkyl group substituted with at least one selected from a phenyl group, a naphthyl group, and an anthracenyl group;

[0270] a phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group;

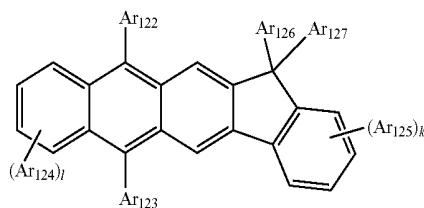
[0271] a phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1 - C_{60} alkyl group, a C_2 - C_{60} alkenyl group, a C_2 - C_{60} alkynyl group, a C_1 - C_{60} alkoxy group, a phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group; and



but embodiments are not limited thereto.

[0272] In some embodiments, the host may include a compound represented by Formula 302:

Formula 302



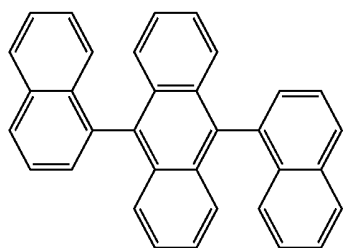
[0273] Ar_{122} to Ar_{125} in Formula 302 may be the same as described herein in connection with Ar_{113} in Formula 301.

[0274] Ar_{126} and Ar_{127} in Formula 302 may be each independently a C_1 - C_{10} alkyl group, e.g., a methyl group, an ethyl group, or a propyl group.

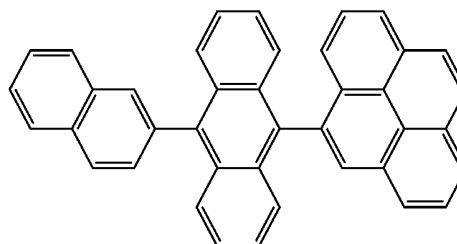
[0275] k and l in Formula 302 may be each independently an integer selected from 0 to 4. In some embodiments, k and l may each be 0, 1, or 2.

[0276] In some embodiments, the compound represented by Formula 301 and the compound represented by Formula 302 may include Compounds HT1 to HT42, but embodiments are not limited thereto:

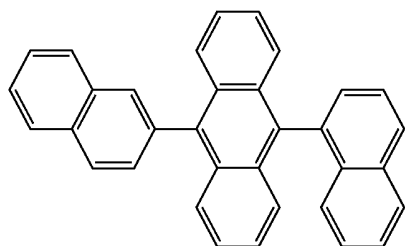
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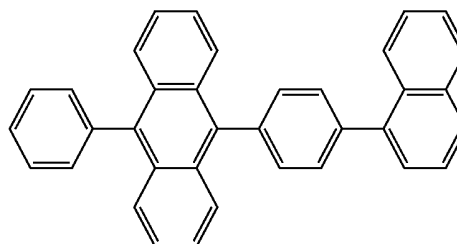
H1



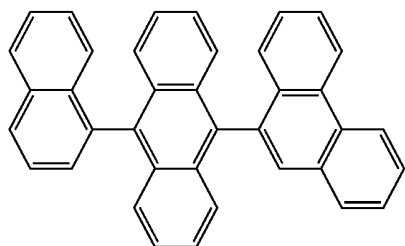
H7



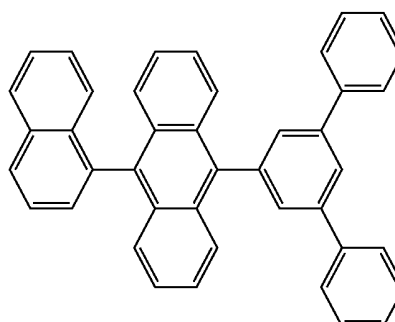
H2



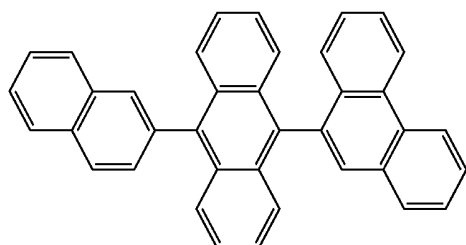
H8



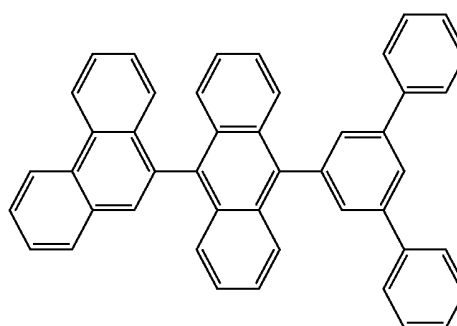
H3



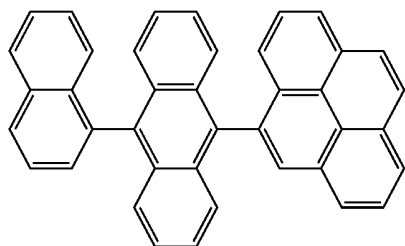
H9



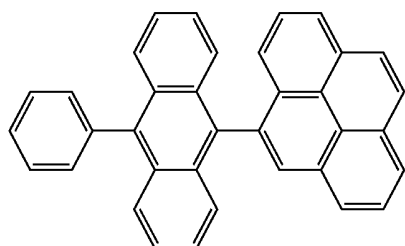
H4



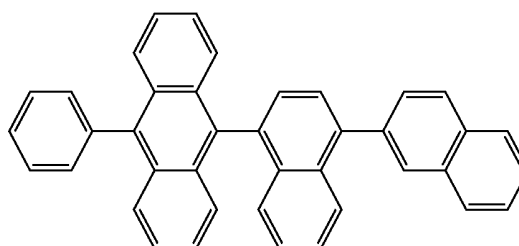
H10



H5

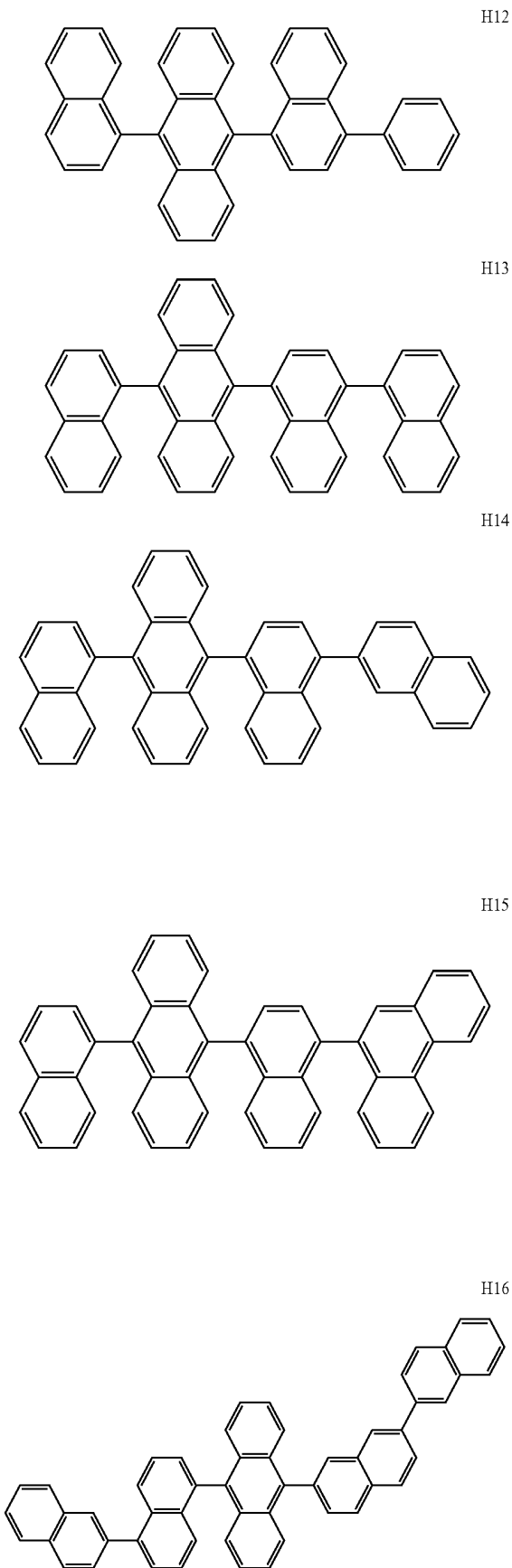


H6

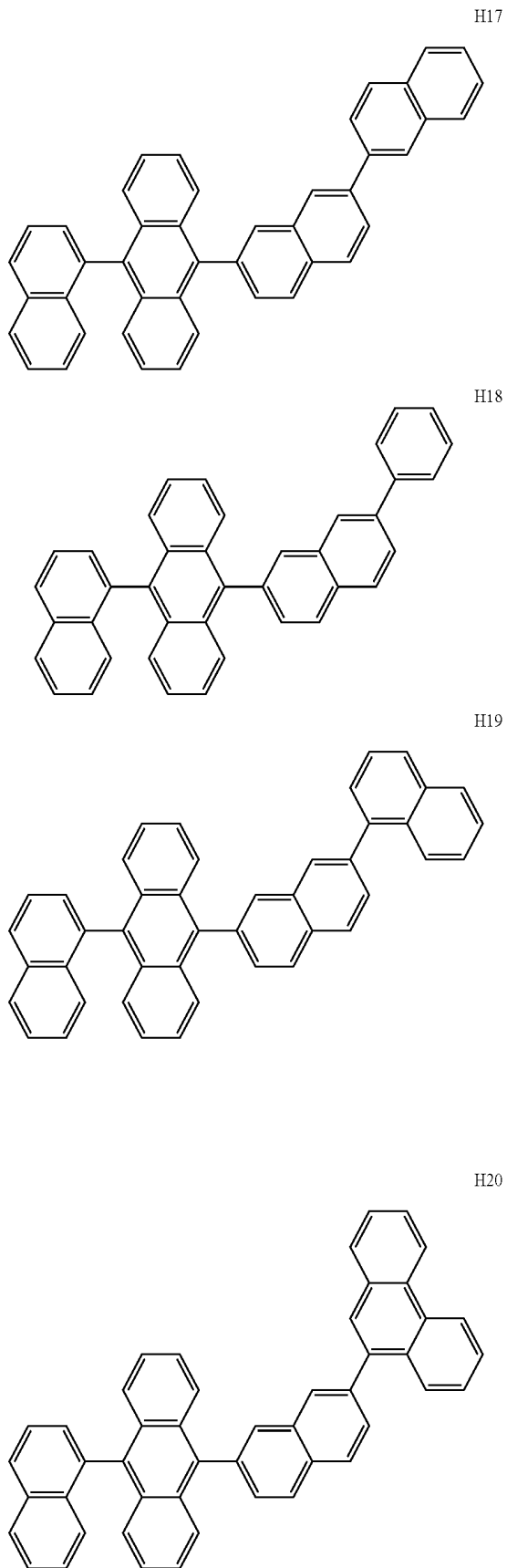


H11

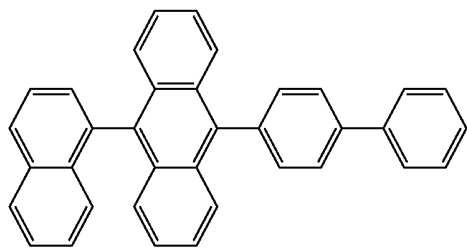
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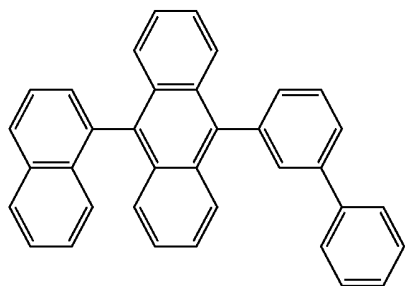
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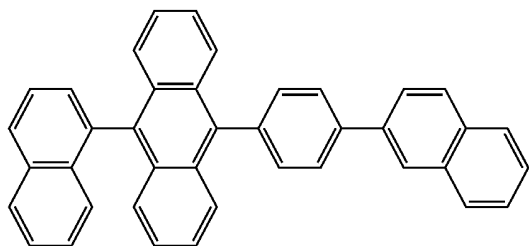
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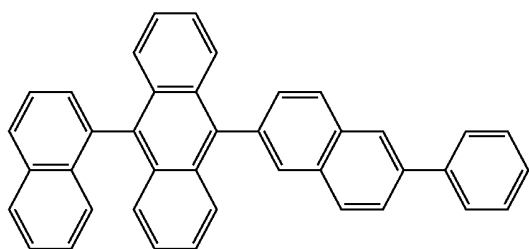
H21



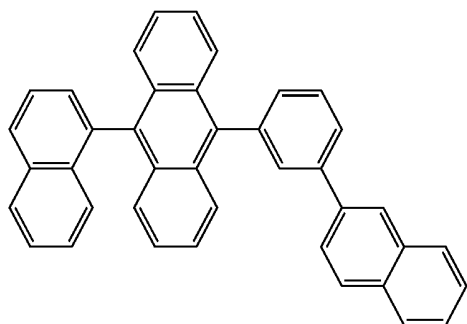
H22



H23

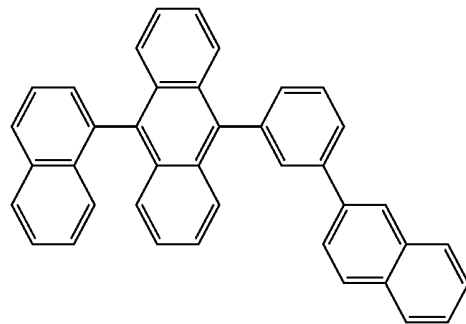


H24

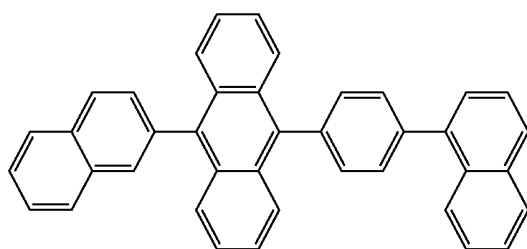


H25

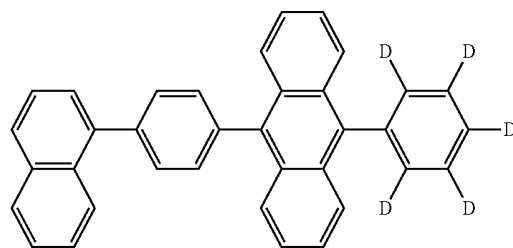
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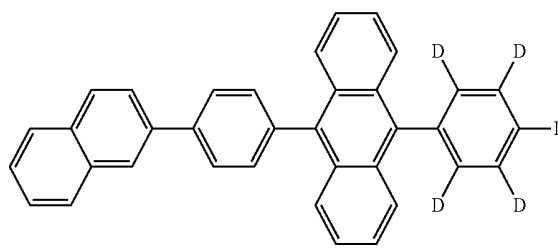
H26



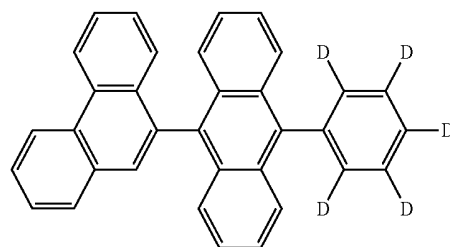
H27



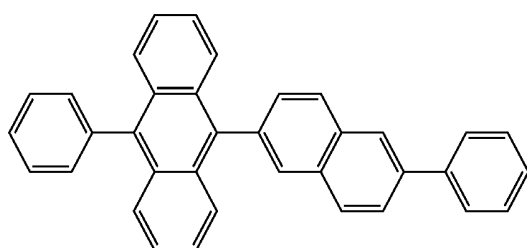
H28



H29



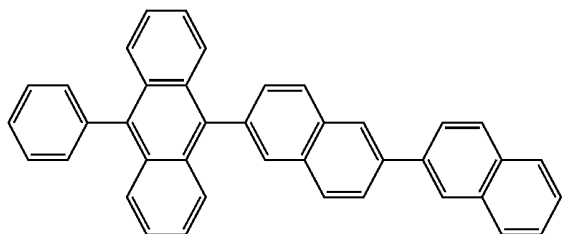
H30



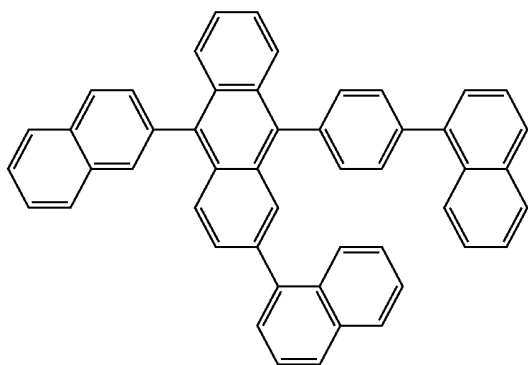
H31

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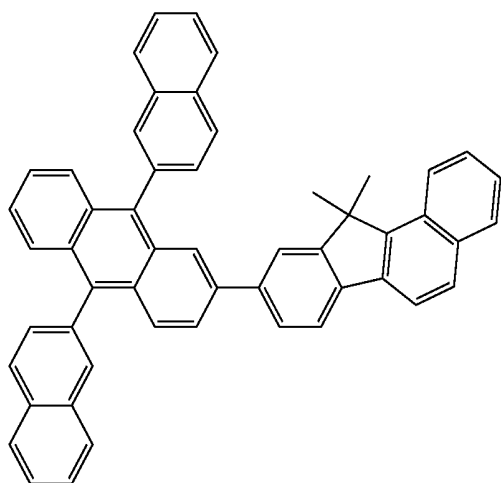
H32



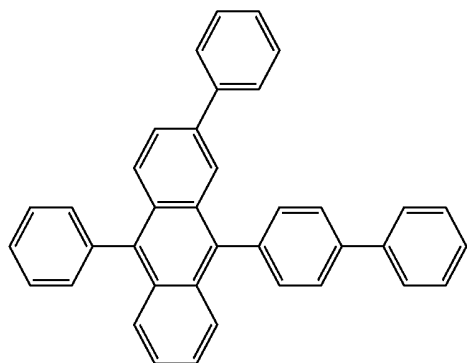
H33



H34

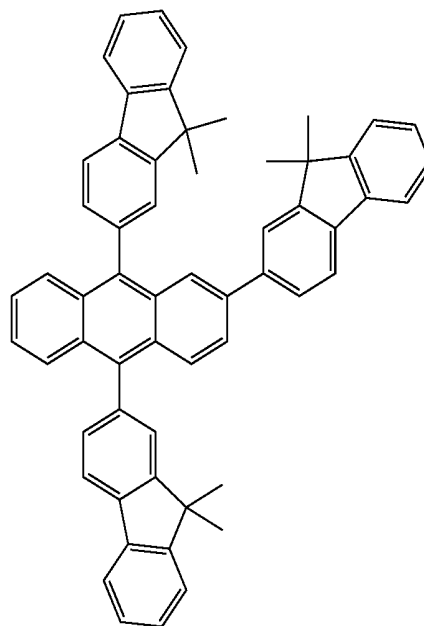


H35

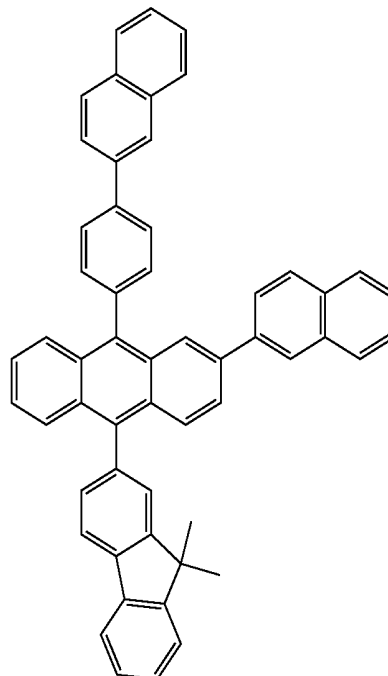


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H36

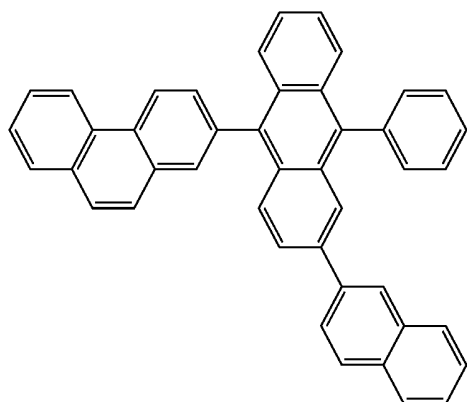


H37



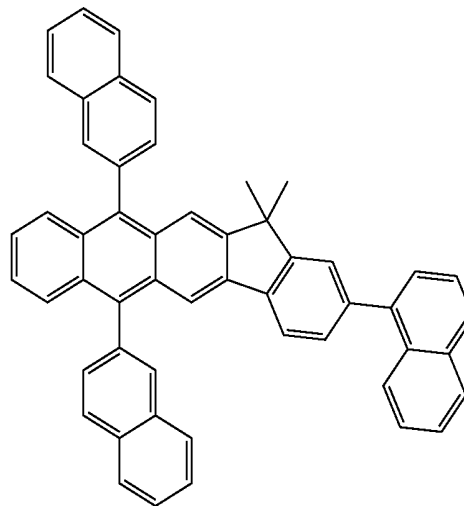
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H38

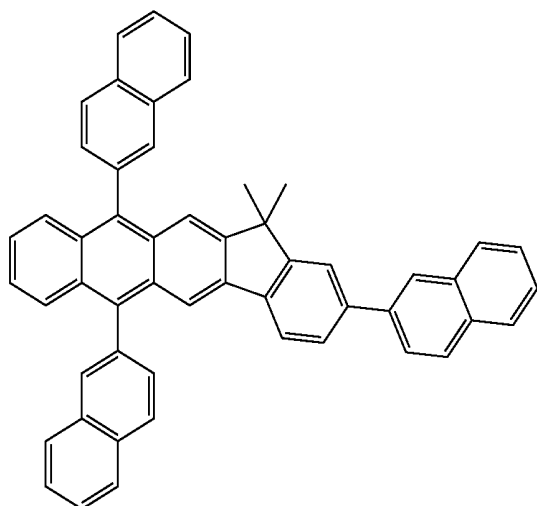


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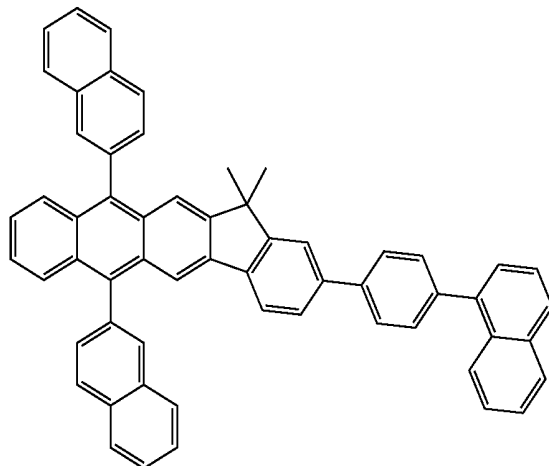
H41



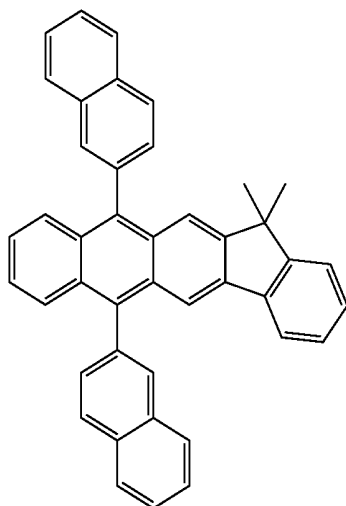
H39



H42



H40



[0277] When the organic light-emitting device is a full color organic light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, and a blue emission layer. In various embodiments, due to a stack structure including a red emission layer, a green emission layer, and/or a blue emission layer, the emission layer may emit white light.

[0278] When the emission layer includes a host and a dopant, an amount of the dopant may be in a range of about 0.01 to about 15 parts by weight based on 100 parts by weight of the host, but is not limited thereto.

[0279] A thickness of the emission layer may be in a range of about 100 Å to about 1,000 Å, for example, about 200 Å to about 600 Å. While not wishing to be bound by theory, it is understood that when the thickness of the emission layer is within this range, excellent light-emission characteristics may be obtained without a substantial increase in driving voltage.

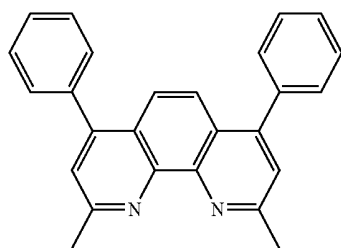
[0280] Then, an electron transport region may be disposed on the emission layer.

[0281] The electron transport region may include at least one selected from a hole blocking layer, an electron transport layer, and an electron injection layer.

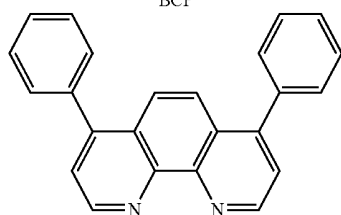
[0282] For example, the electron transport region may have a structure of hole blocking layer/electron transport layer/electron injection layer or a structure of electron transport layer/electron injection layer, but the structure of the electron transport region is not limited thereto. The electron transport layer may have a single-layered structure or a multi-layered structure including two or more different materials.

[0283] Conditions for forming the hole blocking layer, the electron transport layer, and the electron injection layer which constitute the electron transport region may be understood by referring to the conditions for forming the hole injection layer.

