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(54) **ORGANOMETALLIC COMPOUND AND
ORGANIC LIGHT-EMITTING DEVICE
INCLUDING THE SAME**

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(57) **ABSTRACT**

An organometallic compound and an organic light-emitting device including the same.

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FIG. 1

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FIG. 2

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FIG. 3

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FIG. 4

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ORGANOMETALLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from and the benefit of Korean Patent Application No. 10-2018-0146767, filed on Nov. 23, 2018, and Korean Patent Application No. 10-2019-0123360, filed on Oct. 4, 2019, each of which is hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND

Field

[0002] Exemplary embodiments of the invention relate to an organometallic compound and an organic light-emitting device including the same.

Discussion of the Background

[0003] Organic light-emitting devices are self-emission devices that produce full-color images, and also have wide viewing angles, high contrast ratios, short response times, and excellent characteristics in terms of brightness, driving voltage, and response speed, compared to other devices in the art.

[0004] The organic light-emitting device may include a first electrode disposed on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode, which are sequentially disposed on the first electrode. Holes provided from the first electrode may move toward the emission layer through the hole transport region, and electrons provided from the second electrode may move toward the emission layer through the electron transport region. Carriers, such as holes and electrons, recombine in the emission layer to produce excitons. These excitons transit from an excited state to a ground state, thereby generating light.

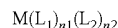
[0005] The above information disclosed in this Background section is only for understanding of the background of the inventive concepts, and, therefore, it may contain information that does not constitute prior art.

SUMMARY

[0006] One or more exemplary embodiments of the invention provide a novel organometallic compound and an organic light-emitting device including the same.

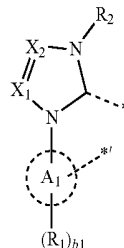
[0007] Additional features of the inventive concepts will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the inventive concepts.

[0008] One or more exemplary embodiments of the inventive concepts includes an organometallic compound represented by Formula 1:

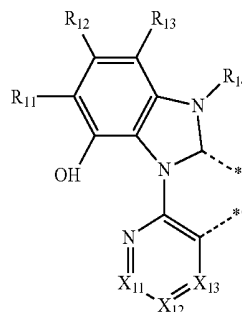


<Formula 1>

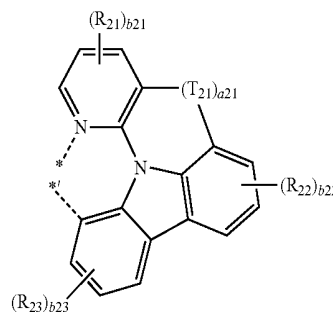
<Formula 2-1>



<Formula 2-2>



<Formula 3>



[0009] In Formula 1:

[0010] M may be selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), and thulium (Tm);

[0011] L₁ may be a ligand represented by Formula 2-1 or 2-2, and n₁ is 1, 2, or 3, wherein, when n₁ is 2 or more, two or more L₁(s) may be identical to or different from each other;

[0012] L₂ may be a ligand represented by Formula 3, and n₂ may be 0, 1, or 2, wherein, when n₂ is 2 or more, two or more L₂(s) may be identical to or different from each other;

[0013] the sum of n₁ and n₂ in Formula 1 may be 2 or 3;

[0014] L₁(s) in the number of n₁ and L₂(s) in the number of n₂ in Formula 1 may optionally be linked to each other via a single bond, a first linking group, or a substituted or unsubstituted C₅-C₆₀ carbocyclic group, and a substituted or unsubstituted C₁-C₆₀ heterocyclic is group;

[0015] the first linking group may be selected from *—N(R₄)—*, *—B(R₄)—*, *—P(R₄)—*, *—C(R₄)(R₅)—*, *—Si(R₄)(R₅)—*, *—Ge(R₄)(R₅)—*, *—S—*, *—Se—*, *—O—*, *—C(=O)—*, *—S(=O)—*, *—S(=O)₂—*, *—C(R₄)=*, *—C(R₄)=*, *—C(R₄)=C(R₅)—*, *—C(=S)—*, and *—C≡C—*;

[0016] A₁ in Formula 2-1 may be selected from a C₅-C₆₀ carbocyclic group and a C₁-C₆₀ heterocyclic group;

[0017] X_1 and X_2 in Formula 2-1 may each independently be N or C(R₃);

[0018] X_{11} and X_{12} in Formula 2-2 may each be C(R₁₅), and X_{13} may be N or C(R₁₅);

[0019] T_{21} in Formula 3 may be selected from *—N(R₂₄)—*, *—B(R₂₄)—*, *—P(R₂₄)—*, *—C(R₂₄)(R₂₅)—*, *—Si(R₂₄)(R₂₅)—*, *—Ge(R₂₄)(R₂₅)—*, *—S—*, *—Se—*, *—O—*40, *—C(=O)—*, *—S(=O)—*, *—S(=O)₂—*, *—C(R₂₄)=*, *—C(R₂₄)—*, *—C(R₂₄)=C(R₂₅)—*, *—C(=S)—*, and *—C≡C—*;

[0020] R_1 to R_5 , R_{11} to R_{15} , and R_{21} to R_{25} in Formulae 2-1, 2-2, and 3 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —P(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), and —P(=O)(Q₁)(Q₂);

[0021] b1 in Formula 2-1 may be an integer from 1 to 6, wherein, when b1 is 2 or more, two or more R₁(s) may be identical to or different from each other;

[0022] b21 to b23 in Formula 3 may each independently be an integer from 1 to 3, wherein, when b21 is 2 or more, two or more R₂₁(s) may be identical to or different from each other, when b22 is 2 or more, two or more R₂₂(s) may be identical to or different from each other, and when b23 is 2 or more, two or more R₂₃(s) may be identical to or different from each other;

[0023] in Formulae 2-1, 2-2, and 2-3, two neighboring substituents among R₁(s) in the number of b1, R₂, R₃, R₁₁ to R₁₄, R₁₅, R₂₁(s) in the number of b21, R₂₂(s) in the number of b22, R₂₃(s) in the number of b23, R₂₄, and R₂₅ may optionally be linked to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₁-C₃₀ heterocyclic group;

[0024] a21 in Formula 3 may be an integer from 1 to 3, wherein, when a21 is 2 or more, two or more T₂₁(s) may be identical to or different from each other;

[0025] * and * in Formulae 2-1 and 2-2 each indicate a binding site to M in Formula 1, and * and * in Formulae 1 and 3 each indicate a binding site to a neighboring atom;

[0026] at least one substituent of the substituted C₅-C₃₀ carbocyclic group, the substituted C₁-C₃₀ heterocyclic group, the substituted C₁-C₆₀ alkyl group, the substituted C₂-C₆₀ alkenyl group, the substituted C₂-C₆₀ alkynyl group, the substituted C₁-C₆₀ alkoxy group, the substituted C₃-C₁₀ cycloalkyl group, the substituted C₁-C₁₀ heterocycloalkyl group, the substituted C₃-C₁₀ cycloalkenyl group, the substituted C₁-C₁₀ heterocycloalkenyl group, the substituted

C₆-C₆₀ aryl group, the substituted C₆-C₆₀ aryloxy group, the substituted C₆-C₆₀ arylthio group, the substituted C₁-C₆₀ heteroaryl group, the substituted C₁-C₆₀ heteroaryloxy group, the substituted C₁-C₆₀ heteroarylthio group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0027] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group;

[0028] 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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, —Si(Q₁₁)(Q₁₂)(Q₁₃), —N(Q₁₁)(Q₁₂), —B(Q₁₁)(Q₁₂), —C(=O)(Q₁₁), —S(=O)₂(Q₁₁), and —P(=O)(Q₁₁)(Q₁₂);

[0029] 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;

[0030] 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, —Si(Q₂₁)(Q₂₂)(Q₂₃), —N(Q₂₁)(Q₂₂), —B(Q₂₁)(Q₂₂), —C(=O)(Q₂₁), —S(=O)₂(Q₂₁), and —P(=O)(Q₂₁)(Q₂₂); and

[0031] —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂), and

[0032] Q₁ to Q₃, Q₁₁ to Q₁₃, Q₂₁ to Q₂₃, and Q₃₁ to Q₃₃ may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, and a monovalent non-aromatic condensed heteropolycyclic group;

group, a C₆-C₆₀ aryl group, a C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C₁-C₆₀ alkyl group to substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a C₆-C₆₀ aryl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a biphenyl group, and a terphenyl group.

[0033] One or more exemplary embodiments of the inventive concepts also provide an organic light-emitting device including: a first electrode; a second electrode facing the first electrode; an organic layer between the first electrode and the second electrode and including an emission layer; and at least one organometallic compound represented by Formula 1.

[0034] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate exemplary embodiments of the invention, and together with the description serve to explain the inventive concepts.

[0036] FIGS. 1, 2, 3, and 4 are each a schematic view of an organic light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0037] In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of various exemplary embodiments or implementations of the invention. As used herein “embodiments” and “implementations” are interchangeable words that are non-limiting examples of devices or methods employing one or more of the inventive concepts disclosed herein. It is apparent, however, that various exemplary embodiments may be practiced without these specific details or with one or more equivalent arrangements. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring various exemplary embodiments. Further, various exemplary embodiments may be different, but do not have to be exclusive. For example, specific shapes, configurations, and characteristics of an exemplary embodiment may be used or implemented in another exemplary embodiment without departing from the inventive concepts.

[0038] Unless otherwise specified, the illustrated exemplary embodiments are to be understood as providing exemplary features of varying detail of some ways in which the inventive concepts may be implemented in practice. Therefore, unless otherwise specified, the features, components, layers, films, regions, and/or aspects, etc. (hereinafter individually or is collectively referred to as “elements”), of the various embodiments may be otherwise combined, separated, interchanged, and/or rearranged without departing from the inventive concepts.

[0039] In the accompanying drawings, the size and relative sizes of elements may be exaggerated for clarity and/or descriptive purposes. When an exemplary embodiment may

be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order when practicable. Also, like reference numerals denote like elements.

[0040] When an element, such as a layer, is referred to as being “on,” “connected to,” or “coupled to” another element or layer, it may be directly on, connected to, or coupled to the other element or layer or intervening elements or layers may be present. When, however, an element or layer is referred to as being “directly on,” “directly connected to,” or “directly coupled to” another element or layer, there are no intervening elements or layers present. To this end, the term “connected” may refer to physical, electrical, and/or fluid connection, with or without intervening elements. For the purposes of this disclosure, “at least one of X, Y, and Z” and “at least one selected from the group consisting of X, Y, and Z” may be construed as X only, Y only, Z only, or any combination of two or more of X, Y, and Z, such as, for instance, XYZ, XYY, YZ, and ZZ. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0041] Although the terms “first,” “second,” etc. may be used herein to describe various types of elements, these elements should not be limited by these terms. These terms are used to distinguish one element from another element. Thus, a first element discussed below could be termed a second element without departing from the teachings of the disclosure.

[0042] Spatially relative terms, such as “beneath,” “below,” “under,” “lower,” “above,” “upper,” “over,” “higher,” “side” (e.g., as in “sidewall”), and the like, may be used herein for descriptive purposes, and, thereby, to describe one element's relationship to another element(s) as to illustrated in the drawings. Spatially relative terms are intended to encompass different orientations of an apparatus in use, operation, and/or manufacture in addition to the orientation depicted in the drawings. For example, if the apparatus in the drawings is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the exemplary term “below” can encompass both an is orientation of above and below. Furthermore, the apparatus may be otherwise oriented (e.g., rotated 90 degrees or at other orientations), and, as such, the spatially relative descriptors used herein interpreted accordingly.

[0043] The terminology used herein is for the purpose of describing particular embodiments 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. Moreover, the terms “comprises,” “comprising,” “includes,” and/or “including,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. It is also noted that, as used herein, the terms “substantially,” “about,” and other similar terms, are used as terms of approximation and not as terms of degree, and, as such, are utilized to account for inherent deviations in measured, calculated, and/or provided values that would be recognized by one of ordinary skill in the art.

[0044] 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 disclosure is a part. 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 should not be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

[0045] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings.

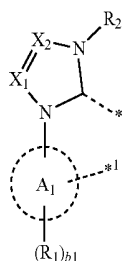
[0046] One or more exemplary embodiments of the inventive concepts include an organometallic compound represented by Formula 1 below:



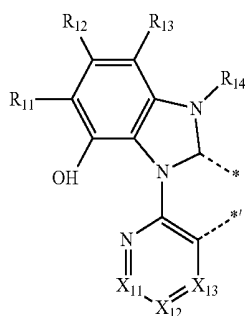
[0047] In Formula 1, M may be selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), and thulium (Tm).

[0048] In one embodiment, M may be selected from Pt, Ir, Pd, Cu, Ag, and Au.

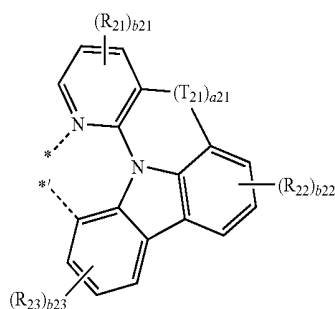
[0049] For example, M may be Pt or Ir, but embodiments of the inventive concepts are not limited thereto:



<Formula 2-1>



<Formula 2-2>



<Formula 3>

[0050] In Formula 1, L_1 may be a ligand represented by Formula 2-1 or 2-2, and $n1$ may be 1, 2, or 3, wherein, when $n1$ is 2 or more, two or more $L_1(s)$ may be identical to or different from each other,

[0051] in Formula 1, L_2 may be a ligand represented by Formula 3, and $n2$ may be 0, 1, or 2, wherein, when $n2$ is 2 or more, two or more $L_2(s)$ may be identical to or different from each other, and

[0052] the sum of $n1$ and $n2$ in Formula 1 may be 2 or 3.

[0053] In one embodiment, in Formula 1, the sum of $n1$ and $n2$ may be 2 and M may be to Pt; or the sum of $n1$ and $n2$ may be 3 and M may be Ir.

[0054] For example, in Formula 1, $n1$ may be 1 and $n2$ may be 1; or $n1$ may be 3 and $n2$ may be 0, but embodiments of the inventive concepts are not limited thereto.

[0055] The organometallic compound may include a four-coordinate or six-coordinate ligand and a metal atom (M_1), and an energy level of a triplet metal centered state (3MC state) of is the organometallic compound (E_{3MC}) may be higher than an energy level of a triplet metal-to-ligand charge transfer state (3MLCT state) of the organometallic compound (E_{3MLCT}).

[0056] For example, the organometallic compound may satisfy $E_3 \geq 5$ kcal/mol, and E_3 may be defined by Equation 1:

$$E_3 = \|E_{3MLCT} - E_{3MC}\| \quad \text{<Equation 1>}$$

[0057] In one embodiment, the organometallic compound may satisfy $E_3 \geq 5$ kcal/mol. In one or more embodiments, the organometallic compound may satisfy $E_3 \geq 8$ kcal/mol, for example $E_3 \geq 19$ kcal/mol, for example $E_3 \geq 30$ kcal/mol.

[0058] For example, the six-coordinate ligand may have a hemicage or fullcage structure.

[0059] In one embodiment, the organometallic compound may satisfy $5 \text{ kcal/mol} \leq E_3 \leq 50 \text{ kcal/mol}$, for example, $8 \text{ kcal/mol} \leq E_3 \leq 30 \text{ kcal/mol}$.

[0060] When the organometallic compound satisfies the range of E_3 , the probability that the organometallic compound transitions from the 3MLCT state to the non-emission state, that is, the 3MC state, decreases. Therefore, the stability of the organometallic compound in an excited state may be excellent, and the efficiency and lifespan of the organic light-emitting device including the organometallic compound may increase.

[0061] In Formula 1, $L_1(s)$ in the number of $n1$ and $L_2(s)$ in the number of $n2$ may optionally be linked to each other via a single bond, a first linking group, a substituted or unsubstituted C_5 - C_{60} carbocyclic group, or a substituted or unsubstituted C_1 - C_{60} heterocyclic group, and

[0062] the first linking group may be selected from $^{*}N(R_4)^{***}$, $^{*}B(R_4)^{***}$, $^{*}P(R_4)^{***}$, $^{*}C(R_4)(R_5)^{***}$, $^{*}Si(R_4)(R_5)^{***}$, $^{*}Ge(R_4)(R_5)^{***}$, $^{*}S^{***}$, $^{*}Se^{***}$, $^{*}O^{***}$, $^{*}C(=O)^{***}$, $^{*}S(=O)^{***}$, $^{*}S(=O)_2^{***}$, $^{*}C(R_4)^{***}$, $^{*}C(R_4)^{***}$, $^{*}C(R_4)=C(R_5)^{***}$, $^{*}C(=S)^{***}$, and $^{*}C \equiv C^{***}$.

[0063] In one embodiment, $n1$ and $n2$ may each be 1, and L_1 may be a group represented by Formula 2-1, and

[0064] one of $R_1(s)$ in the number of $b1$ and one of neighboring $R_{23}(s)$ in the number of $b23$ may be linked to each other via a single bond or a first linking group.

[0065] For example, one of $R_1(s)$ in the number of $b1$ and one of neighboring $R_{23}(s)$ in the number of $b23$ may be linked to each other via a first linking group, and the first

linking group may be $^{*''}-O-^{*''}$, but embodiments of the inventive concepts are not limited thereto.

[0066] In one or more embodiments, $n1$ may be 3, and L_1 may be a group represented by Formula 2-2,

[0067] $X_{13}(s)$ in three $L_1(s)$ may each be $C(R_{15})$,

[0068] three $R_{14}(s)$ in three $L_1(s)$ may be linked to each other via a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, and

[0069] three $R_{15}(s)$ in three $L_1(s)$ may be linked to each other via a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group.

[0070] A_1 in Formula 2-1 may be selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group.

[0071] In one embodiment, A_1 in Formula 2-1 may be selected from:

[0072] a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a cyclopentane group, a cyclopentadiene group, a furan group, a thiophene group, a pyrrole group, a silole group, an oxazole group, an isoxazole group, an oxadiazole group, an isozadiazole group, an oxatriazole group, an isoxatriazole group, a thiazole group, an isothiazole group, a thiadiazole group, an isothiadiadiazole group, a thiatriazole group, an isothiatriazole group, a pyrazole group, an imidazole group, a triazole group, a 1,2,4-triazole group, a tetrazole group, an azasilole group, a diazasilole group, a triazasilole group, a cyclohexane group, and a cyclohexene group;

[0073] a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a is pyridazine group, a triazine group, a cyclopentane group, a cyclopentadiene group, a furan group, a thiophene group, a pyrrole group, a silole group, an oxazole group, an isoxazole group, an oxadiazole group, an isozadiazole group, an oxatriazole group, an isoxatriazole group, a thiazole group, an isothiazole group, a thiadiazole group, an isothiadiadiazole group, a thiatriazole group, an isothiatriazole group, a pyrazole group, an imidazole group, a triazole group, a 1,2,4-triazole group, a tetrazole group, an azasilole group, a diazasilole group, a triazasilole group, a cyclohexane group, and a cyclohexene group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, a cyano group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl 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 indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoqui-

nazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indeno carbazolyl group, an indolocarbazolyl group, $-Si(Q_{31})(Q_{32})(Q_{33})$, $-N(Q_{31})(Q_{32})$, $-B(Q_{31})(Q_{32})$, $-C(=O)(Q_{31})$, $-S(=O)(Q_{31})$, $-S(=O)_2(Q_{31})$, $-P(=O)(Q_{31})(Q_{32})$, and $-P(=S)(Q_{31})(Q_{32})$, and

[0074] Q_{31} to Q_{33} may each independently be selected from hydrogen, deuterium, 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 C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed heteropolycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C_1-C_{60} alkyl group substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, and a cyano group, a C_6-C_{60} aryl group substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, and a cyano group, a biphenyl group, and a terphenyl group.

[0075] For example, A_1 may be selected from: a benzene group; and a benzene group substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, a cyano group, a C_1-C_{20} alkyl group, and a C_1-C_{20} alkoxy group, but embodiments of the inventive concepts are not limited thereto.

[0076] X_1 and X_2 in Formula 2-1 may each independently be N or $C(R_3)$, and X_{11} and X_{12} in Formula 2-2 may each independently be $C(R_{15})$, and X_{13} in Formula 2-2 may be N or $C(R_{15})$.

[0077] In one embodiment, X_1 and X_2 in Formula 2-1 may each independently be $C(R_3)$, and X_{13} in Formula 2-2 may be $C(R_{15})$.

[0078] T_{21} in Formula 3 may be selected from $^{*''}-N(R_{24})-^{*''}$, $^{*''}-B(R_{24})-^{*''}$, $^{*''}-P(R_{24})-^{*''}$, $^{*''}-C(R_{24})(R_{25})-^{*''}$, $^{*''}-Si(R_{24})(R_{25})-^{*''}$, $^{*''}-Ge(R_{24})(R_{25})-^{*''}$, $^{*''}-S-^{*''}$, $^{*''}-Se-^{*''}$, $^{*''}-O-^{*''}$, $^{*''}-C(=O)-^{*''}$, $^{*''}-S(=O)-^{*''}$, $^{*''}-S(=O)_2-^{*''}$, $^{*''}-C(R_{24})-^{*''}$, $^{*''}-C(R_{24})-^{*''}$, $^{*''}-C(R_{24})=C(R_{25})-^{*''}$, $^{*''}-C(=S)-^{*''}$, and $^{*''}-C\equiv C-^{*''}$.

[0079] In one embodiment, in Formula 3, T_{21} may be $^{*''}-C(R_{24})(R_{25})-^{*''}$, and $a21$ may be 1 or 2.

[0080] In Formulae 2-1, 2-2, and 3, R_1 to R_5 , R_{11} to R_{15} , and R_{21} to R_{25} may each independently be selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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 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, —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —P(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), and —P(=O)(Q₁)(Q₂).

[0081] When b1 in Formula 2-1 is an integer from 1 to 6, and b1 is 2 or more, two or more R₁(s) may be identical to or different from each other.

[0082] When b21 to b23 in Formula 3 are each independently an integer from 1 to 3, and b21 is 2 or more, two or more R₂₁(S) may be identical to or different from each other, when b22 is 2 or more, two or more R₂₂(S) may be identical to or different from each other, and when b23 is 2 or more, two or more R₂₃(S) may be identical to or different from each other.

[0083] In Formulae 2-1, 2-2, and 2-3, two neighboring substituents among R₁(s) in the number of b1, R₂, R₃, R₁₁ to R₁₄, R₁₅, R₂₁(S) in the number of b21, R₂₂(S) in the number of b22, R₂₃(S) in the number of b23, R₂₄, and R₂₅ may optionally be linked to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₁-C₃₀ heterocyclic group.

[0084] In one embodiment, in Formulae 2-1, 2-2, and 3, R₁ to R₅, R₁₁ to R₁₅, and R₂₁ to R₂₅ may each independently be selected from: hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, and a C₁-C₂₀ alkoxy group;

[0085] a C₁-C₂₀ alkyl group and a C₁-C₂₀ 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 amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, and a C₁-C₂₀ alkoxy to group;

[0086] a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a pyrrolyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolynyl group, an isoquinolynyl group, a quinoxalynyl group, a quinazolinyl group, a cinnolynyl group, and a triazinyl group; and

[0087] a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolynyl group, an isoquinolynyl group, a quinoxalynyl group, a quinazolinyl group, a cinnolynyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl

group, a pyrazinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolynyl group, an isoquinolynyl group, a quinoxalynyl group, a quinazolinyl group, a cinnolynyl group, and a triazinyl group, —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂); and

[0088] —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), and —P(=O)(Q₁)(Q₂), and

[0089] Q₁ to Q₃ and Q₃₁ to Q₃₃ may each independently be selected from:

[0090] hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C₁-C₂₀ alkyl group, a C₂-C₂₀ alkenyl group, a C₂-C₂₀ alkynyl group, a C₁-C₂₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₂₀ aryl group, a C₁-C₂₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

[0091] For example, R₂ in Formula 2-1 may be selected from: a C₁-C₂₀ alkyl group, —N(Q₁)(Q₂), and a phenyl group; and a C₁-C₂₀ alkyl group, —N(Q₁)(Q₂), and a phenyl group, each substituted with a C₁-C₂₀ alkyl group, and

[0092] Q₁ and Q₂ may each independently be a C₁-C₂₀ alkyl group, but embodiments of the inventive concepts are not limited thereto.

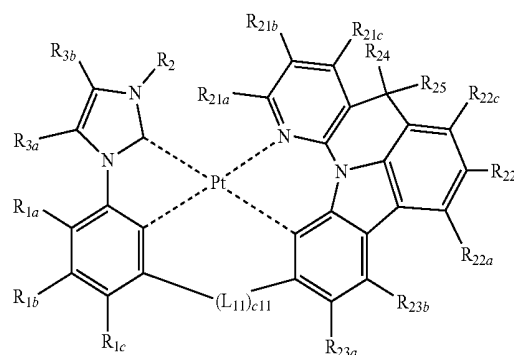
[0093] For example, R₁₁ and R₁₂ in Formula 2-2 may each independently be selected to from hydrogen, —F, —Cl, a cyano group, a C₁-C₂₀ alkyl group, and a phenyl group, but embodiments of the inventive concepts are not limited thereto.

[0094] a21 in Formula 3 may be an integer from 1 to 3, and when a21 is 2 or more, two or more T₂₁(s) may be identical to or different from each other.

[0095] * and *' in Formulae 2-1 and 2-2 each indicate a binding site to M in Formula 1m is and *'' and *''' in Formulae 1 and 3 each indicate a binding site to a neighboring atom.