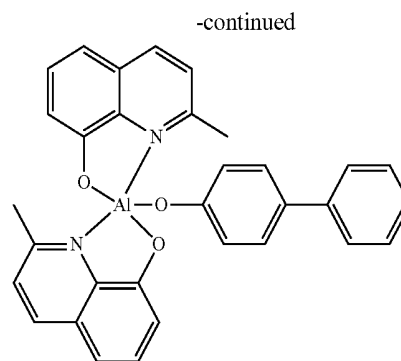
[0284] When the electron transport region includes a hole blocking layer, the hole blocking layer may include, for example, at least one of BCP, Bphen, and BAQ but is not limited thereto:



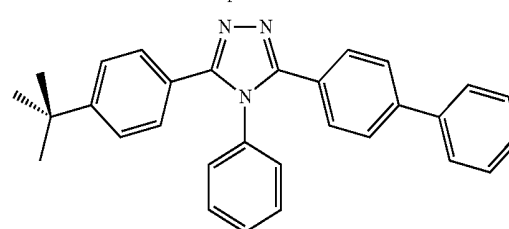
BCP



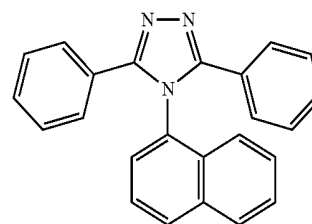
Bphen



BAQ



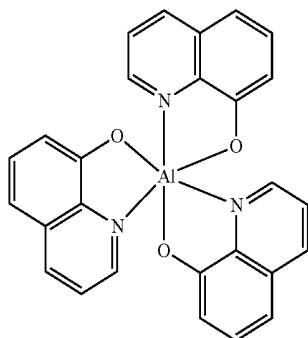
TAZ



NTAZ

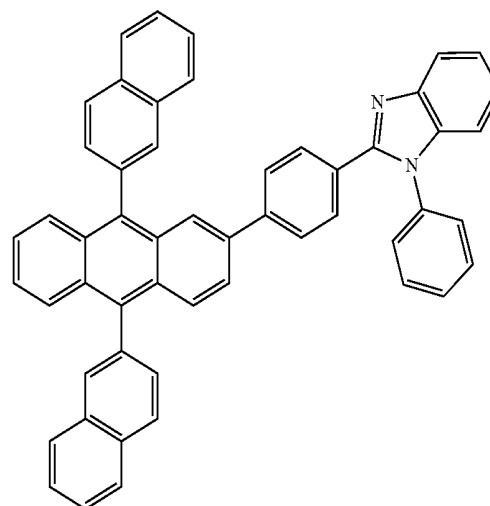
[0285] A thickness of the hole blocking layer may be in a range of about 20 Å to about 1,000 Å, for example, about 30 Å to about 300 Å. While not wishing to be bound by theory, it is understood that when the thickness of the hole blocking layer is within these ranges, the hole blocking layer may have excellent hole blocking characteristics without a substantial increase in driving voltage.

[0286] The electron transport layer may further include at least one selected from BCP, Bphen, Alq₃, BAQ, TAZ, and NTAZ:

Alq₃

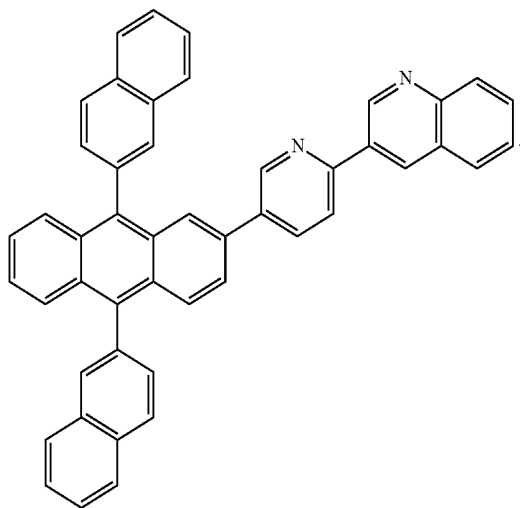
[0287] In various embodiments, the electron transport layer may include at least one of ET1 and ET2, but are not limited thereto:

ET1



-continued

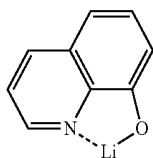
ET2



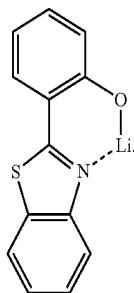
[0288] A thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 150 Å to about 500 Å. While not wishing to be bound by theory, it is understood that when the thickness of the electron transport layer is within the range described above, the electron transport layer may have satisfactory electron transport characteristics without a substantial increase in driving voltage.

[0289] Also, the electron transport layer may further include, in addition to the materials described above, a metal-containing material.

[0290] The metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (lithium quinolate, LiQ) or ET-D2:



ET-D1



ET-D2

[0291] The electron transport region may include an electron injection layer that promotes flow of electrons from the second electrode 19 thereto.

[0292] The electron injection layer may include at least one selected from LiF, NaCl, CsF, Li₂O, and BaO.

[0293] A thickness of the electron injection layer may be in a range of about 1 Å to about 100 Å, for example, about

3 Å to about 90 Å. While not wishing to be bound by theory, it is understood that when the thickness of the electron injection layer is within the ranges described above, the electron injection layer may have satisfactory electron injection characteristics without a substantial increase in driving voltage.

[0294] The second electrode 19 is disposed on the organic layer 15. The second electrode 19 may be a cathode. A material for forming the second electrode 19 may be metal, an alloy, an electrically conductive compound, and a combination thereof, which have a relatively low work function. For example, lithium (Li), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), or magnesium-silver (Mg—Ag) may be formed as the material for forming the second electrode 19. To manufacture a top emission-type light-emitting device, a transmissive electrode formed using ITO or IZO may be used as the second electrode 19.

[0295] Hereinbefore, the organic light-emitting device has been described with reference to FIG. 1, but is not limited thereto.

[0296] Hereinbefore the organic light-emitting device 10 has been described with reference to FIG. 1, but embodiments are not limited thereto.

[0297] According to an aspect of another embodiment, there is provided a composition for diagnosing that includes at least one organometallic compound represented by Formula 1.

[0298] Since the organometallic compound represented by Formula 1 may provide high emission efficiency, the diagnostic efficiency of the composition for diagnosing that includes the organometallic compound represented by Formula 1 may be excellent.

[0299] The composition for diagnosing may be used in various manners, such as in a diagnostic kit, a diagnostic reagent, a biosensor, or a biomarker.

[0300] The term “C₁-C₆₀ alkyl group” as used herein refers to a linear or branched aliphatic saturated hydrocarbon monovalent group having 1 to 60 carbon atoms, and examples thereof include a methyl group, an ethyl group, a propyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an iso-amyl group, and a hexyl group. The term “C₁-C₆₀ alkylene group” as used herein refers to a divalent group having the same structure as the C₁-C₆₀ alkyl group.

[0301] The term “C₁-C₆₀ alkoxy group” as used herein refers to a monovalent group represented by —OA₁₀₁ (wherein A₁₀₁ is the C₁-C₆₀ alkyl group), and examples thereof include a methoxy group, an ethoxy group, and an iso-propyloxy (iso-propoxy) group.

[0302] The term “C₂-C₆₀ alkenyl group” as used herein refers to a group formed by including at least one carbon-carbon double bond in the middle or at the terminal of the C₂-C₆₀ alkyl group, and detailed examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term “C₂-C₆₀ alkenylene group” as used herein refers to a divalent group having the same structure as the C₂-C₆₀ alkenyl group.

[0303] The term “C₂-C₆₀ alkynyl group” as used herein refers to a group formed by including at least one carbon-carbon triple bond in the middle or at the terminal of the C₂-C₆₀ alkyl group, and detailed examples thereof include an ethynyl group and a propenyl group. The term “C₂-C₆₀

alkynylene group” as used herein refers to a divalent group having the same structure as the C₂-C₆₀ alkynyl group.

[0304] The term “C₃-C₁₀ cycloalkyl group” as used herein refers to a monovalent saturated hydrocarbon monocyclic group having 3 to 10 carbon atoms, and non-limiting examples thereof include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group. The term “C₃-C₁₀ cycloalkylene group,” as used herein, refers to a divalent group having the same structure as the C₃-C₁₀ cycloalkyl group.

[0305] The term “C₁-C₁₀ heterocycloalkyl group” as used herein refers to a monovalent saturated monocyclic group having at least one heteroatom selected from N, O, P, Si, and S as a ring-forming atom and 1 to 10 carbon atoms, and non-limiting examples thereof include a tetrahydrofuran group and a tetrahydrothiophenyl group. The term “C₁-C₁₀ heterocycloalkylene group” as used herein refers to a divalent group having the same structure as the C₁-C₁₀ heterocycloalkyl group.

[0306] The term “C₃-C₁₀ cycloalkenyl group” as used herein refers to a monovalent monocyclic group that has 3 to 10 carbon atoms and at least one carbon-carbon double bond in the ring thereof and which is not aromatic. Non-limiting examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term “C₃-C₁₀ cycloalkenylene group” as used herein refers to a divalent group having the same structure as the C₃-C₁₀ cycloalkenyl group.

[0307] The term “C₁-C₁₀ heterocycloalkenyl group” as used herein refers to a monovalent monocyclic group that has at least one heteroatom selected from N, O, P, Si, and S as a ring-forming atom, 1 to 10 carbon atoms, and at least one carbon-carbon double bond in its ring. Non-limiting examples of the C₁-C₁₀ heterocycloalkenyl group include a 2,3-dihydrofuran group and a 2,3-dihydrothiophenyl group. The term “C₁-C₁₀ heterocycloalkenylene group,” as used herein, refers to a divalent group having the same structure as the C₁-C₁₀ heterocycloalkenyl group.

[0308] The term “C₆-C₆₀ aryl group” as used herein refers to a monovalent group having an aromatic system having 6 to 60 carbon atoms, and the term “C₆-C₆₀ arylene group” as used herein refers to a divalent group having an aromatic system having 6 to 60 carbon atoms. Non-limiting examples of the C₆-C₆₀ aryl group include a phenyl group, a naphthyl group, an anthracenyl group, a phenanthrenyl group, a pyrenyl group, and a chrysenyl group. When the C₆-C₆₀ aryl group and the C₆-C₆₀ arylene group each include two or more rings, the rings may be fused to each other.

[0309] The term “C₁-C₆₀ heteroaryl group” as used herein refers to a monovalent group having a cyclic aromatic system that has at least one heteroatom selected from N, O, P, Si, and S as a ring-forming atom, and 1 to 60 carbon atoms. The term “C₁-C₆₀ heteroarylene group” as used herein refers to a divalent group having an aromatic system that has at least one heteroatom selected from N, O, P, and S as a ring-forming atom, and 1 to 60 carbon atoms. Non-limiting examples of the C₁-C₆₀ heteroaryl group include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, and an isoquinolinyl group. When the C₁-C₆₀ heteroaryl group and the C₁-C₆₀ heteroarylene group each include two or more rings, the rings may be fused to each other.

[0310] The term “C₆-C₆₀ aryloxy group” as used herein indicates —OA₁₀₂ (wherein A₁₀₂ is the C₆-C₆₀ aryl group), and a C₆-C₆₀ arylthio group used herein indicates —SA₁₀₃ (wherein A₁₀₃ is the C₆-C₆₀ aryl group).

[0311] The term “monovalent non-aromatic condensed polycyclic group” as used herein refers to a monovalent group (e.g., having 8 to 60 carbon atoms) that has two or more rings condensed to each other, only carbon atoms as a ring-forming atom, and which is non-aromatic in the entire molecular structure. Examples of the monovalent non-aromatic condensed polycyclic group include a fluorenyl group. The term “divalent non-aromatic condensed polycyclic group” as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed polycyclic group.

[0312] The term “monovalent non-aromatic condensed heteropolycyclic group” as used herein refers to a monovalent group (for example, having 2 to 60 carbon atoms) that has two or more rings condensed to each other, has a heteroatom selected from N, O, P, and S, other than carbon atoms, as a ring-forming atom, and which is non-aromatic in the entire molecular structure. Non-limiting examples of the monovalent non-aromatic condensed heteropolycyclic group include a carbazolyl group. The term “divalent non-aromatic condensed heteropolycyclic group” as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0313] At least one of substituents of the substituted C₅-C₃₀ carbocyclic group, substituted C₂-C₃₀ heterocyclic group, substituted C₁-C₆₀ alkyl group, substituted C₂-C₆₀ alkenyl group, substituted C₂-C₆₀ alkynyl group, substituted C₁-C₆₀ alkoxy group, substituted C₃-C₁₀ cycloalkyl group, substituted C₁-C₁₀ heterocycloalkyl group, substituted C₃-C₁₀ cycloalkenyl group, substituted C₁-C₁₀ heterocycloalkenyl group, substituted C₆-C₆₀ aryl group, substituted C₆-C₆₀ aryloxy group, substituted C₆-C₆₀ arylthio group, substituted C₁-C₆₀ heteroaryl group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0314] deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group;

[0315] a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic con-

densed heteropolycyclic group, $-\text{N}(\text{Q}_{11})(\text{Q}_{12})$, $-\text{Si}(\text{Q}_{13})(\text{Q}_{14})(\text{Q}_{15})$, $-\text{B}(\text{Q}_{16})(\text{Q}_{17})$, and $-\text{P}(=\text{O})(\text{Q}_{18})(\text{Q}_{19})$;

[0316] a C_3 - C_{10} cycloalkyl group, a C_1 - C_{10} heterocycloalkyl group, a C_3 - C_{10} cycloalkenyl group, a C_1 - C_{10} heterocycloalkenyl group, a C_6 - C_{60} aryl group, a C_6 - C_{60} aryloxy group, a C_6 - C_{60} arylthio group, a C_1 - C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0317] a C_3 - C_{10} cycloalkyl group, a C_1 - C_{10} heterocycloalkyl group, a C_3 - C_{10} cycloalkenyl group, a C_1 - C_{10} heterocycloalkenyl group, a C_6 - C_{60} aryl group, a C_6 - C_{60} aryloxy group, a C_6 - C_{60} arylthio group, a C_1 - C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, $-\text{F}$, $-\text{Cl}$, $-\text{Br}$, $-\text{I}$, $-\text{CD}_3$, $-\text{CD}_2\text{H}$, $-\text{CDH}_2$, $-\text{CF}_3$, $-\text{CF}_2\text{H}$, $-\text{CFH}_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1 - C_{60} alkyl group, a C_2 - C_{60} alkenyl group, a C_2 - C_{60} alkynyl group, a C_1 - C_{60} alkoxy group, a C_3 - C_{10} cycloalkyl group, a C_1 - C_{10} heterocycloalkyl group, a C_3 - C_{10} cycloalkenyl group, a C_1 - C_{10} heterocycloalkenyl group, a C_6 - C_{60} aryl group, a C_6 - C_{60} aryloxy group, a C_6 - C_{60} arylthio group, a C_1 - C_{60} heteroaryl group, a monovalent non-aromatic condensed heteropolycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $-\text{N}(\text{Q}_{21})(\text{Q}_{22})$, $-\text{Si}(\text{Q}_{23})(\text{Q}_{24})(\text{Q}_{25})$, $-\text{B}(\text{Q}_{26})(\text{Q}_{27})$, and $-\text{P}(=\text{O})(\text{Q}_{28})(\text{Q}_{29})$; and

[0318] $-\text{N}(\text{Q}_{31})(\text{Q}_{32})$, $-\text{Si}(\text{Q}_{33})(\text{Q}_{34})(\text{Q}_{35})$, $-\text{B}(\text{Q}_{36})(\text{Q}_{37})$, and $-\text{P}(=\text{O})(\text{Q}_{38})(\text{Q}_{39})$,

[0319] wherein Q_1 to Q_9 , Q_{11} to Q_{19} , Q_{21} to Q_{29} , and Q_{31} to Q_{39} may be each independently selected from hydrogen, deuterium, $-\text{F}$, $-\text{Cl}$, $-\text{Br}$, $-\text{I}$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1 - C_{60} alkyl group, a C_2 - C_{60} alkenyl group, a C_2 - C_{60} alkynyl group, a C_1 - C_{60} alkoxy group, a C_3 - C_{10} cycloalkyl group, a C_1 - C_{10} heterocycloalkyl group, a C_3 - C_{10} cycloalkenyl group, a C_1 - C_{10} heterocycloalkenyl group, a C_6 - C_{60} aryl group, a C_6 - C_{60} aryl group substituted with at least one selected from a C_1 - C_{60} alkyl group and a C_6 - C_{60} aryl group, a C_6 - C_{60} aryloxy group, a C_6 - C_{60} arylthio group, a C_1 - C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

[0320] When a group containing a specified number of carbon atoms is substituted with any of the groups listed in the preceding paragraphs, the number of carbon atoms in the resulting "substituted" group is defined as the sum of the carbon atoms contained in the original (unsubstituted) group and the carbon atoms (if any) contained in the substituent. For example, when the term "substituted C_1 - C_{60} alkyl" refers to a C_1 - C_{60} alkyl group substituted with C_6 - C_{60} aryl group, the total number of carbon atoms in the resulting aryl substituted alkyl group is C_7 - C_{120} .

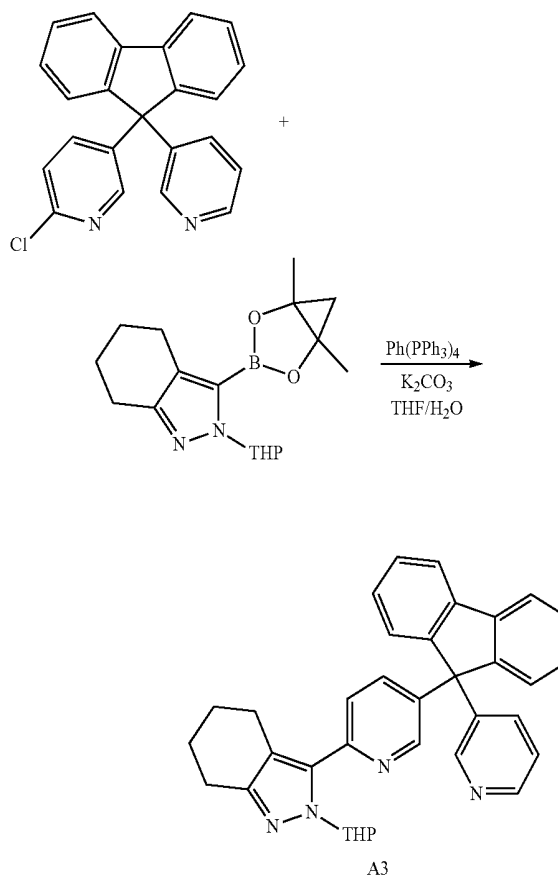
[0321] Hereinafter, a compound and an organic light-emitting device according to embodiments are described in detail with reference to Synthesis Example and Examples. However, the organic light-emitting device is not limited

thereto. The wording "B was used instead of A" used in describing Synthesis Examples means that an amount of A used was identical to an amount of B used, in terms of a molar equivalent.

Example

Synthesis Example 1: Synthesis of Compound 33

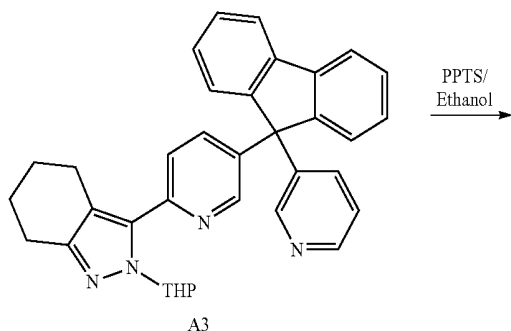
[0322] Synthesis of Intermediate A3



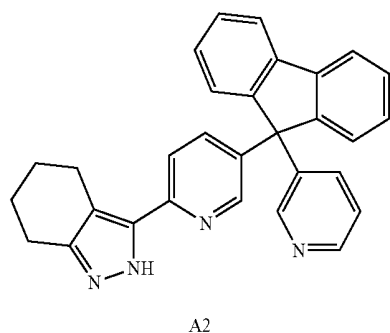
[0323] 5 grams (g) (14.1 millimoles, mmol) of 2-chloro-5-(9-(pyridin-3-yl)-9H-fluoren-9-yl)pyridine, 5.35 g (16.9 mmol) of 3-(1,5-dimethyl-2,4-dioxo-3-borabicyclo[3.1.0]hexan-3-yl)-2-(tetrahydro-2H-pyran-2-yl)-4,5,6,7-tetrahydro-2H-indazole, 1.14 g (1.0 mmol) of $\text{Pd}(\text{PPh}_3)_4$, and 3.89 g (28.2 mmol) of K_2CO_3 were mixed together with 60 milliliters (mL) of tetrahydrofuran (THF) and 30 mL of water (H_2O). The mixture was stirred at a temperature of about 75°C . for about 18 hours. The temperature was then lowered to room temperature, followed by filtering of the mixture. An organic layer was extracted from the resultant using methylene chloride (MC), and an anhydrous magnesium sulfate (MgSO_4) was added thereto to dry the organic layer. The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate (EA) and hexane at a ratio of 10:90 to obtain 5.03 g (81%) of Intermediate A3.

Synthesis of Intermediate A2

[0324]



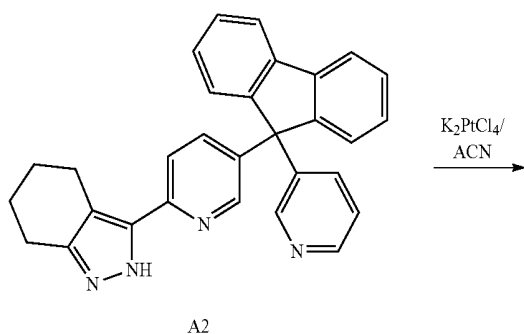
A3



A2

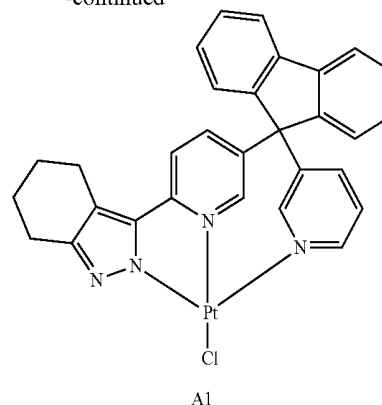
[0325] 5.03 g (11.4 mmol) of Intermediate A3 and 1.20 g (5.7 mmol) of pyridinium p-toluenesulfonate (PPTS) were mixed together with 100 mL of ethanol. The mixture was stirred at a temperature of about 78° C. for about 12 hours. The temperature was then lowered to room temperature, followed by filtering of the mixture. An organic layer was extracted from the resultant using MC, and an anhydrous magnesium sulfate ($MgSO_4$) was added thereto to dry the organic layer. The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using EA, hexane, and methanol at a ratio of 24:75:1 to obtain 3.17 g (75%) of Intermediate A2.

[0326] Synthesis of Intermediate A1



A2

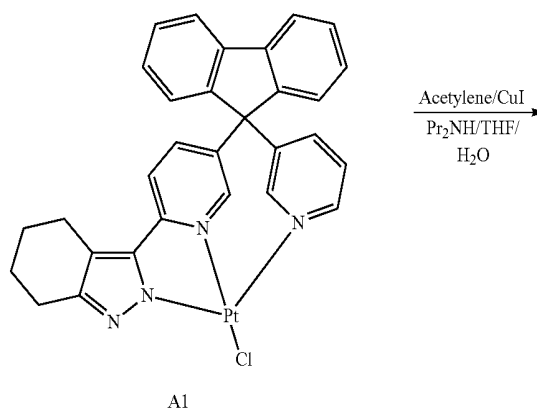
-continued



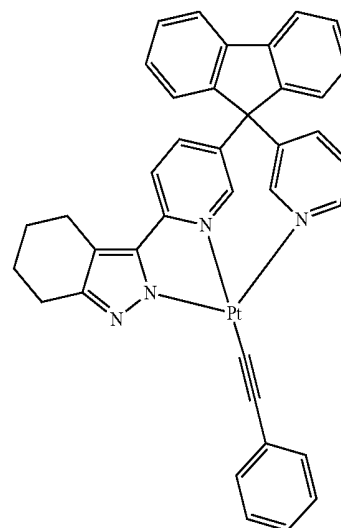
A1

[0327] 3.1 g (7.04 mmol) of Intermediate A₂ and 2.92 g (7.04 mmol) of K_2PtCl_4 were mixed together with 60 mL of acetonitrile (ACN). The mixture was stirred at a temperature of about 100° C. for about 24 hours to carry out the reaction. Thereafter, the temperature was lowered. The mixture obtained therefrom was filtered to obtain a solid. The solid was thoroughly washed with methanol and water and dried to obtain 2.83 g (60%) of Intermediate A1.

[0328] Synthesis of Compound 33



A1



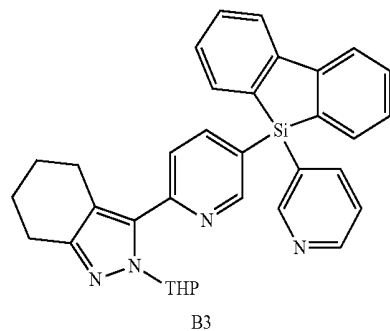
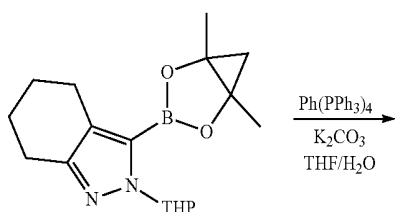
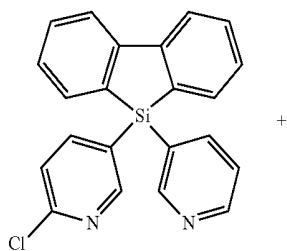
Compound 33

[0329] 2.8 g (4.18 mmol) of Intermediate A1, 0.51 g (5.01 mmol) of acetylene, 0.04 g (0.21 mmol) of CuI, and 1.27 g (12.54 mmol) of diisopropylamine were mixed together with 40 mL of THF and 20 mL of water. The mixture was stirred at a temperature of about 85° C. for about 24 hours to carry out reaction. Thereafter, the temperature was lowered. The mixture obtained therefrom was filtered to obtain a solid. The solid was thoroughly washed with ethanol and was subsequently purified by column chromatography using ethanol and hexane at a ratio of about 20:80 to obtain 1.08 g (35%) of Compound 33. The identity of the obtained compound was confirmed by using mass spectroscopy and high-performance liquid chromatography (HPLC) analysis.

[0330] HRMS(MALDI) calcd for $C_{38}H_{28}N_4Pt$: m/z 735.1962, Found: 735.1960.