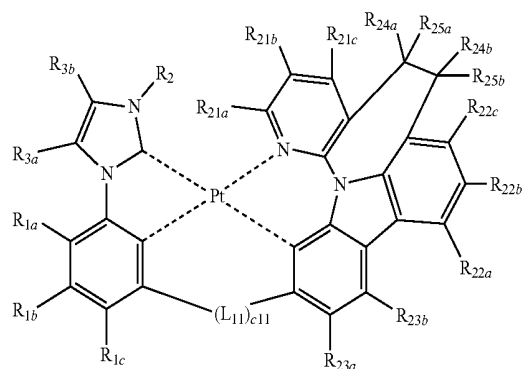
[0096] In one embodiment, the organometallic compound represented by Formula 1 may be a group represented by one of Formulae 1-1 to 1-5:

1-1



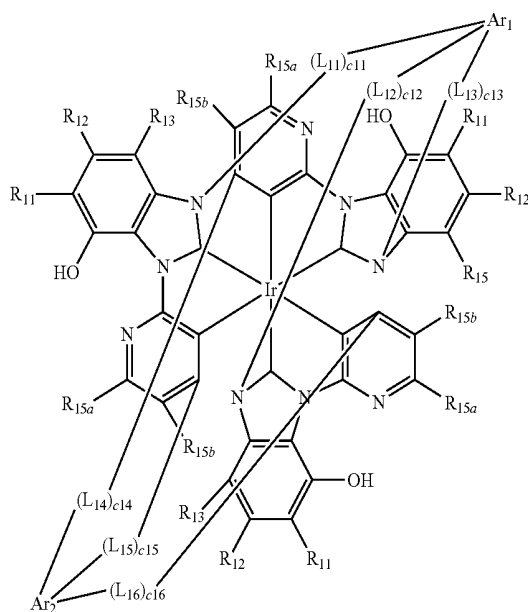
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1-2

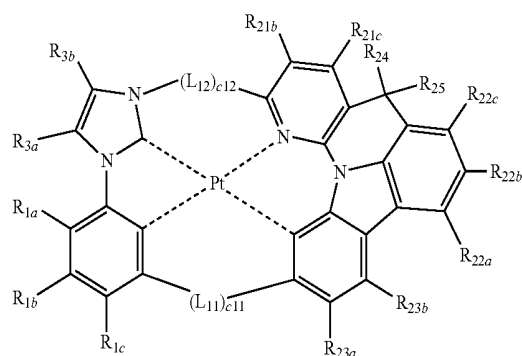


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1-5



1-3



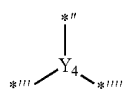
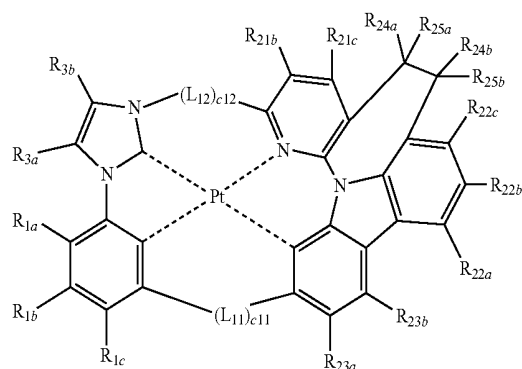
[0097] In Formulae 1-1 to 1-5,

[0098] L_{11} to L_{15} may each independently be selected from a single bond, $^{*''}\text{N}(\text{R}_4)\text{---}^{*''}$, $^{*''}\text{B}(\text{R}_4)\text{---}^{*''}$, $^{*''}\text{P}(\text{R}_4)\text{---}^{*''}$, $^{*''}\text{C}(\text{R}_4)(\text{R}_5)\text{---}^{*''}$, $^{*''}\text{Si}(\text{R}_4)(\text{R}_5)\text{---}^{*''}$, $^{*''}\text{Ge}(\text{R}_4)(\text{R}_5)\text{---}^{*''}$, $^{*''}\text{S}\text{---}^{*''}$, $^{*''}\text{Se}\text{---}^{*''}$, $^{*''}\text{O}\text{---}^{*''}$, $^{*''}\text{C}(=\text{O})\text{---}^{*''}$, $^{*''}\text{S}(=\text{O})\text{---}^{*''}$, $^{*''}\text{S}(=\text{O})_2\text{---}^{*''}$, $^{*''}\text{C}(\text{R}_4)=^{*''}$, $^{*''}\text{C}(\text{R}_4)\text{---}^{*''}$, $^{*''}\text{C}(\text{R}_4)=\text{C}(\text{R}_5)\text{---}^{*''}$, $^{*''}\text{C}(=\text{S})\text{---}^{*''}$, and $^{*''}\text{C}\equiv\text{C}\text{---}^{*''}$,

[0099] c_{11} to c_{15} may each independently be an integer from 1 to 3, wherein, when c_{11} is 2 or more, two or more $L_{11}(s)$ may be identical to or different from each other, when c_{12} is 2 or more, two or more $L_{12}(s)$ may be identical to or different from each other, when c_{13} is 2 or more, two or more $L_{13}(s)$ may be identical to or different from each other, when c_{14} is 2 or more, two or more $L_{14}(s)$ may be identical to or different from each other, and when c_{15} is 2 or more, two or more $L_{15}(s)$ may be identical to or different from each other,

[0100] Ar_1 and Ar_2 may each independently be selected from a substituted or unsubstituted trivalent $\text{C}_5\text{--C}_{30}$ carbocyclic group, a substituted or unsubstituted trivalent $\text{C}_1\text{--C}_{30}$ heterocyclic group, and a group represented by

1-4



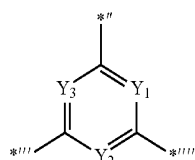
Y_4 may be N or C(R_{40}), and $^{*''}$, $^{*''}$, and $^{*''}$ each indicate a binding site to a neighboring atom,

[0101] c_{11} and c_{12} may each independently be an integer from 1 to 3, wherein, when c_{11} is 2 or more, two or more $L_{11}(s)$ may be identical to or different from each other, and when c_{12} is 2 or more, two or more $L_{12}(s)$ may be identical to or different from each other, and

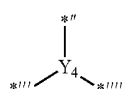
[0102] R_{1a} to R_{1c} , R_{3a} to R_{3b} , R_{15a} to R_{15b} , R_{21a} to R_{21c} , R_{22a} to R_{22c} , R_{23a} to R_{23b} , R_{24a} to R_{24b} , R_{25a} to R_{25b} , and R_{30} may each independently be the same as defined in

connection with R_1 , R_3 , R_{15} , and R_{21} to R_{25} , and R_2 , R_4 , R_5 , and R_{11} to R_{13} may each independently be the same as defined in connection with R_2 , R_4 , R_5 , and R_{11} to R_{13} .

[0103] For example, Ar_1 and Ar_2 may each independently be selected from groups represented by Formula 2A or 2B, but embodiments of the inventive concepts are not limited thereto:



<Formula 2A>

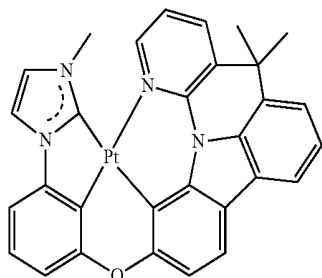


<Formula 2B>

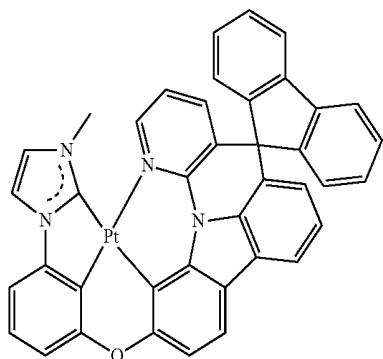
[0104] In Formulae 2A and 2B,

[0105] Y_1 to Y_4 may each independently be N or C(R_{40}), and $*$ '', $*$ '', and $*$ ''' each indicate a binding site to a neighboring atom.

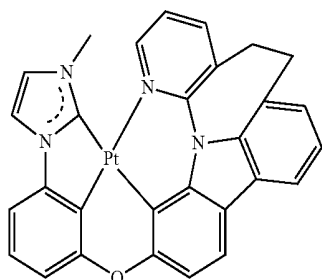
[0106] In one embodiment, the organometallic compound may be selected from Compounds 1 to 14, but embodiments of the inventive concepts are not limited thereto:



1

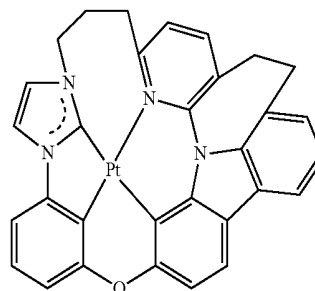


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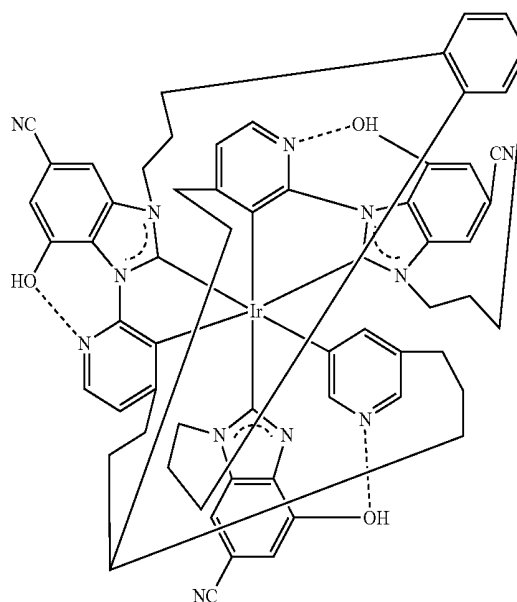


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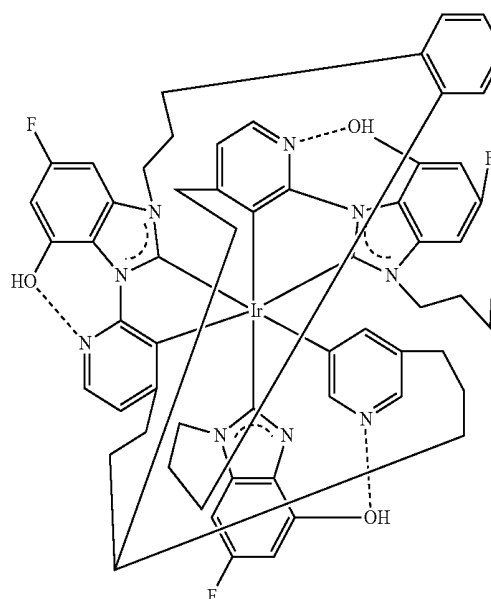
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4



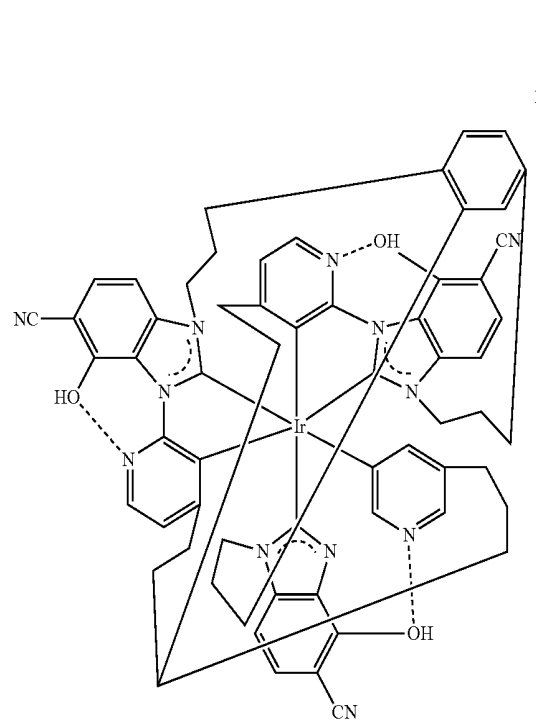
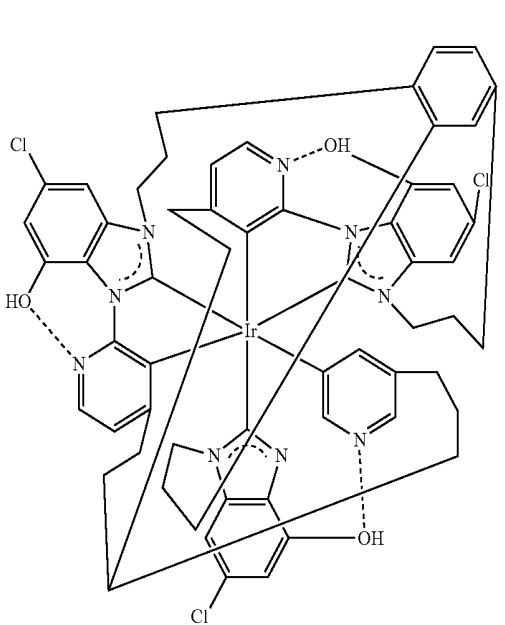
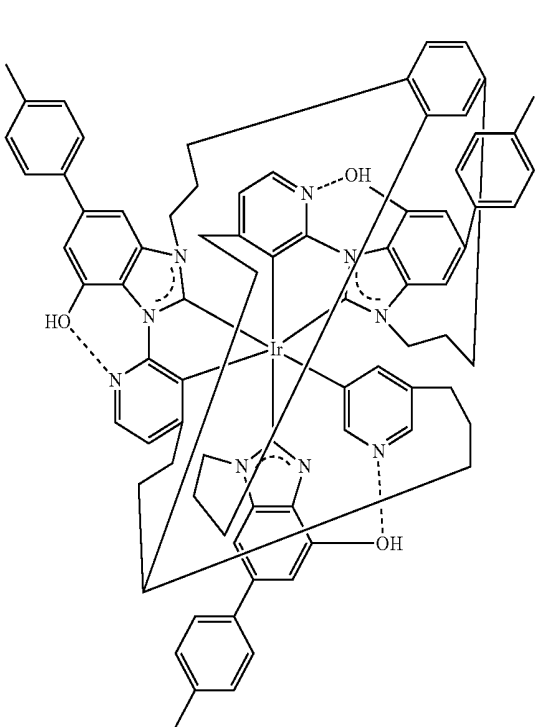
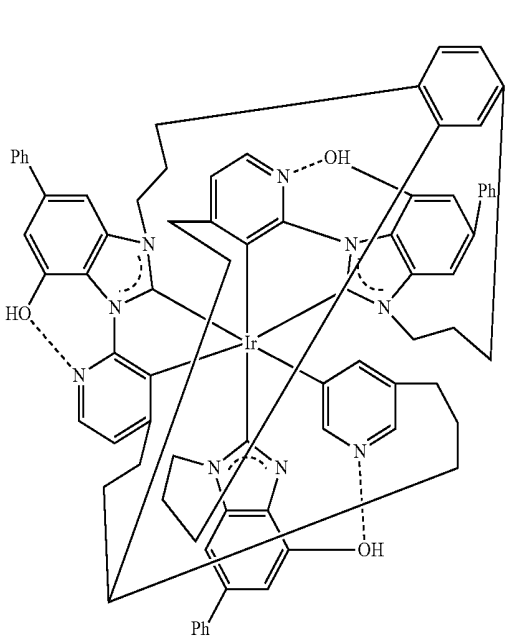
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6

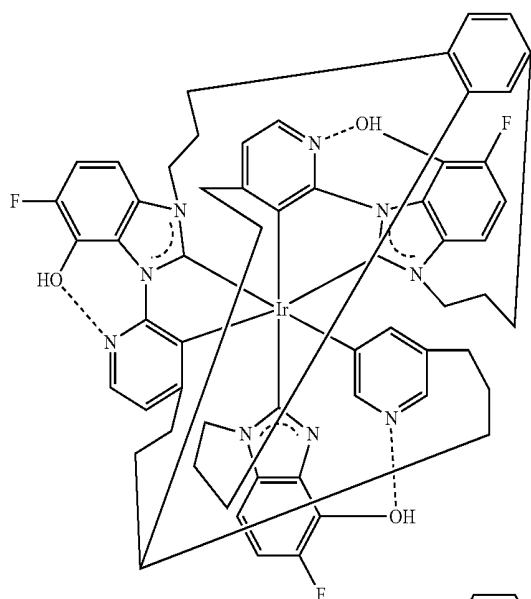
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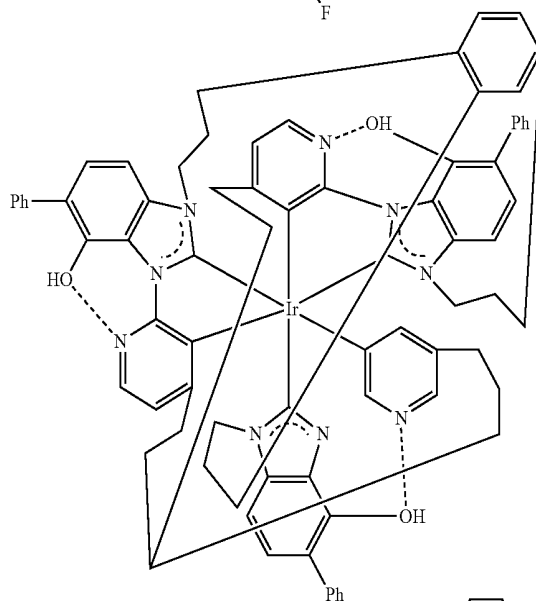


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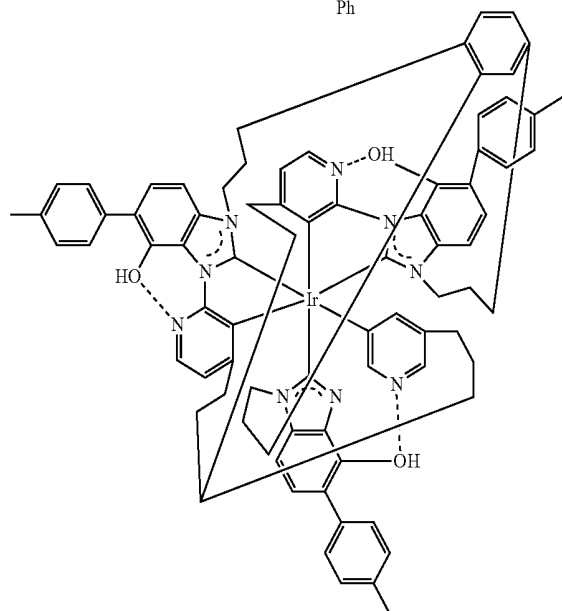
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12

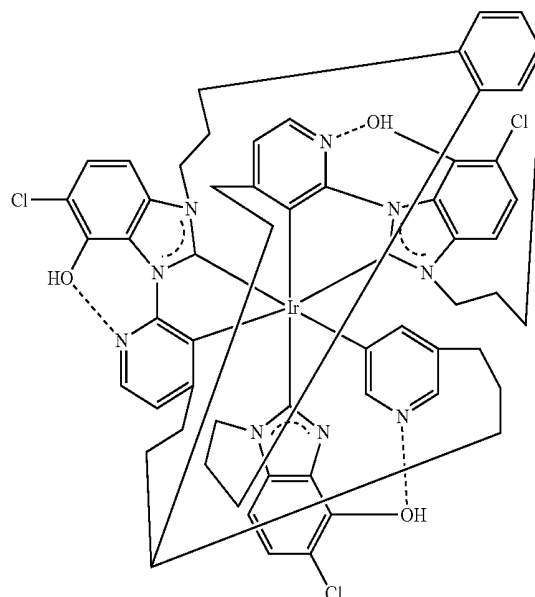


13



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14



[0107] Since the organometallic compound represented by Formula 1 essentially includes a hydroxyl group (—OH group) and a nitrogen atom at a specific position in a ligand represented by Formula 2-2, stable blue phosphorescence may be emitted through acquisition of attractive interaction energy caused by a hydrogen bond between the hydroxyl group and the nitrogen atom of neighboring ligands.

[0108] Since the organometallic compound represented by Formula 1 has a structure in which a carbazole moiety and a pyridine moiety are essentially linked to each other via a linker (T_{21}), as in a ligand represented by Formula 3, the lifespan and efficiency of the device may be improved by a mechanism that greatly increases energy necessary for ligand rupture in triplet.

[0109] When the organometallic compound represented by Formula 1 optionally includes three ligands represented by Formula 2-2, the three ligands are linked to each other via a group (clipping linker) represented by Formula 2A or 2B. Therefore, the organometallic compound may have a six-coordinate ligand of a three-dimensional hemicage or fullcage structure, and the stability and durability of the organometallic compound may be excellent even in an excited state.

[0110] Since the clipping linker links carbocyclic groups or heterocyclic groups included in the ligand, it is possible to prevent the phenomenon in which, when the organometallic compound is applied to the organic light-emitting device, the triplet exciton transitions to the non-emission state, that is, the ^3MC state, by ligand rupture. Therefore, the stability of the organometallic compound in the excited state may be excellent, and the lifespan and efficiency of the organic light-emitting device may be excellent.

[0111] In one embodiment, the organometallic compound represented by Formula 1 may satisfy the range of E_3 described above. At this time, the probability that the organometallic compound represented by Formula 1 transitions from the $^3\text{MCLT}$ state to the non-emission state, that is, the ^3MC state, decreases. Therefore, the stability of the organometallic compound in the excited state may be excel-

lent, and the efficiency and lifespan of the organic light-emitting device including the organometallic compound may increase.

[0112] The organometallic compound may emit blue light. For example, the organometallic compound may emit blue light (bottom emission CIE_{x,y} color coordinates X=0.13, Y=0.05 to 0.18) having a maximum emission wavelength of about 440 nm or more and about 490 nm or less, but embodiments of the inventive concepts are not limited thereto. Therefore, the organometallic compound represented by Formula 1 may be usefully used for manufacturing an organic light-emitting device that emits blue light.

[0113] A synthesis method for the organometallic compound represented by Formula 1 would be apparent to those of ordinary skill in the art by referring to the following examples.

[0114] At least one of 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 may be included in an emission layer. The organometallic compound may act as a dopant in the emission layer. In one or more embodiments, the organometallic compound of Formula 1 may be used as a material for a capping layer located outside a pair of electrodes of an organic light-emitting device.

[0115] One or more exemplary embodiments of the inventive concepts include an organic light-emitting device including: a first electrode; a second electrode facing the first electrode; an organic layer between the first electrode and the second electrode; and at least one organometallic compound represented by Formula 1. For example, the organic layer includes at least one of organometallic compounds.

[0116] The expression “(an organic layer) includes at least one of organometallic compounds” used herein may include a case in which “(an organic layer) includes identical organometallic compounds represented by Formula 1” and a case in which “(an organic layer) includes two or more different organometallic compounds represented by Formula 1”.

[0117] For example, the organic layer may include, as the organometallic compound, only Compound 1. In this regard, Compound 1 may exist only in the emission layer of the organic light-emitting device. In one or more embodiments, the organic layer may include, as the organometallic compound, Compound 1 and Compound 2. In this regard, Compound 1 and Compound 2 may exist in an identical layer (for example, Compound 1 and Compound 2 may all exist in an emission layer), or different layers (for example, Compound 1 may exist in an emission layer and Compound 2 may exist in an electron transport region).

[0118] According to one embodiment,

[0119] the first electrode of the organic light-emitting device may be an anode,

[0120] the second electrode of the organic light-emitting device may be a cathode, and

[0121] the organic layer may further include a hole transport region between the first electrode and the emission layer and an electron transport region between the emission layer and the second electrode,

[0122] the hole transport region may include a hole injection layer, a hole transport layer, an emission auxiliary layer, an electron blocking layer, or any combination thereof, and

[0123] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0124] The term “an 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 an organic light-emitting device. A material included in the “organic layer” is not limited to an organic material.

[0125] In one embodiment, the emission layer includes the organometallic compound represented by Formula 1. In one embodiment, the emission layer includes the organometallic compound represented by Formula 1.

[0126] In one embodiment, the hole transport region includes an electron blocking layer, which includes the organometallic compound.

[0127] In one or more embodiments, the hole transport region includes a hole blocking layer, which includes the organometallic compound.

[0128] In one embodiment, the hole transport region may include a p-dopant having a lowest unoccupied molecular orbital (LUMO) energy level of -3.5 eV or less.

[0129] FIG. 1 is a schematic cross-sectional view of an organic light-emitting device 10 according to an embodiment. The organic light-emitting device 10 includes a first electrode 110, an organic layer 150, and a second electrode 190.

[0130] Hereinafter, the structure of the organic light-emitting device 10 according to an embodiment and a method of manufacturing the organic light-emitting device 10 will be described in connection with FIG. 1.

[0131] In FIG. 1, a substrate may be additionally disposed under the first electrode 110 or above the second electrode 190. The substrate may be a glass substrate or a plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and water resistance.

[0132] The first electrode 110 may be formed by depositing or sputtering a material for forming the first electrode 110 on the substrate. When the first electrode 110 is an anode, the material for forming the first electrode 110 may be selected from materials with a high work function to facilitate hole injection.

[0133] The first electrode 110 may be a reflective electrode, a semi-reflective electrode, or a transmissive electrode. When the first electrode 110 is a transmissive electrode, a material for forming a first electrode may be selected from indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO₂), zinc oxide (ZnO), and any combinations thereof, but embodiments of the inventive concepts are not limited thereto. In one or more embodiments, when the first electrode 110 is a semi-transmissive electrode or a reflective electrode, a material for forming a first electrode may be selected from magnesium (Mg), silver (Ag), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), and any combinations thereof, but embodiments of the inventive concepts are not limited thereto.

[0134] The first electrode 110 may have a single-layered structure, or a multi-layered structure including two or more layers. For example, the first electrode 110 may have a three-layered structure of ITO/Ag/ITO, but the structure of the first electrode 110 is not limited thereto.

[0135] The organic layer 150 is disposed on the first electrode 110. The organic layer 150 may include an emission layer.

[0136] The organic layer 150 may further include a hole transport region between the first electrode 110 and the

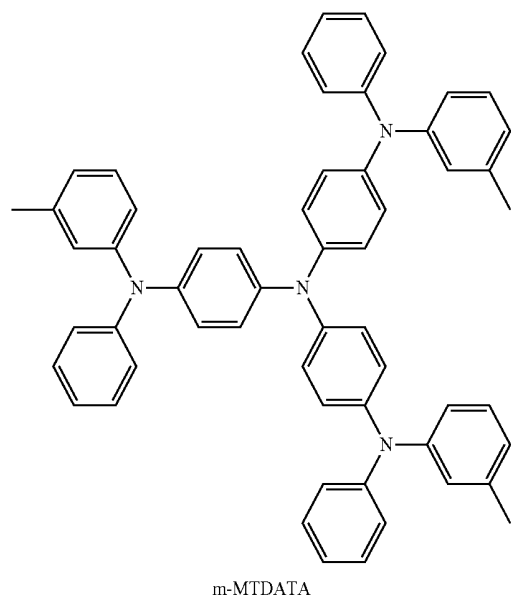
emission layer and an electron transport region between the emission layer and the second electrode **190**.

[0137] The hole transport region in organic layer **150** may have i) a single-layered structure including a single layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.

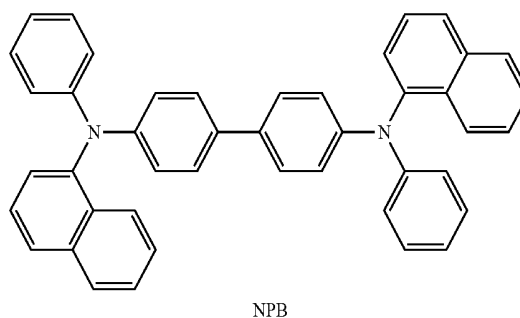
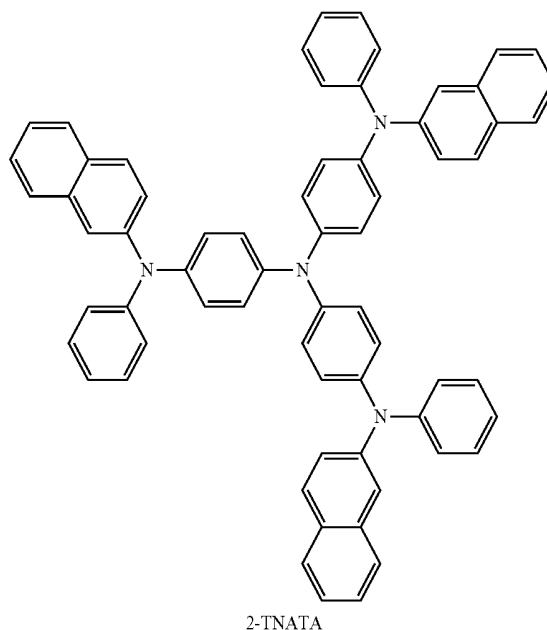
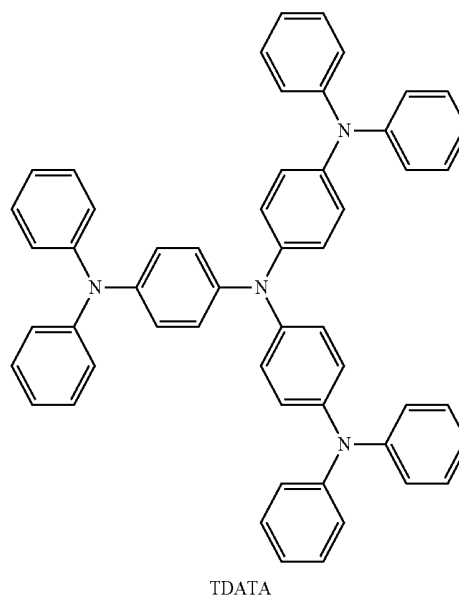
[0138] The hole transport region may include at least one layer selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

[0139] For example, the hole transport region may have a single-layered structure including a single layer including a plurality of different materials, or a multi-layered structure having a hole injection layer/hole transport layer structure, a hole injection layer/hole transport layer/emission auxiliary layer structure, a hole injection layer/emission auxiliary layer structure, a hole transport layer/emission auxiliary layer structure, or a hole injection layer/hole transport layer/electron blocking layer structure, wherein for each structure, constituting layers are sequentially stacked from the first electrode **110** in this stated order, but the structure of the hole transport region is not limited thereto.