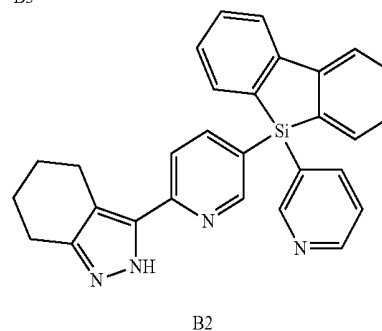
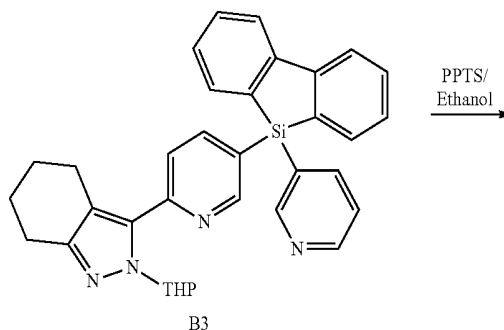
Synthesis Example 2: Synthesis of Compound 34

[0331] Synthesis of Intermediate B3



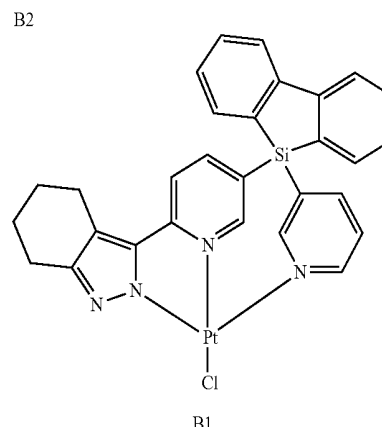
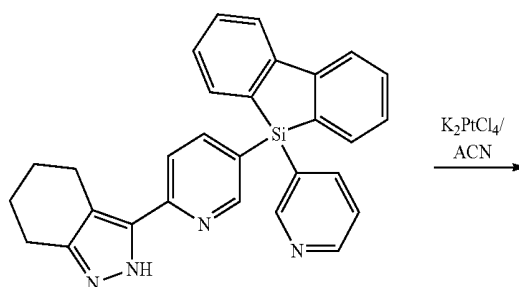
[0332] 5.54 g (76%) of Intermediate B3 was obtained in the same manner as Intermediate A3 in Synthesis Example 1, except that 5.0 g (13.5 mmol) of 2-chloro-5-(5-(pyridin-3-yl)-9H-dibenzo[b,d]silol-5-yl)pyridine was used instead of 2-chloro-5-(9-(pyridin-3-yl)-9H-fluoren-9-yl)pyridine.

[0333] Synthesis of Intermediate B2



[0334] 4.02 g (86%) of Intermediate B2 was obtained in the same manner as Intermediate A2 in Synthesis Example 1, except that 5.54 g (10.2 mmol) of Intermediate B3 was used instead of Intermediate A3.

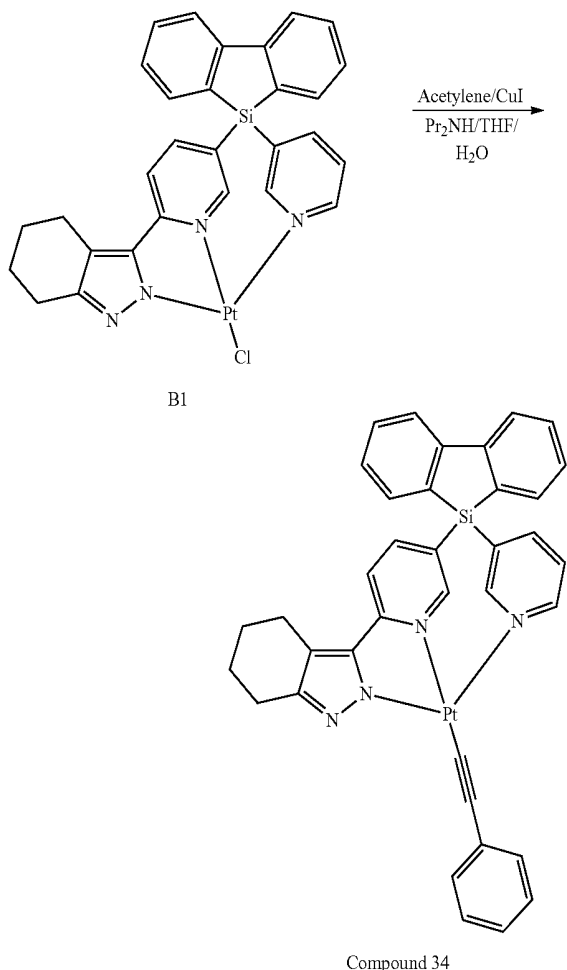
[0335] Synthesis of Intermediate B1



[0336] 3.31 g (55%) of Intermediate B1 was obtained in the same manner as Intermediate A1 in Synthesis Example

1, except that 4.00 g (8.76 mmol) of Intermediate B2 was used instead of Intermediate A2.

[0337] Synthesis of Compound 34



[0338] 1.12 g (31%) of Compound 34 was obtained in the same manner as Compound 33 in Synthesis Example 1, except that 3.30 g (4.81 mmol) of Intermediate B1 was used instead of Intermediate A1. The identity of the obtained compound was confirmed by using mass spectroscopy and HPLC analysis.

[0339] HRMS(MALDI) calcd for $C_{37}H_{28}N_4PtSi$: m/z 751.8280, Found: 751.8278.

Example 1

[0340] An ITO glass substrate was cut to a size of 50 millimeters (mm)×50 mm×0.5 mm. Then the glass substrate was sonicated in acetone iso-propyl alcohol and pure water for about 15 minutes in each solvent, and cleaned by exposure to ultraviolet rays with ozone for 30 minutes.

[0341] Then, a hole injection layer was formed on an ITO electrode (anode) that is on the glass substrate by vacuum-depositing m-MTDATA at a deposition rate of about 1 Angstrom per second (Å/sec) to have a thickness of about 600 Å. A hole transport layer was formed on the hole injection layer by vacuum-depositing α-NPD at a deposition rate of about 1 Å/sec to have a thickness of about 250 Angstroms (Å).

[0342] An emission layer was formed on the hole transport layer by co-depositing Compound 33 (dopant) and CBP (host) at a deposition rate of about 0.1 Å/sec and 1 Å/sec, respectively, to have a thickness of about 400 Å.

[0343] A hole blocking layer was formed on the emission layer by vacuum-depositing BAQ at a deposition rate of 1 Å/sec to have a thickness of about 50 Å. The electron transport layer was formed on the hole blocking layer by vacuum-depositing Alq_3 to have a thickness of about 300 Å. An electron injection layer was formed on the electron transport layer by vacuum-depositing LiF to have a thickness of about 10 Å. A second electrode (cathode) was formed on the electron injection layer by vacuum-depositing Al to have a thickness of about 1,200 Å. Accordingly, the manufacture of an organic light-emitting device was completed, in which the organic light-emitting device included a structure of ITO/m-MTDATA (600 Å)/α-NPD (250 Å)/CBP+10% (Compound 33) (400 Å)/BAQ (50 Å)/ Alq_3 (300 Å)/LiF (10 Å)/Al (1,200 Å).

Examples 2 and Comparative Examples 1 and 2

[0344] An organic light-emitting device was manufactured in the same manner as in Example 1, except that the compounds listed in Table 2 were used instead of Compound 33 as a dopant in the formation of the emission layer.

Evaluation Example 1: Evaluation of Characteristics of Organic Light-Emitting Device

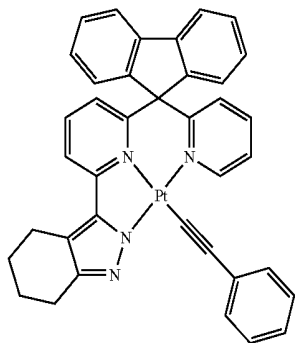
[0345] The driving voltage, emission efficiency, power efficiency, color-coordination, quantum efficiency, and lifespan (T_{95}) of the organic light-emitting devices manufactured in Examples 1 and 2 and Comparative Examples 1 and 2 were evaluated. The results thereof are shown in Table 2. A Keithley 2400 current voltmeter and a luminance meter (Minolta Cs-1000A) were used in the evaluation. The lifespan (T_{95}) refers to time required for the initial luminance of 6,000 nit of the organic light-emitting device to reduce by 95%.

TABLE 2

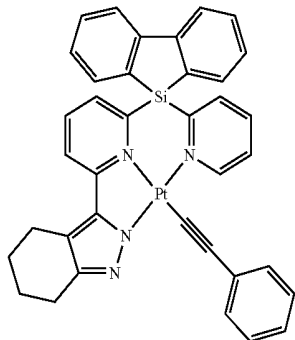
	Dopant	Driv-	Emis-	Power	Quantum		Life-span (hr)	
		ing vol- tage (V)	sion Effi- ciency (cd/A)	Effi- ciency (lm/W)	CIEx (%)	CIEy (%)		
Exam- ple 1	Com- pound 33	5.0	47.8	29.1	0.369	0.602	17.2	180
Exam- ple 2	Com- pound 34	5.2	45.2	28.0	0.363	0.598	16.5	185
Compa- rative Exam- ple 1	Com- pound A	6.9	20.1	13.4	0.390	0.623	8.3	63

TABLE 2-continued

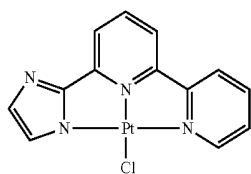
Dopant	Driving voltage (V)	Emission Efficiency (cd/A)	Power Efficiency (lm/W)	Color		Quantum efficiency (%)	Lifetime (hr) (T_{95})
				CIE _x	CIE _y		
Comparative Example 2	6.8	25.2	15.1	0.386	0.635	9.2	50



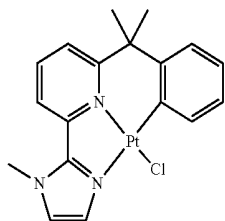
Compound 33



Compound 34



Compound A



Compound B

[0346] Referring to Table 2, it was found that the organic light-emitting devices manufactured in Examples 1 and 2 had excellent driving voltage, emission efficiency, power efficiency, color-coordination, quantum efficiency, and lifespan characteristics, as compared with the organic light-emitting devices of Comparative Examples 1 and 2.

[0347] The organometallic compound has excellent electric characteristics and thermal stability. Accordingly, an organic light-emitting device using the organometallic com-

ound has a low driving voltage, high emission efficiency, high power efficiency, high color coordination, and excellent lifespan characteristics. Further, a composition for diagnosing including the organometallic compound may have high diagnostic efficiency, since the organometallic compound has excellent phosphorescent emission characteristics.

[0348] It should be understood that embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

[0349] While one or more embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present disclosure as defined by the following claims.

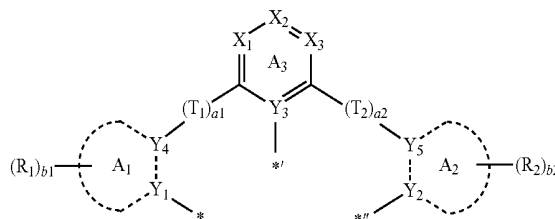
What is claimed is:

1. An organometallic compound represented by Formula 1:



Formula 1

Formula 2



wherein, in Formulae 1 and 2,

M is beryllium, magnesium, aluminum, calcium, titanium, manganese, cobalt, copper, zinc, gallium, germanium, zirconium, ruthenium, rhodium, palladium, silver, rhenium, gold, or platinum,

L_1 is selected from tridentate ligands represented by Formula 2,

L_2 is selected from monodentate organic ligands,

*, **, and *** in Formula 2 each indicate a binding site to M in Formula 1,

Y_1 to Y_3 are each nitrogen,

Y_4 and Y_5 are each carbon,

Y_1 is bound to Y_4 via a single or double bond, Y_2 is bound to Y_5 via a single or double bond,

provided that one selected from a bond between Y_1 and M, a bond between Y_2 and M, and a bond between ligand L_2 and M is a coordinate bond, while the rest are each a covalent bond,

a bond between Y_3 and M is a coordinate bond,

ring A_1 is a 5-membered ring comprising at least one nitrogen as a ring-forming atom,

ring A_2 is a 6-membered ring comprising at least one nitrogen as a ring-forming atom,

X_1 is N or $C(R_3)$, X_2 is N or $C(R_4)$, X_3 is N or $C(R_5)$, at least two selected from R_3 to R_5 are optionally bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group,

T_1 is a group selected from a single bond, $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-C(R_6)=*$, $*=C(R_6)-*$, $*-C(R_6)=C(R_7)-*$, $*-C(=O)-*$, $*-C(=S)-*$, $*-C=C-*$, $*-N(R_6)-*$, $*-Si(R_6)(R_7)-*$, and $*-P(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom,

T_2 is a group selected from $*-O-*$, $*-S-*$, $*-C(R_6)(R_7)-*$, $*-C(R_6)=*$, $*=C(R_6)-*$, $*-C(R_6)=C(R_7)-*$, $*-C(=O)-*$, $*-C(=S)-*$, $*-C=C-*$, $*-N(R_6)-*$, $*-Si(R_6)(R_7)-*$, and $*-P(R_6)(R_7)-*$, wherein $*$ and $*$ in each of the foregoing groups independently indicate a binding site to a neighboring atom,

R_6 and R_7 are optionally bound to each other to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{30} heterocyclic group,

$a1$ and $a2$ are each independently an integer selected from 1 to 3,

R_1 to R_7 are each independently selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-SF_5$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_1)(Q_2)$, $-Si(Q_3)(Q_4)(Q_5)$, $-B(Q_6)(Q_7)$, and $-P(=O)(Q_8)(Q_9)$,

$b1$ and $b2$ are each independently an integer selected from 0 to 3, and when $b1$ is 2 or greater, groups R_1 are identical to or different from each other, and when $b2$ is 2 or greater, groups R_2 are identical to or different from each other,

two of the $b1$ number of groups R_1 are optionally bound to each other to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{30} heterocyclic group,

two of the $b2$ number of groups R_2 are optionally bound to each other to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{30} heterocyclic group,

at least one of substituents of the substituted C_5-C_{30} carbocyclic group, substituted C_2-C_{30} heterocyclic group, substituted C_1-C_{60} alkyl group, substituted C_2-C_{60} alkenyl group, substituted C_2-C_{60} alkynyl group, substituted C_1-C_{60} alkoxy group, substituted C_3-C_{10} cycloalkyl group, substituted C_1-C_{10} heterocycloalkyl group, substituted C_3-C_{10} cycloalkenyl group,

substituted C_1-C_{10} heterocycloalkenyl group, substituted C_6-C_{60} aryl group, substituted C_6-C_{60} aryloxy group, substituted C_6-C_{60} arylthio group, substituted C_1-C_{60} heteroaryl group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_{11})(Q_{12})$, $-Si(Q_{13})(Q_{14})(Q_{15})$, $-B(Q_{16})(Q_{17})$, and $-P(=O)(Q_{18})(Q_{19})$;

a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_{21})(Q_{22})$, $-Si(Q_{23})(Q_{24})(Q_{25})$, $-B(Q_{26})(Q_{27})$, and $-P(=O)(Q_{28})(Q_{29})$; and

—N(Q₃₁)(Q₃₂), —Si(Q₃₃)(Q₃₄)(Q₃₅), —B(Q₃₆)(Q₃₇),
and —P(=O)(Q₃₈)(Q₃₉),

wherein Q₁ to Q₉, Q₁₁ to Q₁₉, Q₂₁ to Q₂₉, and Q₃₁ to Q₃₉ are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryl group substituted with at least one selected from a C₁-C₆₀ alkyl group and a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

2. The organometallic compound of claim 1, wherein

a bond between Y₁ and M and a bond between ligand L₂ and M are each a covalent bond, and a bond between Y₃ and M and a bond between Y₂ and M are each a coordinate bond,

a bond between Y₁ and M and a bond between Y₂ and M are each covalent bond, and a bond between Y₃ and M and a bond between ligand L₂ and M are each a coordinate bond, or

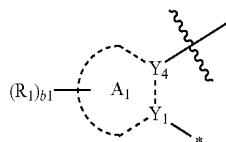
a bond between Y₂ and M and a bond between ligand L₂ and M are each a covalent bond, and a bond between Y₁ and M and a bond between Y₃ and M are each a coordinate bond.

3. The organometallic compound of claim 1, wherein ring A₁ is selected from a pyrrole ring, a pyrazole ring, an imidazole ring, a triazole ring, a tetrazole ring, an oxazole ring, an isoxazole ring, a thiazole ring, an isothiazole ring, an oxadiazole ring, a thiadiazole ring, a benzopyrazole ring, and a benzimidazole ring.

4. The organometallic compound of claim 1, wherein ring A₂ is selected from a pyridine ring, a pyrimidine ring, a pyrazine ring, a pyridazine ring, a triazine ring, a quinoline ring, an isoquinoline ring, a quinoxaline ring, a quinazoline ring, and a phenanthroline ring.

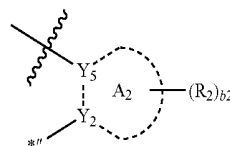
5. The organometallic compound of claim 1, wherein

a moiety in Formula 2 represented by



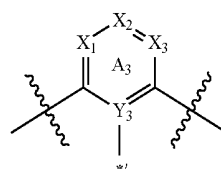
is represented by one of Formulae 3-1 to 3-25, 3-31 to 3-74, and 3-81 to 3-92,

a moiety in Formula 2 represented by

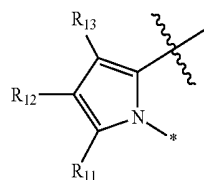


is represented by one of Formulae 4-1 to 4-53, and

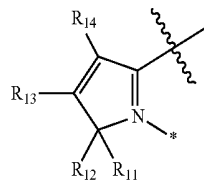
a moiety in Formula 2 represented by



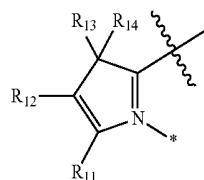
is represented by one of Formulae 5-1 to 5-48:



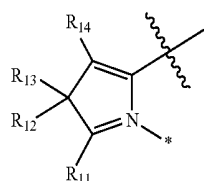
Formula 3-1



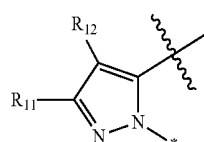
Formula 3-2



Formula 3-3

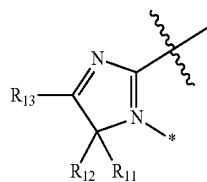
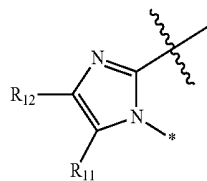
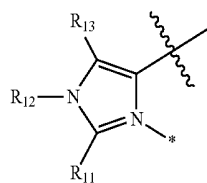
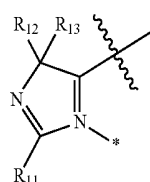
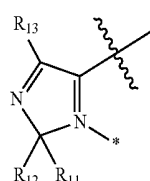
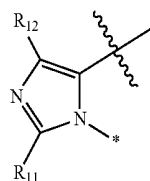
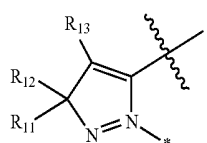
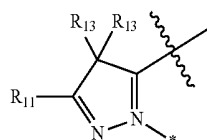
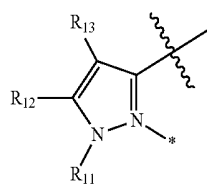


Formula 3-4

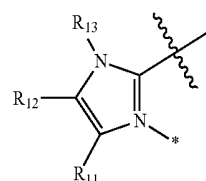


Formula 3-5

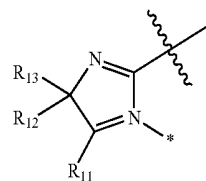
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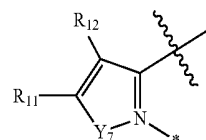
Formula 3-6



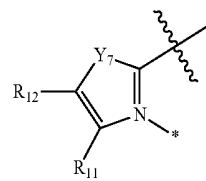
Formula 3-7



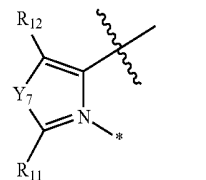
Formula 3-8



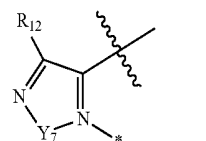
Formula 3-9



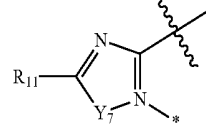
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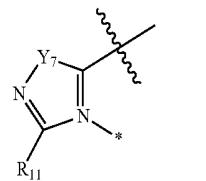
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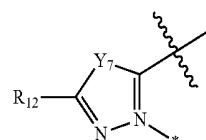
Formula 3-12



Formula 3-13



Formula 3-14



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Formula 3-15

Formula 3-16

Formula 3-17

Formula 3-18

Formula 3-19

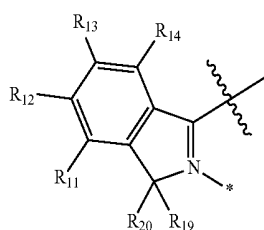
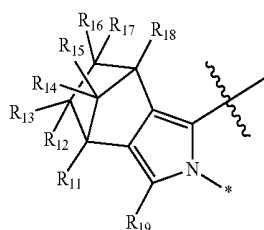
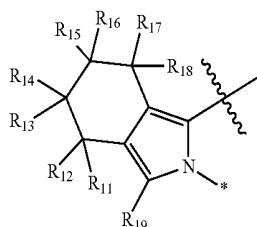
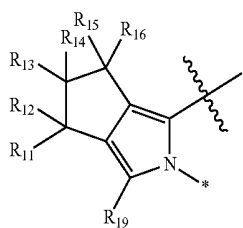
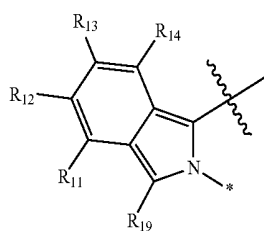
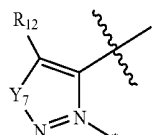
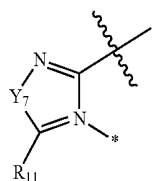
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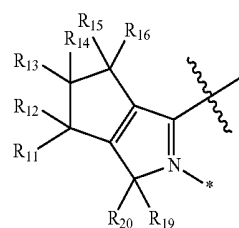
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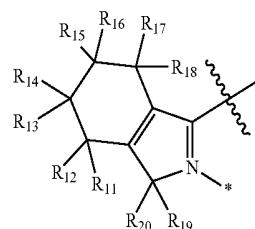
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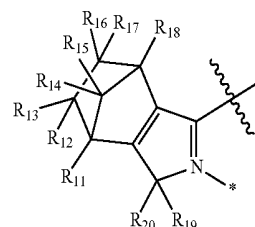
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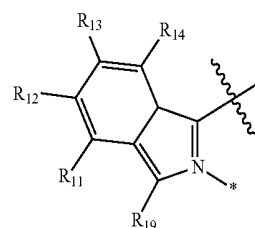
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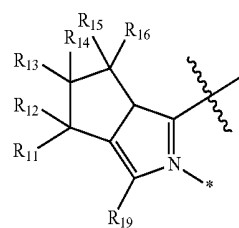
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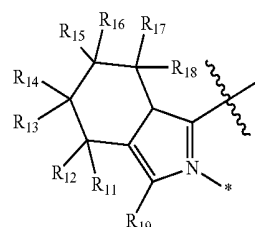
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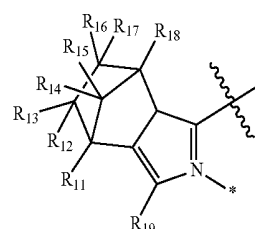
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Formula 3-34



Formula 3-35



Formula 3-36

Formula 3-37

Formula 3-38

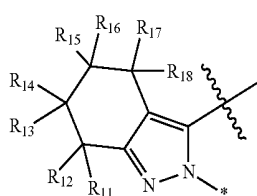
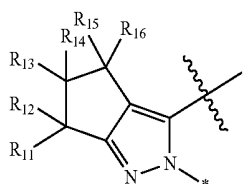
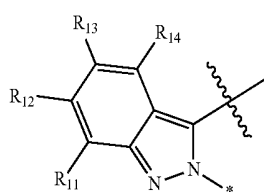
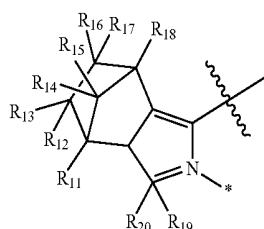
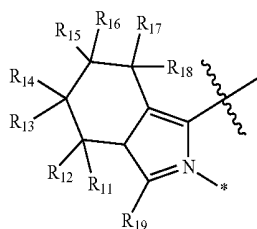
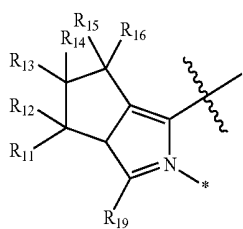
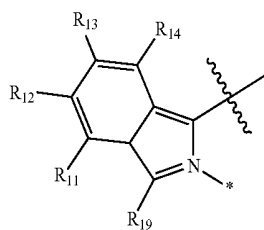
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Formula 3-40

Formula 3-41

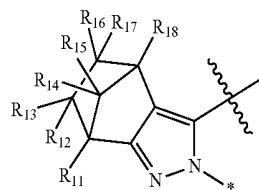
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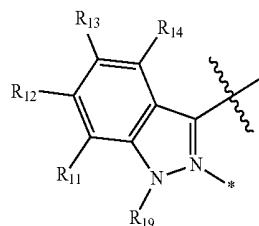
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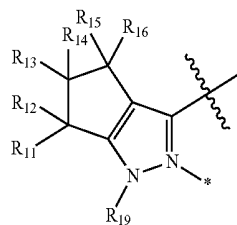
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Formula 3-44



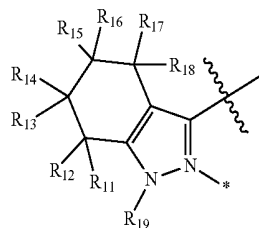
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Formula 3-45



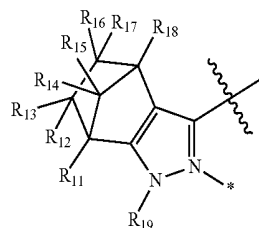
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Formula 3-46



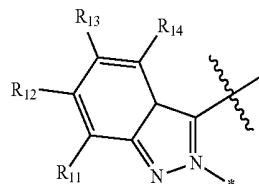
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Formula 3-47



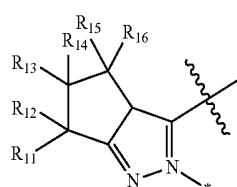
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Formula 3-48



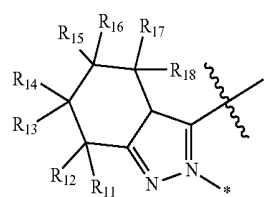
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Formula 3-49

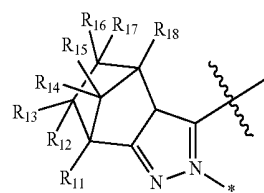


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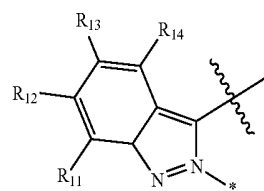
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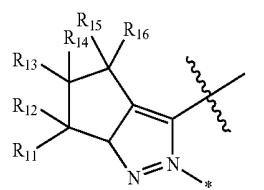
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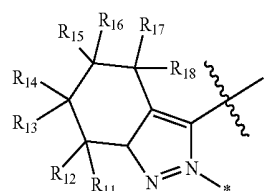
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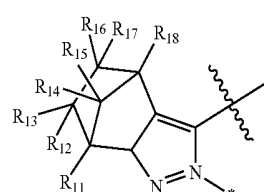
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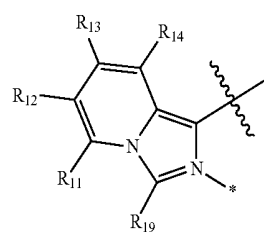
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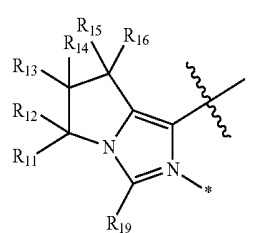
Formula 3-61



Formula 3-62

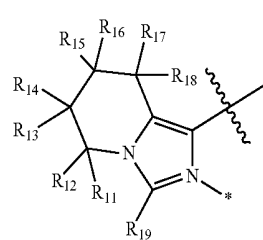


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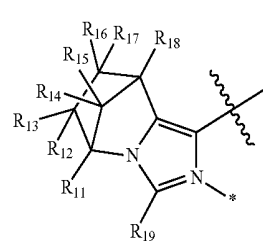


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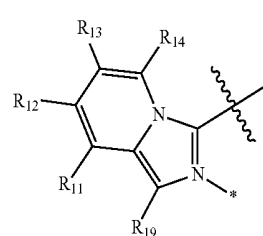
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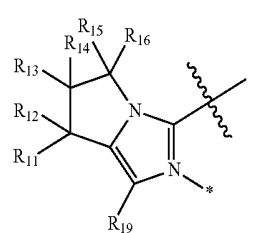
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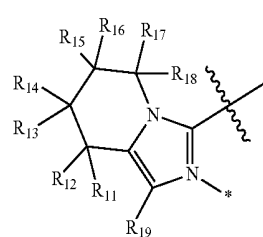
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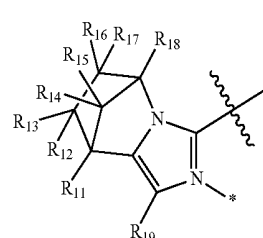
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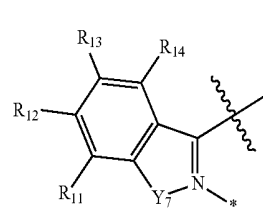
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Formula 3-69

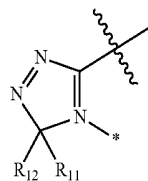
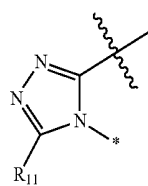
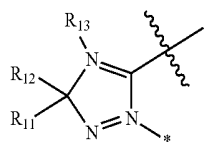
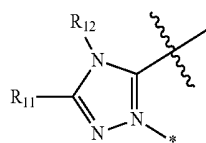
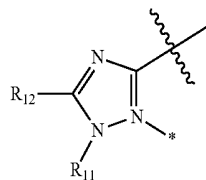
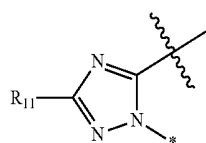
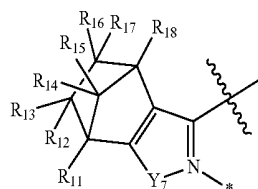
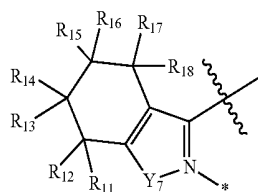
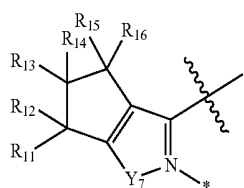


Formula 3-70



Formula 3-71

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Formula 3-72

Formula 3-73

Formula 3-74

Formula 3-81

Formula 3-82

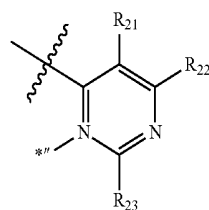
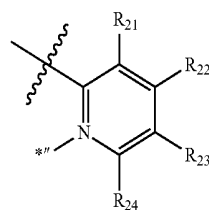
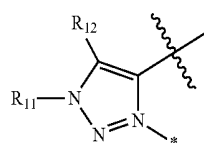
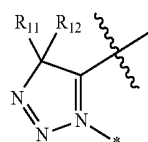
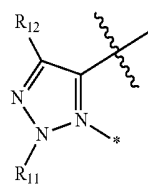
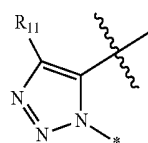
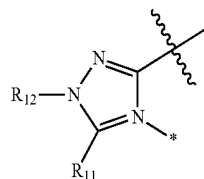
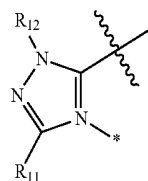
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Formula 3-84

Formula 3-85

Formula 3-86

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Formula 3-87

Formula 3-88

Formula 3-89

Formula 3-90

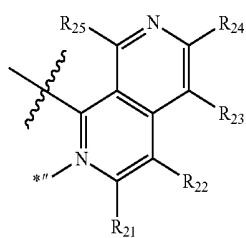
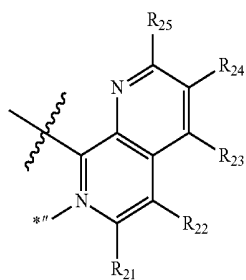
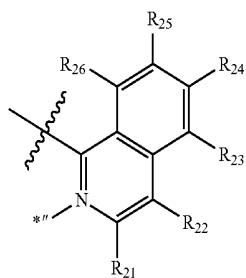
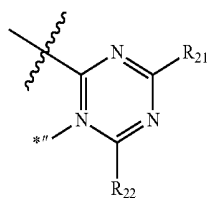
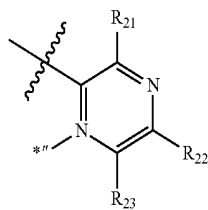
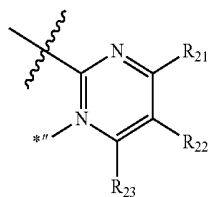
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Formula 3-92

Formula 4-1

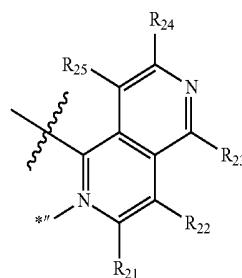
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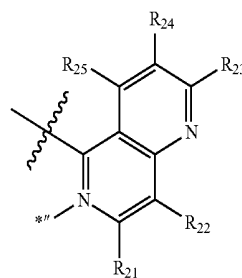


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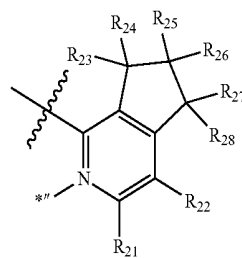
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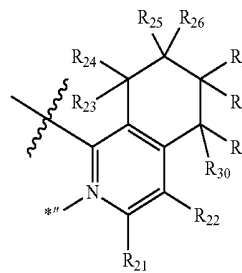
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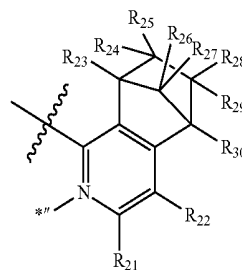
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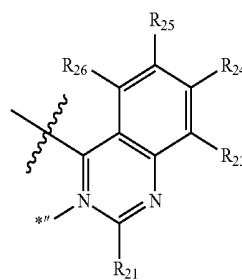
Formula 4-6



Formula 4-7



Formula 4-8



Formula 4-9

Formula 4-10

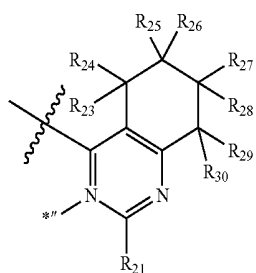
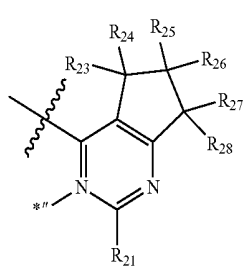
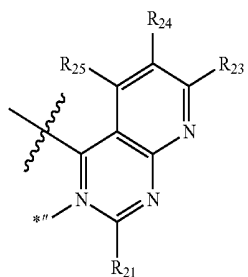
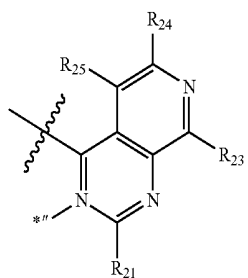
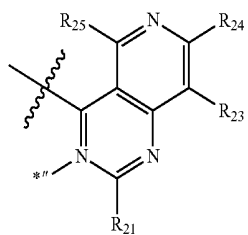
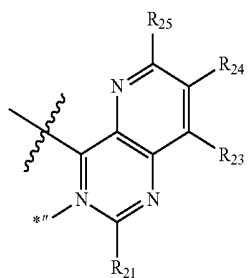
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Formula 4-12

Formula 4-13

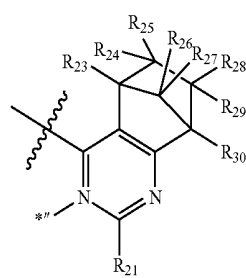
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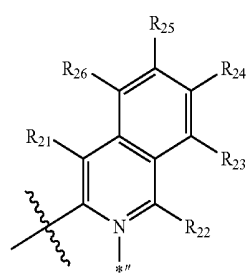


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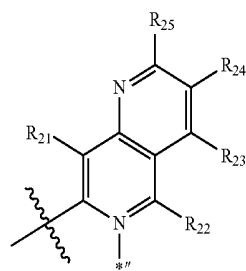
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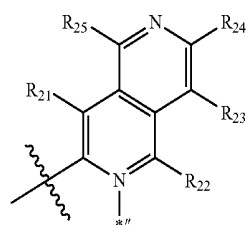
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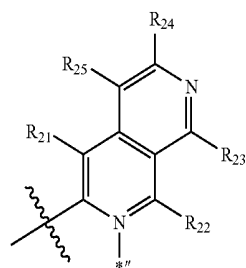
Formula 4-17



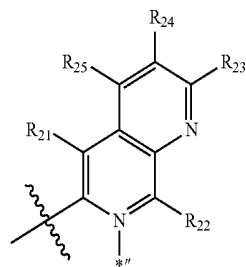
Formula 4-18



Formula 4-19



Formula 4-20



Formula 4-21

Formula 4-22

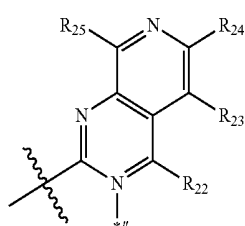
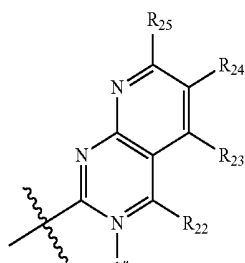
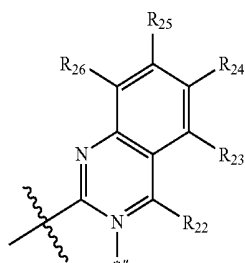
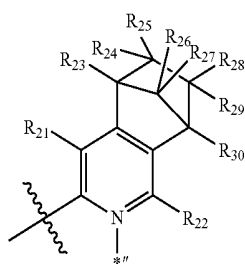
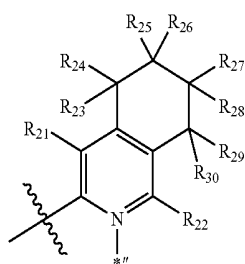
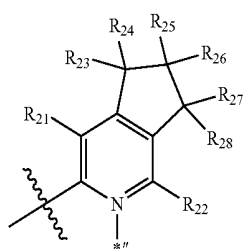
Formula 4-23

Formula 4-24

Formula 4-25

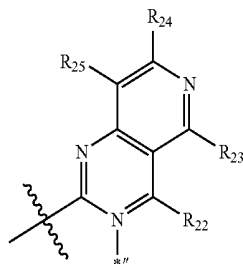
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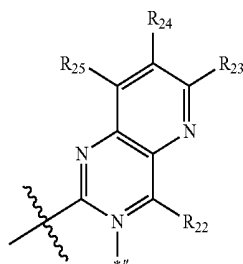


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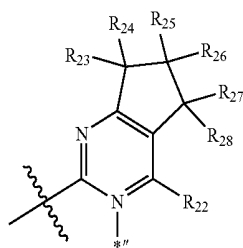
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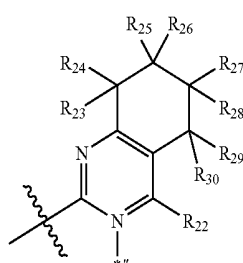
Formula 4-28



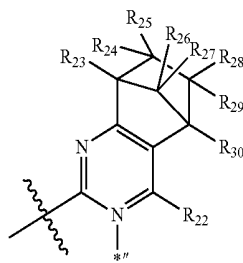
Formula 4-29



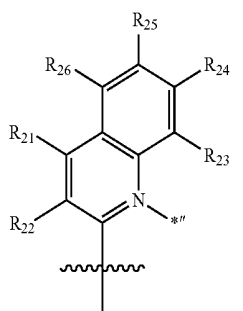
Formula 4-30



Formula 4-31



Formula 4-32



Formula 4-33

Formula 4-34

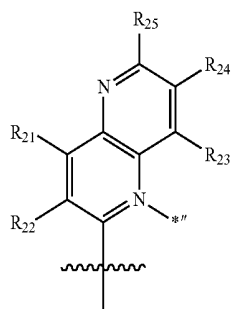
Formula 4-35

Formula 4-36

Formula 4-37

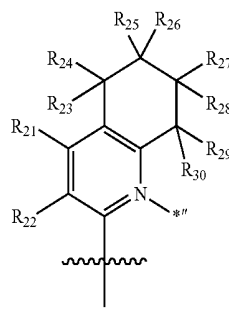
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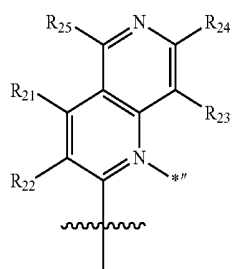


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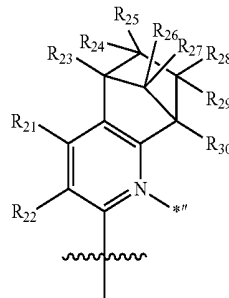
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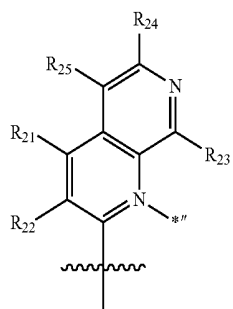
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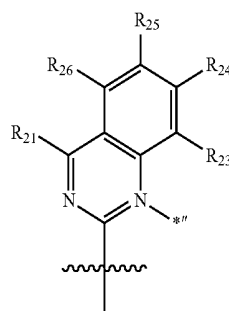
Formula 4-40



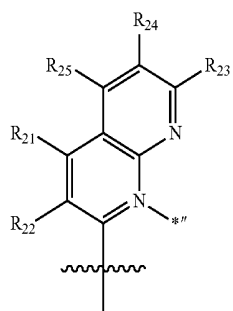
Formula 4-45



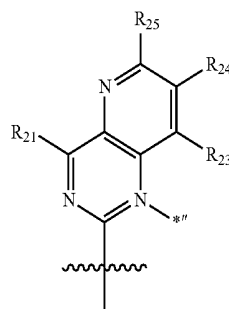
Formula 4-41



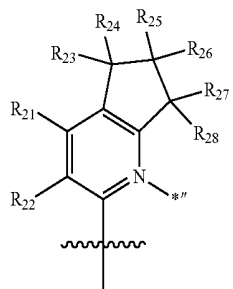
Formula 4-46



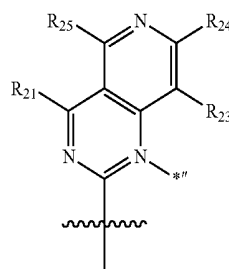
Formula 4-42



Formula 4-47

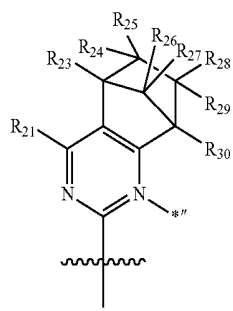
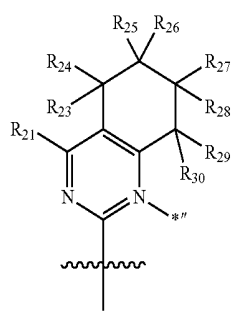
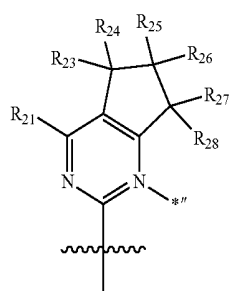
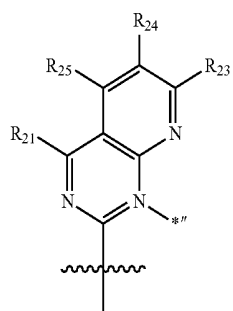
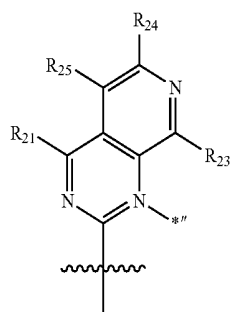


Formula 4-43



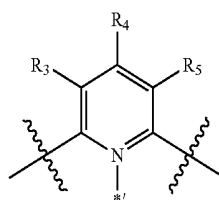
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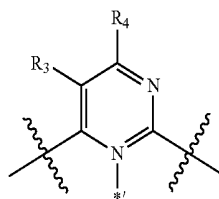


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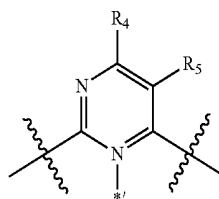
Formula 4-49



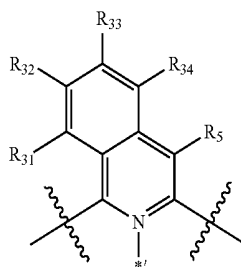
Formula 4-50



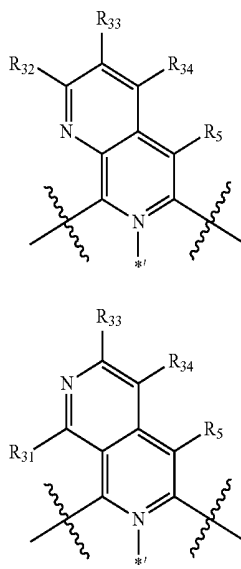
Formula 4-51



Formula 4-52



Formula 4-53



Formula 5-1

Formula 5-2

Formula 5-3

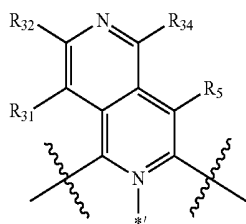
Formula 5-4

Formula 5-5

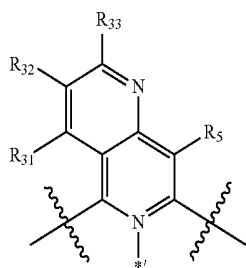
Formula 5-6

Formula 5-7

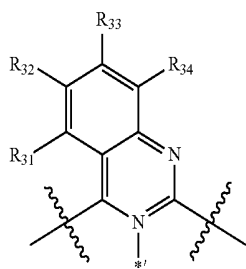
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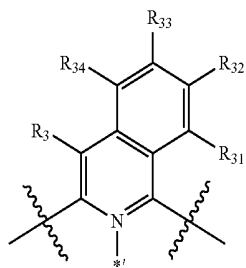
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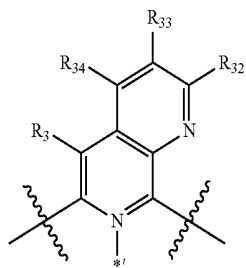
Formula 5-9



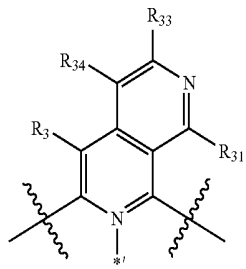
Formula 5-10



Formula 5-11

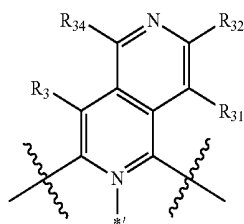


Formula 5-12

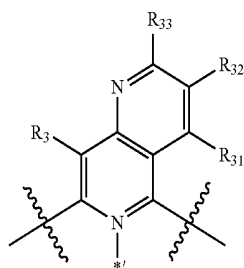


Formula 5-13

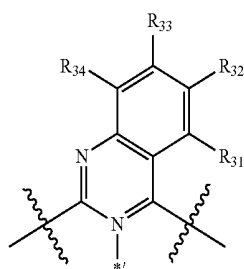
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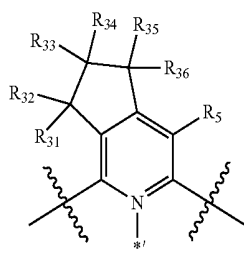
Formula 5-14



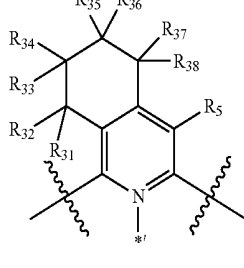
Formula 5-15



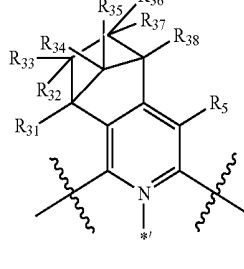
Formula 5-16



Formula 5-17

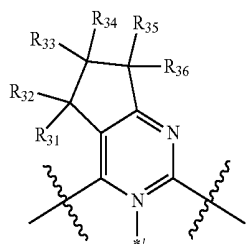


Formula 5-18

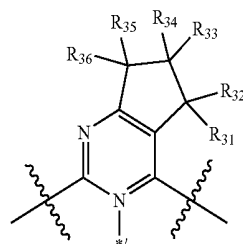


Formula 5-19

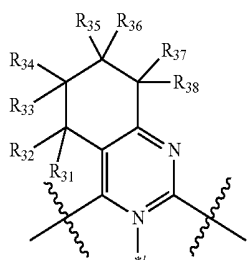
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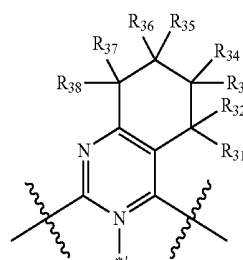
Formula 5-20



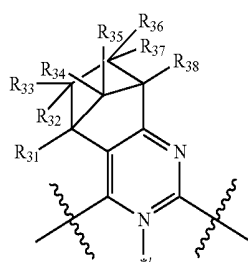
Formula 5-26



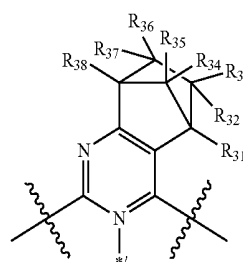
Formula 5-21



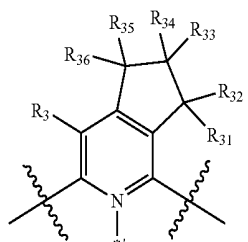
Formula 5-27



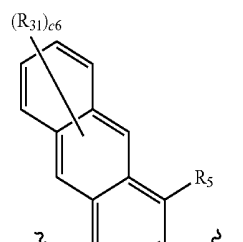
Formula 5-22



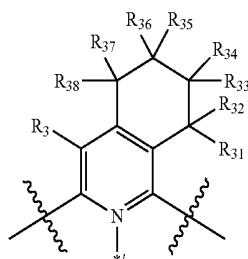
Formula 5-28



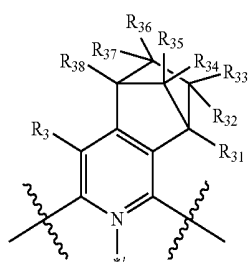
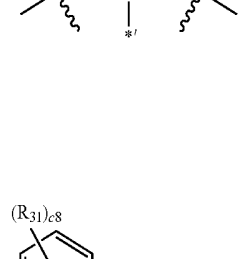
Formula 5-23



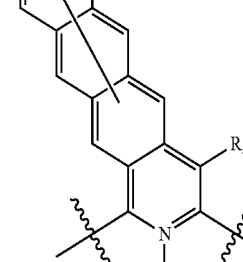
Formula 5-29



Formula 5-24

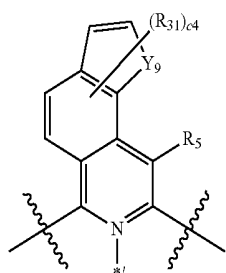
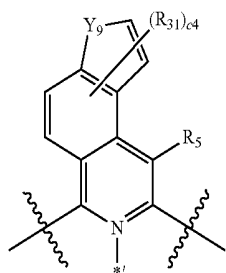
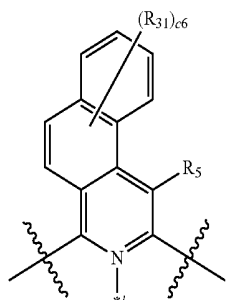
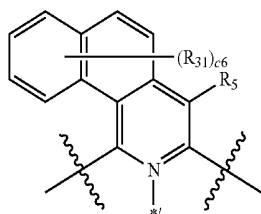
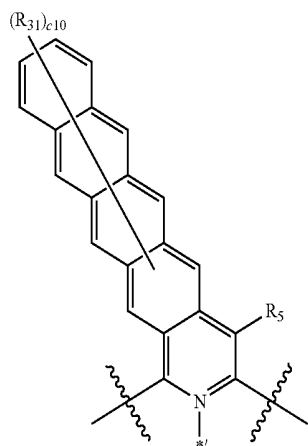