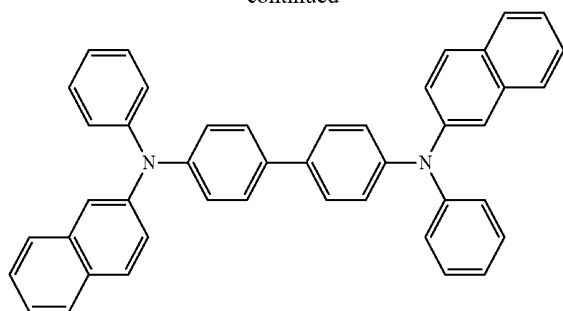
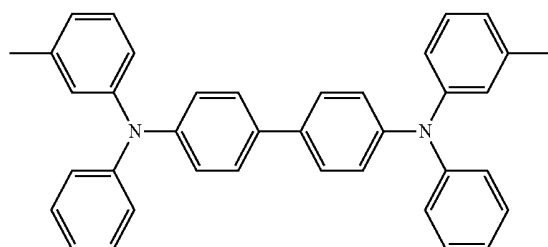
[0140] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB (NPB), β -NPB, TPD, spiro-TPD, spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4''-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzenesulfonic acid (PANI/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrenesulfonate) (PANI/PSS), a compound represented by Formula 201, and a compound represented by Formula 202:



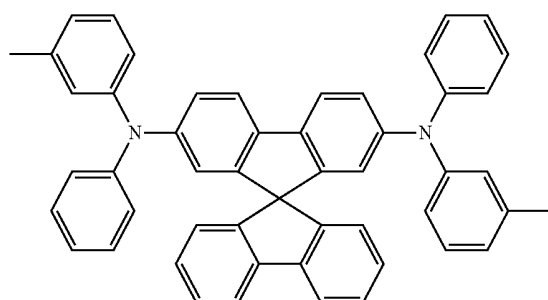
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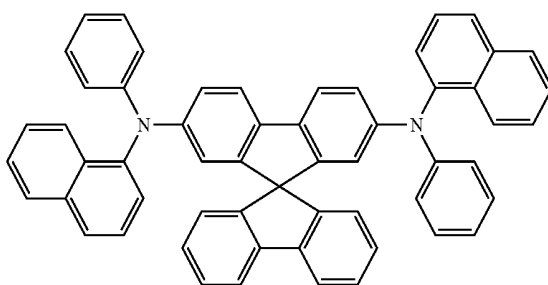
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 β -NPB

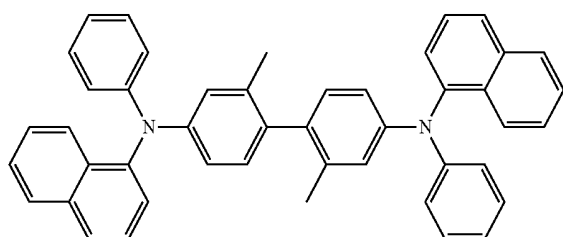
TPD



Spiro-TPD

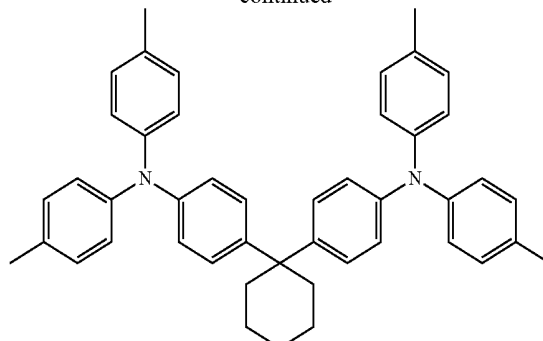


Spiro-NPB

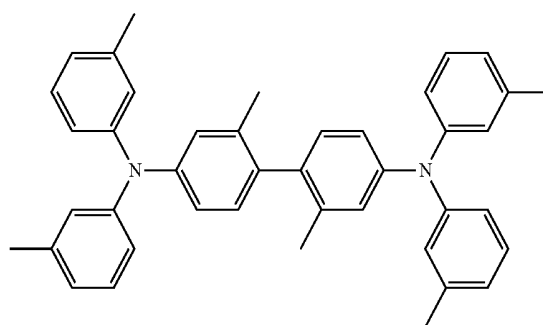


methylated NPB

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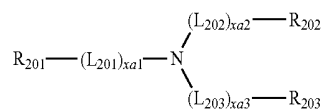


TAPC

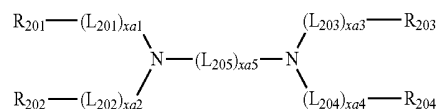


HMTPD

<Formula 201>



<Formula 202>

**[0141]** In Formulae 201 and 202,

[0142] L_{201} to L_{204} may each independently be selected from a substituted or unsubstituted C_3 - C_{10} cycloalkylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkenylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6 - C_{60} arylene group, a substituted or unsubstituted C_1 - C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0143] L_{205} may be selected from *---O---* , *---S---* , $\text{*---N(Q}_{201}\text{)---*}$, a substituted or unsubstituted C_1 - C_{20} alkylene group, a substituted or unsubstituted C_2 - C_{20} alkenylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkenylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6 - C_{60} arylene group, a substituted or unsubstituted C_1 - C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0144] xa1 to xa4 may each independently be an integer from 0 to 3,

[0145] xa5 may be an integer from 1 to 10, and

[0146] R₂₀₁ to R₂₀₄ and Q₂₀₁ may each independently be selected from 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 C₁-C₆₀ arylthio group, a substituted or unsubstituted C₁-C₆₀ heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0147] For example, in Formula 202, R₂₀₁ and R₂₀₂ may optionally be linked to each other via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R₂₀₃ and R₂₀₄ may optionally be linked to each other via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0148] In one embodiment, in Formulae 201 and 202,

[0149] L₂₀₁ to L₂₀₅ may each independently be selected from:

[0150] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylenylene group, a furanylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, and a pyridinylenylene group; and

[0151] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylenylene group, a furanylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, and a pyridinylenylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono

group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C₁-C₁₀ alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —Si(Q₃₁)(Q₃₂)(Q₃₃), and —N(Q₃₁)(Q₃₂), and

[0152] Q₃₁ to Q₃₃ may each independently be selected from a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0153] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0154] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0155] In one or more embodiments, R₂₀₁ to R₂₀₄ and Q₂₀₁ may each independently be selected from a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and

[0156] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl 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 amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1 - C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —Si(Q_{31})(Q_{32})(Q_{33}), and —N(Q_{31})(Q_{32}), and

[0157] Q_{31} to Q_{33} are the same as described above.

[0158] In one or more embodiments, at least one selected from R_{201} to R_{203} in Formula 201 may each independently be selected from:

[0159] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0160] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1 - C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

[0161] but embodiments of the inventive concepts are not limited thereto.

[0162] In one or more embodiments, in Formula 202, i) R_{201} and R_{202} may be linked to to each other via to each other via a single bond, and/or ii) R_{203} and R_{204} may be linked to each other via a single bond.

[0163] In one or more embodiments, at least one selected from R_{201} to R_{204} in Formula 202 may each independently be selected from:

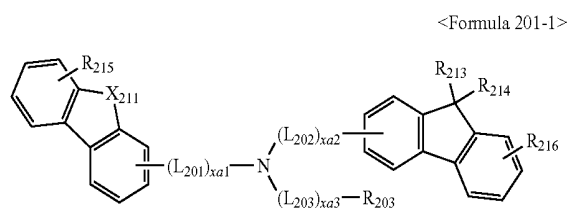
[0164] a carbazolyl group; and

[0165] a carbazolyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1 - C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl

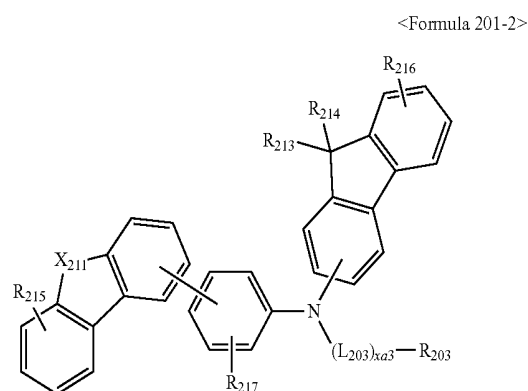
group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

[0166] but embodiments of the inventive concepts are not limited thereto.

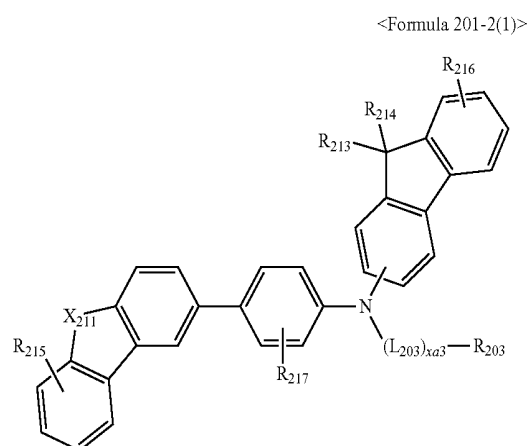
[0167] The compound represented by Formula 201 may be represented by Formula 201-1 below:



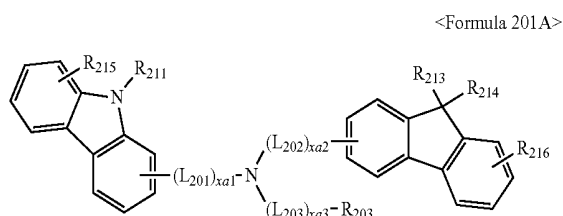
[0168] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201-2 below, but embodiments of the inventive concepts are not limited thereto:



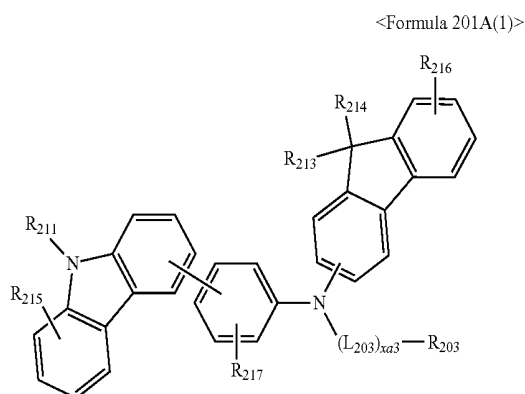
[0169] In one or more embodiments, the compound represented by Formula 201 may be represented by Formula 201-2(1) below, but embodiments of the inventive concepts are not limited thereto:



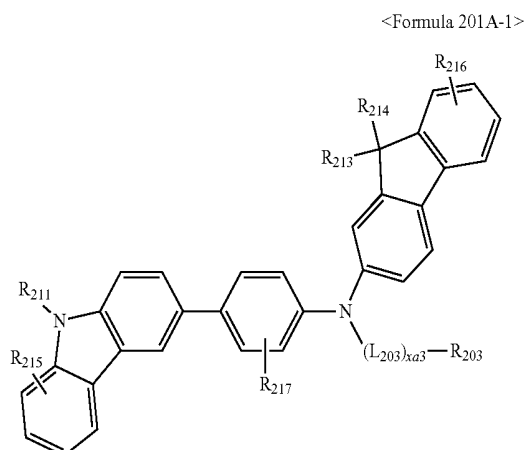
[0170] In one or more embodiments, the compound represented by Formula 201 may be represented by Formula 201A below:



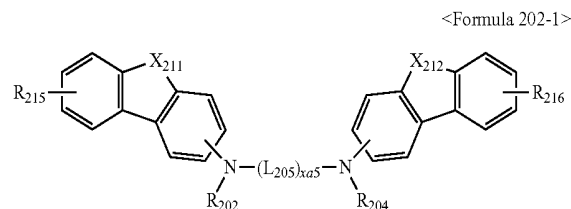
[0171] In one or more embodiments, the compound represented by Formula 201 may be represented by Formula 201A(1) below, but embodiments of the inventive concepts are not limited thereto:



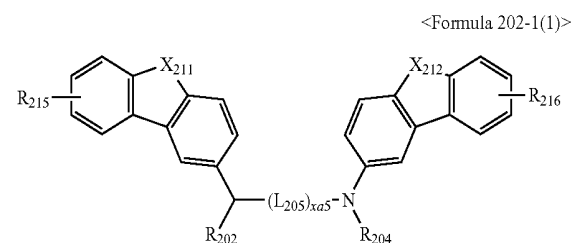
[0172] In one or more embodiments, the compound represented by Formula 201 may be represented by Formula 201A-1 below, but embodiments of the inventive concepts are not limited thereto:



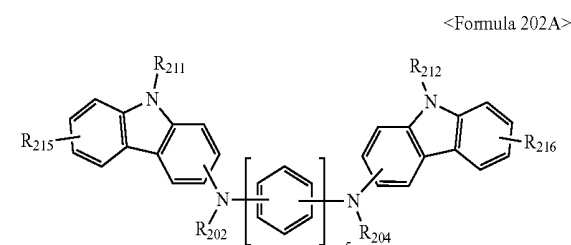
[0173] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202-1 below:



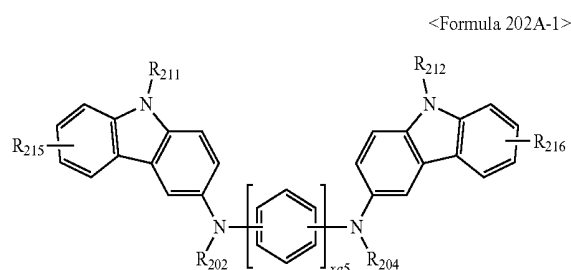
[0174] In one or more embodiments, the compound represented by Formula 202 may be represented by Formula 202-1(1) below:



[0175] In one or more embodiments, the compound represented by Formula 202 may be represented by Formula 202A below:



[0176] In one or more embodiments, the compound represented by Formula 202 may be represented by Formula 202A-1 below:



[0177] In Formulae 201-1, 201-2, 201-2(1), 201A, 201A(1), 202-1, 202-1(1), 202A, and 202A-1,

[0178] L_{201} to L_{203} , $xa1$ to $xa3$, $xa5$, and R_{202} to R_{204} are the same as described above,

[0179] L_{205} may be selected from a phenylene group and a fluorenylene group,

[0180] X_{211} may be selected from O, S, and N(R_{211}),

[0181] X_{212} may be selected from O, S, and N(R_{212}),

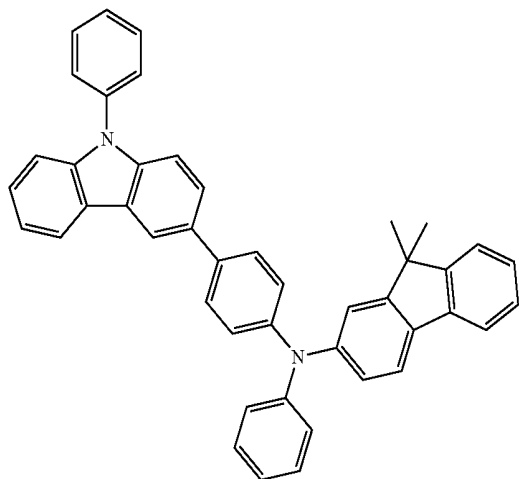
[0182] R_{211} and R_{212} are each the same as defined in connection with R_{203} , and

[0183] R_{213} to R_{217} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1 - C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaph-

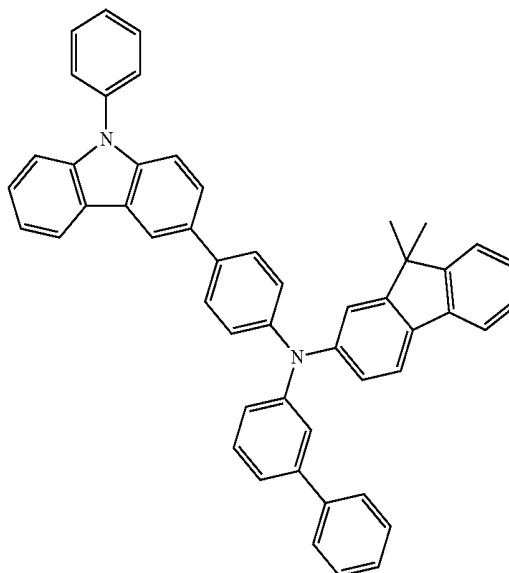
thyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group.

[0184] The hole transport region may include at least one compound selected from Compounds HT1 to HT48, but embodiments of the inventive concepts are not limited thereto:

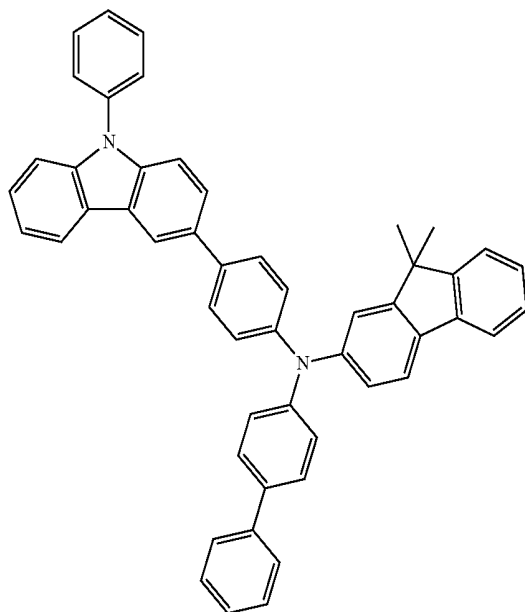
HT1



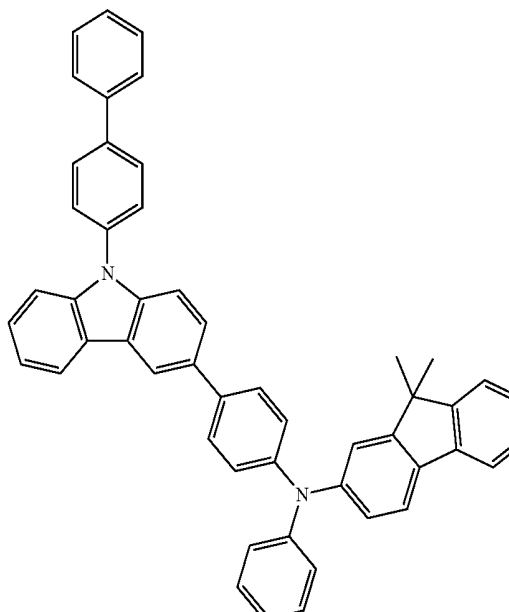
HT2



HT3

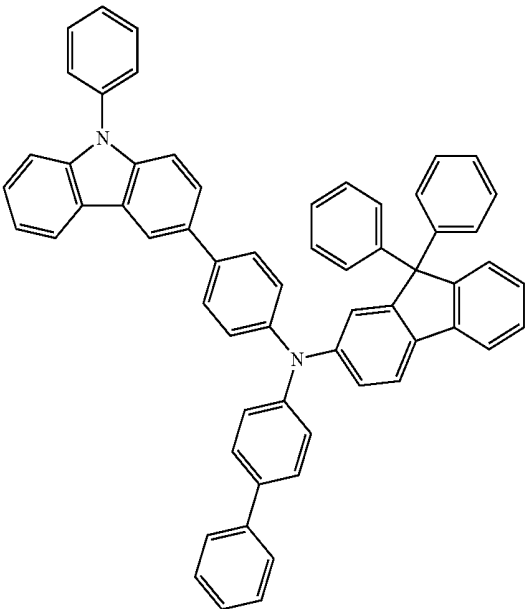
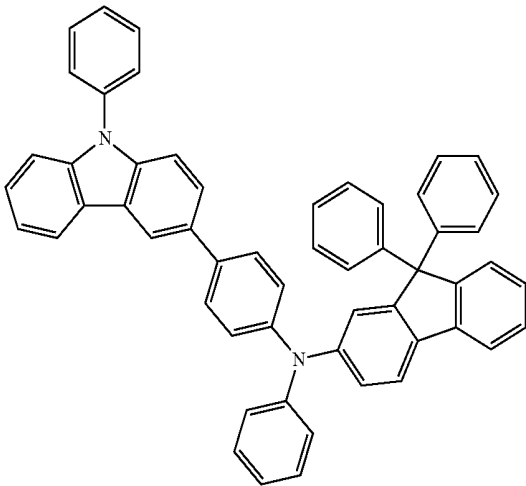


HT4



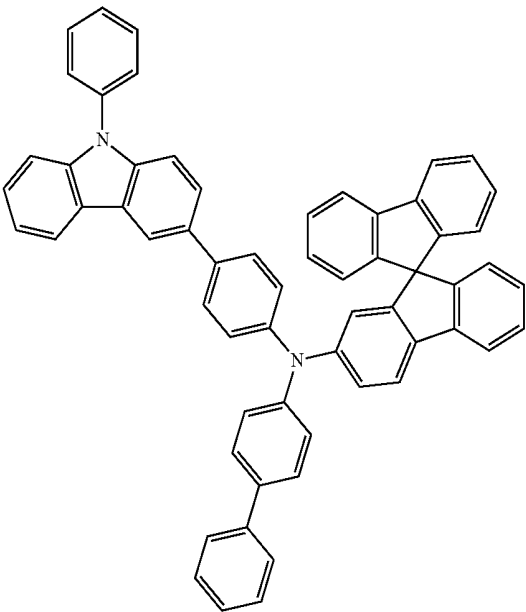
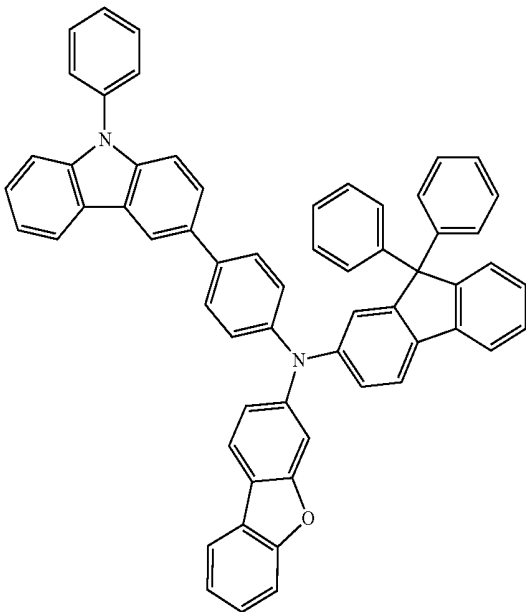
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HT5

HT6



HT7

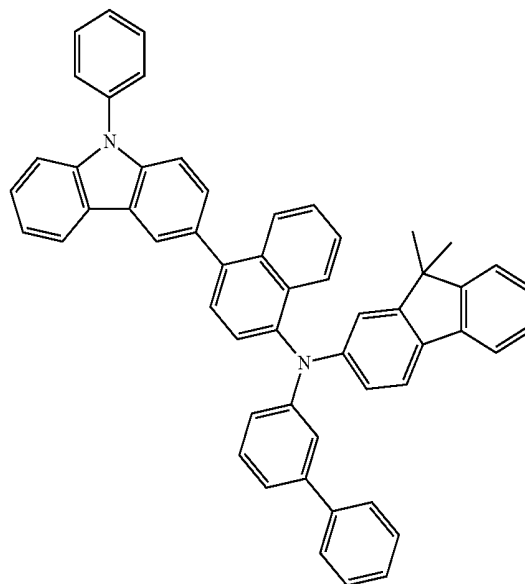
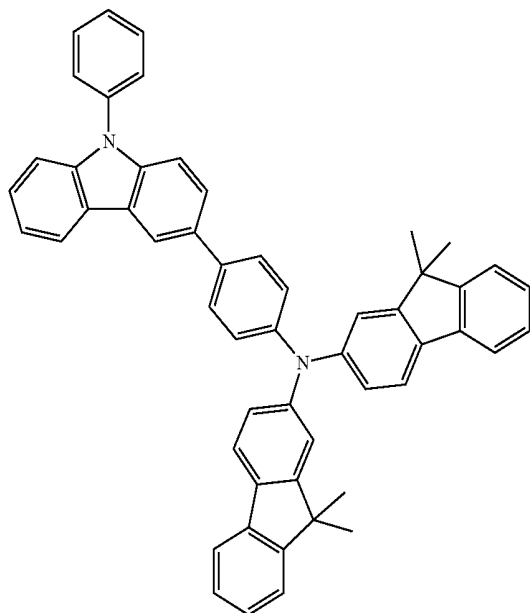
HT8



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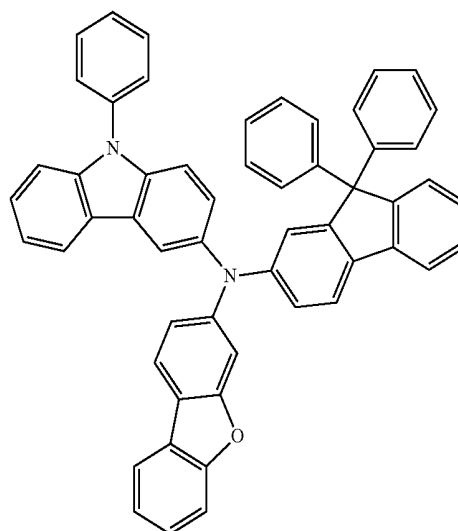
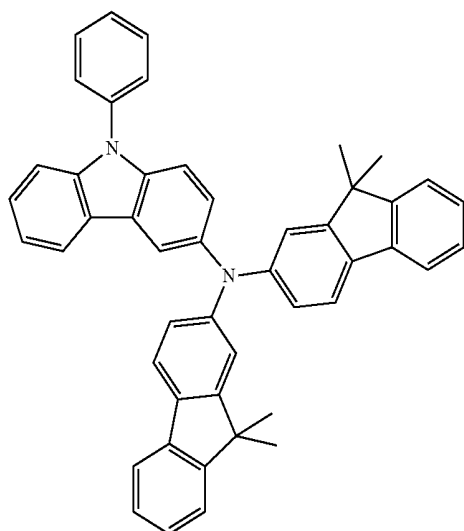
HT9

HT10



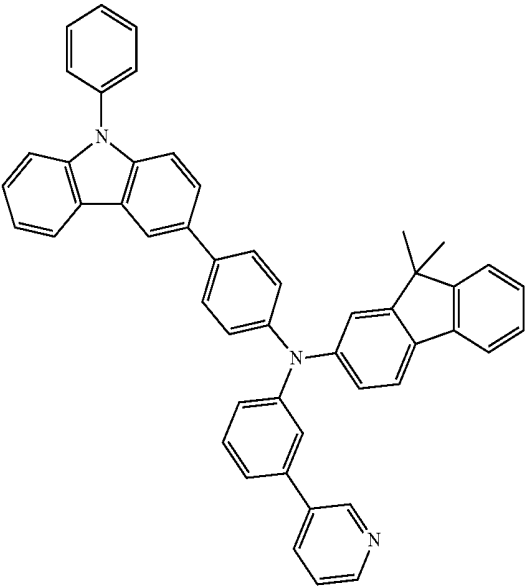
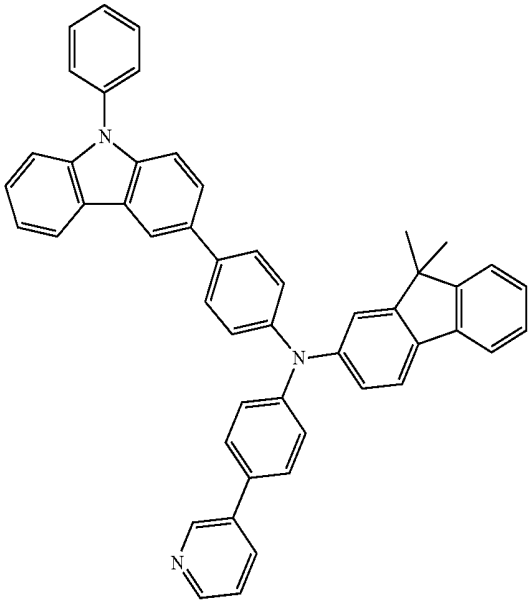
HT11