Formula 5-25



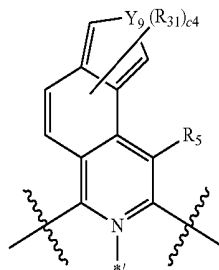
Formula 5-30

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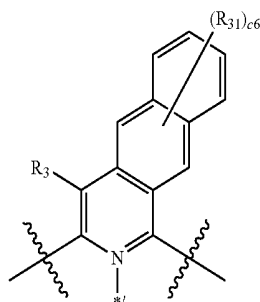
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Formula 5-31



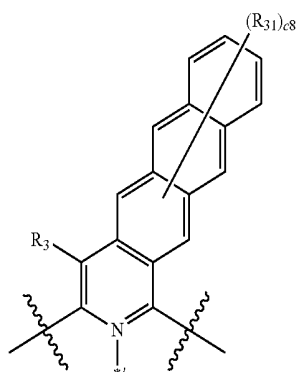
Formula 5-36

Formula 5-32



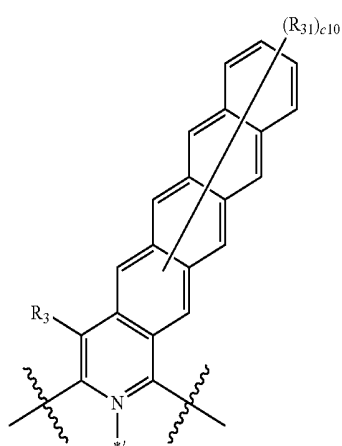
Formula 5-37

Formula 5-33



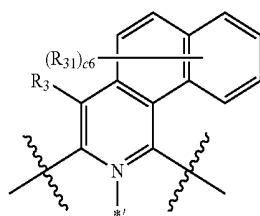
Formula 5-38

Formula 5-34



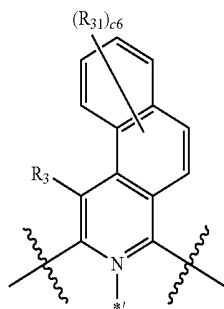
Formula 5-39

Formula 5-35

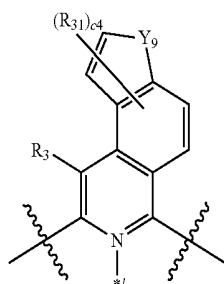


Formula 5-40

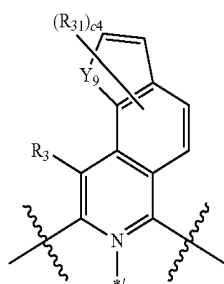
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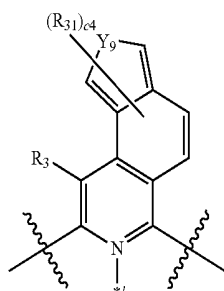
Formula 5-41



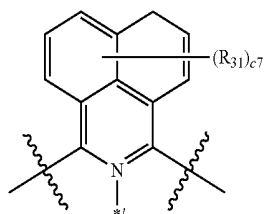
Formula 5-42



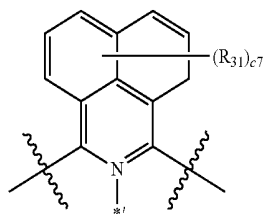
Formula 5-43



Formula 5-44

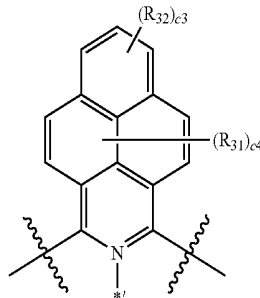


Formula 5-45

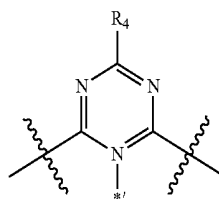


Formula 5-46

-continued



Formula 5-47



Formula 5-48

wherein, in Formulae 3-1 to 3-25, 3-31 to 3-74, 3-81 to 3-92, 4-1 to 4-53, and 5-1 to 5-48,

Y_7 and Y_8 are each independently O or S,

Y_9 is O, S, or N(R_{39}),

R_3 to R_5 are the same as R_3 to R_5 defined in claim 1,

R_{21} to R_{30} are each independently the same as R_2 defined in claim 1,

R_{31} to R_{39} are each independently the same as R_3 defined in claim 1,

c_3 is an integer selected from 0 to 3,

c_4 is an integer selected from 0 to 4,

c_6 is an integer selected from 0 to 6,

c_7 is an integer selected from 0 to 7,

c_8 is an integer selected from 0 to 8,

c_{10} is an integer selected from 0 to 10, and

*, *', and *'' each indicate a binding site to M in Formula 1.

6. The organometallic compound of claim 5, wherein R_3 to R_5 and R_{11} to R_{39} are each independently selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, $-SF_5$, a C_1 - C_{20} alkyl group, and a C_1 - C_{20} alkoxy group;

a C_1 - C_{20} alkyl group and a C_1 - C_{20} alkoxy group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1 - C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group;

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a

triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group; and

—N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), and —P(=O)(Q₈)(Q₉),

wherein Q₁ to Q₉ are each independently selected from —CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDCH₃, —CHDCH₂H, —CHDCDH₂, —CHDCH₂CD₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group.

7. The organometallic compound of claim 5, wherein R₃ to R₅ and R₁₁ to R₃₉ are each independently selected from hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group,

an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuran group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuran group, and a dibenzothiophenyl group; and

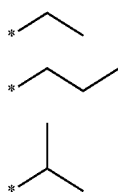
—N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), and —P(=O)(Q₈)(Q₉),

wherein Q₁ to Q₉ are each independently selected from —CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDC₂H₃, —CHDCD₂H, —CHDCDH₂, —CHDCD₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group.

8. The organometallic compound of claim 5, wherein R₃ to R₅ and R₁₁ to R₃₉ are each independently selected from hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, —CH₃, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, groups represented by Formulae 9-1 to 9-19, groups represented by Formulae 10-1 to 10-38, and —Si(Q₃)(Q₄)(Q₅):



Formula 9-1

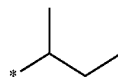
Formula 9-2

Formula 9-3

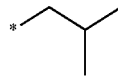
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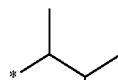
Formula 9-4



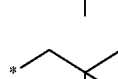
Formula 9-5



Formula 9-6



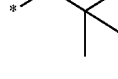
Formula 9-7



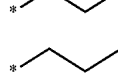
Formula 9-8



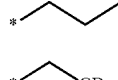
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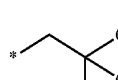
Formula 9-10



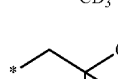
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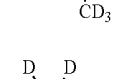
Formula 9-12



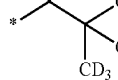
Formula 9-13



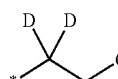
Formula 9-14



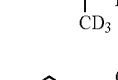
Formula 9-15



Formula 9-16



Formula 9-17

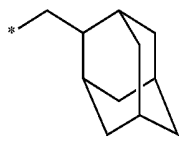
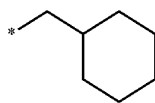
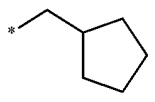
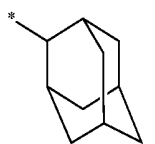
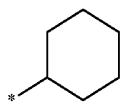
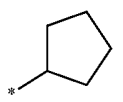
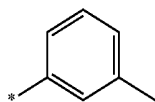
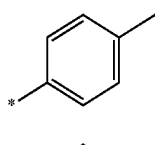
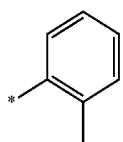
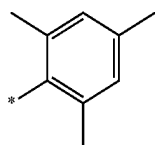
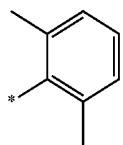
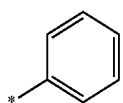


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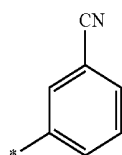


Formula 9-19

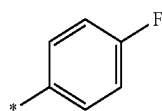
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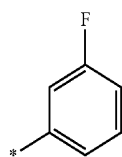
Formula 10-1



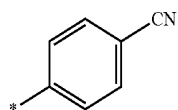
Formula 10-2



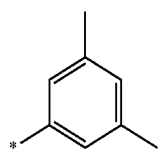
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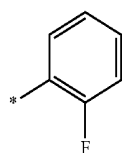
Formula 10-4



Formula 10-5

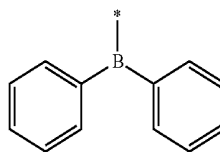


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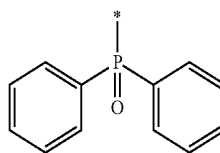
Formula 10-7

Formula 10-8

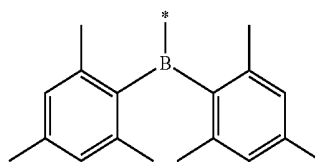


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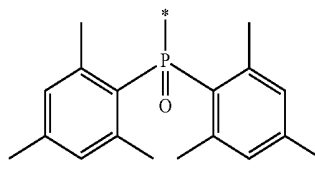
Formula 10-10



Formula 10-11



Formula 10-12



Formula 10-13

Formula 10-14

Formula 10-15

Formula 10-16

Formula 10-17

Formula 10-18

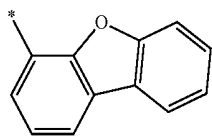
Formula 10-19

Formula 10-20

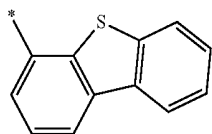
Formula 10-21

Formula 10-22

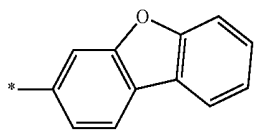
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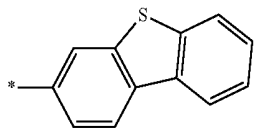
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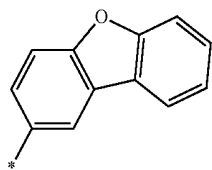
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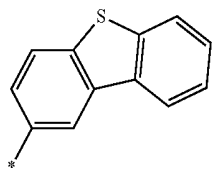
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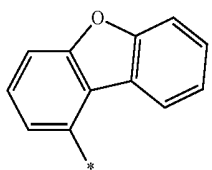
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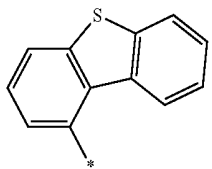
Formula 10-27



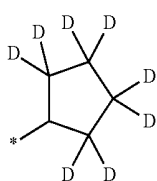
Formula 10-28



Formula 10-29

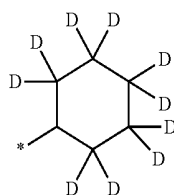


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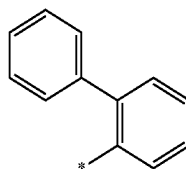


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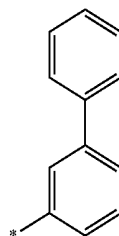
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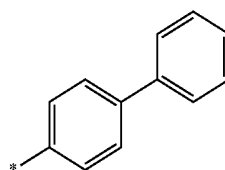
Formula 10-32



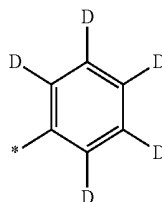
Formula 10-33



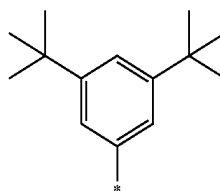
Formula 10-34



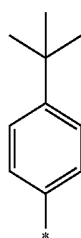
Formula 10-35



Formula 10-36



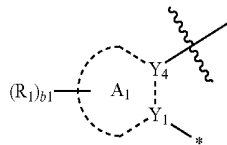
Formula 10-37



Formula 10-38

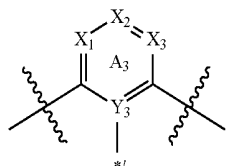
wherein, in Formulae 9-1 to 9-19 and 10-1 to 10-38, * indicates a binding site to an adjacent atom.

9. The organometallic compound of claim 5, wherein the moiety represented by



in Formula 2 is represented by one of Formulae 3-1, 3-5, 3-9, 3-13, 3-31 to 3-34, 3-47 to 3-50, 3-81, 3-85, and 3-89.

10. The organometallic compound of claim 5, wherein the moiety represented by



in Formula 2 is represented by one of Formulae 5-1 to 5-28, 5-29, and 5-45.

11. The organometallic compound of claim 1, wherein

T₁ is a single bond,

T₂ is a group selected from *—O—*, *—S—*, *—C(R₆)(R₇)—*, *—N(R₆)—*, and *—Si(R₆)(R₇)—*, wherein * and *' in each of the foregoing groups independently indicate a binding site to a neighboring atom, and

R₆ and R₇ are optionally bound to each other via a first linking group,

wherein the first linking group is selected from

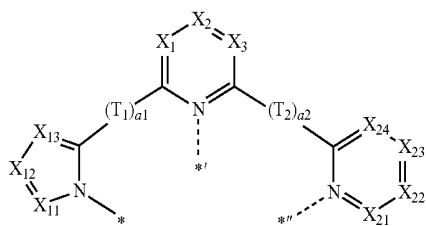
a single bond, a C₁-C₃ alkenylene group, and a C₂-C₃ alkenylene group;

a C₁-C₃ alkenylene group and a C₂-C₃ alkenylene group, each substituted with at least one selected from deuterium, a cyano group, C₁-C₁₀alkyl group, C₁-C₁₀ alkoxy group, a phenyl group, and a biphenyl group, and

a₂ is 1.

12. The organometallic compound of claim 1, wherein L₁ in Formula 1 is selected from ligands represented by Formula 2-1:

Formula 2-1



wherein, in Formula 2-1,

T₁, T₂, a₁, a₂, X₁ to X₃, *, *', and *'' are the same as T₁, T₂, a₁, a₂, X₁ to X₃, *, *', and *'' defined in claim 1,

X₁₁ is C or N(R_{11a}), X₁₂ is C or N(R_{12a}), X₁₃ is C or N(R_{13a}), X₂₁ is C or N(R_{21a}), X₂₂ is C or N(R_{22a}), X₂₃ is C or N(R_{23a}), X₂₄ is C or N(R_{24a}),

R_{11a} to R_{13a} are each the same as defined in claim 1 in connection with R₁,

R_{21a} to R_{24a} are each the same as defined in claim 1 in connection with R₂,

at least two of R_{11a} to R_{13a} are optionally bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group, and

at least two of R_{21a} to R_{24a} are optionally bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group.

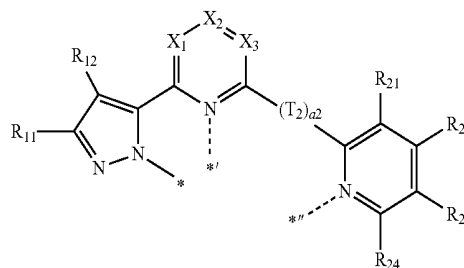
13. The organometallic compound of claim 12, wherein a) two of R_{11a} to R_{13a} or b) two of R_{21a} to R_{24a} are optionally bound to each other to form one selected from

a cyclopentane group, a cyclohexane group, an adamantane group, a norbornane group, a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a pyrene group, and a chrysene group; and

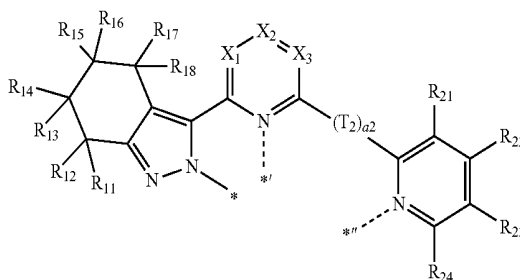
a cyclopentane group, a cyclohexane group, an adamantane group, a norbornane group, a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a pyrene group, and a chrysene group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group.

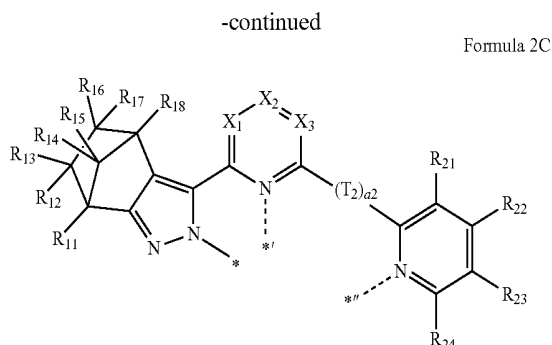
14. The organometallic compound of claim 1, wherein L₁ in Formula 1 is selected from ligands represented by one of Formulae 2A to 2C:

Formula 2A



Formula 2B





wherein, in Formulae 2A to 2C,

T_2 , a2, X_1 to X_3 , *, *', and *'' are the same as T_2 , a2, X_1 to X_3 , *, *', and *'' defined in claim 1,

R_{11} to R_{18} are each the same as defined in claim 1 in connection with R_1 ,

R_{21} to R_{24} are each the same as defined in claim 1 in connection with R_2 , and at least two of R_{21} to R_{24} are optionally bound to each other to form a substituted or unsubstituted C_5 - C_{30} carbocyclic group or a substituted or unsubstituted C_2 - C_{30} heterocyclic group.

15. The organometallic compound of claim 1, wherein L_2 in Formula 1 is selected from ligands represented by Formula 6-1:



wherein, in Formula 6-1,

T_3 is a group selected from a single bond, $*-O-*'$, $*-S-*'$, $*-C(R_{62})(R_{63})-*'$, $*-C(R_{62})=*'$, $*=C(R_{62})-*'$, $*-C(R_{62})=C(R_{63})-*'$, $*-C(=O)-*'$, $*-C(=S)-*'$, $*-C=C-*'$, and $*-N(R_{62})-*'$, wherein * and *' in each of the foregoing groups independently indicate a binding site to a neighboring atom,

a_3 is an integer selected from 1 to 5,

R_{61} is selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, $-SF_5$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1 - C_{60} alkyl group, a substituted or unsubstituted C_2 - C_{60} alkenyl group, a substituted or unsubstituted C_2 - C_{60} alkynyl group, a substituted or unsubstituted C_1 - C_{60} alkoxy group, a substituted or unsubstituted C_3 - C_{10} cycloalkyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3 - C_{10} cycloalkenyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6 - C_{60} aryl group, a substituted or unsubstituted C_6 - C_{60} aryloxy group, a substituted or unsubstituted C_6 - C_{60} arylthio group, a substituted or unsubstituted C_1 - C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-N(Q_1)(Q_2)$, $-Si(Q_3)(Q_4)(Q_5)$, $-B(Q_6)(Q_7)$, $-P(=O)(Q_8)(Q_9)$, and $P(Q_{41})(Q_{42})(Q_{43})$,

wherein Q_1 to Q_9 and Q_{41} to Q_{43} are each independently selected from

$-CH_3$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CH_2CH_3$, $-CH_2CD_3$, $-CH_2CD_2H$, $-CH_2CDH_2$, $-CHDCH_3$, $-CHDCD_2H$, $-CHDCDH_2$, $-CHDCD_3$, $-CD_2CD_3$, $-CD_2CD_2H$, and $-CD_2CDH_2$;

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C_1 - C_{10} alkyl group, and a phenyl group,

R_{62} to R_{63} are each independently selected from

hydrogen, deuterium, $-F$, a cyano group, a nitro group, $-SF_5$, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, $-F$, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a cyano group, a nitro group, a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamanta-

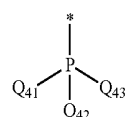
nyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

R₆₂ and R₆₃ are optionally bound to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₂-C₃₀ heterocyclic group, and

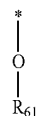
* in Formula 1 indicates a binding site to M.

16. The organometallic compound of claim 1, wherein L₂ in Formula 1 is selected from ligands represented by one of Formulae 13-1 to 13-49 and 14-1 to 14-28:

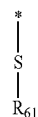
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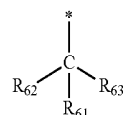
Formula 13-1



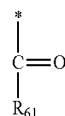
Formula 13-2



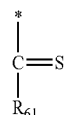
Formula 13-3



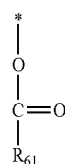
Formula 13-4



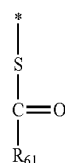
Formula 13-5



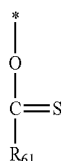
Formula 13-6



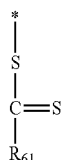
Formula 13-7



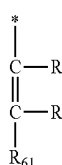
Formula 13-8



Formula 13-9



Formula 13-10



Formula 13-11



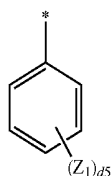
Formula 13-12



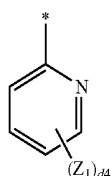
Formula 13-13



Formula 13-14

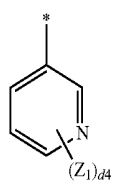


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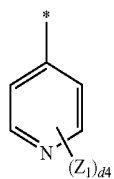


Formula 13-16

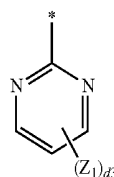
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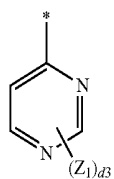
Formula 13-17



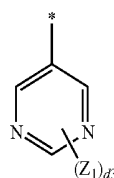
Formula 13-18



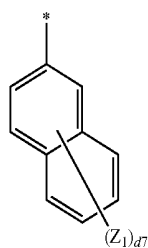
Formula 13-19



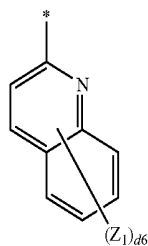
Formula 13-20



Formula 13-21

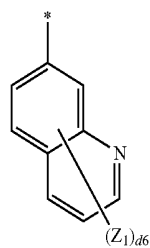


Formula 13-22

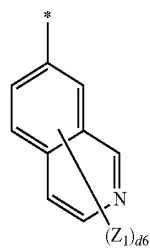


Formula 13-23

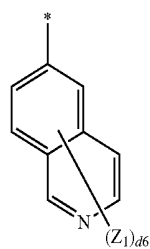
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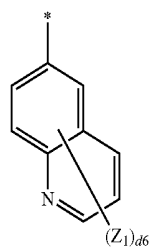
Formula 13-24



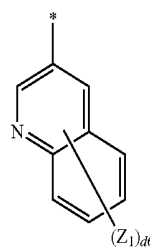
Formula 13-25



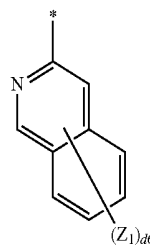
Formula 13-26



Formula 13-27

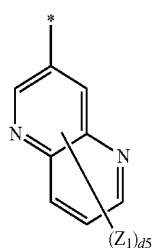
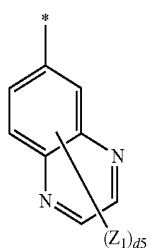
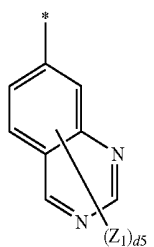
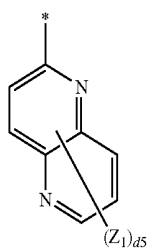
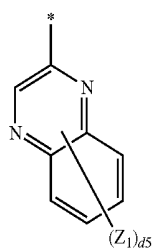
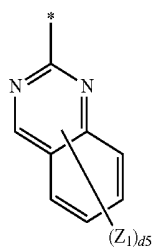


Formula 13-28

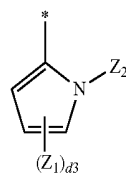


Formula 13-29

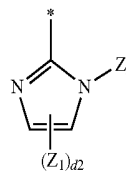
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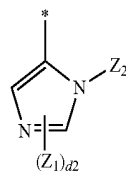
Formula 13-30



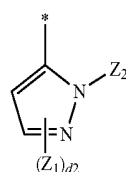
Formula 13-31



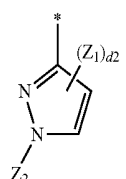
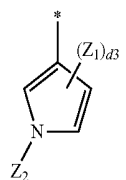
Formula 13-32



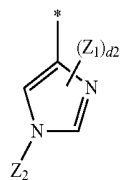
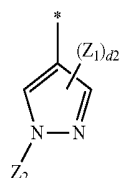
Formula 13-33



Formula 13-34



Formula 13-35



-continued

Formula 13-36

Formula 13-37

Formula 13-38

Formula 13-39

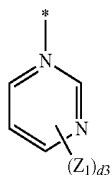
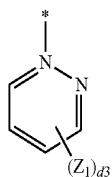
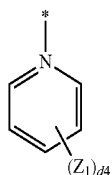
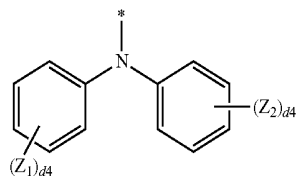
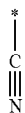
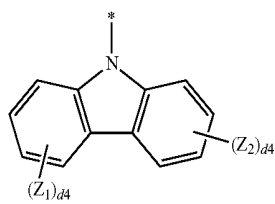
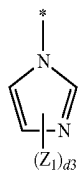
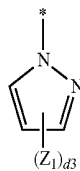
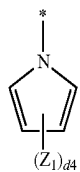
Formula 13-40

Formula 13-41

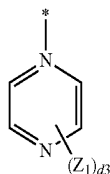
Formula 13-42

Formula 13-43

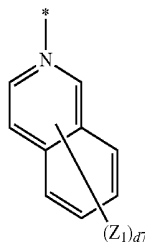
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Formula 13-44

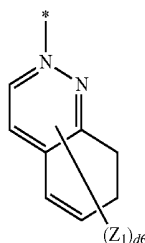


Formula 13-45



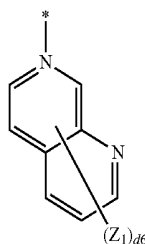
Formula 13-46

Formula 13-47



Formula 13-48

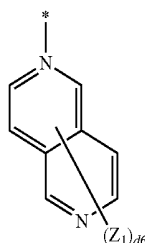
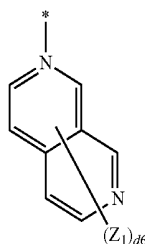
Formula 13-49