HT12



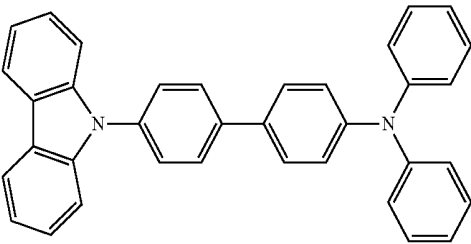
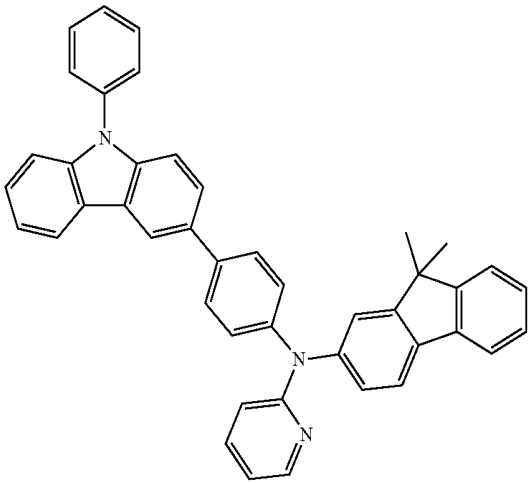
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HT13

HT14



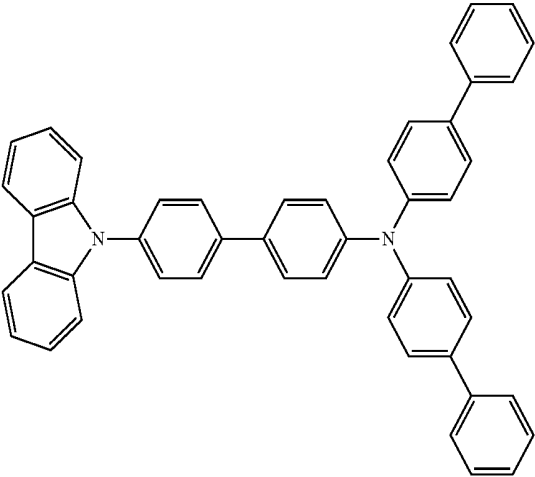
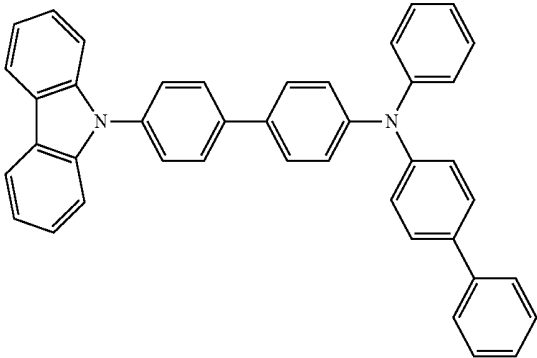
HT15

HT16



HT17

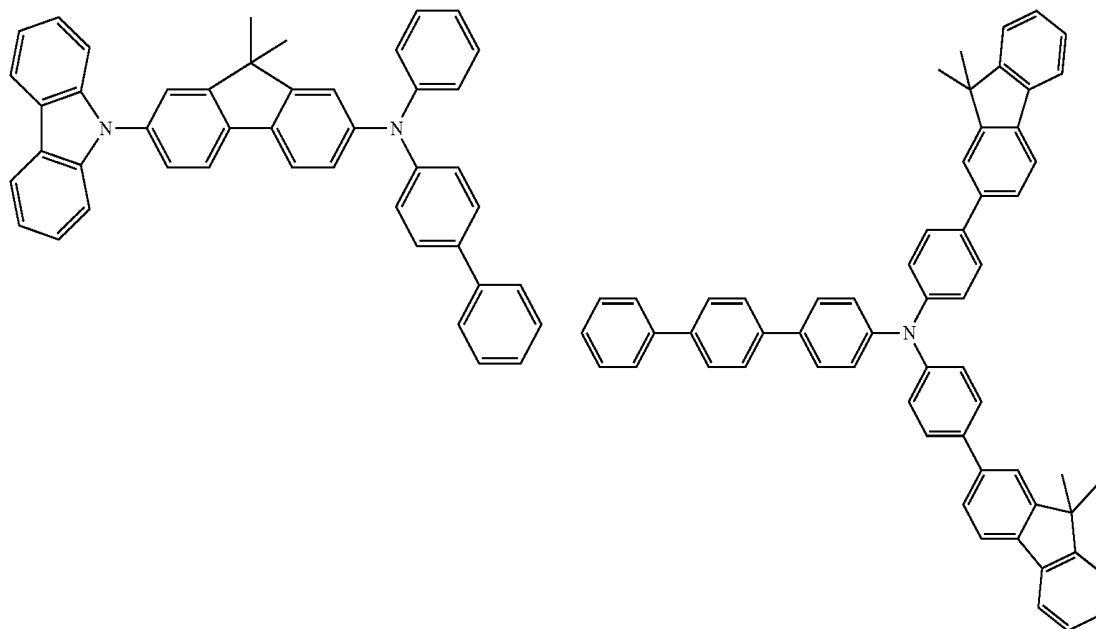
HT18



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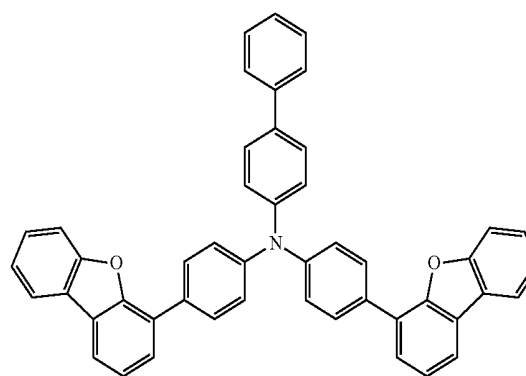
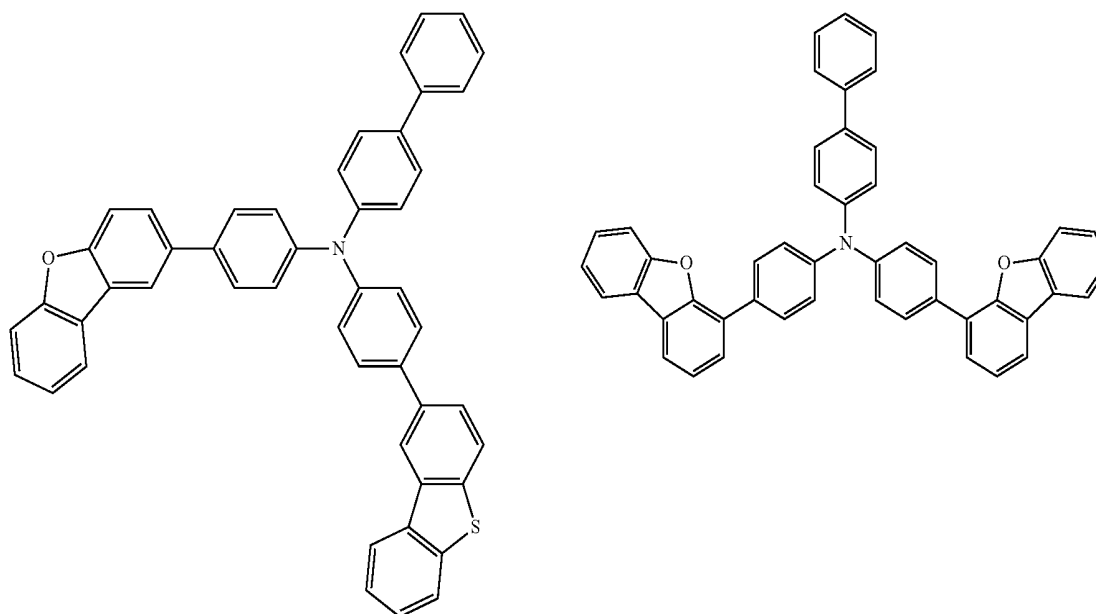
HT19

HT20



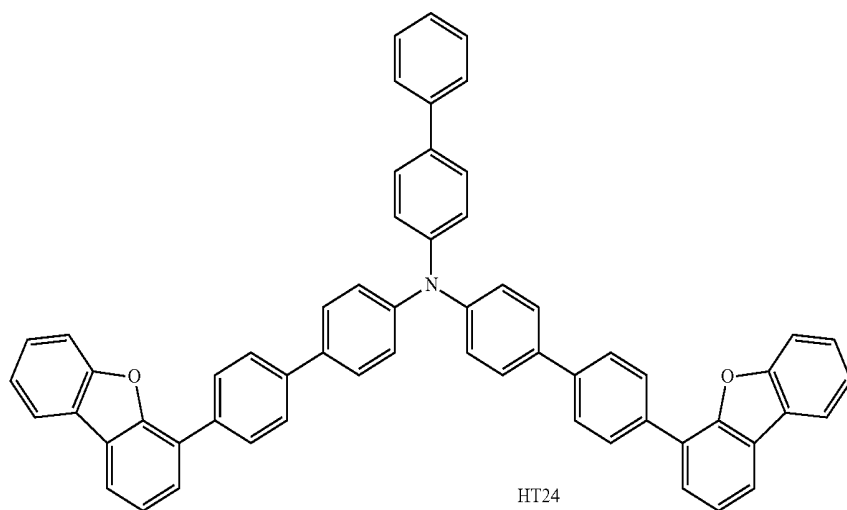
HT21

HT22



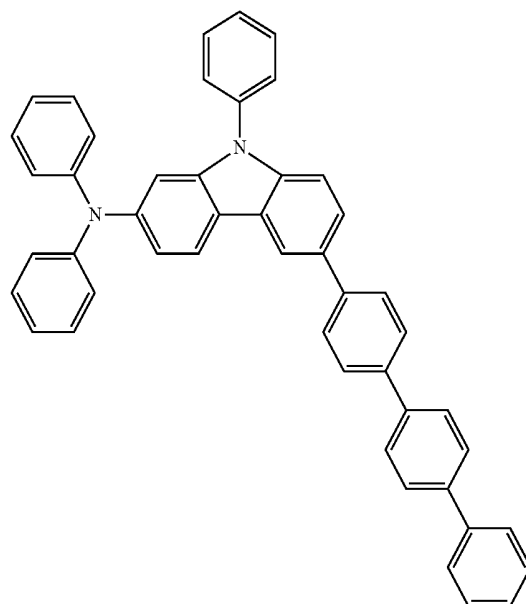
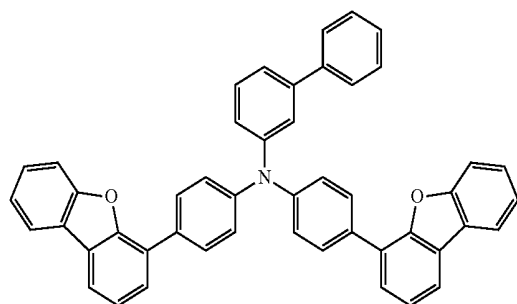
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HT23



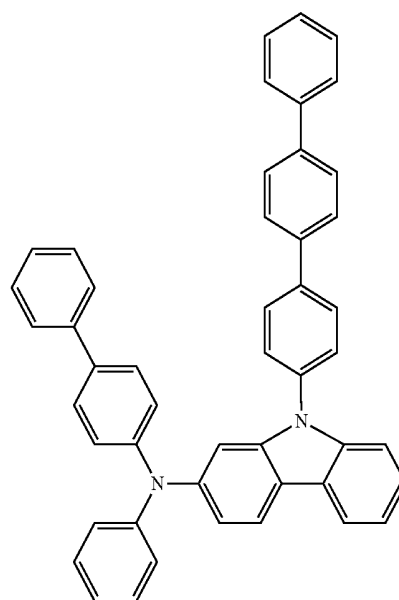
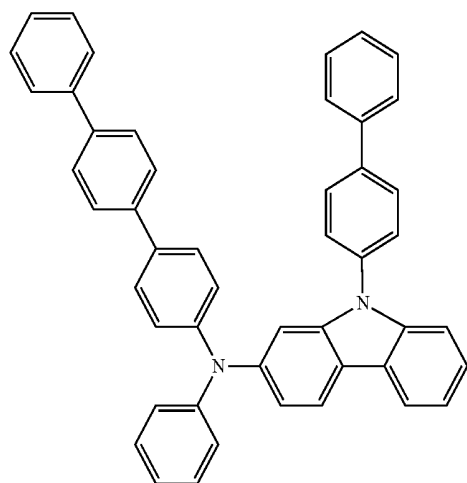
HT24

HT25

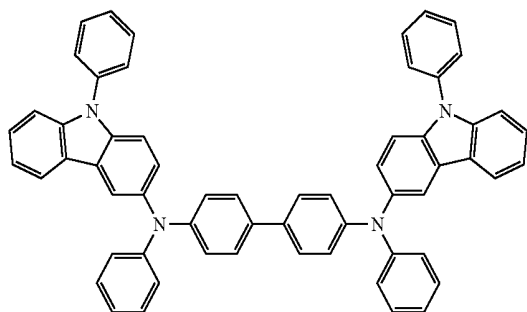


HT26

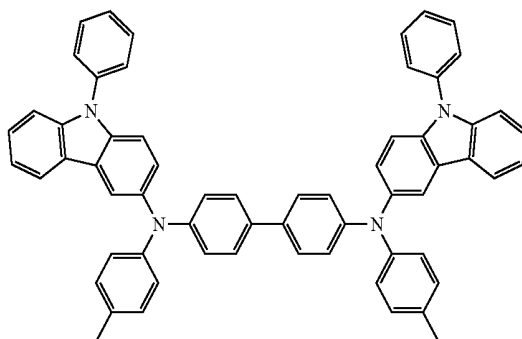
HT27



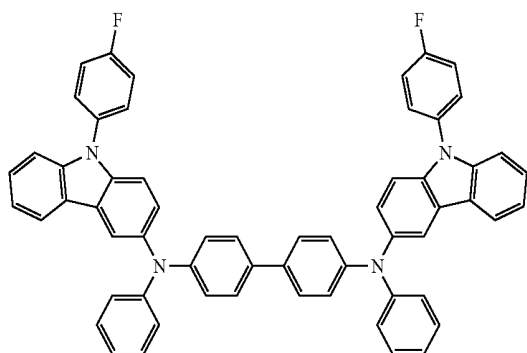
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HT28



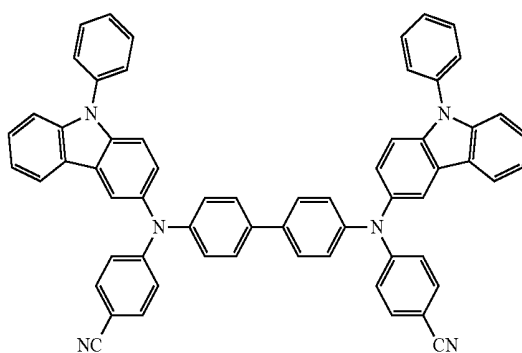
HT29



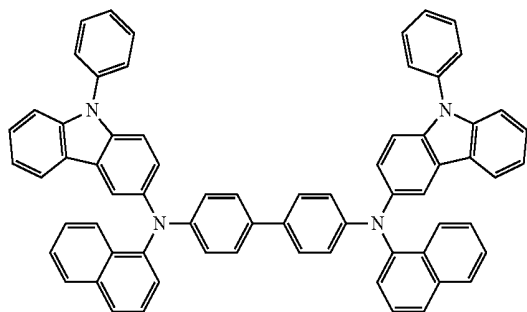
HT30



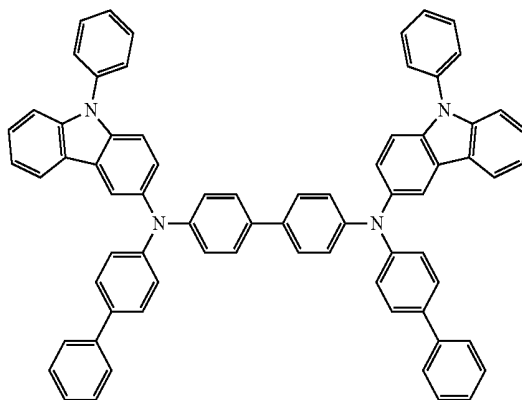
HT31



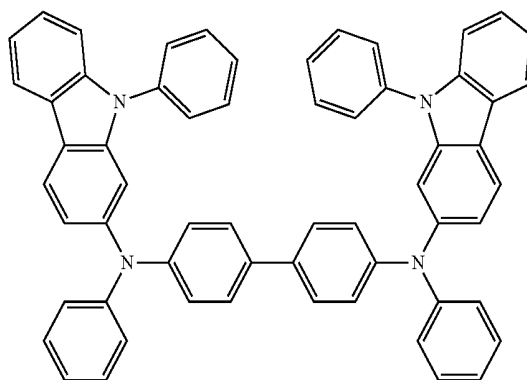
HT32



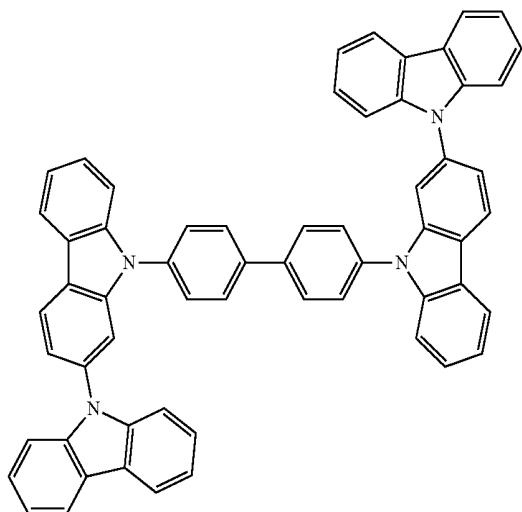
HT33



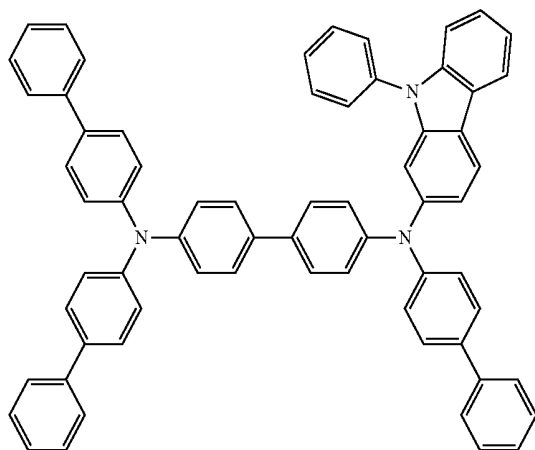
HT34



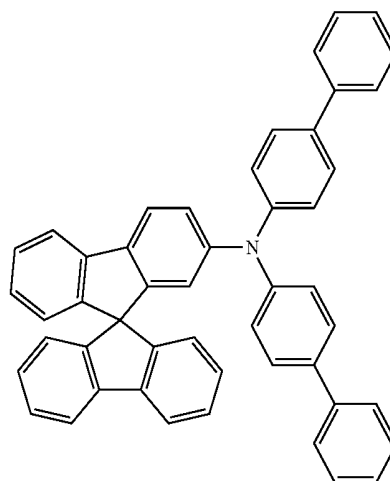
HT35



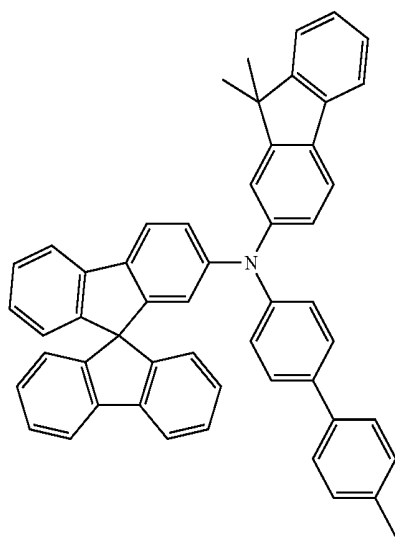
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HT36



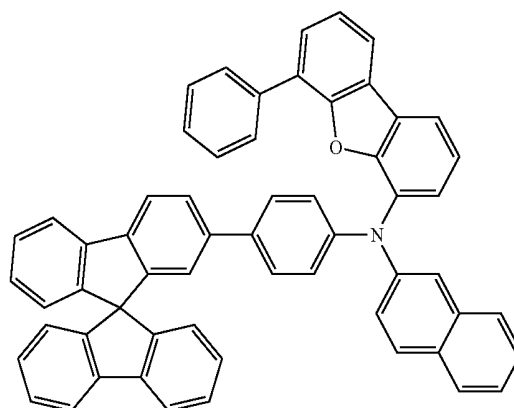
HT37



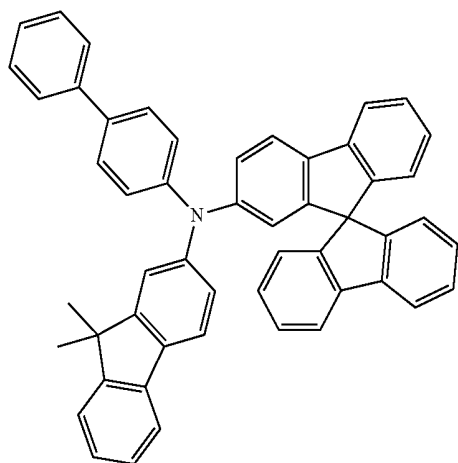
HT38



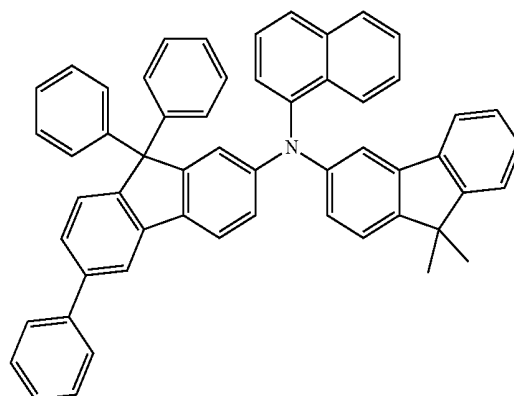
HT39



HT40

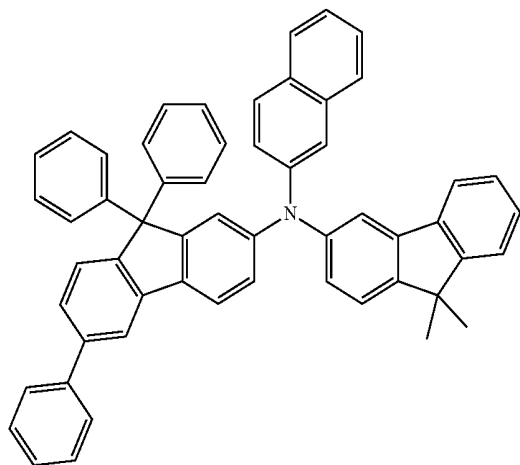


HT41

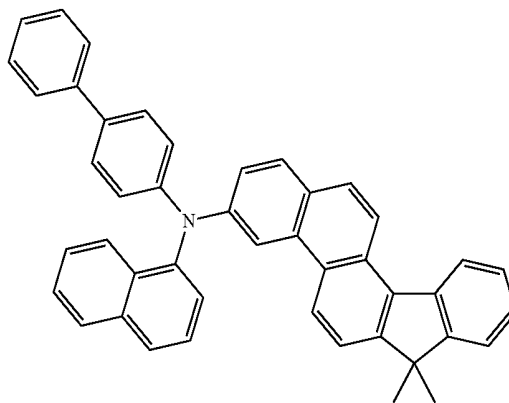


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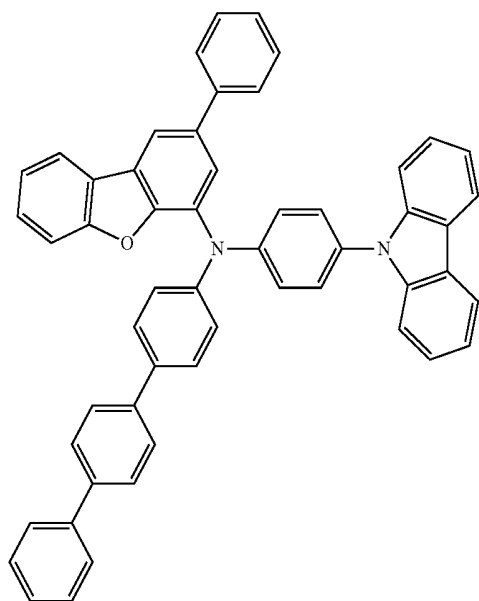
HT42



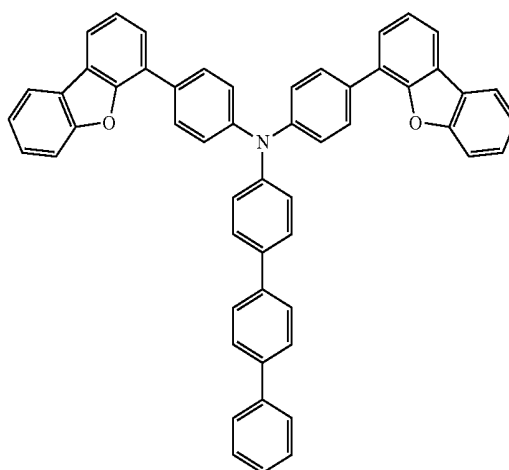
HT43



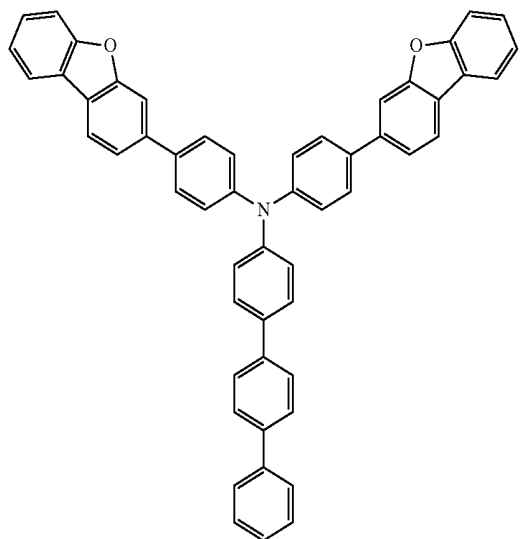
HT44



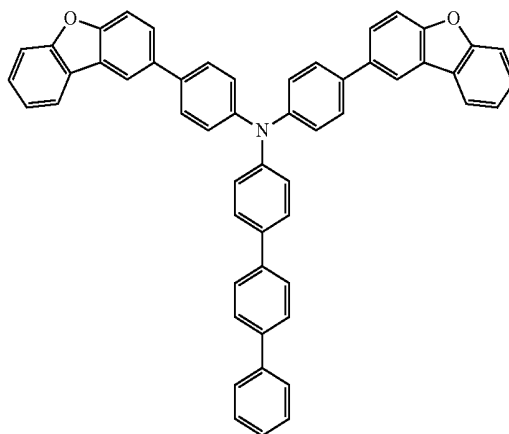
HT45



HT46

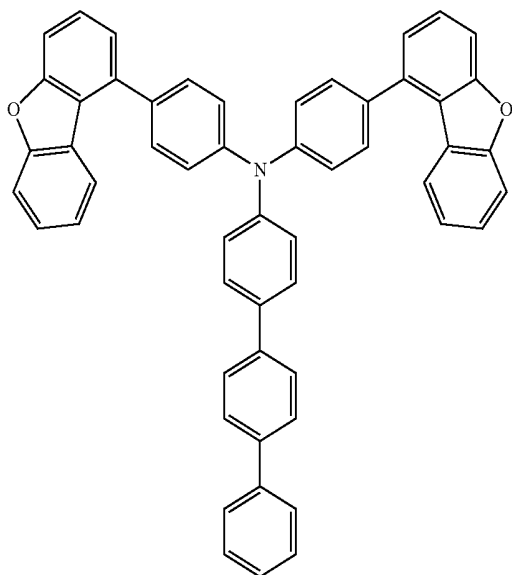


HT47



-continued

HT48



[0185] 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 selected from a hole injection layer and a hole transport layer, the thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, and for example, about 100 Å to about 1,000 Å, and the thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, and for example, about 100 Å to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within these ranges, satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

[0186] The emission auxiliary layer may increase light-emission efficiency by compensating for an optical resonance distance according to the wavelength of light emitted by to an emission layer, and the electron blocking layer may block the flow of electrons from an electron transport region. The emission auxiliary layer and the electron blocking layer may include the materials as described above.