Formula 14-1

Formula 14-2

Formula 14-3



-continued

Formula 14-4

Formula 14-5

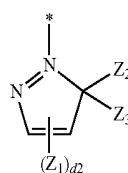
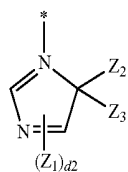
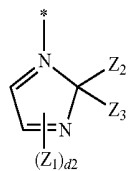
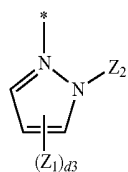
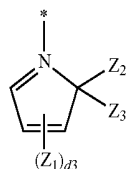
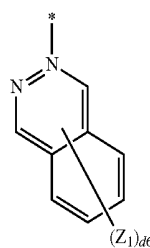
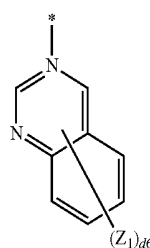
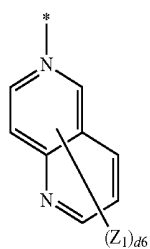
Formula 14-6

Formula 14-7

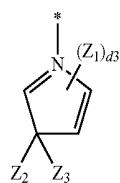
Formula 14-8

Formula 14-9

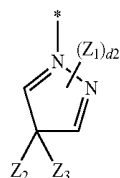
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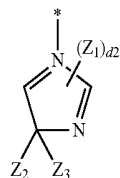
Formula 14-10



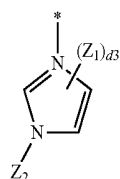
Formula 14-11



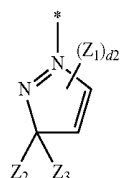
Formula 14-12



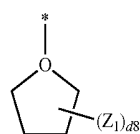
Formula 14-13



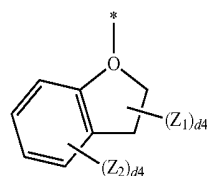
Formula 14-14



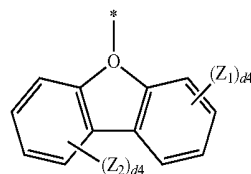
Formula 14-15



Formula 14-16



Formula 14-17



Formula 14-18

Formula 14-19

Formula 14-20

Formula 14-21

Formula 14-22

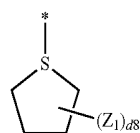
Formula 14-23

Formula 14-24

Formula 14-25

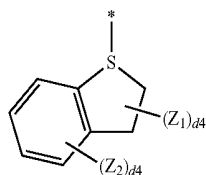
Formula 14-26

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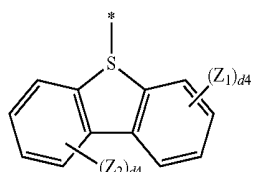


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Formula 14-27



Formula 14-28



wherein, in Formulae 13-1 to 13-49 and 14-1 to 14-28, R_{61} is selected from

hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, —SF₅, a C₁-C₂₀ alkyl group, and a C₁-C₂₀ alkoxy group;

a C₁-C₂₀ alkyl group and a C₁-C₂₀ alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₁₀ alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, and

a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group;

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazoliny group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group; and

—N(Q₁)(Q₂), —Si(Q₃)(Q₄)(Q₅), —B(Q₆)(Q₇), —P(=O)(Q₈)(Q₉), and P(Q₄₁)(Q₄₂)(Q₄₃),

Z₁ to Z₃ are each independently selected from

hydrogen, deuterium, —F, a cyano group, a nitro group, —SF₅, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, an n-hexyl group, an iso-hexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an iso-heptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an iso-octyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an iso-nonyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an iso-decyl group, a sec-decyl group, a tert-decyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a pentoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a cyano group, a nitro group, a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

—N(Q₃₁)(Q₃₂), —Si(Q₃₃)(Q₃₄)(Q₃₅), —B(Q₃₆)(Q₃₇), and —P(=O)(Q₃₈)(Q₃₉),

wherein Q₁ to Q₉, Q₃₁ to Q₃₉ and Q₄₁ to Q₄₃ are each independently selected from

—CH₃, —CD₃, —CD₂H, —CDH₂, —CH₂CH₃, —CH₂CD₃, —CH₂CD₂H, —CH₂CDH₂, —CHDC₃, —CHDCD₂H, —CHDCDH₂, —CHDCD₃, —CD₂CD₃, —CD₂CD₂H, and —CD₂CDH₂;

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl

group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group; and

an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, and a naphthyl group, each substituted with at least one selected from deuterium, a C₁-C₁₀ alkyl group, and a phenyl group,

d2 is an integer selected from 1 and 2,

d3 is an integer selected from 1 to 3,

d4 is an integer selected from 1 to 4,

d5 is an integer selected from 1 to 5,

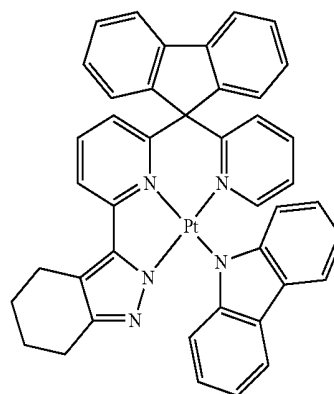
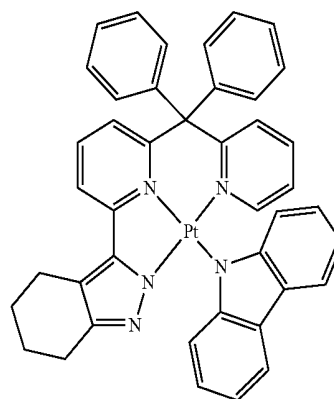
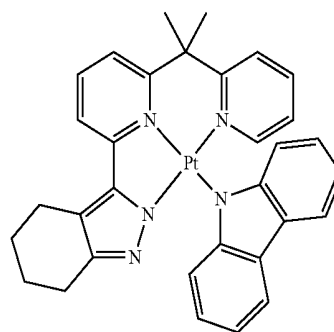
d6 is an integer selected from 1 to 6,

d7 is an integer selected from 1 to 7,

d8 is an integer selected from 1 to 8, and

* in Formula 1 indicates a binding site to M.

17. The organometallic compound of claim 1, wherein the organometallic compound is one of Compounds 1 to 180:

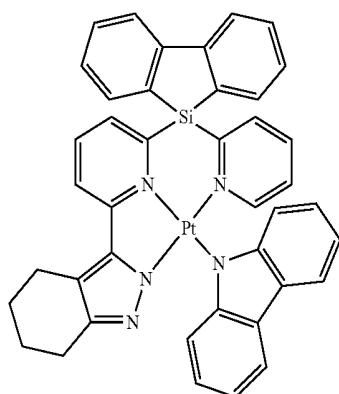


1

2

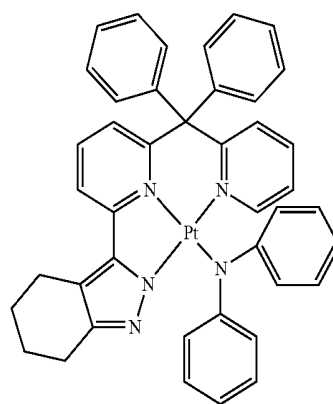
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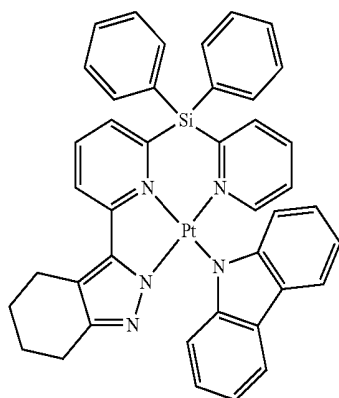
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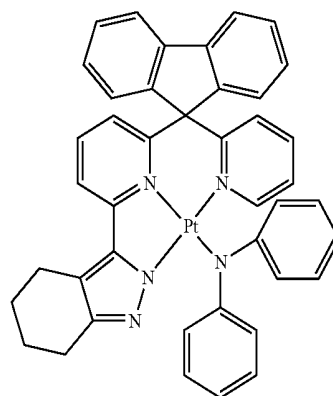


8

5

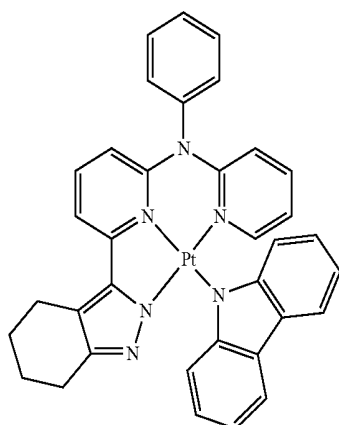


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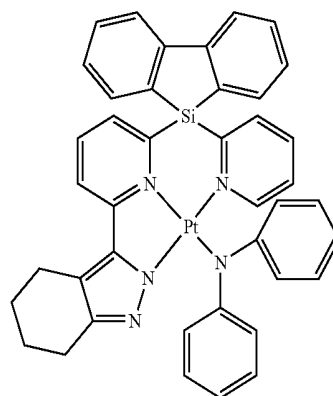


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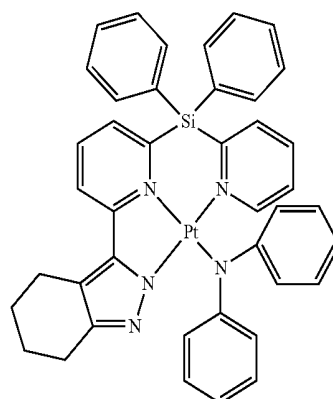
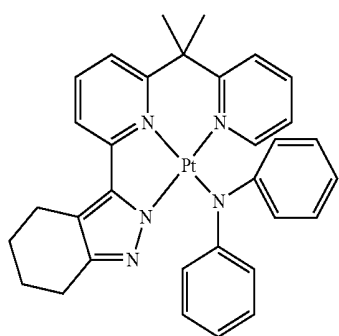
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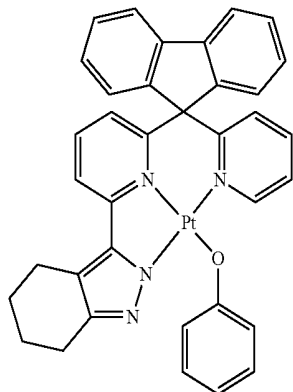
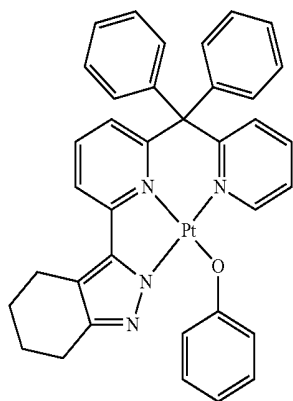
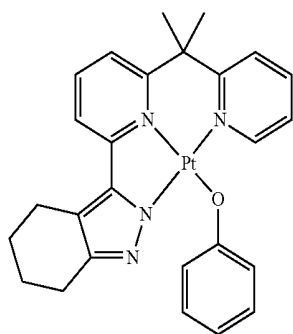
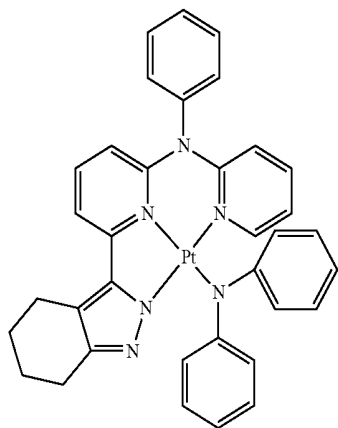
11



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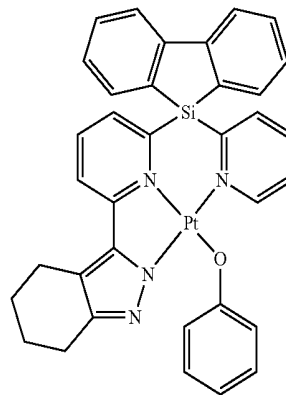


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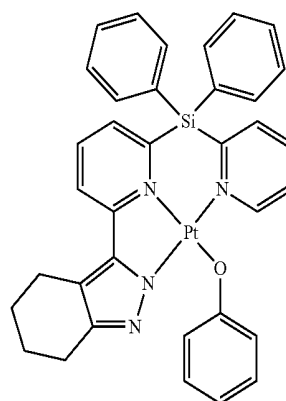
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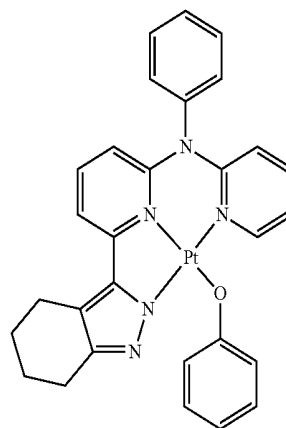
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13



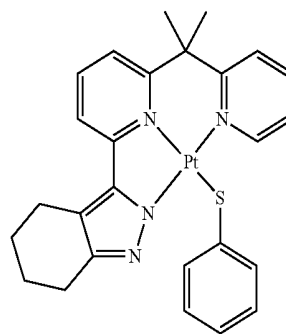
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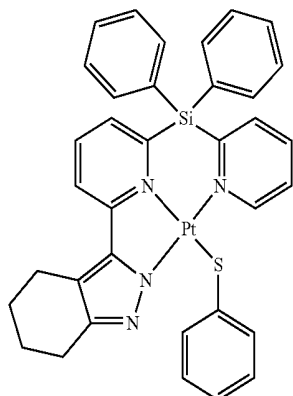
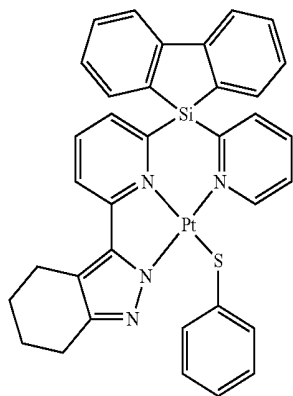
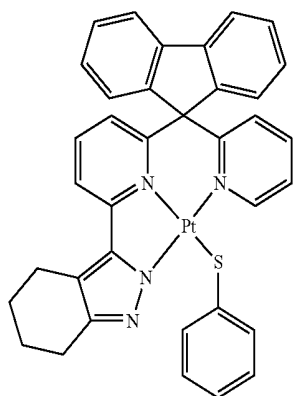
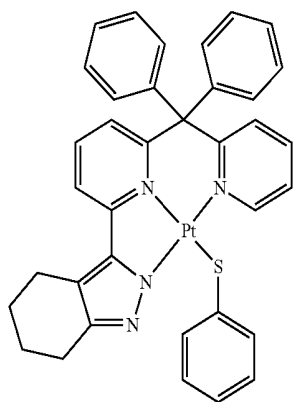
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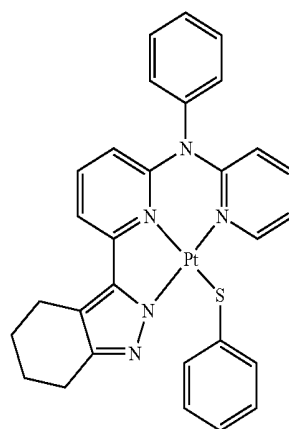
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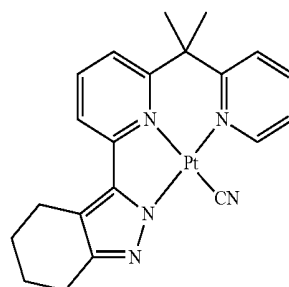


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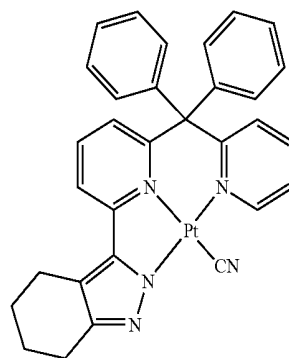
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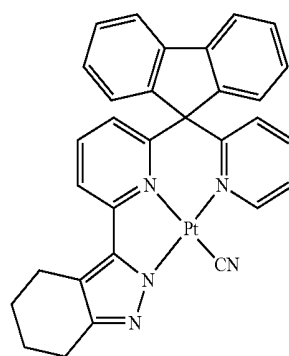
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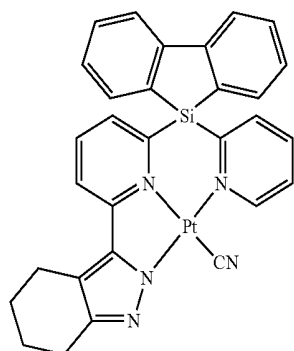
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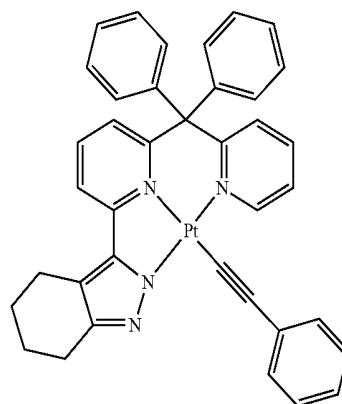
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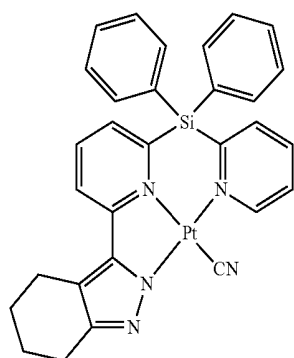
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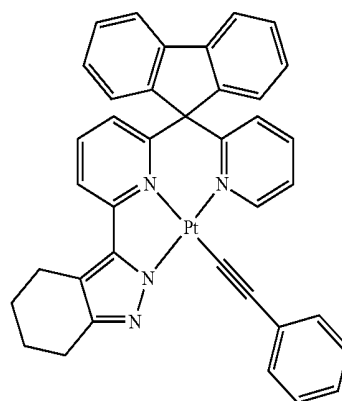


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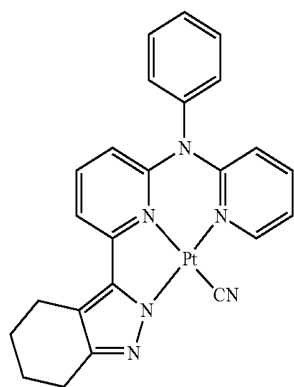
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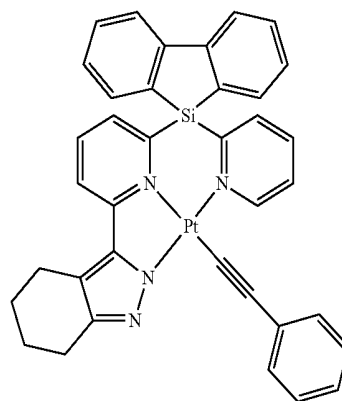
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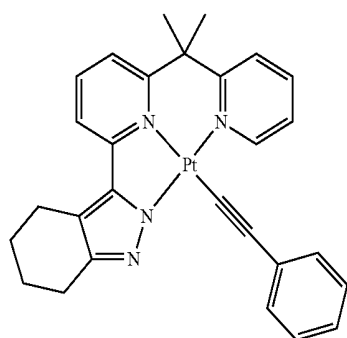
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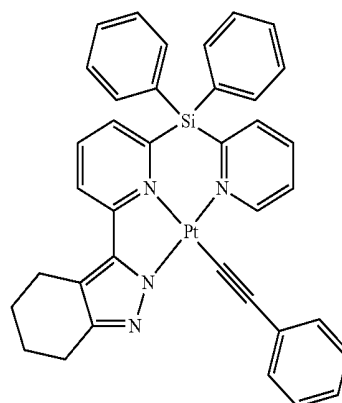
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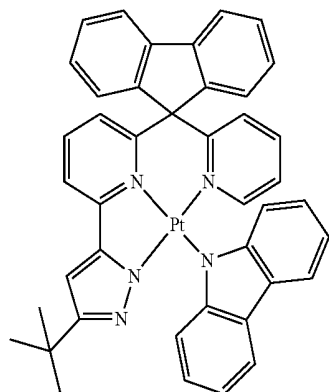
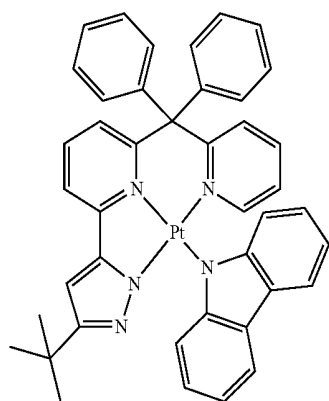
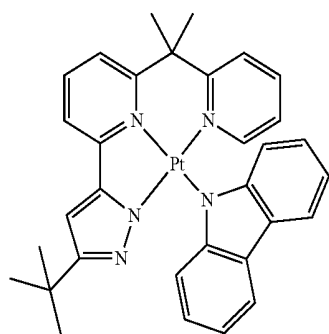
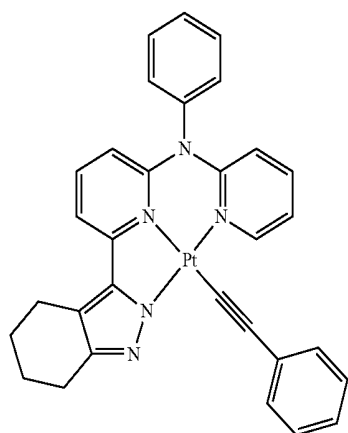
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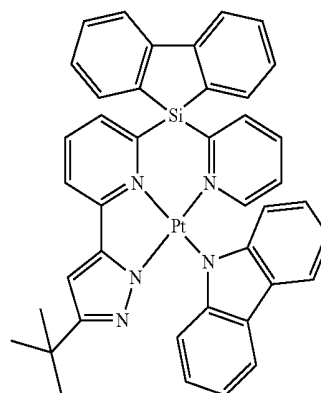


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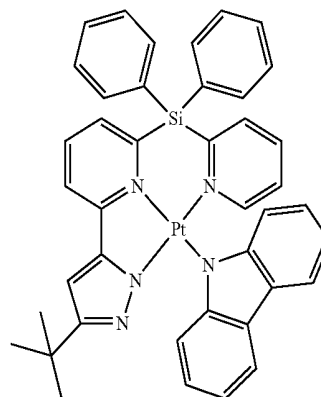
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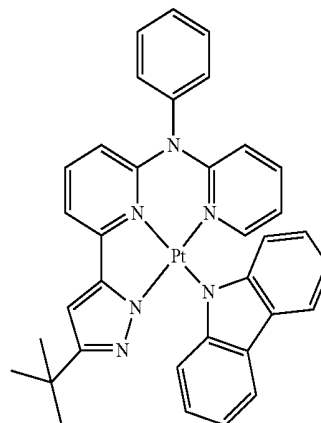
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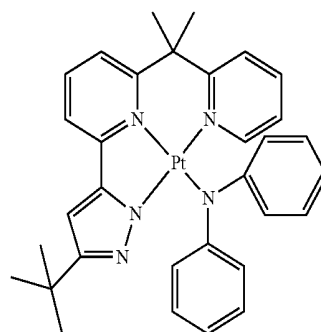
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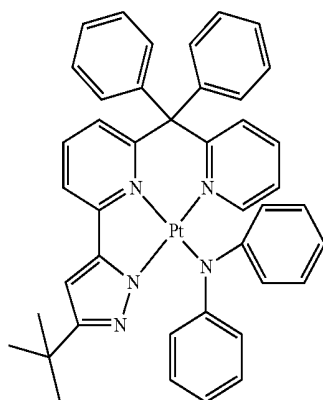
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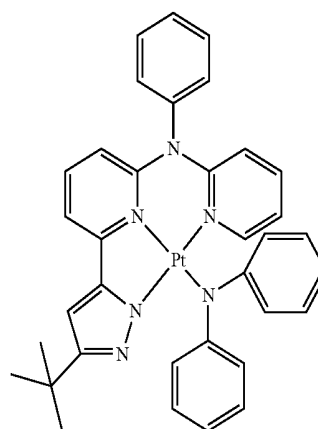
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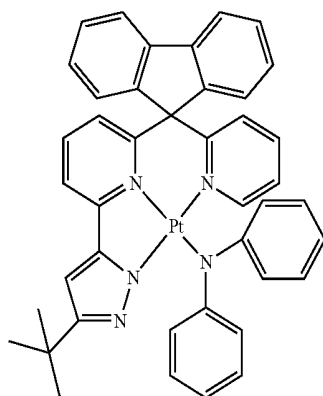


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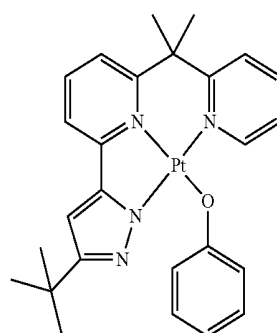
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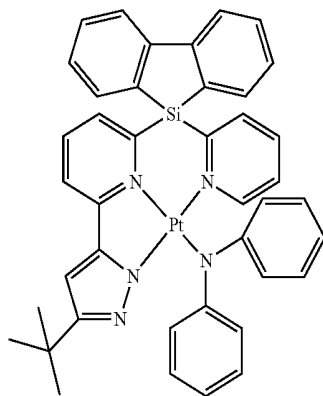
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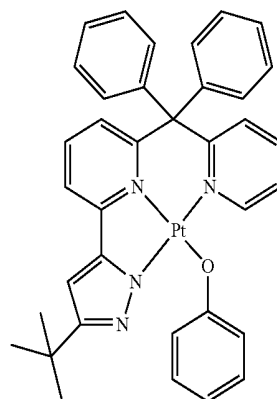
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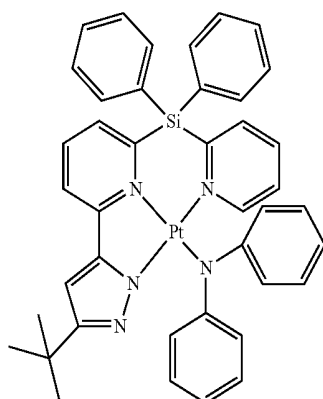
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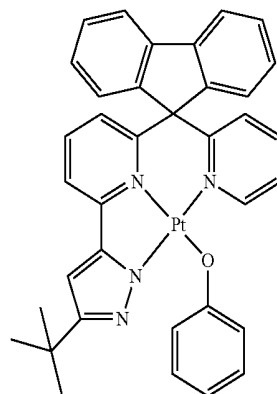
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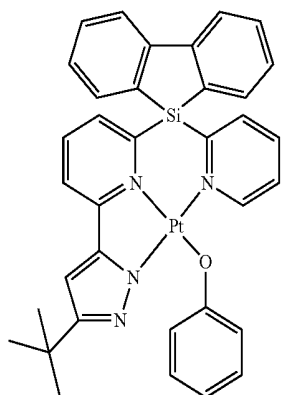