[0187] 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.

[0188] The charge-generation material may be, for example, a p-dopant.

[0189] In one embodiment, the p dopant may have a LUMO energy level of -3.5 eV or less.

[0190] The p-dopant may include at least one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments of the inventive concepts are not limited thereto.

[0191] In one embodiment, the p-dopant may include at least one selected from:

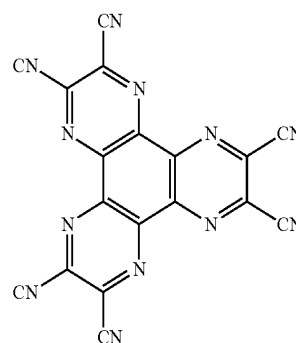
[0192] a quinone derivative, such as tetracyanoquinodimethane (TCNQ) and 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ);

[0193] a metal oxide, such as tungsten oxide or molybdenum oxide;

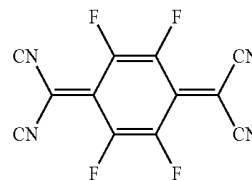
[0194] 1,4,5,8,9,12-Hexaazatriphenylene-hexacarbonitrile (HAT-CN); and

[0195] a compound represented by Formula 221 below,

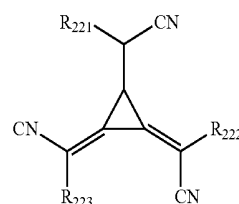
[0196] but embodiments of the inventive concepts are not limited thereto:



<HAT-CN>



<F4-TCNQ>



<Formula 221>

[0197] In Formula 221,

[0198] R_{221} to R_{223} may each independently be selected from 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_1 - C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, wherein at least one selected from R_{221} to R_{223} may have at least one substituent selected from a cyano group, —F, —Cl, —Br, —I, a C_1 - C_{20} alkyl group substituted with —F, a C_1 - C_{20} alkyl group substituted with —Cl, a C_1 - C_{20} alkyl group substituted with —Br, and a C_1 - C_{20} alkyl group substituted with —I.

[0199] When the organic light-emitting device 10 is a full-color organic light-emitting device, the emission layer in organic layer 150 may be patterned into a red emission layer, a green emission layer, or a blue emission layer, according to a sub-pixel. In one or more embodiments, the emission layer may have a stacked structure of two or more layers selected from a red emission layer, a green emission layer, and a blue emission layer, in which the two or more layers contact each other or are separated from each other. In one or more embodiments, the emission layer may include two or more materials selected from a red light-emitting material, a green light-emitting material, and a blue light-emitting material, in which the two or more materials are mixed with each other in a single layer to emit white light.

[0200] The emission layer may include a host and a dopant. The dopant may include at least one selected from a phosphorescent dopant and a fluorescent dopant. The phosphorescent dopant may include the organometallic compound represented by Formula 1.

[0201] In the emission layer, an amount of the dopant may be in a range of about 0.01 parts by weight to about 15 parts by weight based on 100 parts by weight of the host, but embodiments of the inventive concepts are not limited thereto.

[0202] 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. 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.

[0203] In one or more embodiments, the host in the emission layer may include a compound represented by Formula 301 below:



[0204] In Formula 301,

[0205] Ar_{301} may be a substituted or unsubstituted C_5 - C_{60} carbocyclic group or a substituted or unsubstituted C_1 - C_{60} heterocyclic group,

[0206] $xb11$ may be 1, 2, or 3,

[0207] L_{301} may be selected from a substituted or unsubstituted C_3 - C_{10} cycloalkylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkenylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6 - C_{60} arylene group, a substituted

or unsubstituted C_1 - C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0208] $xb1$ may be an integer from 0 to 5,

[0209] R_{301} may be selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, —Si(Q_{301})(Q_{302})(Q_{303}), —N(Q_{301})(Q_{302}), —B(Q_{301})(Q_{302}), —C(=O)(Q_{301}), —S(=O)₂(Q_{301}), and —P(=O)(Q_{301})(Q_{302}),

[0210] $xb21$ may be an integer from 1 to 5, and

[0211] Q_{301} to Q_{303} may each independently be selected from a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments of the inventive concepts are not limited thereto.

[0212] In one embodiment, Ar_{301} in Formula 301 may be selected from:

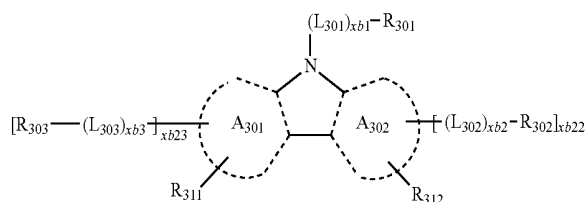
[0213] a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group; and

[0214] a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)₂(Q_{31}), and —P(=O)(Q_{31})(Q_{32}), and

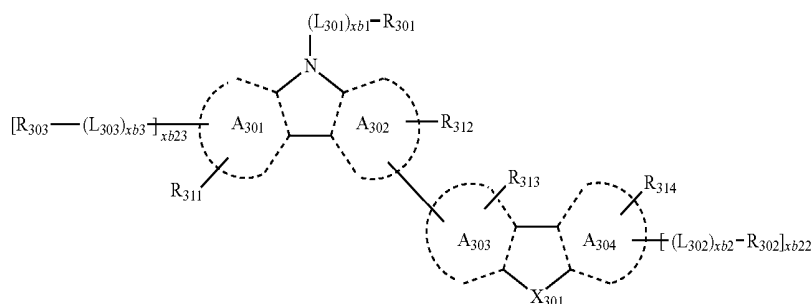
[0215] Q_{31} to Q_{33} may each independently be selected from a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments of the inventive concepts are not limited thereto.

[0216] When $xb11$ in Formula 301 is 2 or more, two or more Ar_{301} (s) may be linked to each other via a single bond.

[0217] In one or more embodiments, the compound represented by Formula 301 may be represented by Formula 301-1 or 301-2:



<Formula 301-1>



<Formula 301-2>

[0218] In Formulae 301-1 and 301-2,

[0219] ring A₃₀₁ to ring A₃₀₄ may each independently be selected from a benzene ring, a naphthalene ring, a phenanthrene ring, a fluoranthene ring, a triphenylene ring, a pyrene ring, a chrysene ring, a pyridine ring, a pyrimidine ring, an indene ring, a fluorene ring, a spiro-bifluorene ring, a benzofluorene ring, a dibenzofluorene ring, an indole ring, a carbazole ring, a benzocarbazole ring, a dibenzocarbazole ring, a furan ring, a benzofuran ring, a dibenzofuran ring, a naphthofuran ring, a benzonaphthofuran ring, a dinaphthofuran ring, a thiophene ring, a benzothiophene ring, a dibenzothiophene ring, a naphthothiophene ring, a benzonaphthothiophene ring, and a dinaphthothiophene ring,

[0220] X₃₀₁ may be O, S, or N-[(L₃₀₄)_{xb4}-R₃₀₄],

[0221] R₃₁₁ to R₃₁₄ may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂),

[0222] xb22 and xb23 may each independently be 0, 1, or 2,

[0223] L₃₀₁, xb1, R₃₀₁, and Q₃₁ to Q₃₃ are each the same as described above,

[0224] L₃₀₂ to L₃₀₄ are each independently the same as described in connection with L₃₀₁,

[0225] xb2 to xb4 each independently the same as described in connection with xb1, and

[0226] R₃₀₂ to R₃₀₄ each independently the same as described in connection with R₃₀₁.

[0227] For example, in Formulae 301, 301-1, and 301-2, L₃₀₁ to L₃₀₄ may each to independently be selected from:

[0228] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group,

a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a

thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group; and

[0229] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a

pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylenylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazoyl group, —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)₂(Q_{31}), and —P(=O)(Q_{31})(Q_{32}), and

[0230] Q_{31} to Q_{33} are the same as described above.

[0231] In one embodiment, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

[0232] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl

group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazoyl group; and

[0233] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazoyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazoyl group, —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)₂(Q_{31}), and —P(=O)(Q_{31})(Q_{32}), and

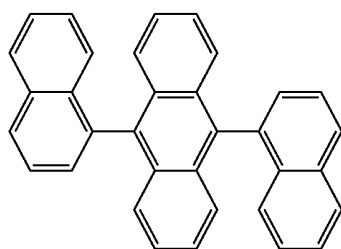
[0234] Q_{31} to Q_{33} are the same as described above.

[0235] In one embodiment, the host may include an alkaline earth-metal complex. For example, the host may be

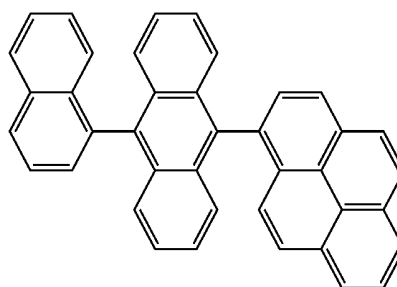
selected from a Be complex (for example, Compound H55), a Mg complex, and a Zn complex.

[0236] In one or more embodiments, the host may include at least one selected from 9,10-di(2-naphthyl)anthracene (ADN), 2-methyl-9,10-bis(naphthalen-2-yl)anthracene (MADN), 9,10-di-(2-naphthyl)-2-t-butyl-anthracene (TBADN), 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP), 1,3-di-9-carbazolylbenzene (mCP), 1,3,5-tri(carbazol-9-yl)benzene (TCP), and Compounds H1 to H55, but embodiments of the inventive concepts are not limited thereto:

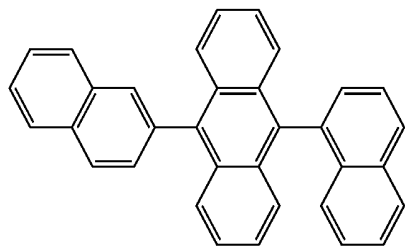
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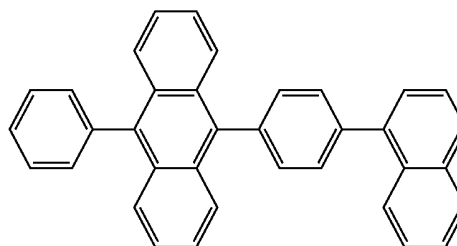
H1



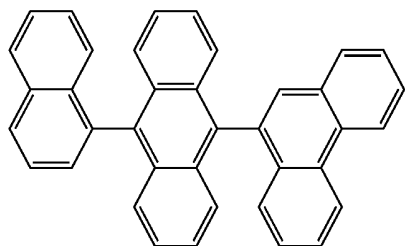
H6



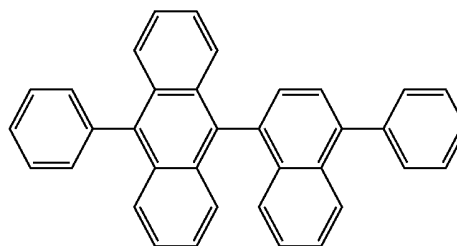
H2



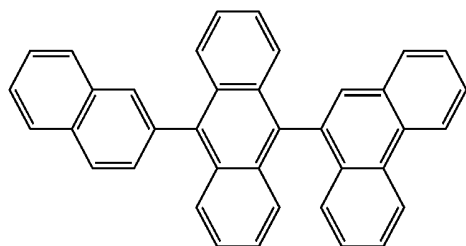
H7



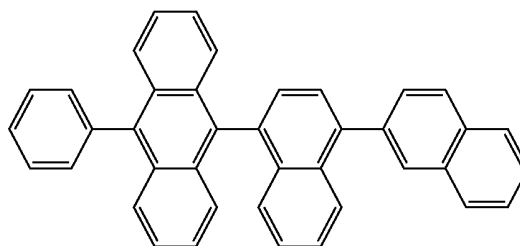
H3



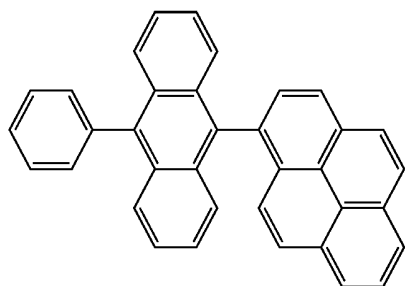
H8



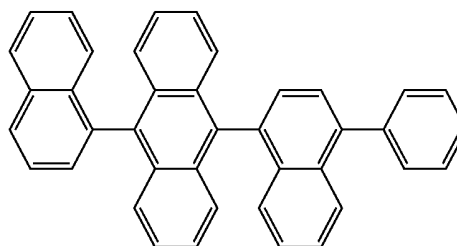
H4



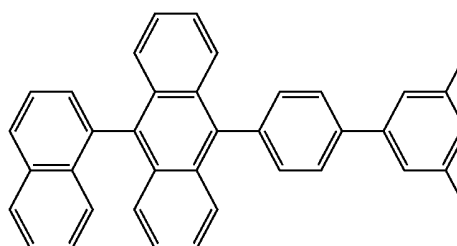
H9



H5

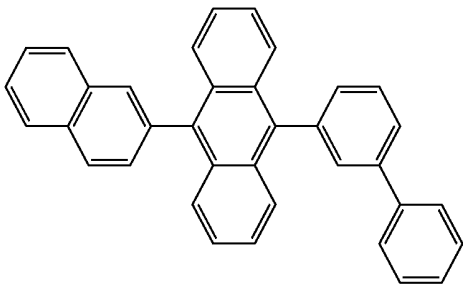


H10



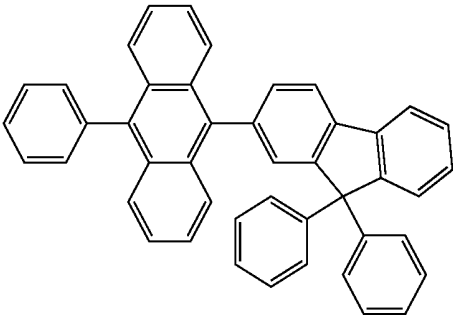
H11

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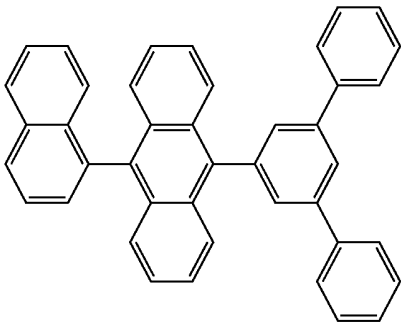


H12

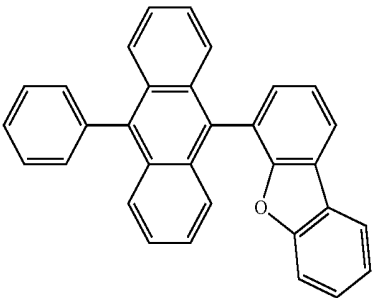
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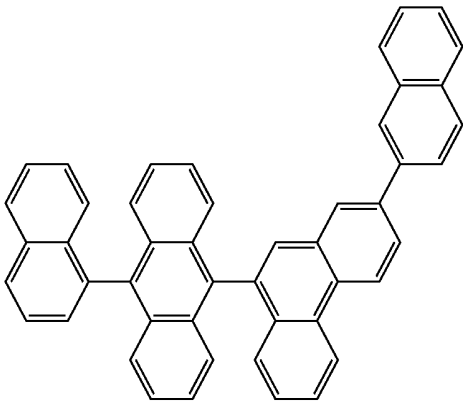
H17



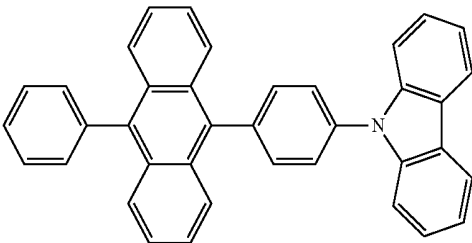
H13



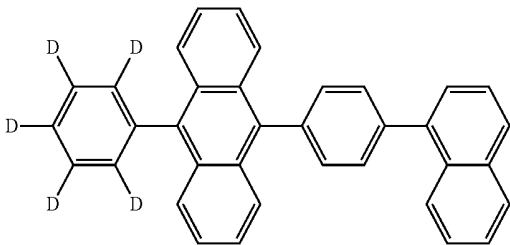
H18



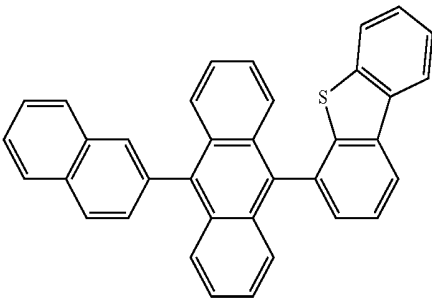
H14



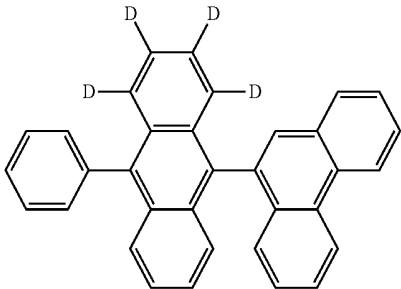
H19



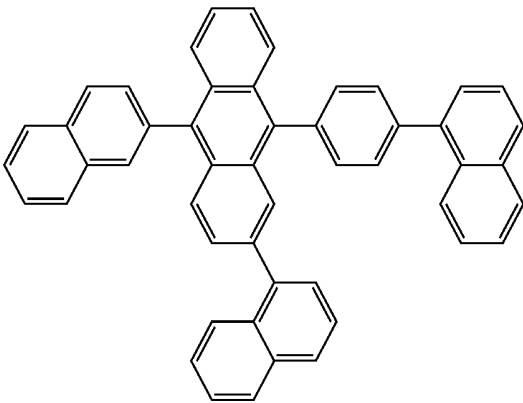
H15



H20

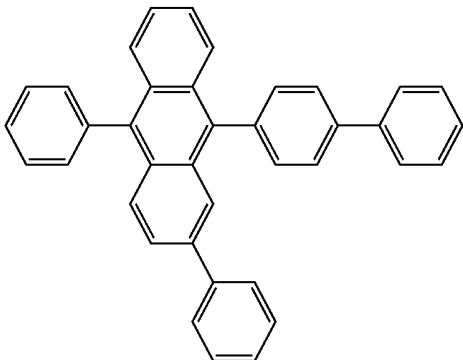


H16



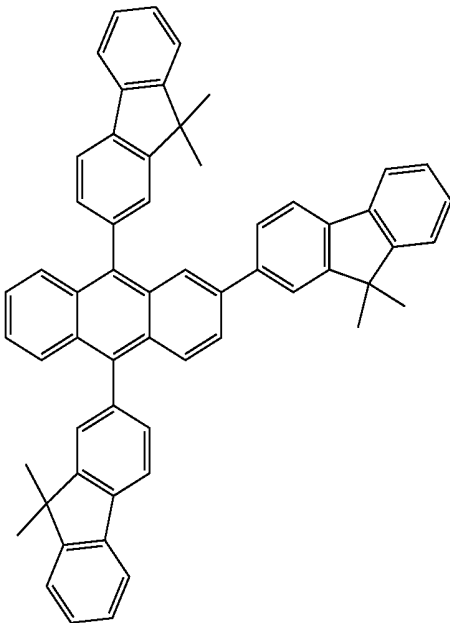
H21

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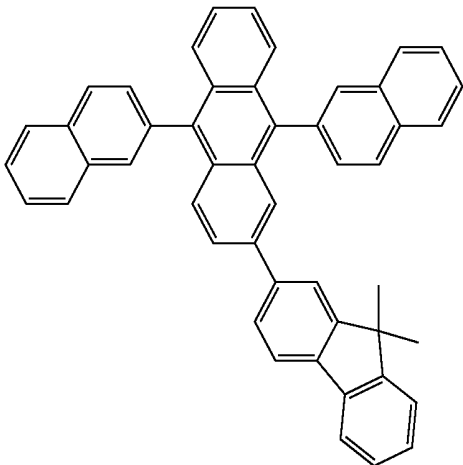


H22

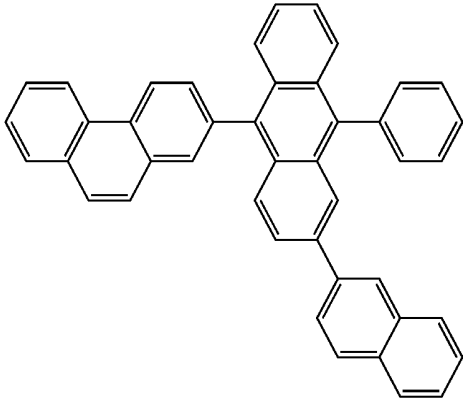
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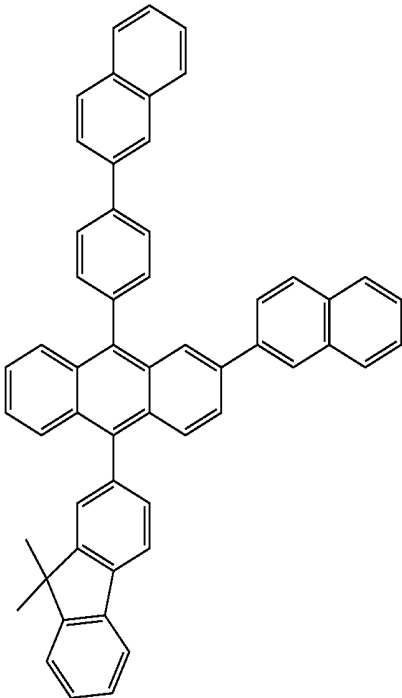
H25



H23

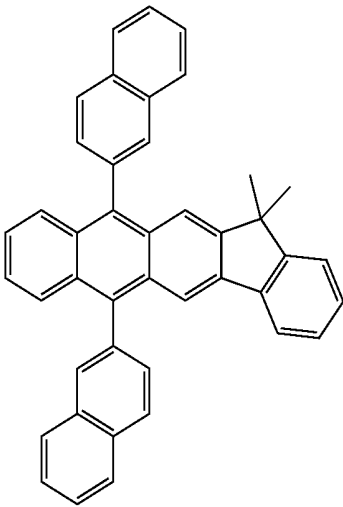


H24



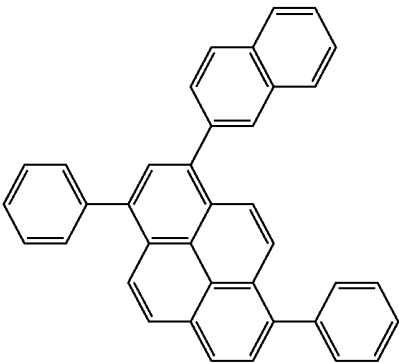
H26

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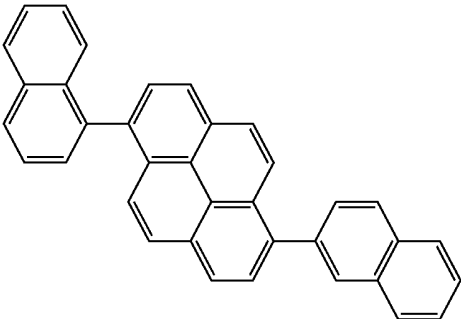


H27

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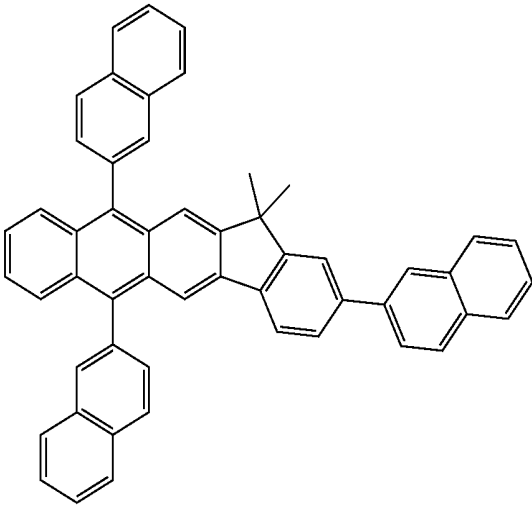


H30

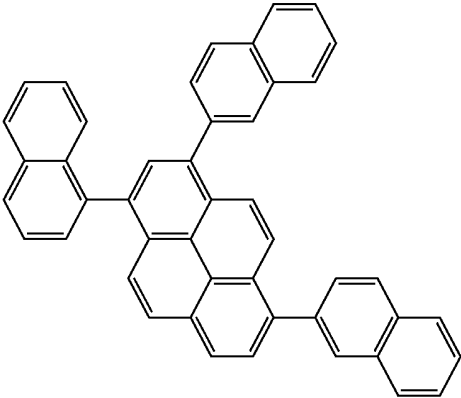


H31

H28

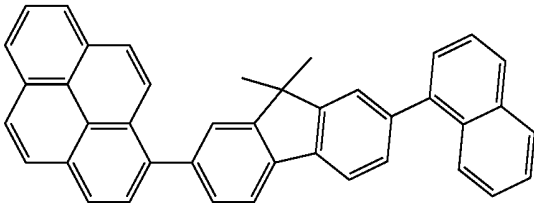


H32

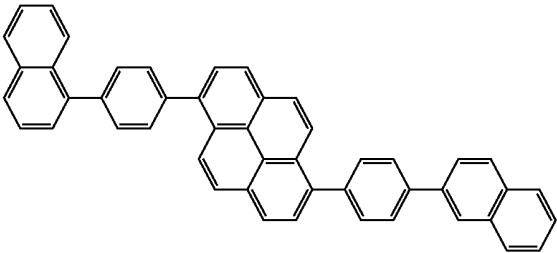
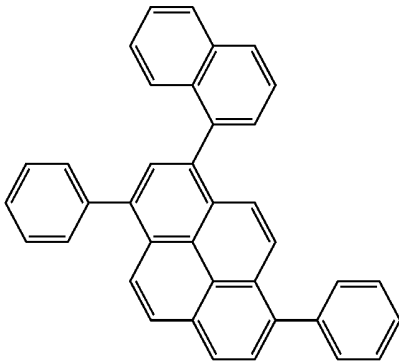


H33

H29

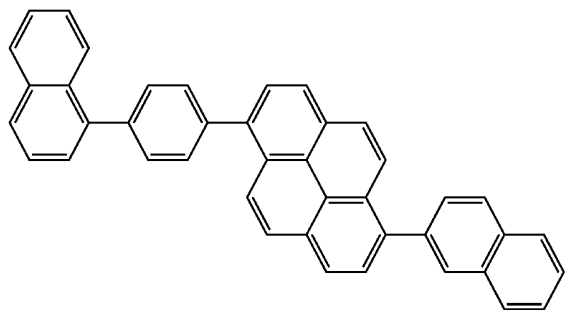


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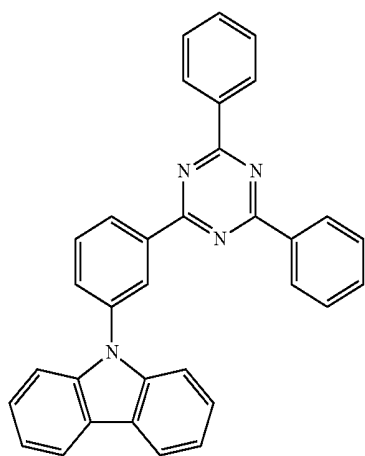


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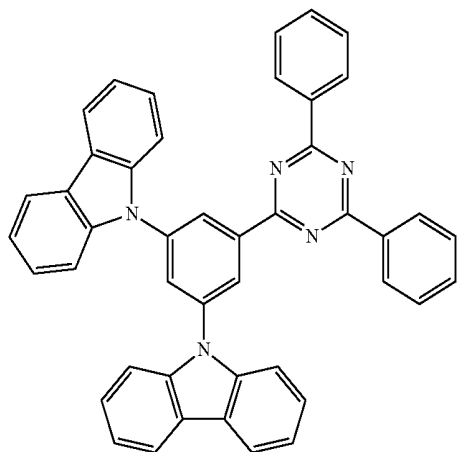
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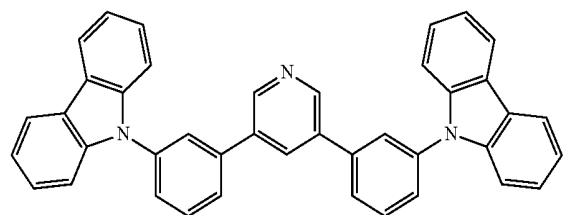
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H37

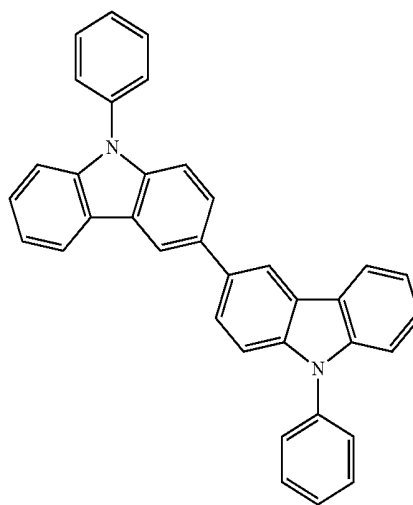


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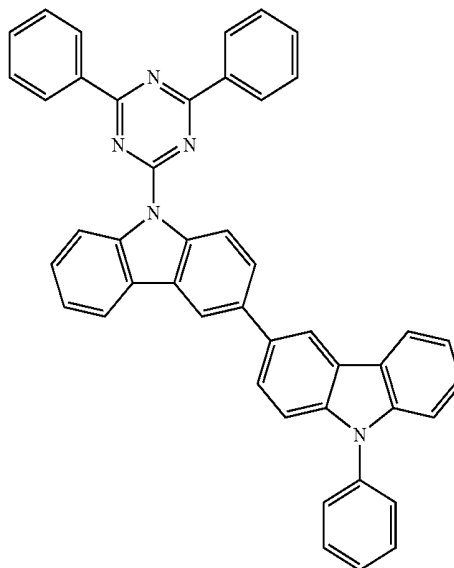


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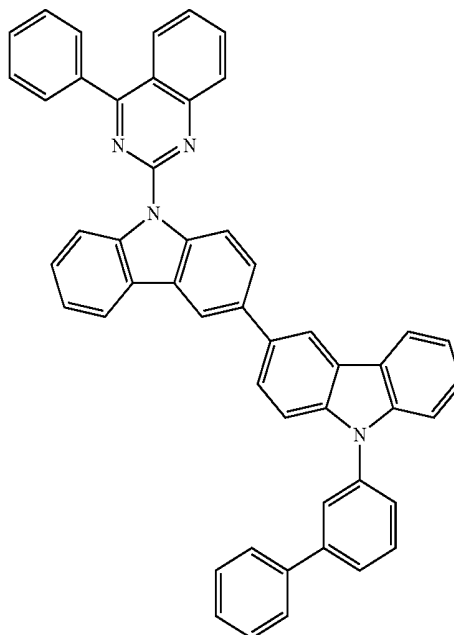
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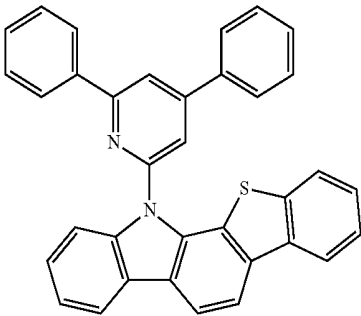
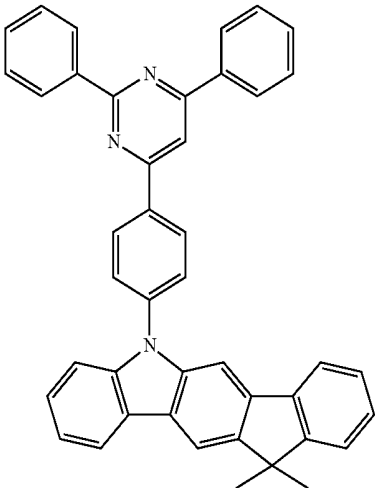
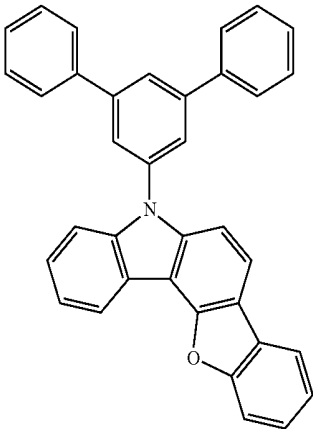
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H41

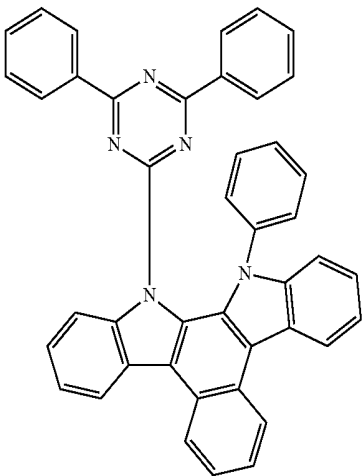


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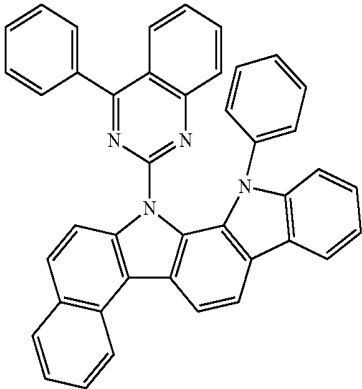
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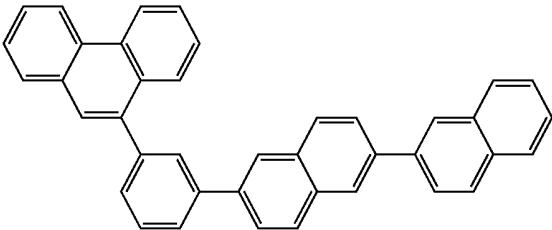


H45

H43

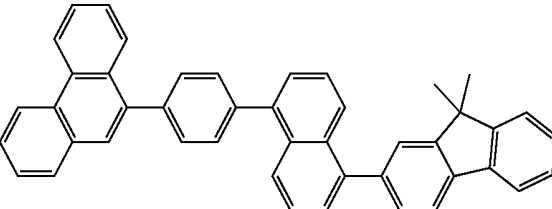


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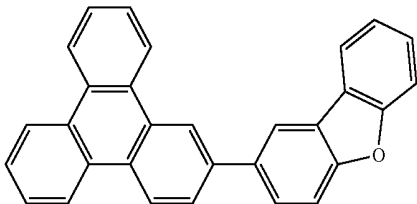
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H44

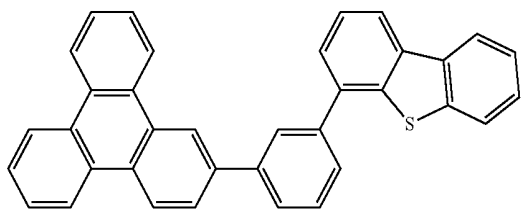


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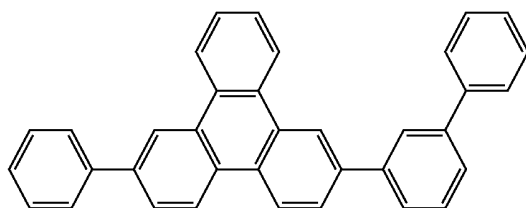
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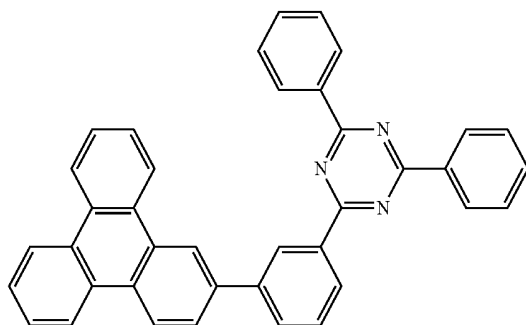
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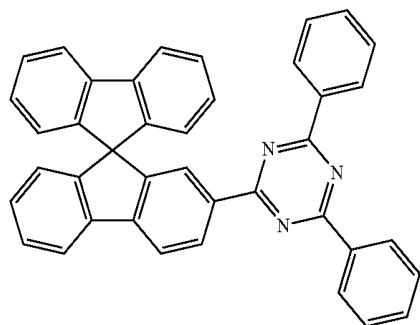
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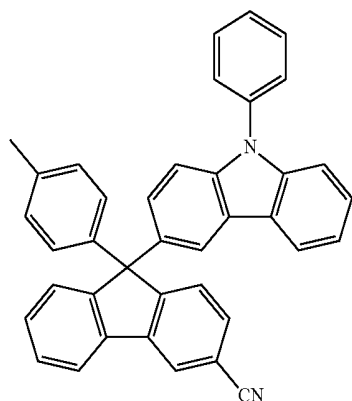
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H52

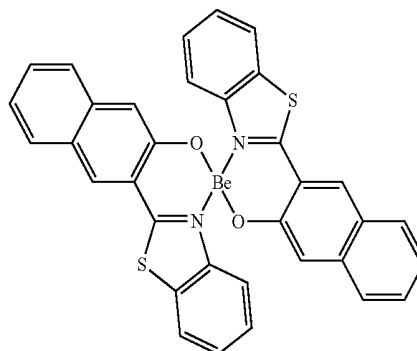


H53



H54

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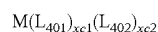
H55

[0237] In one embodiment, the host may include at least one selected from a silicon-containing compound (for example, BCPDS used in the following examples or the like) and a phosphine oxide-containing compound (for example, POPCPA used in the following examples or the like).

[0238] In one embodiment, the host may include only one compound, or two or more different compounds (for example, a host used in the following examples includes BCPDS and POPCPA).

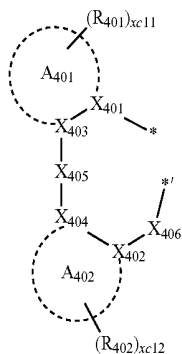
[0239] The phosphorescent dopant included in the emission layer in organic layer 150 to may include an organometallic compound represented by Formula 1:

[0240] In addition, the phosphorescent dopant may include an organometallic complex represented by Formula 401 below:



<Formula 401>

<Formula 402>



[0241] In Formulae 401 and 402,

[0242] M may be selected from Ir, Pt, Pd, Os, Ti, Zr, Hf, Eu, Tb, Rh, and Tm,

[0243] L_{401} may be selected from ligands represented by Formula 402, and $xc1$ may be 1, 2, or 3, wherein, when $xc1$ is 2 or more, two or more $L_{401}(s)$ may be identical to or different from each other,

[0244] L_{402} may be an organic ligand, and $xc2$ may be an integer from 0 to 4, wherein, when $xc2$ is 2 or more, two or more $L_{402}(s)$ may be identical to or different from each other,

[0245] X_{401} to X_{404} may each independently be nitrogen or carbon,

[0246] X_{401} and X_{403} may be linked to each other via a single bond or a double bond, and X_{402} and X_{404} may be linked to each other via a single bond or a double bond,

[0247] A_{401} and A_{402} may each independently be selected from a C_5 - C_{60} carbocyclic group or a C_1 - C_{60} heterocyclic group,

[0248] X_{405} may be a single bond, $*-O-*$, $*-S-*$, $*-C(=O)-*$, $*-N(Q_{411})-*$, $*-C(Q_{411})(Q_{412})-*$, $*-C(Q_{411})=C(Q_{412})-*$, $*-C(Q_{411})=*$, or $*=C=*$, wherein Q_{411} and Q_{412} may each independently be hydrogen, deuterium, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group,

[0249] X_{406} may be a single bond, O, or S,

[0250] R_{401} and R_{402} may each independently be selected from hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1 - C_{20} alkyl group, a substituted or unsubstituted C_1 - C_{20} 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, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-Si(Q_{401})(Q_{402})(Q_{403})$, $-N(Q_{401})(Q_{402})$, $-B(Q_{401})(Q_{402})$, $-C(=O)(Q_{401})$, $-S(=O)_2(Q_{401})$, and $-P(=O)(Q_{401})(Q_{402})$, wherein Q_{401} to Q_{403} may each independently be selected from a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a C_6 - C_{20} aryl group, and a C_1 - C_{20} heteroaryl group,

[0251] $xc11$ and $xc12$ may each independently be an integer from 0 to 10, and

[0252] $*$ and $*$ in Formula 402 each indicate a binding site to M in Formula 401.

[0253] In one embodiment, A_{401} and A_{402} in Formula 402 may each independently be selected from a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, an indene group, a pyrrole group, a thiophene group, a furan group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a quinoxaline group, a quinazoline group, a carbazole group, a benzimidazole group, a benzofuran group, a benzothiophene group, an isobenzothiophene group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a dibenzofuran group, and a dibenzothiophene group.

[0254] In one or more embodiments, in Formula 402, i) X_{401} may be nitrogen, and X_{402} may be carbon, or ii) X_{401} and X_{402} may be nitrogen at the same time.

[0255] In one or more embodiments, R_{401} and R_{402} in Formula 402 may each independently be selected from:

[0256] hydrogen, deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, and a C_1 - C_{20} alkoxy group;

[0257] a C_1 - C_{20} alkyl group and a C_1 - C_{20} alkoxy group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a phenyl group, a naphthyl group, a cyclopentyl group, a cyclohexyl group, an adamantanyl group, a norbornanyl group, and a norbornenyl group;

[0258] a cyclopentyl group, a cyclohexyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

[0259] a cyclopentyl group, a cyclohexyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, $-F$, $-Cl$, $-Br$, $-I$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

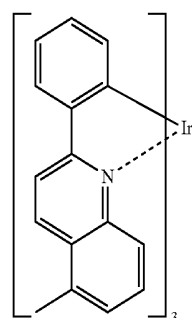
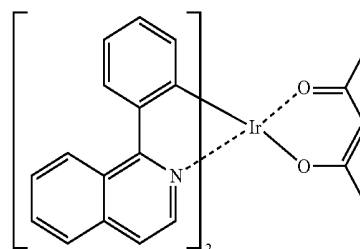
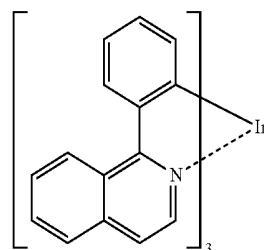
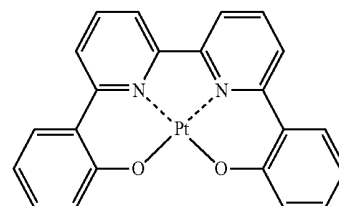
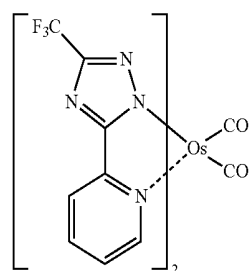
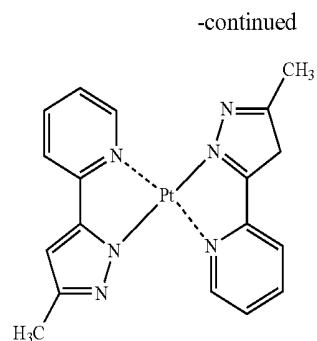
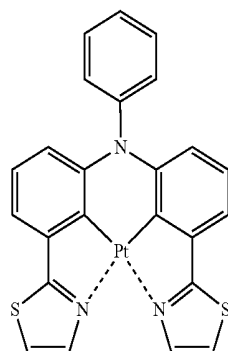
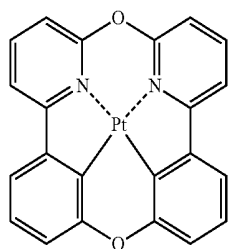
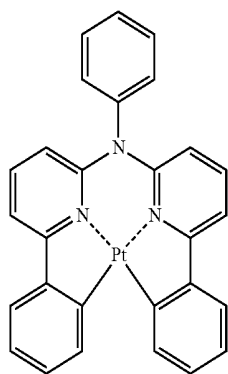
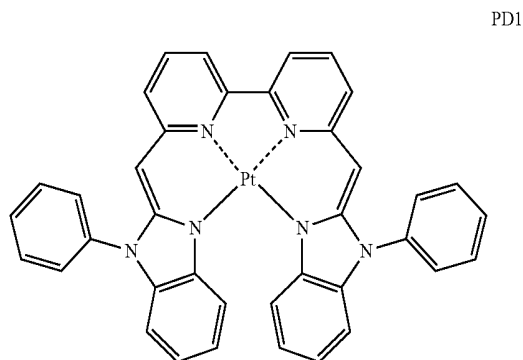
[0260] $-Si(Q_{401})(Q_{402})(Q_{403})$, $-N(Q_{401})(Q_{402})$, $-B(Q_{401})(Q_{402})$, $-C(=O)(Q_{401})$, $-S(=O)_2(Q_{401})$, and $-P(=O)(Q_{401})(Q_{402})$, and

[0261] Q_{401} to Q_{403} may each independently be selected from a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a phenyl group, a biphenyl group, and a naphthyl group, but embodiments of the inventive concepts are not limited thereto.

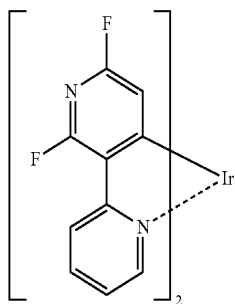
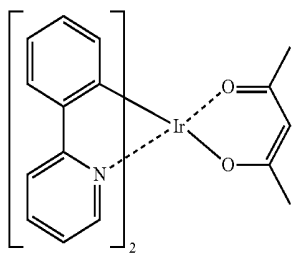
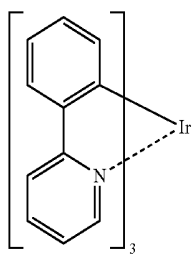
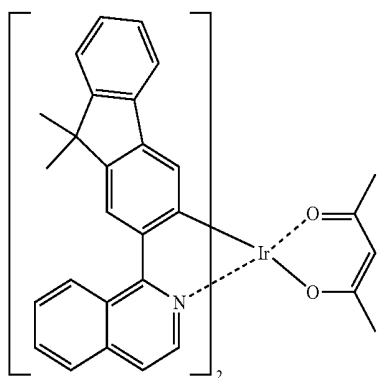
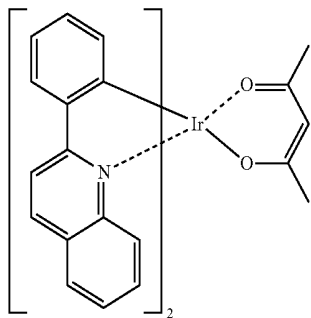
[0262] In one or more embodiments, when $xc1$ in Formula 401 is 2 or more, two $A_{401}(s)$ in two or more $L_{401}(s)$ may optionally be linked to each other via X_{407} , which is a linking group, or two $A_{402}(s)$ in two or more $L_{401}(s)$ may optionally be linked to each other via X_{408} , which is a linking group (see Compounds PD1 to PD4 and PD7). X_{407} and X_{408} may each independently be a single bond, $*-O-*$, $*-S-*$, $*-C(=O)-*$, $*-N(Q_{413})-*$, $*-C(Q_{413})(Q_{414})-*$, or $*-C(Q_{413})=C(Q_{414})-*$ (wherein Q_{413} and Q_{414} may each independently be hydrogen, deuterium, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group), but embodiments of the inventive concepts are not limited thereto.

[0263] L_{402} in Formula 401 may be a monovalent, divalent, or trivalent organic ligand. For example, L_{402} may be selected from halogen, diketone (for example, acetylacetonate), carboxylic acid (for example, picolinate), $-C(=O)$, isonitrile, $-CN$, and a phosphorus-containing material (for example, phosphine, or phosphite), but embodiments of the inventive concepts are not limited thereto.

[0264] In one or more embodiments, the phosphorescent dopant may be selected from, for example, Compounds PD1 to PD25, but embodiments of the inventive concepts are not to be limited thereto:

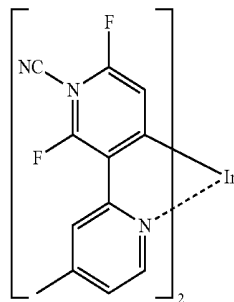


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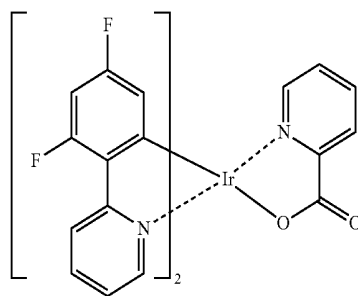
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PD11



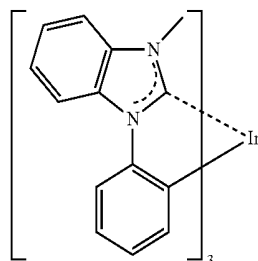
PD16

PD12



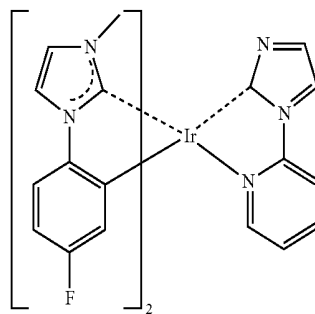
PD17

PD13



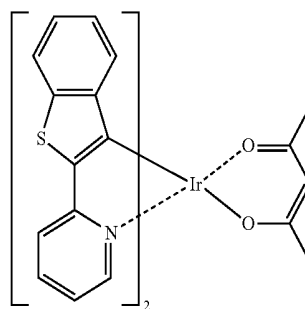
PD18

PD14



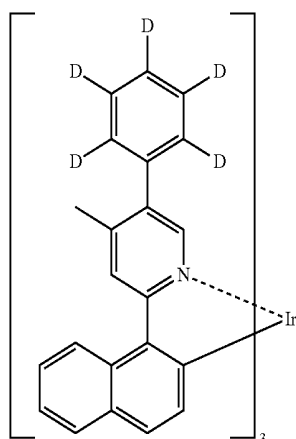
PD19

PD15



PD20

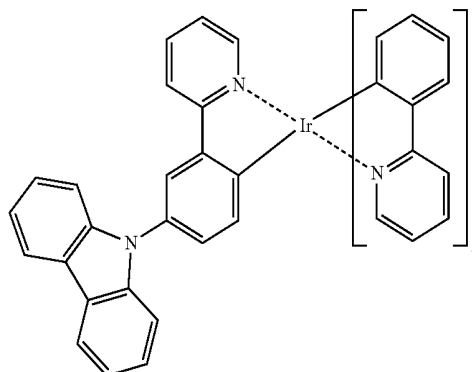
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PD21

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PD25

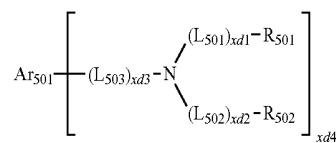


[0265] The fluorescent dopant in the emission layer may include an arylamine compound or a styrylamine compound.

[0266] The fluorescent dopant may include a compound represented by Formula 501 below:

PD22

<Formula 501>



[0267] In Formula 501,

[0268] Ar_{501} may be a substituted or unsubstituted C_5 - C_{60} carbocyclic group or a substituted or unsubstituted C_1 - C_{60} heterocyclic group,

[0269] L_{501} to L_{503} may each independently be selected from a substituted or unsubstituted C_3 - C_{10} cycloalkylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkenylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6 - C_{60} arylene group, a substituted or unsubstituted C_1 - C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0270] $xd1$ to xd may each independently be an integer from 0 to 3,

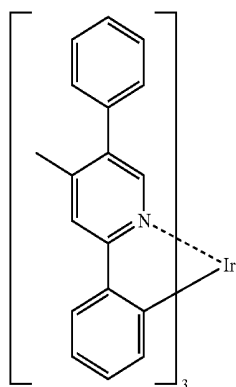
[0271] R_{501} and R_{502} may each independently be selected from a substituted or unsubstituted C_3 - C_{10} cycloalkyl group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3 - C_{10} cycloalkenyl group, a substituted or unsubstituted C_1 - C_{10} 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, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and

[0272] $xd4$ may be an integer from 1 to 6.

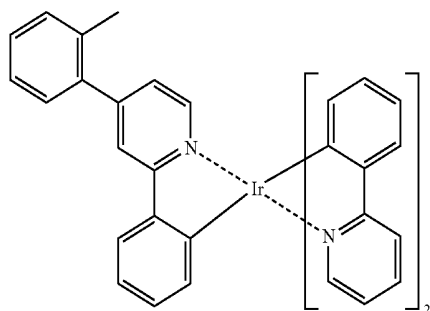
[0273] In one embodiment, Ar_{501} in Formula 501 may be selected from:

[0274] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a

PD23



PD24



dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group; and

[0275] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group, each substituted with at least one is selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0276] In one or more embodiments, L₅₀₁ to L₅₀₃ in Formula 501 may each independently be selected from:

[0277] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a thiophenylenylene group, a furanylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, and a pyridinylenylene group; and

[0278] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a thiophenylenylene group, a furanylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, and a pyridinylenylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group,

a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, and a pyridinyl group.

[0279] In one or more embodiments, R₅₀₁ and R₅₀₂ in Formula 501 may each independently be selected from:

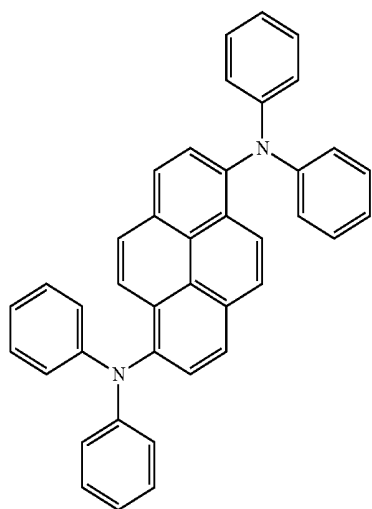
[0280] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, and a pyridinyl group; and

[0281] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl 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 amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, and a pyridinyl group, and —Si(Q₃₁)(Q₃₂)(Q₃₃), and

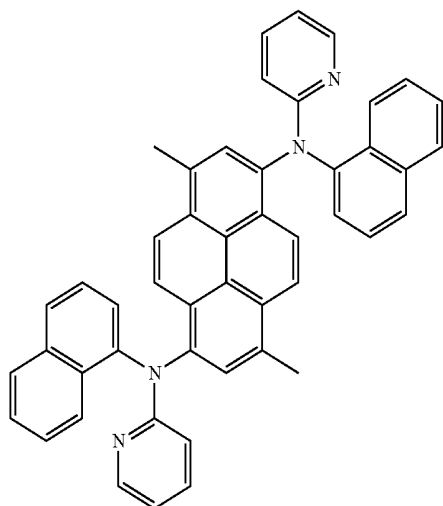
[0282] Q₃₁ to Q₃₃ may each independently be selected from a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0283] In one or more embodiments, xd4 in Formula 501 may be 2, but embodiments of the inventive concepts are not limited thereto.