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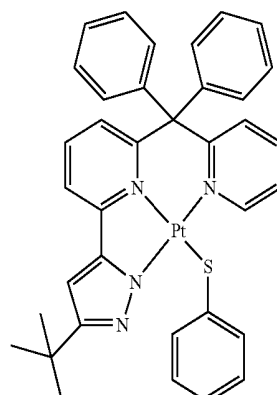
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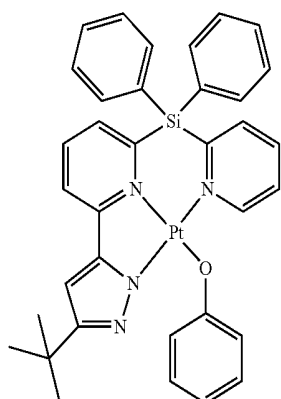


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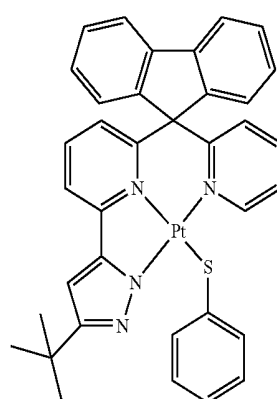
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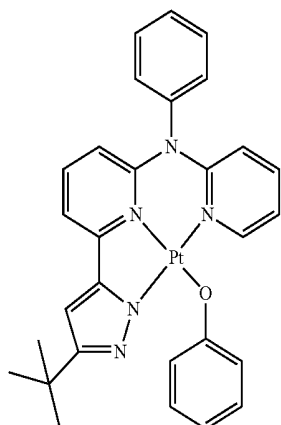
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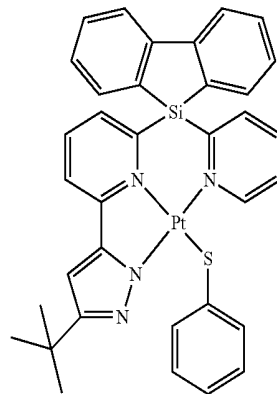
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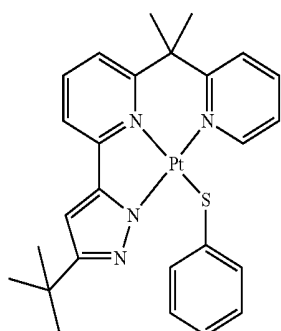
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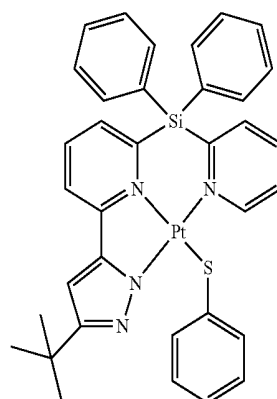
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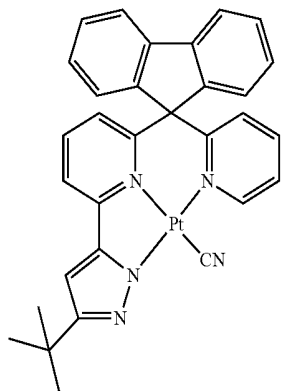
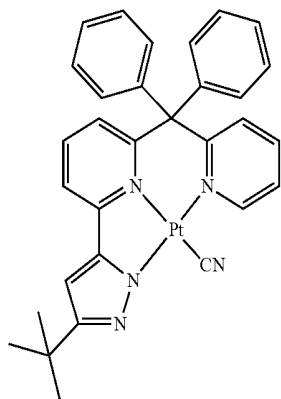
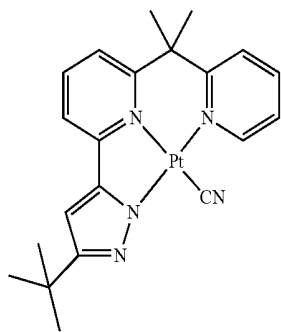
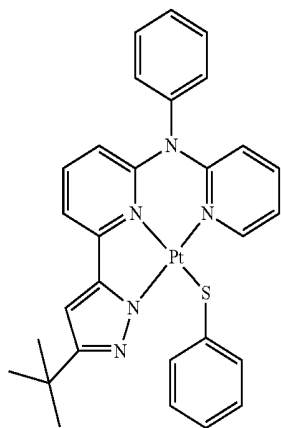


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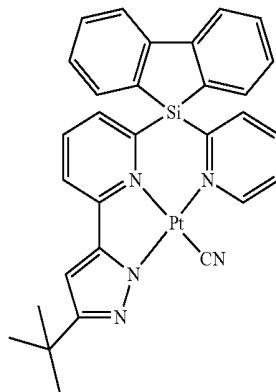
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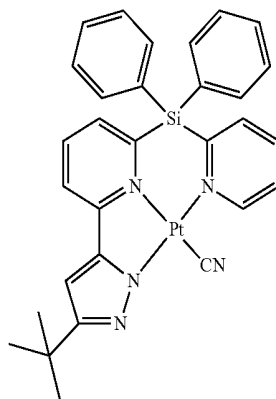
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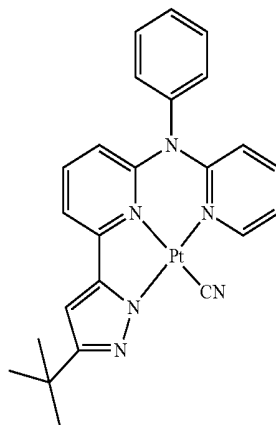
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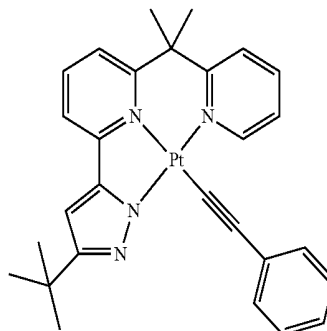
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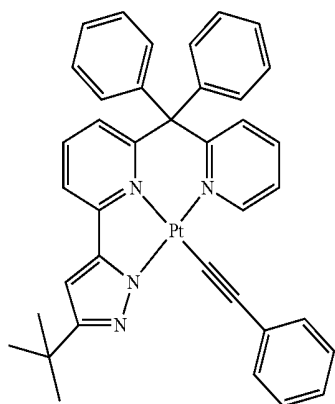
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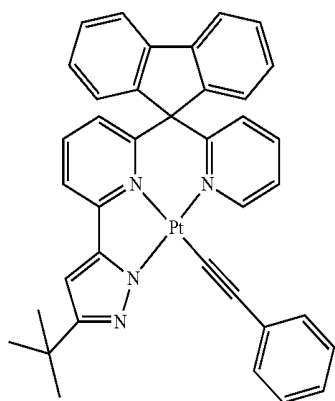


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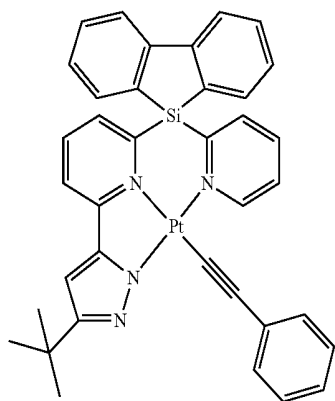
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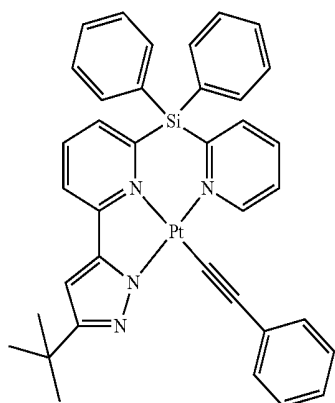
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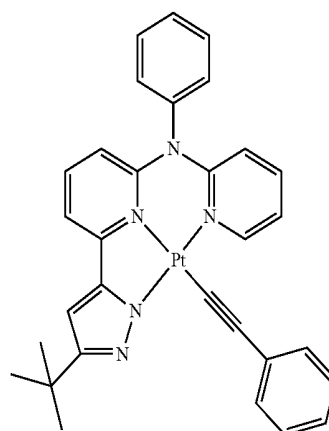


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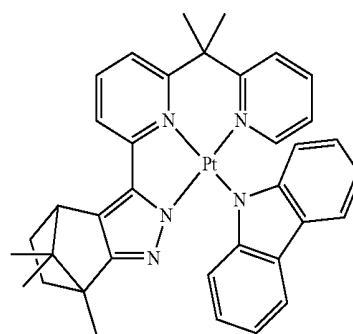


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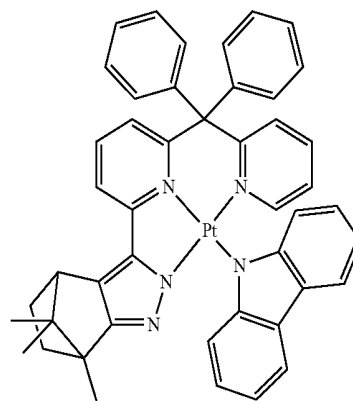
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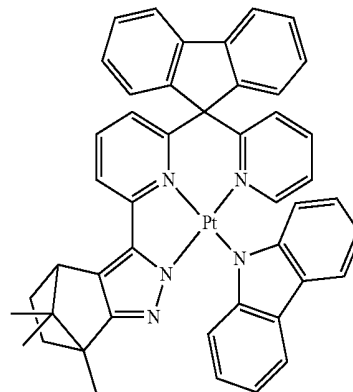
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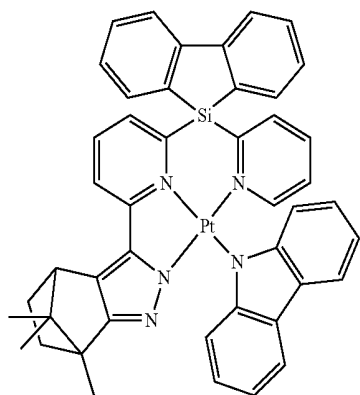


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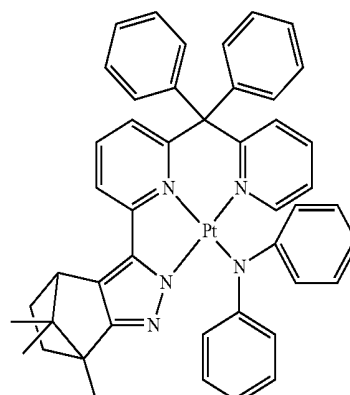
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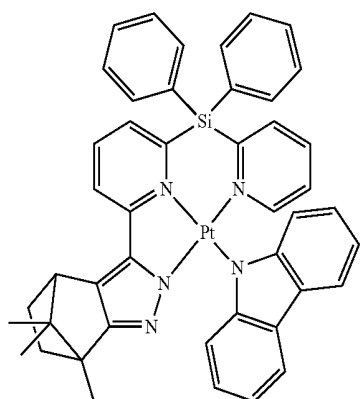


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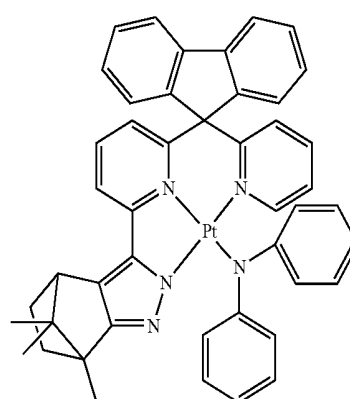
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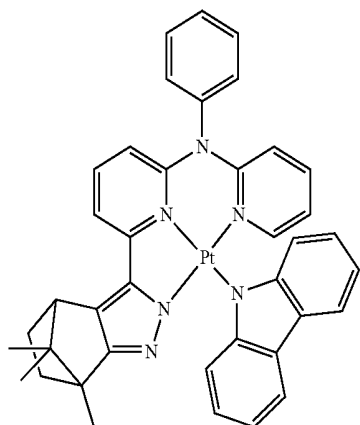
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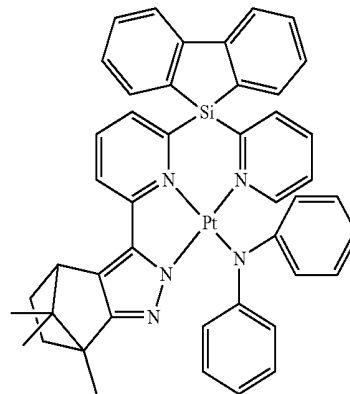
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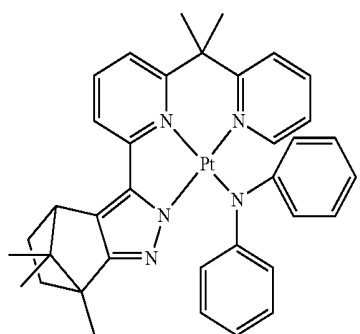
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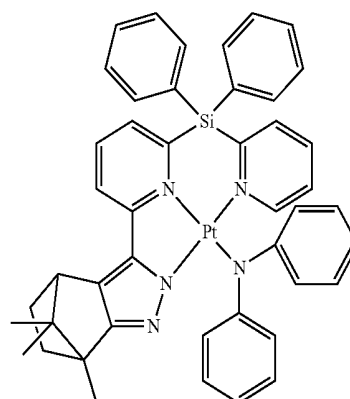
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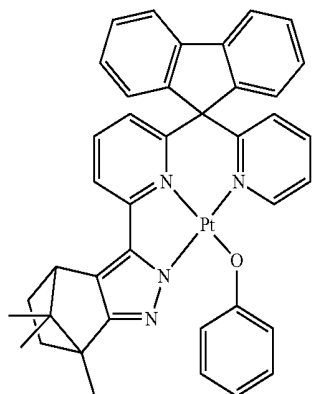
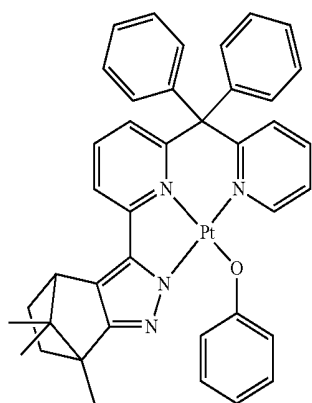
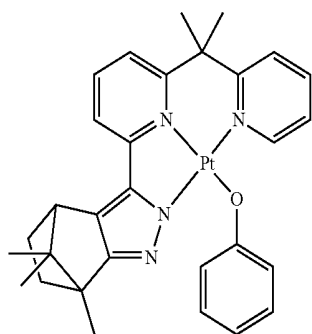
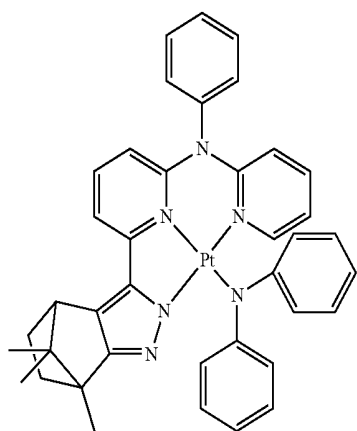


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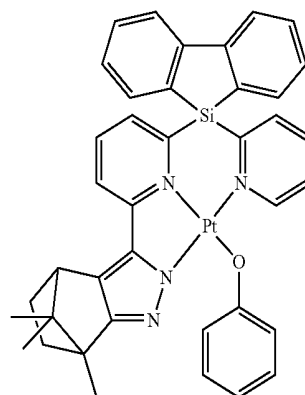
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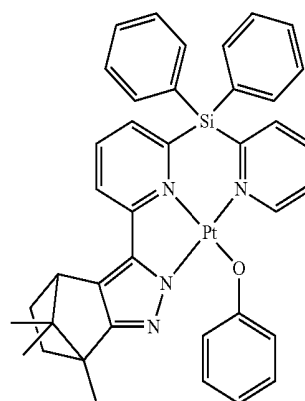
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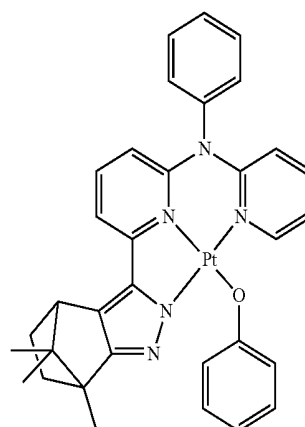
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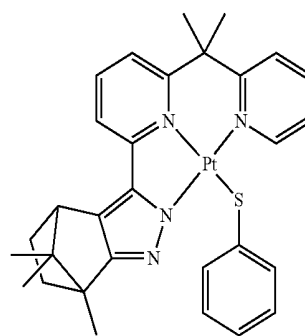
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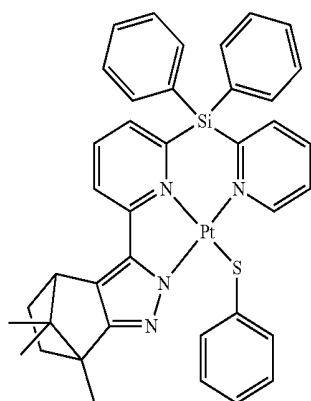
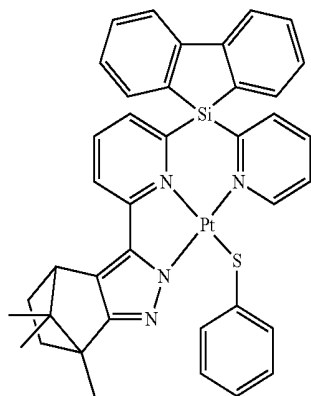
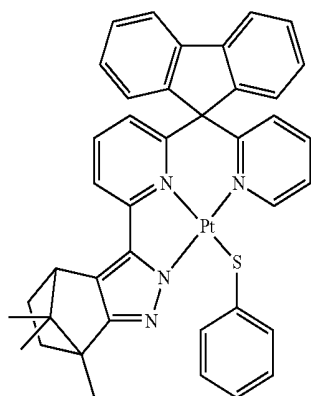
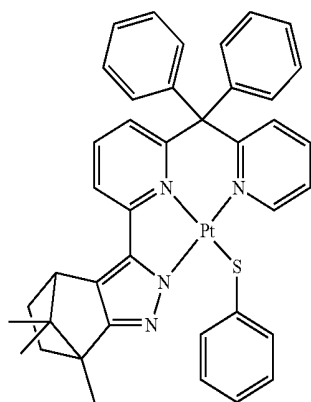
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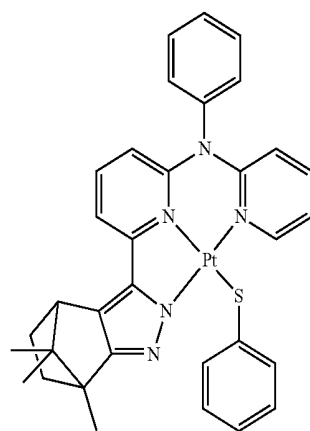
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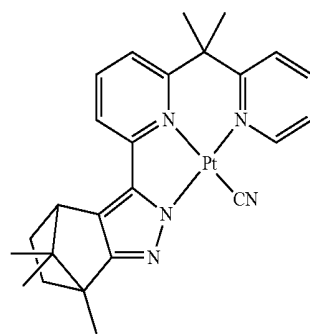
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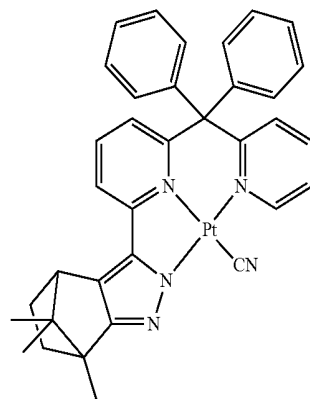
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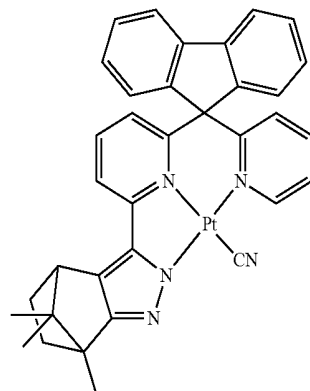
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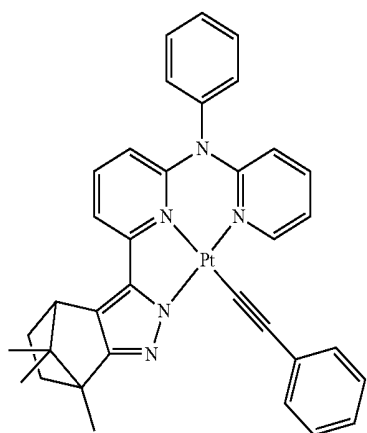
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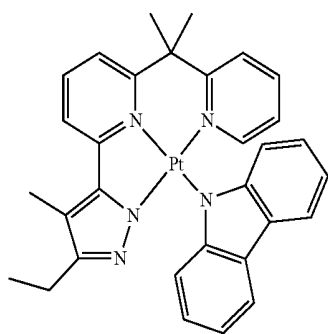


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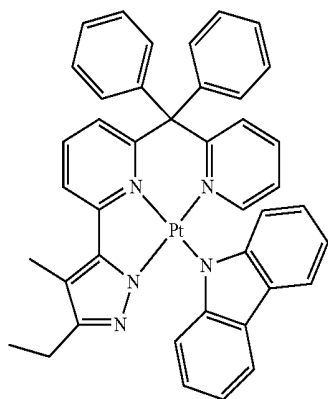
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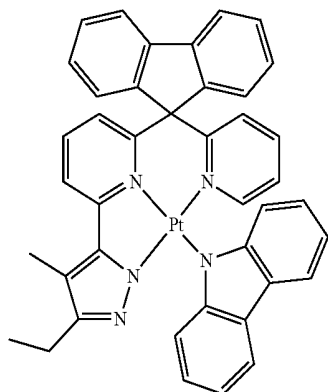
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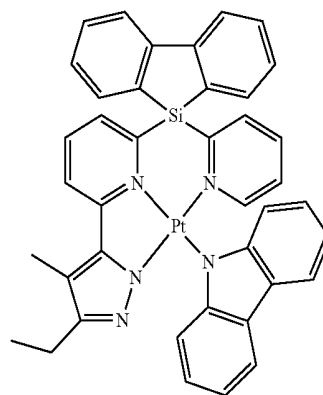


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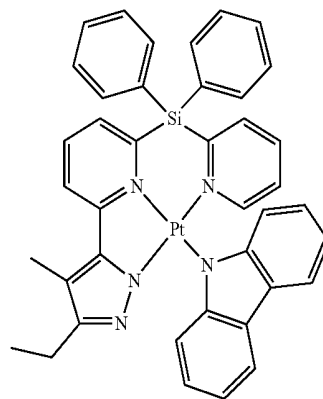


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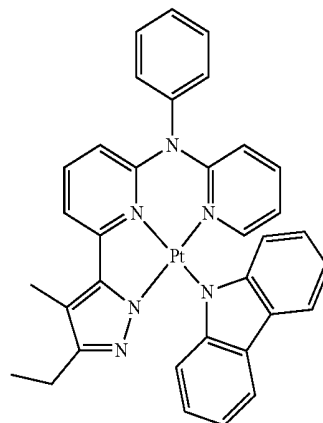
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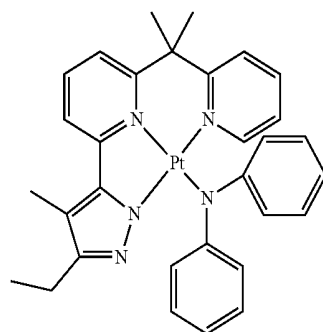
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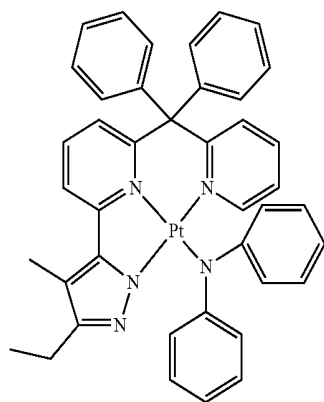


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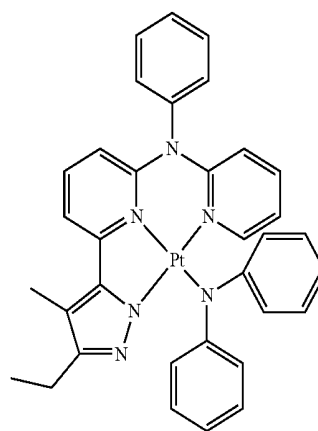
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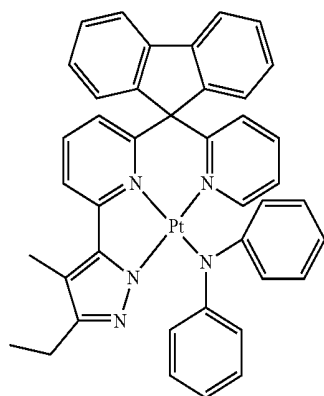