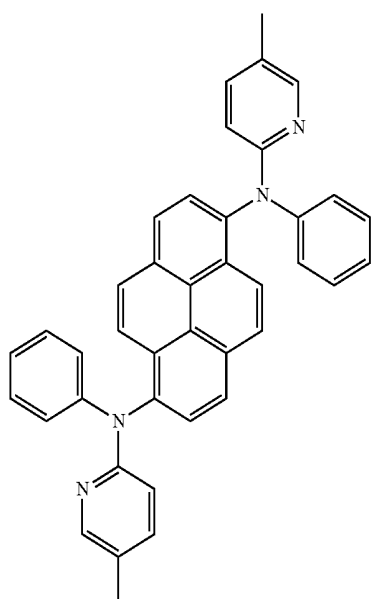
[0284] For example, the fluorescent dopant may be selected from Compounds FD1 to FD22:



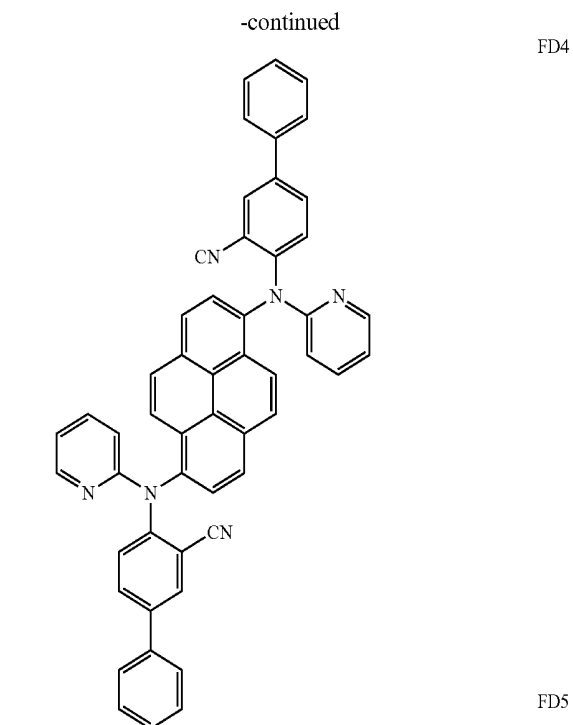
FD1



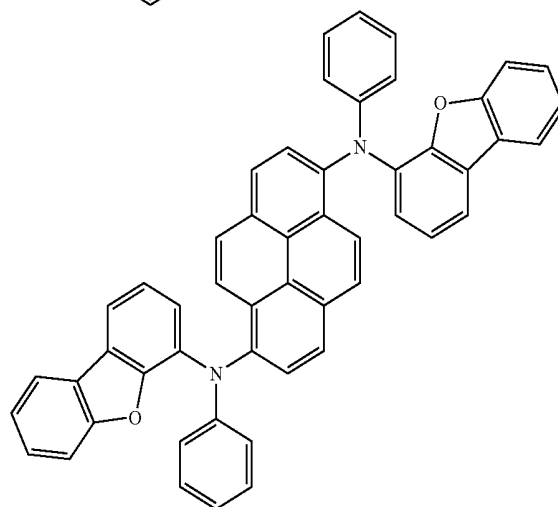
FD2



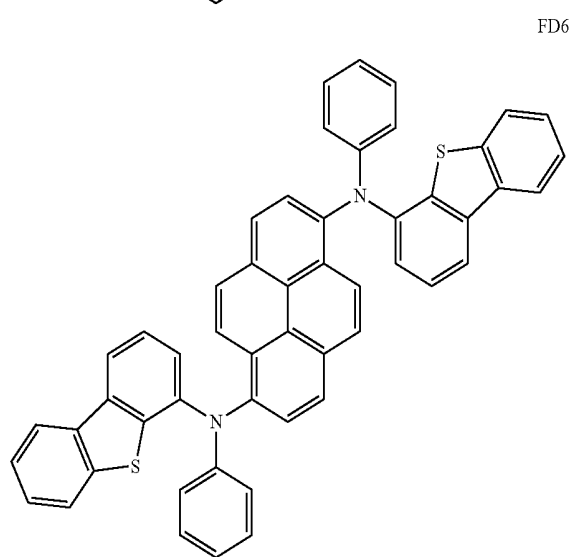
FD3



FD4



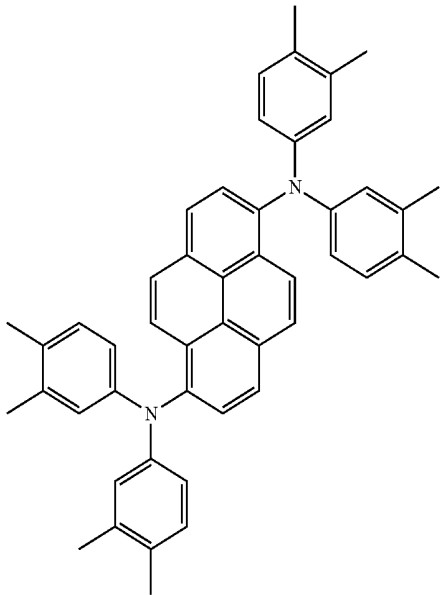
FD5



FD6

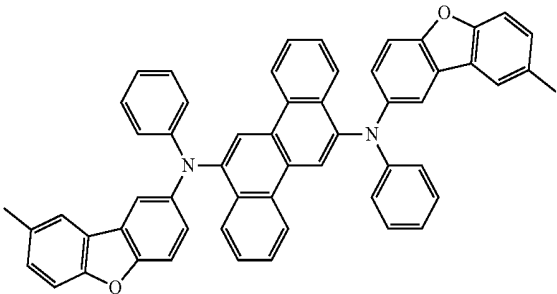
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FD7

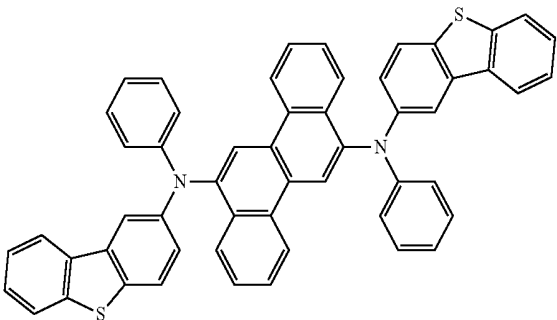


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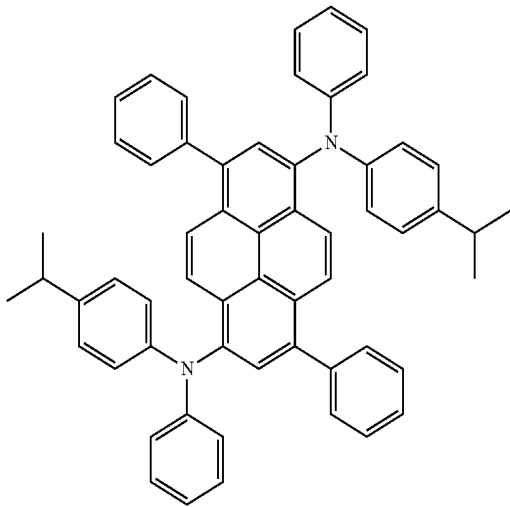
FD10



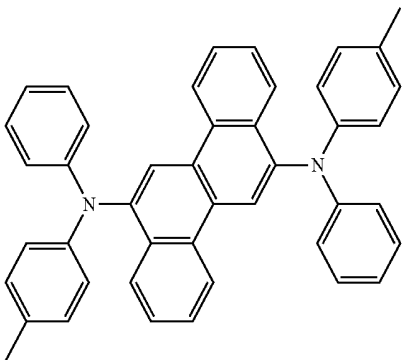
FD11



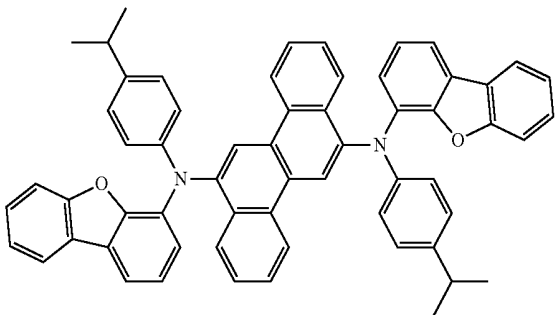
FD8



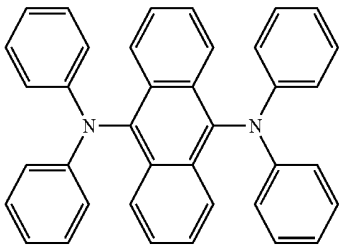
FD12



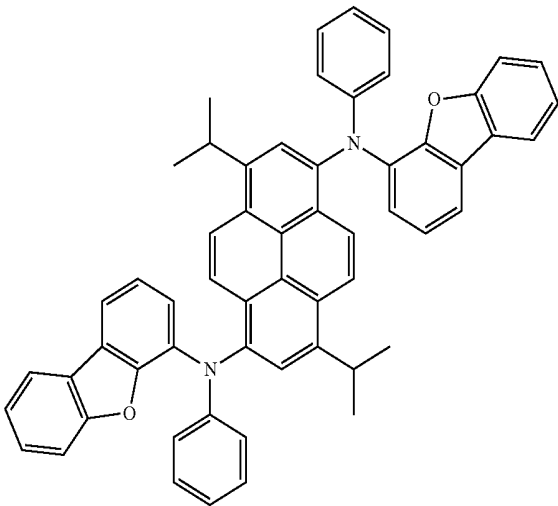
FD13



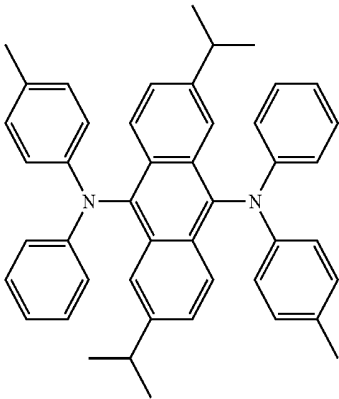
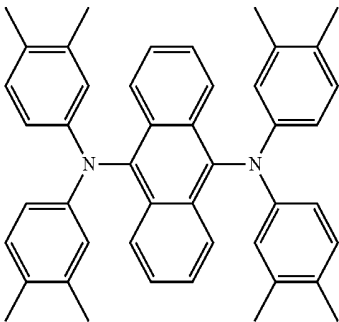
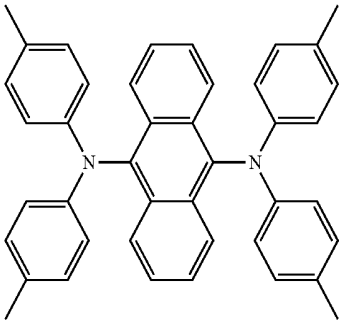
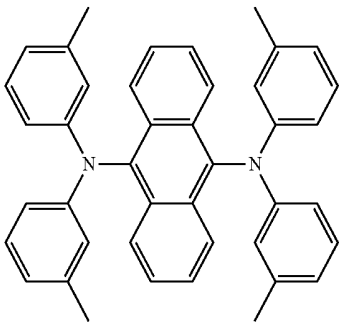
FD14



FD9



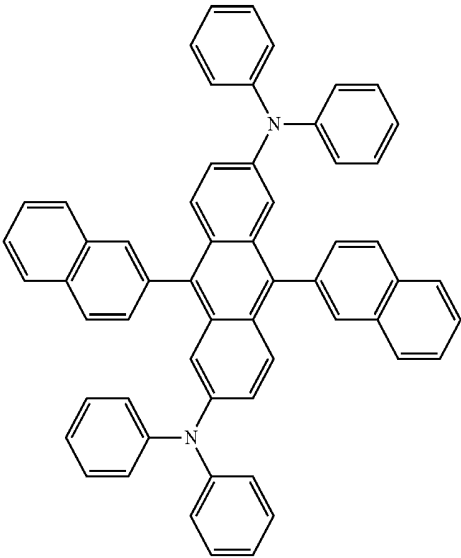
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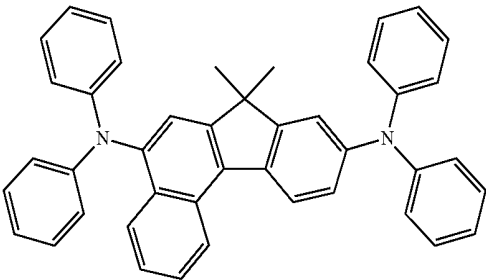
FD15

FD19



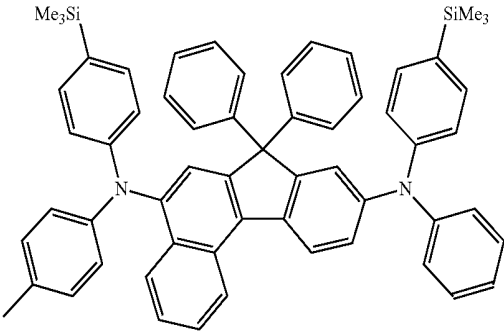
FD16

FD20



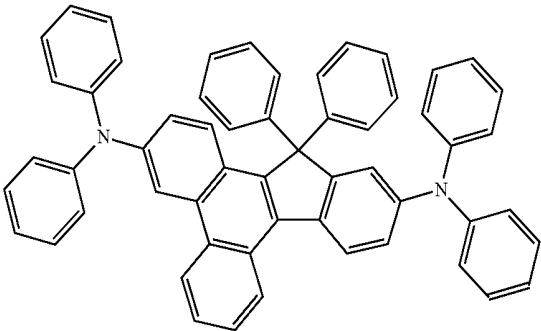
FD17

FD21



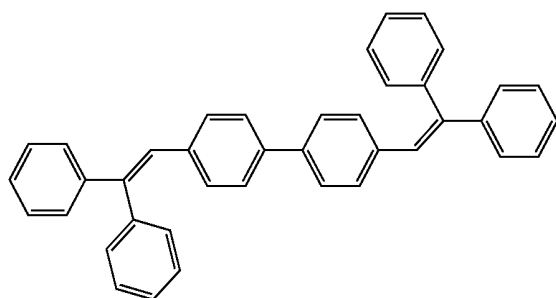
FD18

FD22

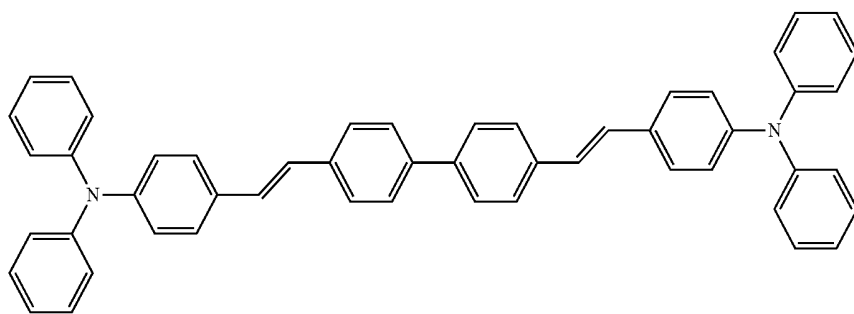


[0285] In one or more embodiments, the fluorescent dopant may be selected from the following compounds, but embodiments of the inventive concepts are not limited thereto:

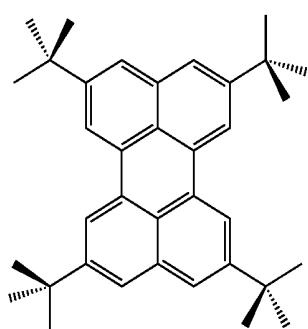
layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.



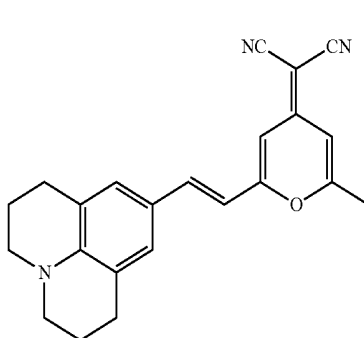
DPVBi



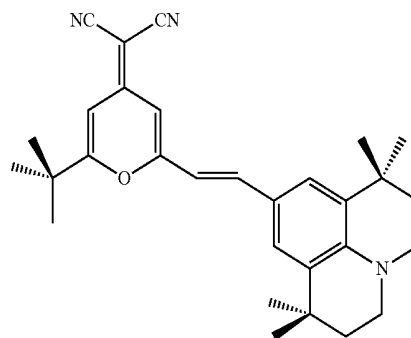
DPAVBi



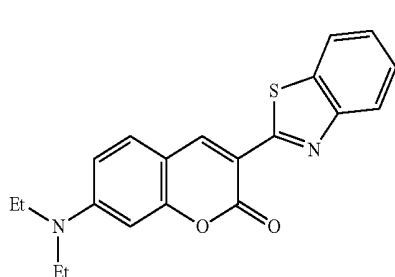
TBPe



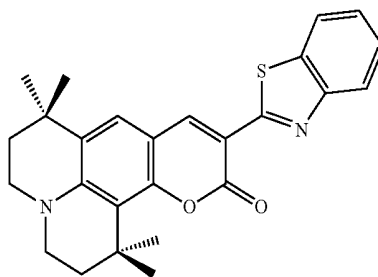
DCM



DCJTb



Coumarin 6



C545T

[0286] The electron transport region in organic layer 150 may have i) a single-layered structure including a single

[0287] The electron transport region may include at least one layer selected from a buffer layer, a hole blocking layer,

an electron control layer, an electron transport layer, and an electron injection layer, but embodiments of the inventive concepts are not limited thereto.

[0288] For example, the electron transport region may have an electron transport to layer/electron injection layer structure, a hole blocking layer/electron transport layer/electron injection layer structure, an electron control layer/electron transport layer/electron injection layer structure, or a buffer layer/electron transport layer/electron injection layer structure, wherein for each structure, constituting layers are sequentially stacked from an emission layer. However, embodiments of the structure of the electron transport region are not limited thereto.

[0289] The electron transport region (for example, a buffer layer, a hole blocking layer, an electron control layer, or an electron transport layer in the electron transport region) may include a metal-free compound containing at least one π electron-depleted nitrogen-containing ring.

[0290] The “ π electron-depleted nitrogen-containing ring” indicates a C_1 - C_{60} heterocyclic group having at least one $*-N=*$ moiety as a ring-forming moiety.

[0291] For example, the “ π electron-depleted nitrogen-containing ring” may be i) a 5-membered to 7-membered heteromonocyclic group having at least one $*-N=*$ moiety, ii) a heteropolycyclic group in which two or more 5-membered to 7-membered heteromonocyclic groups each having at least one $*-N=*$ moiety are condensed with each other, or iii) a heteropolycyclic group in which at least one of 5-membered to 7-membered heteromonocyclic groups, each having at least one $*-N=*$ moiety, is condensed with at least one C_5 - C_{60} carbocyclic group.

[0292] Examples of the π electron-depleted nitrogen-containing ring include 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 indazole ring, a purine ring, a quinoline ring, an isoquinoline ring, a benzoquinoline ring, a phthalazine ring, a naphthyridine ring, a quinoxaline ring, a quinazoline ring, a cinnoline ring, a phenanthridine ring, an acridine ring, a phenanthroline ring, a phenazine ring, a benzimidazole ring, an isobenzothiazole ring, a benzoxazole ring, an isobenzoxazole ring, a triazole ring, a tetrazole ring, an oxadiazole ring, a triazine ring, a thiadiazole ring, an imidazopyridine ring, an imidazopyrimidine ring, and an azacarbazole ring, but are not limited thereto.

[0293] For example, the electron transport region may include a compound represented by Formula 601 below:



[0294] In Formula 601,

[0295] Ar_{601} may be a substituted or unsubstituted C_5 - C_{60} carbocyclic group or a substituted or unsubstituted C_1 - C_{60} heterocyclic group,

[0296] $xe11$ may be 1, 2, or 3,

[0297] L_{601} may be selected from a substituted or unsubstituted C_3 - C_{10} cycloalkylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3 - C_{10} cycloalkenylene group, a substituted or unsubstituted C_1 - C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6 - C_{60} arylene group, a substituted or unsubstituted C_1 - C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0298] $xe1$ may be an integer from 0 to 5,

[0299] R_{601} may be selected from 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, $-Si(Q_{601})(Q_{602})(Q_{603})$, $-C(=O)(Q_{601})$, $-S(=O)_2(Q_{601})$, and $-P(=O)(Q_{601})(Q_{602})$,

[0300] Q_{601} to Q_{603} may each independently be a C_1 - C_{10} alkyl group, a C_1 - C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, and

[0301] $xe21$ may be an integer from 1 to 5.

[0302] In one embodiment, at least one of $Ar_{601}(s)$ in the number of $xe11$ and $R_{601}(s)$ in the number of $xe21$ may include the π electron-depleted nitrogen-containing ring.

[0303] In one embodiment, Ar_{601} in Formula 601 may be selected from:

[0304] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group; and

[0305] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group; and

azole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, —Si(Q₃₁)(Q₃₂)(Q₃₃), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂), and

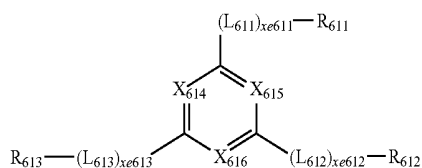
[0306] Q₃₁ to Q₃₃ may each independently be selected from a C₁-C₁₀ alkyl group, a C₁-C₁₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0307] When xe11 in Formula 601 is 2 or more, two or more Ar₆₀₁(s) may be linked to each other via a single bond.

[0308] In one or more embodiments, Ar₆₀₁ in Formula 601 may be an anthracene group.

[0309] In one or more embodiments, a compound represented by Formula 601 may be represented by Formula 601-1 below:

<Formula 601-1>



[0310] In Formula 601-1,

[0311] X₆₁₄ may be N or C(R₆₁₄), X₆₁₅ may be N or C(R₆₁₅), X₆₁₆ may be N or C(R₆₁₆), and at least one selected from X₆₁₄ to X₆₁₆ may be N,

[0312] L₆₁₁ to L₆₁₃ may each independently be the same as described in connection with L₆₀₁,

[0313] xe611 to xe613 may each independently be defined the same as xe1,

[0314] R₆₁₁ to R₆₁₃ may each independently be the same as described in connection with R₆₀₁, and

[0315] R₆₁₄ to R₆₁₆ may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0316] In one embodiment, L₆₀₁ and L₆₁₁ to L₆₁₃ in Formulae 601 and 601-1 may each independently be selected from:

[0317] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group; and

an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group; and

[0318] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylene group, a pentacenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazoyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazoyl group, a dibenzocarbazoyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolynyl group, an isoquinolynyl group, a benzoquinolynyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalynyl group, a quinazolynyl group, a cinnolynyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

linyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group,

[0319] but embodiments of the inventive concepts are not limited thereto.

[0320] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0321] In one or more embodiments, R₆₀₁ and R₆₁₁ to R₁₃ in Formula 601 and 601-1 may each independently be selected from:

[0322] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group;

[0323] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetra-

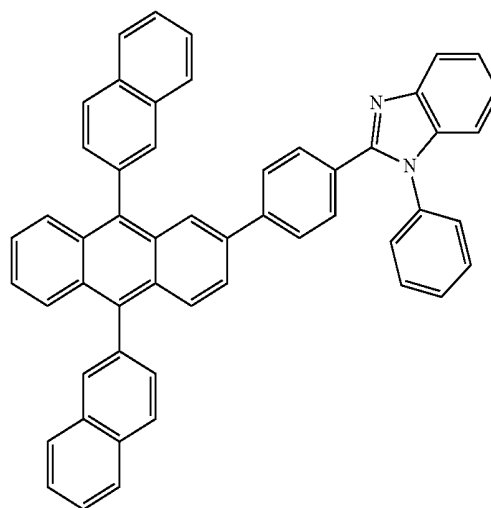
zolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

[0324] —S(=O)₂(Q₆₀₁) and —P(=O)(Q₆₀₁)(Q₆₀₂), and

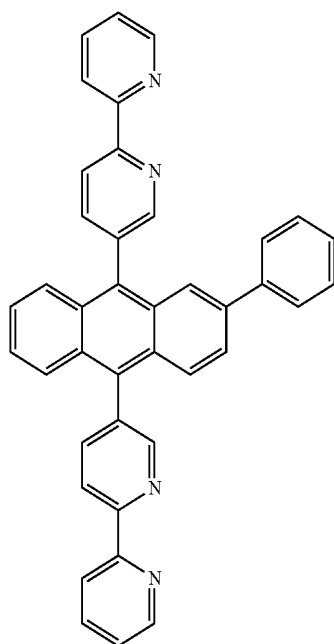
[0325] Q₆₀₁ and Q₆₀₂ are the same as described above.

[0326] The electron transport region may include at least one compound selected from Compounds ET1 to ET36, but embodiments of the inventive concepts are not limited thereto:

ET1

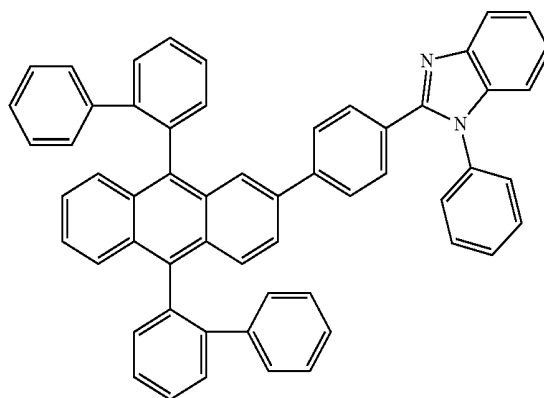


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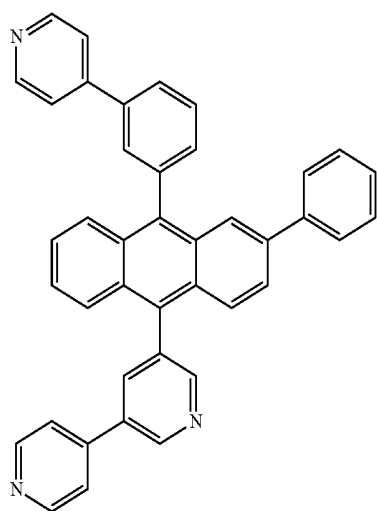


ET2

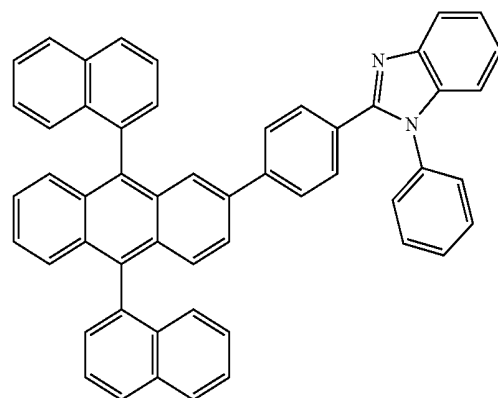
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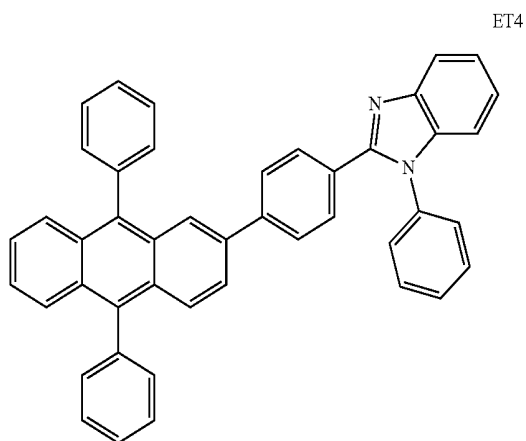
ET5



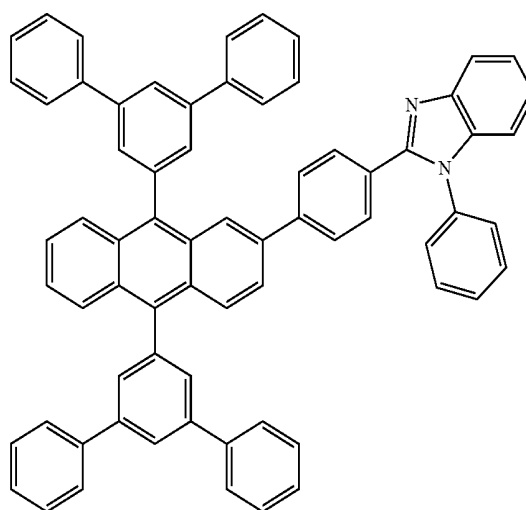
ET3



ET6



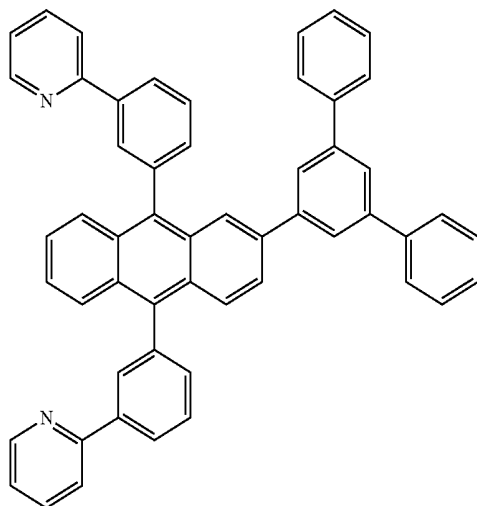
ET4



ET7

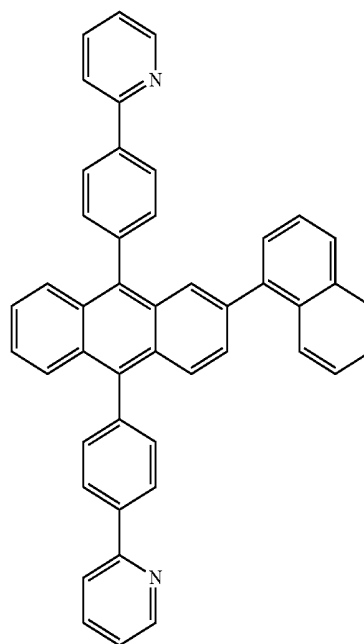
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ET8