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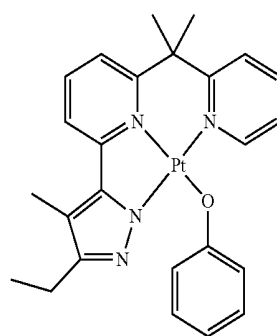
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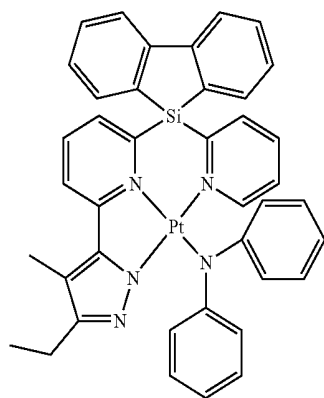
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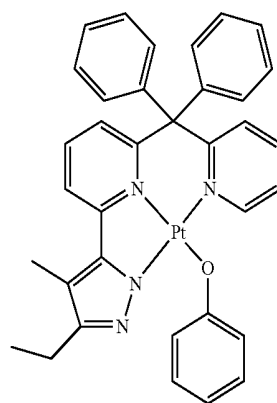
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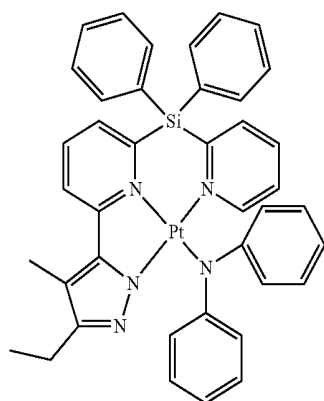
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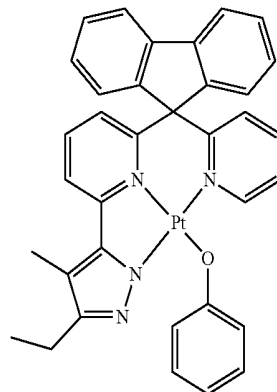
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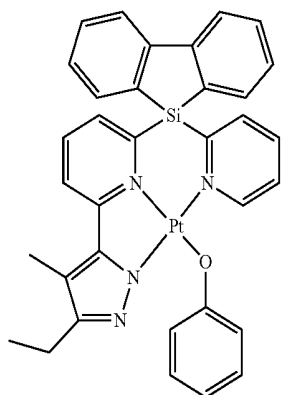
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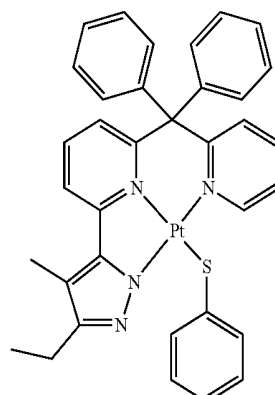
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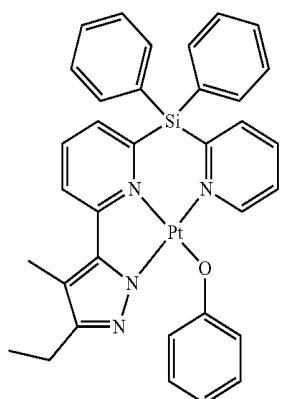
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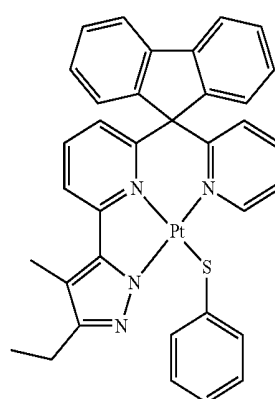


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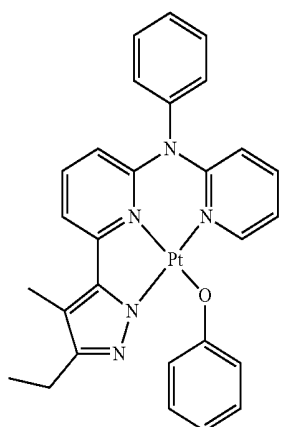
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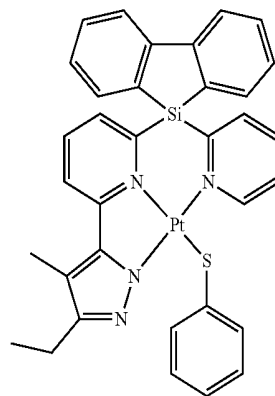
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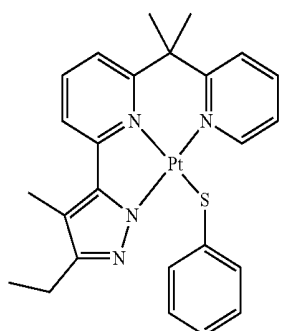
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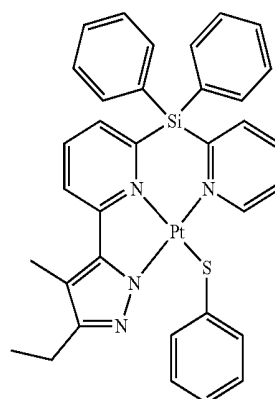
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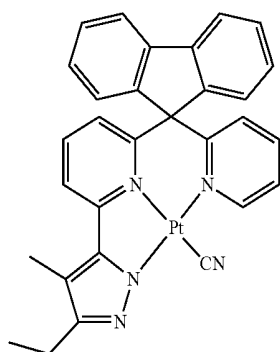
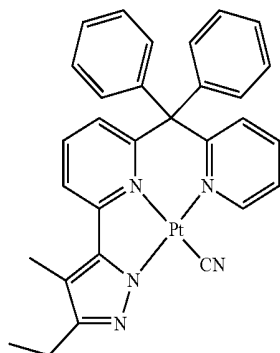
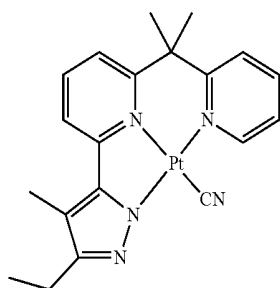
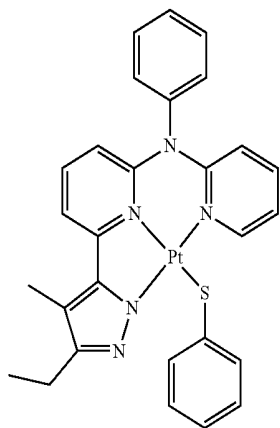


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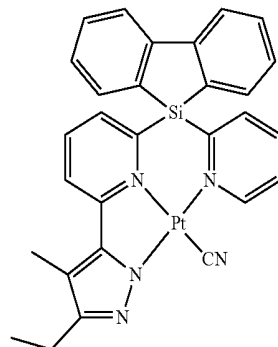
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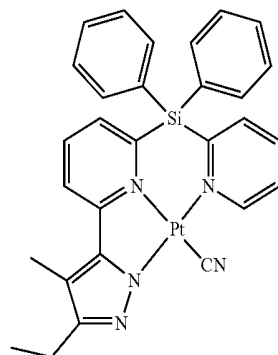
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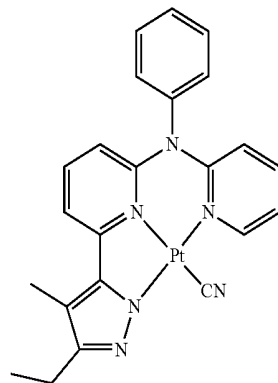
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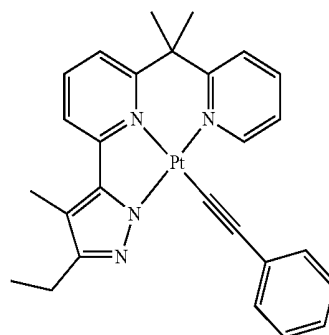
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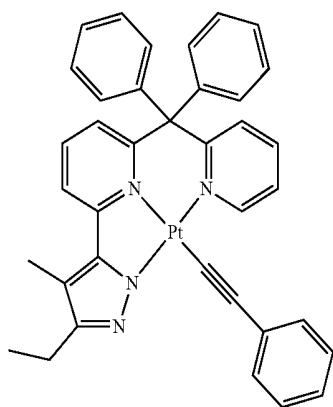
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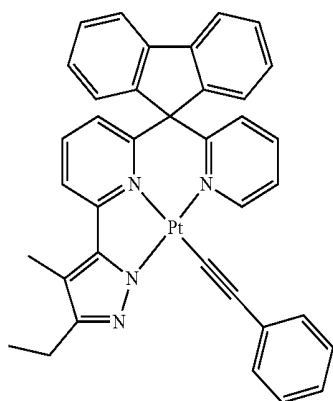


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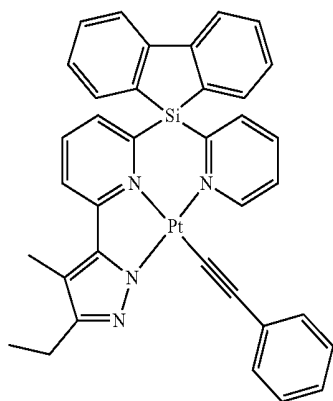
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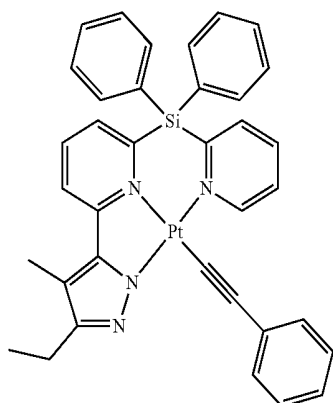
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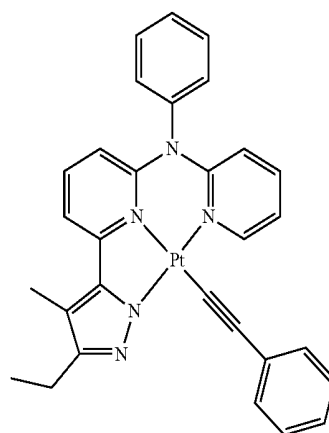


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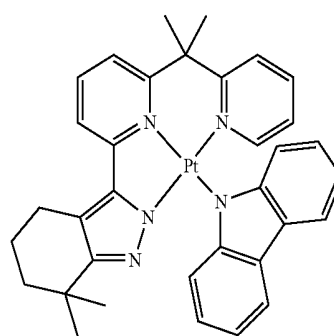


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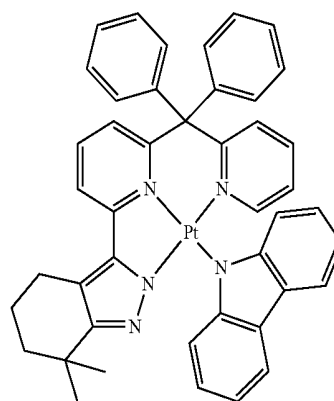
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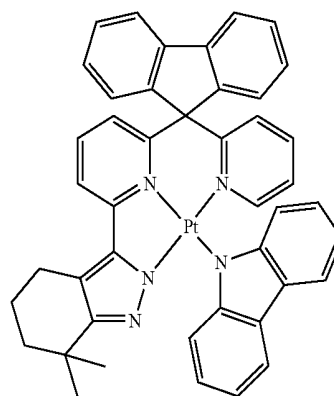
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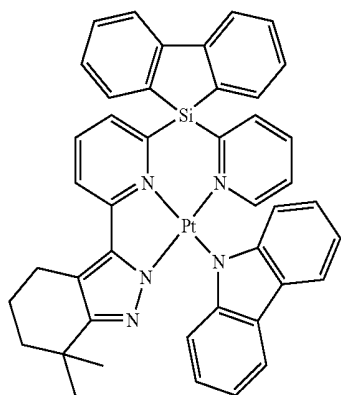


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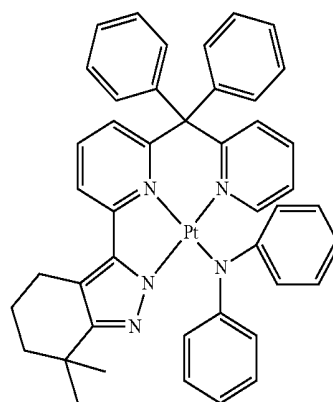
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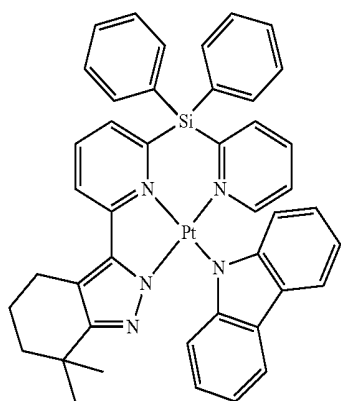


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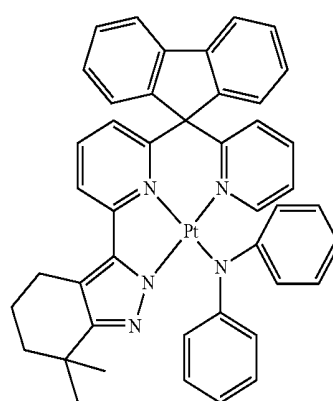
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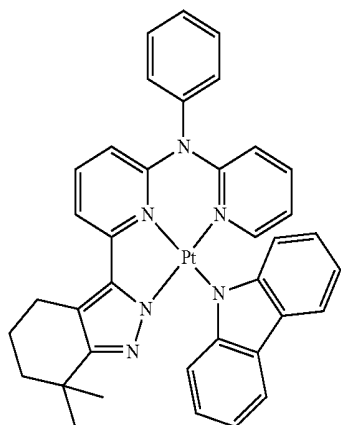
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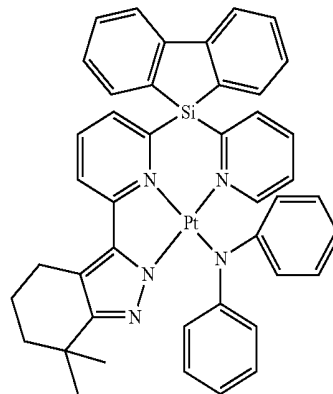
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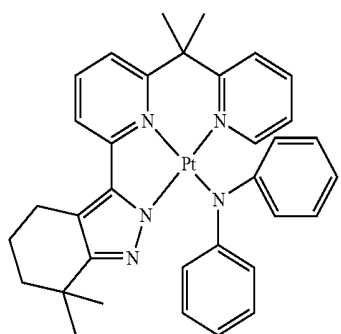
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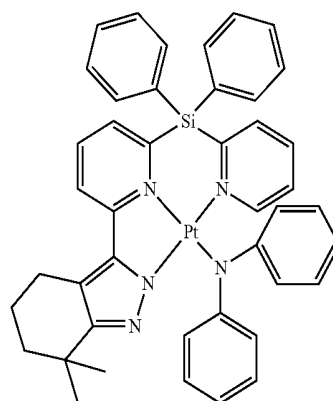
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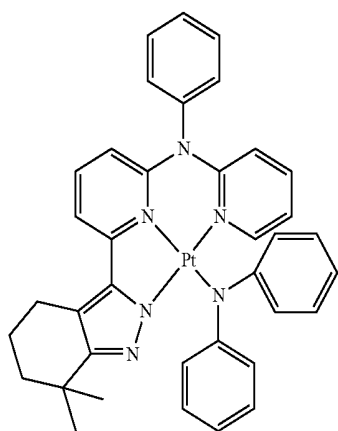


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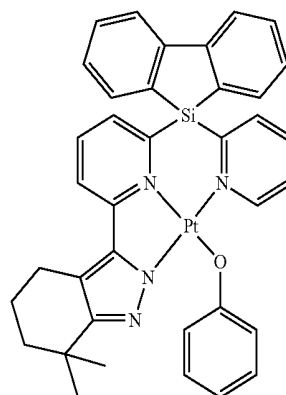
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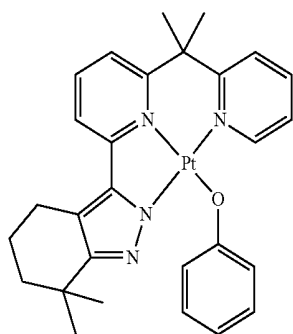


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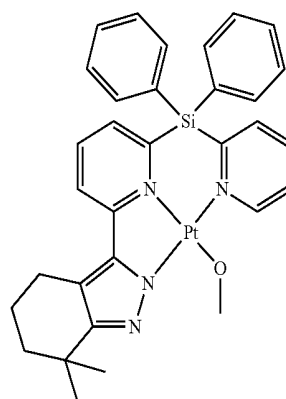
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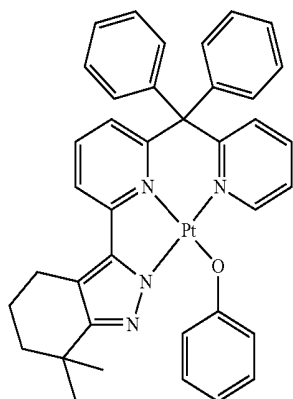
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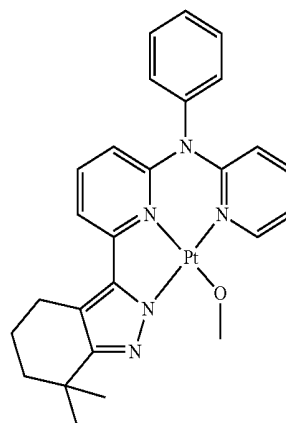
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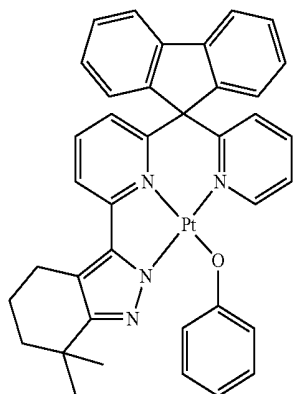
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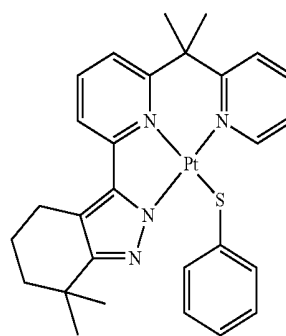
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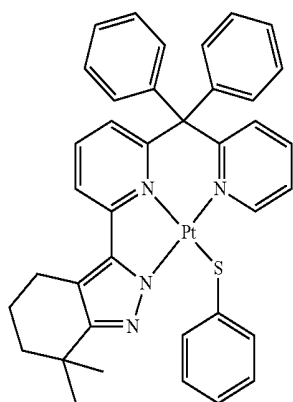


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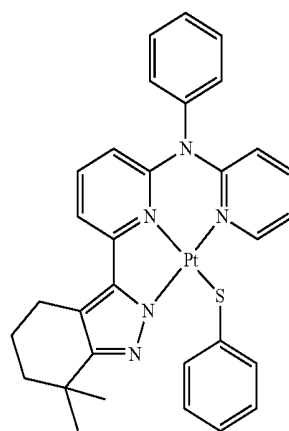
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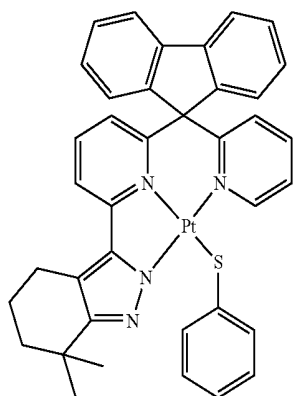


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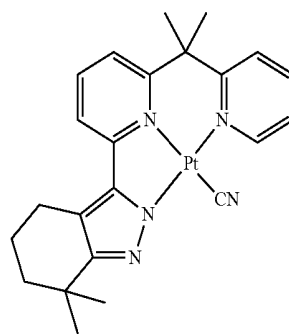
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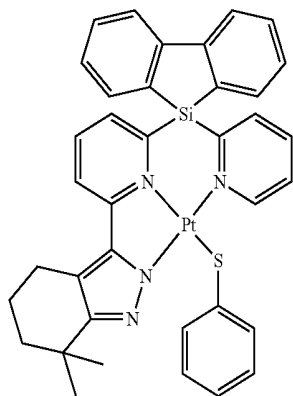
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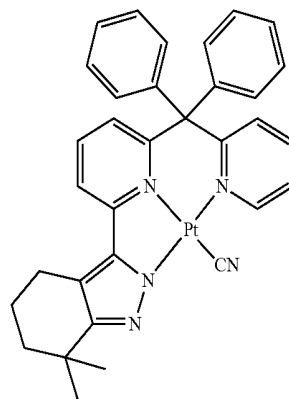
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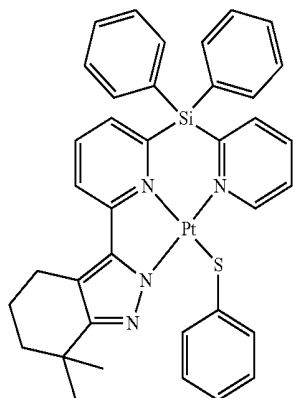
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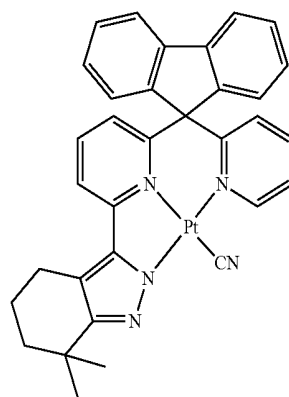
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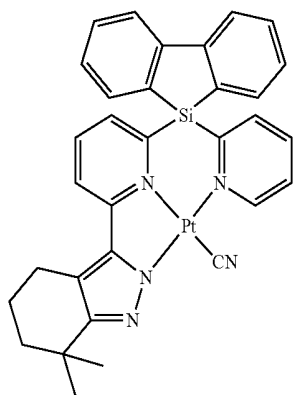


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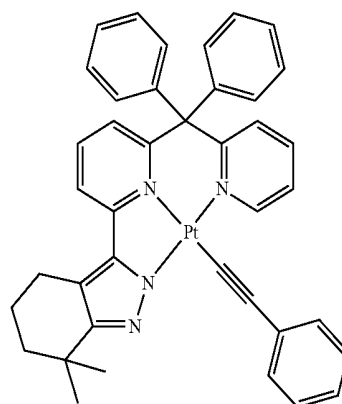
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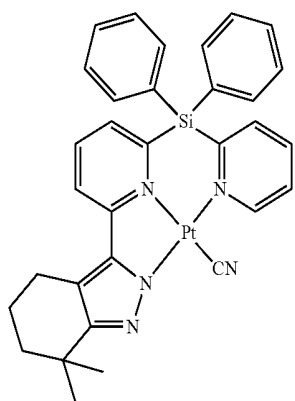


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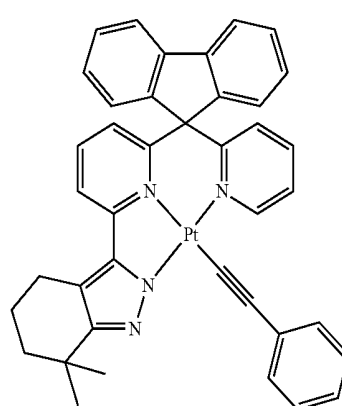
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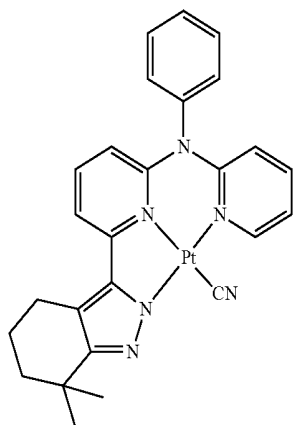
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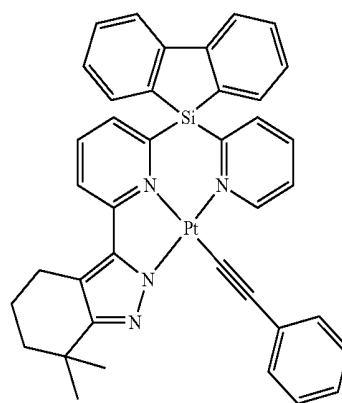
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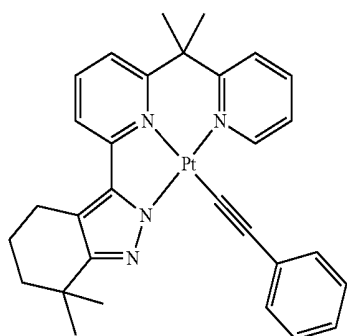
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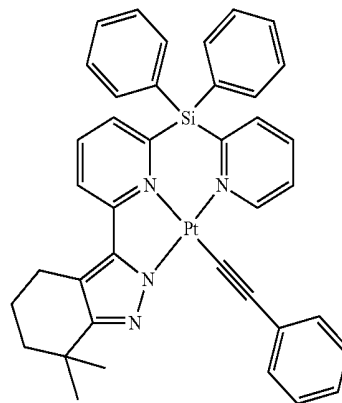
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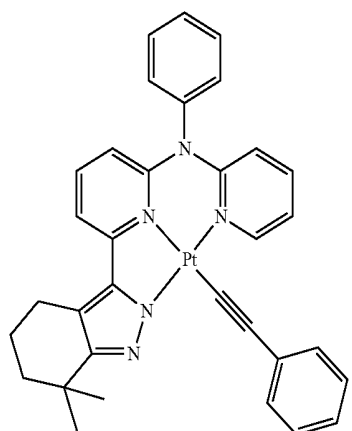
175



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18. An organic light-emitting device comprising:

a first electrode;

a negative electrode; and

an organic layer disposed between the first electrode and the second electrode,

wherein the organic layer comprises an emission layer and at least one organometallic compound of claim 1.

19. The organic light-emitting device of claim 18, wherein the emission layer comprises the organometallic compound.

20. A composition for diagnosing comprising at least one organometallic compound of claim 1.

* * * * *

专利名称(译)	有机金属化合物，有机发光器件和用于诊断的组合物包括有机金属化合物		
公开(公告)号	US20170237022A1	公开(公告)日	2017-08-17
申请号	US15/218714	申请日	2016-07-25
[标]申请(专利权)人(译)	三星电子株式会社		
申请(专利权)人(译)	SAMSUNG ELECTRONICS CO. , LTD.		
当前申请(专利权)人(译)	SAMSUNG ELECTRONICS CO. , LTD.		
[标]发明人	LEE JIYOUN KWAK YOONHYUN KWON OHYUN LEE SUNYOUNG CHOI HYEONHO KIM JIWHAN		
发明人	LEE, JIYOUN KWAK, YOONHYUN KWON, OHYUN LEE, SUNYOUNG CHOI, HYEONHO KIM, JIWHAN		
IPC分类号	H01L51/00 C07F15/00 C09K11/06		
CPC分类号	H01L51/0087 C09K11/06 C07F15/0086 H01L51/0094 C09K2211/185 C09K2211/1007 C09K2211/1011 C09K2211/1044 H01L51/5016 C09K2211/1096		
优先权	1020160015675 2016-02-11 KR		
其他公开文献	US10529935		
外部链接	Espacenet USPTO		

摘要(译)

由式1表示的有机金属化合物： $M(L1)(L2)$ 公式1 其中，在式1中，M，L1和L2是相同的如说明书中所述。