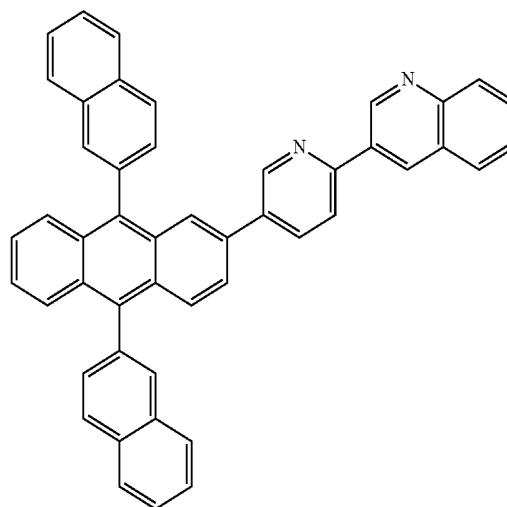


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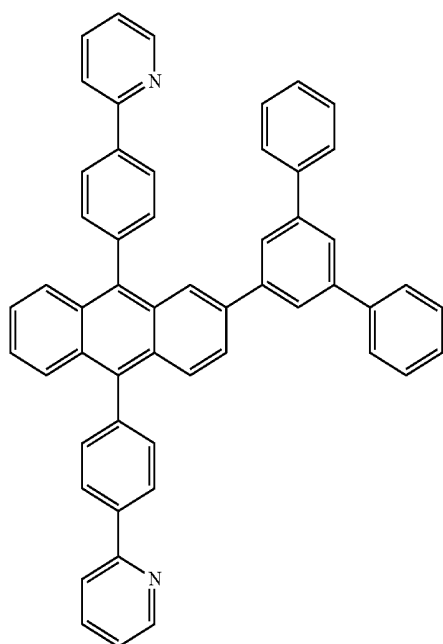
ET10



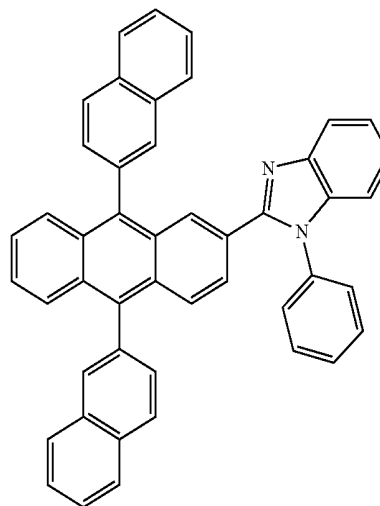
ET11



ET9

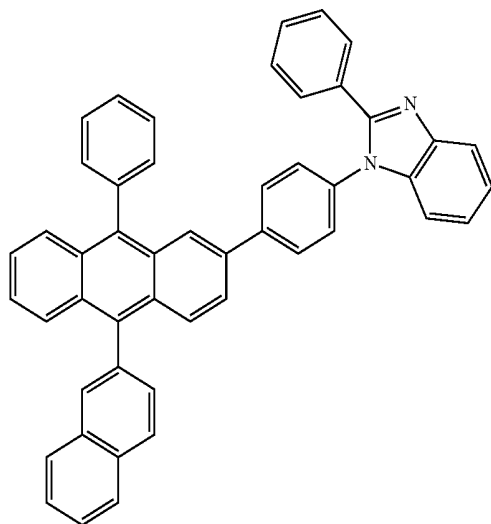


ET12



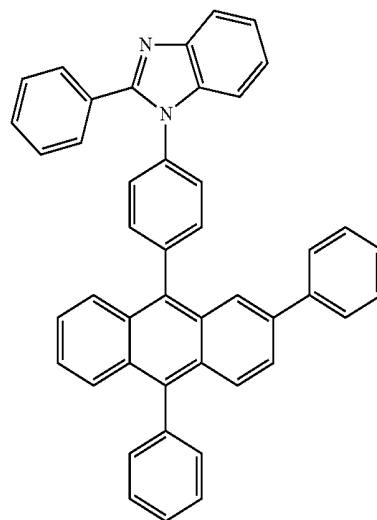
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ET13

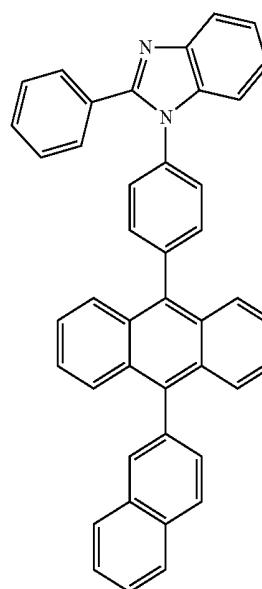


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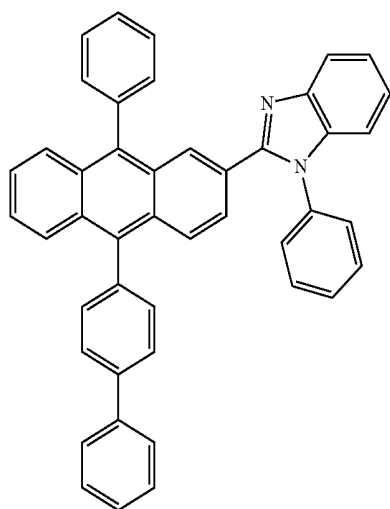
ET16



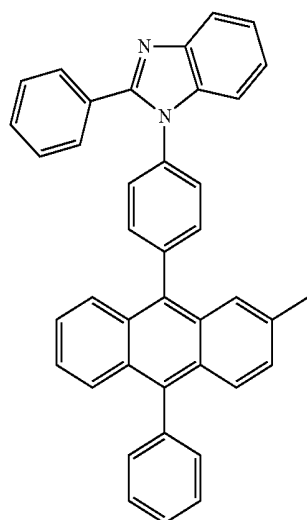
ET17



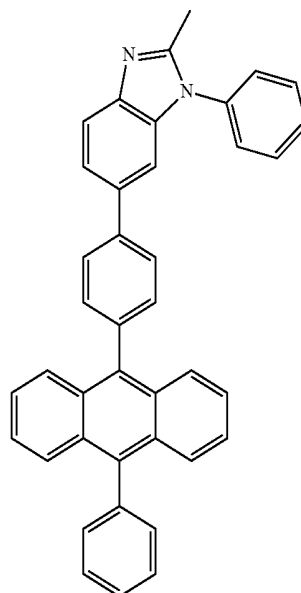
ET14



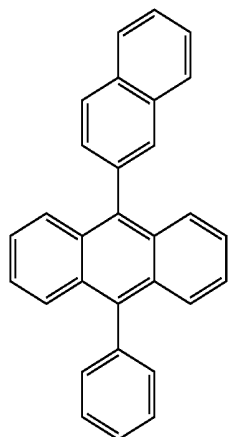
ET15



ET18



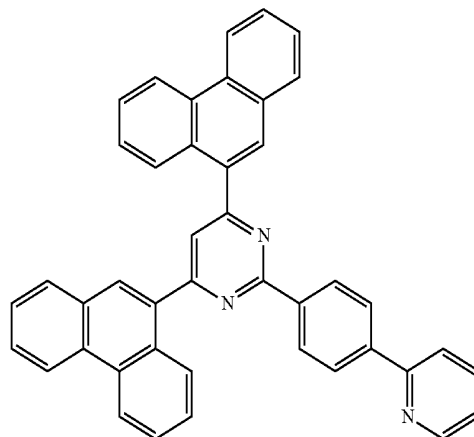
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ET19

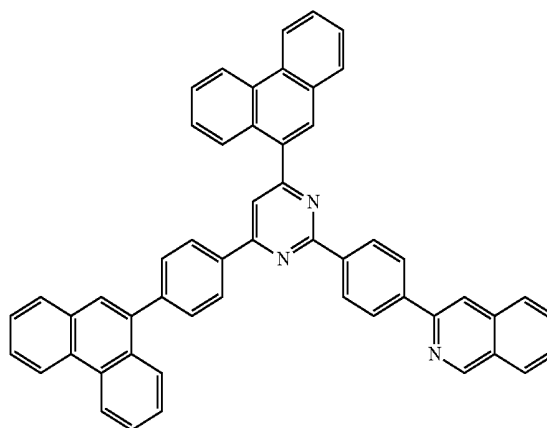
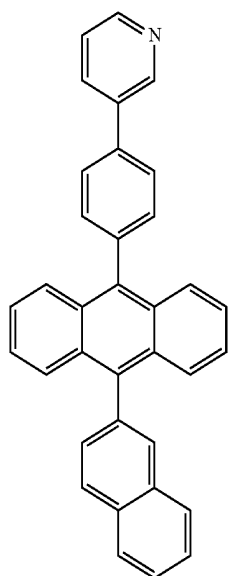
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ET22



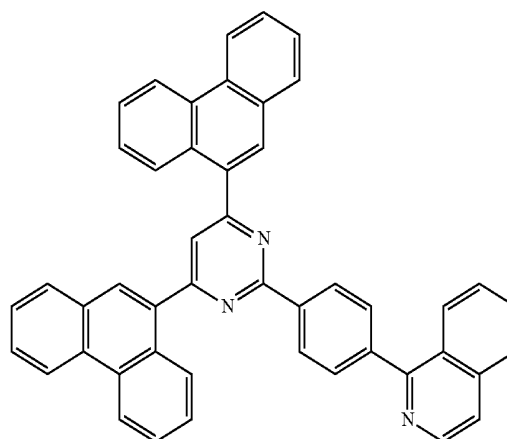
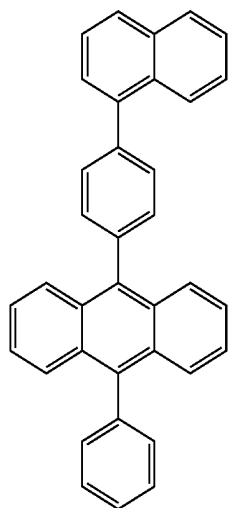
ET20

ET23



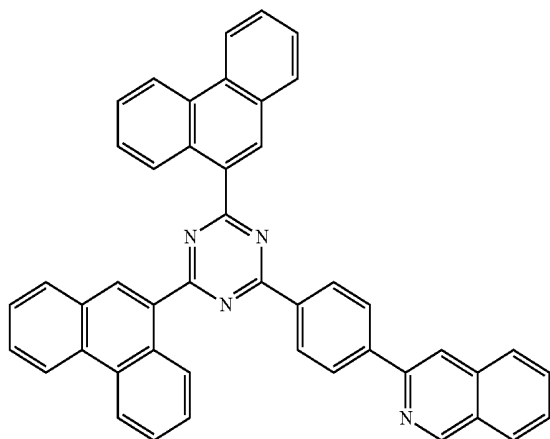
ET21

ET24



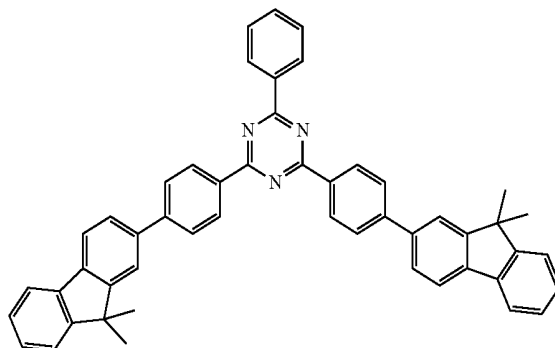
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ET25



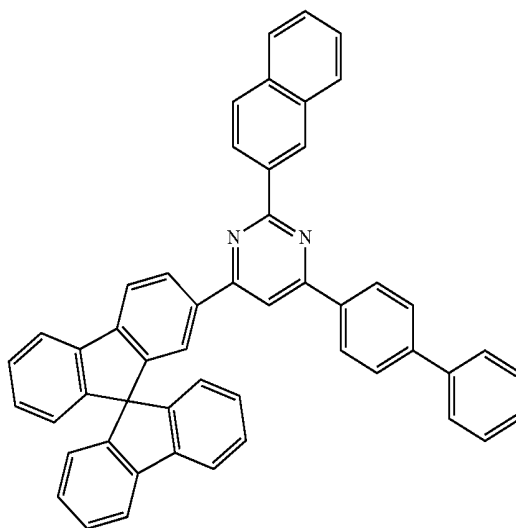
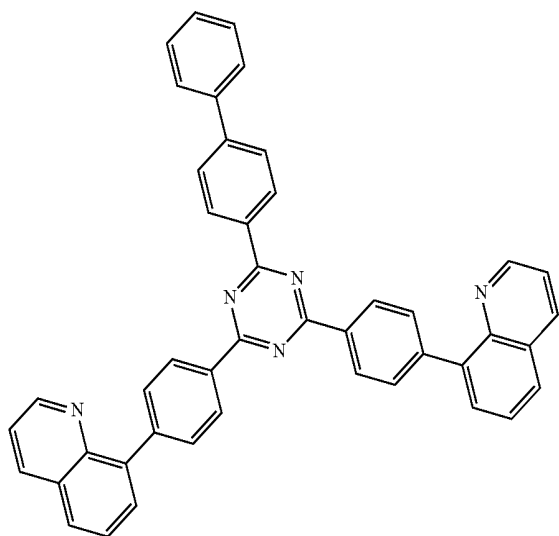
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ET28



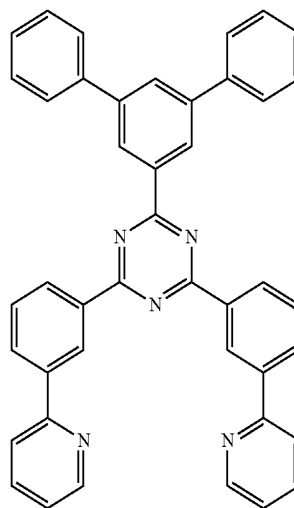
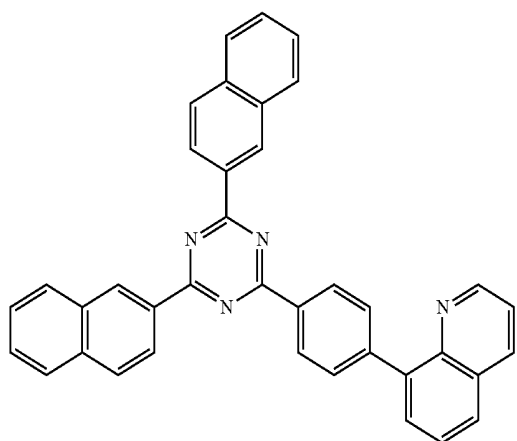
ET29

ET26

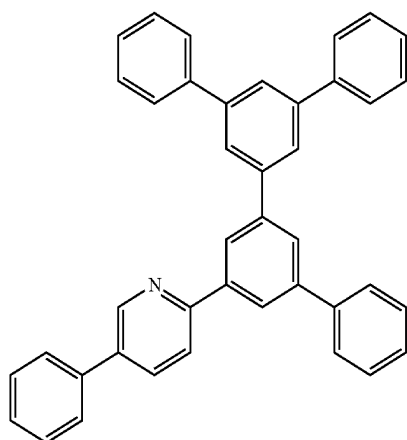


ET30

ET27

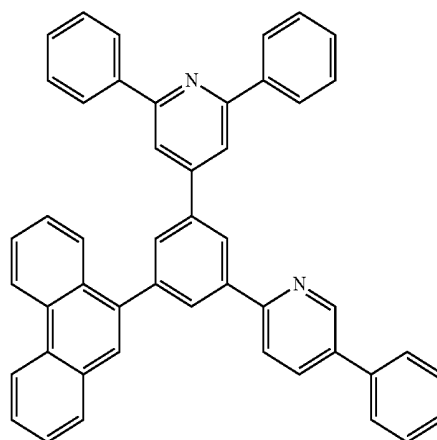


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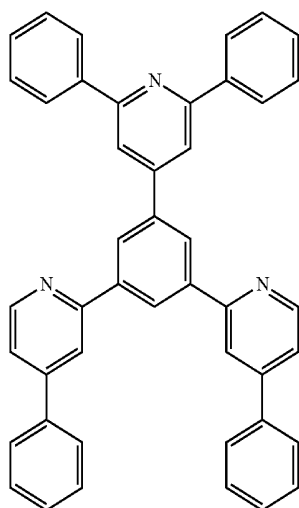
ET31

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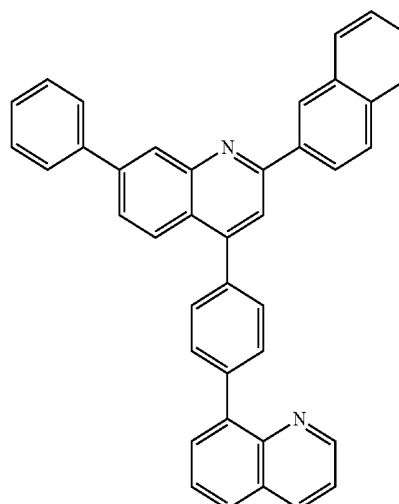


ET34

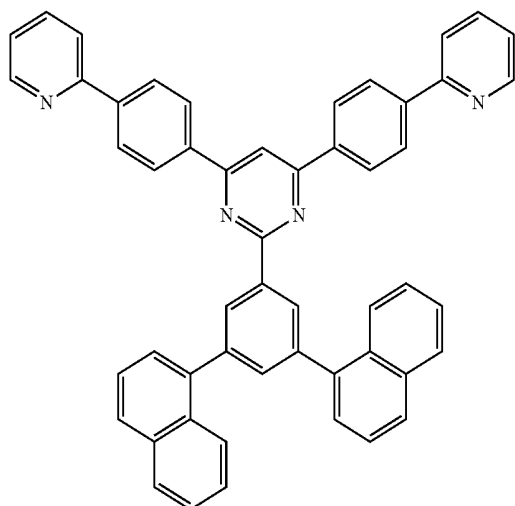
ET32



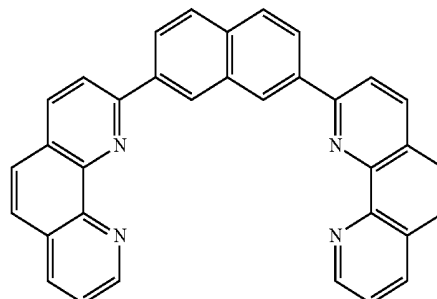
ET35



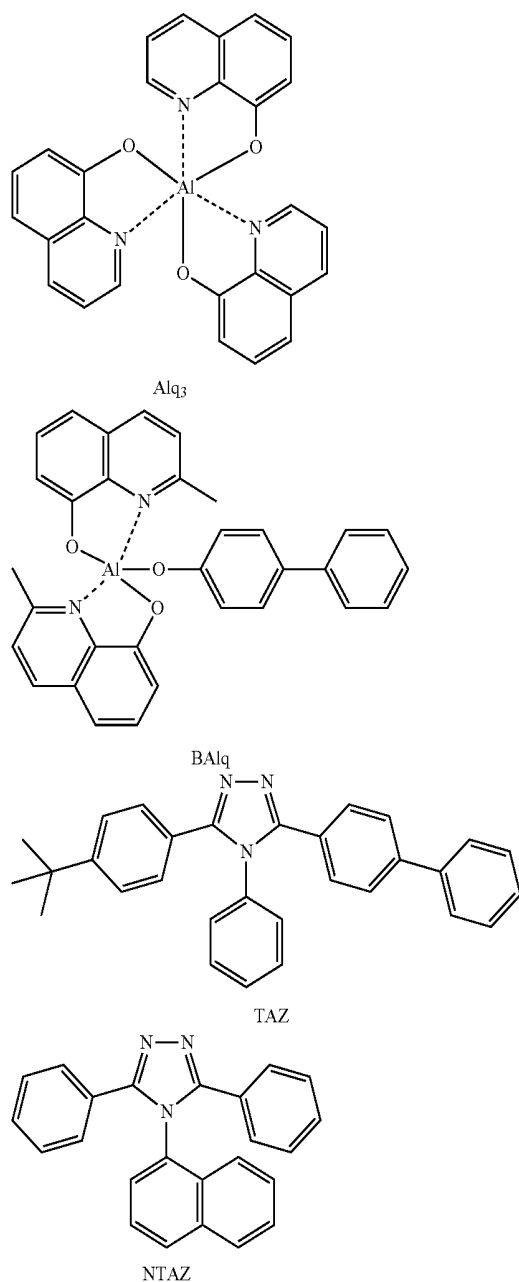
ET33



ET36



[0327] In one embodiment, the electron transport region may include at least one selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq₃, BALq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ:



[0328] In one or more embodiments, the electron transport region may include a phosphine oxide-containing compound, but embodiments of the inventive concepts are not limited thereto. In one embodiment, the phosphine oxide-containing compound may be used in a hole blocking layer in the electron transport region, but embodiments of the inventive concepts are not limited thereto.

[0329] Thicknesses of the buffer layer, the hole blocking layer, and the electron control layer may each be in a range of about 20 Å to about 1,000 Å, for example, about 30 Å to about 300 Å. When the thicknesses of the buffer layer, the hole blocking layer, and the electron control layer are within these ranges, the electron blocking layer may have excellent electron blocking characteristics or electron control characteristics without a substantial increase in driving voltage.

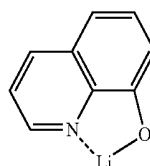
[0330] A thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within the range described above, the electron transport layer may have satisfactory electron transport characteristics without a substantial increase in driving voltage.

[0331] The electron transport region (for example, the electron transport layer in the electron transport region) may further include, in addition to the materials described above, a metal-containing material.

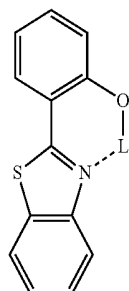
[0332] The metal-containing material may include at least one selected from alkali metal complex and alkaline earth-metal complex. The alkali metal complex may include a metal ion selected from a Li ion, a Na ion, a K ion, a Rb ion, and a Cs ion, and the alkaline earth-metal complex may include a metal ion selected from a Be ion, a Mg ion, a Ca ion, a Sr ion, and a Ba ion. A ligand coordinated with the metal ion of the alkali metal complex or the alkaline earth-metal complex may be selected from a hydroxy quinoline, a hydroxy isoquinoline, a hydroxy benzoquinoline, a hydroxy acridine, a hydroxy phenanthridine, a hydroxy phenylloxazole, a hydroxy phenylthiazole, a hydroxy diphenylloxadiazole, a hydroxy diphenylthiadiazole, a hydroxy phenylpyridine, a hydroxy phenylbenzimidazole, a hydroxy phenylbenzothiazole, a bipyridine, a phenanthroline, and a cyclopentadiene, but embodiments of the inventive concepts are not limited thereto.

[0333] For example, 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



[0334] The electron transport region may include an electron injection layer that facilitates electron injection from the second electrode 190. The electron injection layer may directly contact the second electrode 190.

[0335] The electron injection layer may have i) a single-layered structure including a single layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.

[0336] The electron injection layer may include an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth-metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth-metal complex, a rare earth metal complex, or any combinations thereof.

[0337] The alkali metal may be selected from Li, Na, K, Rb, and Cs. In one embodiment, the alkali metal may be Li, Na, or Cs. In one or more embodiments, the alkali metal may be Li or Cs, but embodiments of the inventive concepts are not limited thereto.

[0338] The alkaline earth metal may be selected from Mg, Ca, Sr, and Ba.

[0339] The rare earth metal may be selected from Sc, Y, Ce, Tb, Yb, and Gd.

[0340] The alkali metal compound, the alkaline earth-metal compound, and the rare earth metal compound may be selected from oxides and halides (for example, fluorides, chlorides, bromides, or iodides) of the alkali metal, the alkaline earth-metal, and the rare earth metal.

[0341] The alkali metal compound may be selected from alkali metal oxides, such as Li_2O , Cs_2O , or K_2O , and alkali metal halides, such as LiF, NaF, CsF, KF, LiI, NaI, CsI, or KI. In one embodiment, the alkali metal compound may be selected from LiF, Li_2O , NaF, LiI, NaI, CsI, to and KI, but embodiments of the inventive concepts are not limited thereto.

[0342] The alkaline earth-metal compound may be selected from alkaline earth-metal oxides, such as BaO, SrO, CaO, $\text{Ba}_x\text{Sr}_{1-x}\text{O}$ ($0 < x < 1$), or $\text{Ba}_x\text{Ca}_{1-x}\text{O}$ ($0 < x < 1$). In one embodiment, the alkaline earth-metal compound may be selected from BaO, SrO, and CaO, but embodiments of the inventive concepts are not limited thereto.

[0343] The rare earth metal compound may be selected from YbF_3 , ScF_3 , ScO_3 , Sc_2O_3 , Y_2O_3 , Ce_2O_3 , GdF_3 , and TbF_3 . In one embodiment, the rare earth metal compound may be selected from YbF_3 , ScF_3 , TbF_3 , YbI_3 , ScI_3 , and Tb_3 , but embodiments of the inventive concepts are not limited thereto.

[0344] The alkali metal complex, the alkaline earth-metal complex, and the rare earth metal complex may include an ion of alkali metal, alkaline earth-metal, and rare earth metal as described above, and a ligand coordinated with a metal ion of the alkali metal complex, the alkaline earth-metal complex, or the rare earth metal complex may be selected from hydroxy quinoline, hydroxy isoquinoline, hydroxy benzoquinoline, hydroxy acridine, hydroxy phenanthridine, hydroxy phenyloxazole, hydroxy phenylthiazole, hydroxy diphenyloxadiazole, hydroxy diphenylthiadiazole, hydroxy phenylpyridine, hydroxy phenylbenzimidazole, hydroxy phenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments of the inventive concepts are not limited thereto.

[0345] The electron injection layer may consist of an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth-metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth-metal complex, a rare earth metal complex, or any combinations thereof, as described above. In one or more embodiments, the electron injection layer may further include an organic material. When the electron injection

layer further includes an organic material, an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth-metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth-metal complex, a rare earth metal complex, or any combinations thereof may be homogeneously or non-homogeneously dispersed in a matrix including the organic material.

[0346] 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. When the thickness of the electron injection layer is within the range described above, the electron injection layer may have satisfactory electron injection characteristics without a substantial increase in driving voltage.

[0347] The second electrode **190** may be disposed on the organic layer **150** having such a structure. The second electrode **190** may be a cathode which is an electron injection electrode, and in this regard, a material for forming the second electrode **190** may be selected from metal, an alloy, an electrically conductive compound, and a combination thereof, which have a relatively low work function.

[0348] The second electrode **190** may include at least one selected from lithium (Li), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ITO, and IZO, but embodiments of the inventive concepts are not limited thereto. The second electrode **190** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0349] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

[0350] FIG. 2 is a schematic view of an organic light-emitting device **20** according to an embodiment. The organic light-emitting device **20** includes a first capping layer **210**, the first electrode **110**, the organic layer **150**, and the second electrode **190**, which are sequentially stacked in this stated order. FIG. 3 is a schematic view of an organic light-emitting device **30** according to an embodiment. The organic light-emitting device **30** includes the first electrode **110**, the organic layer **150**, the second electrode **190**, and a second capping layer **220**, which are sequentially stacked in this stated order. FIG. 4 is a schematic view of an organic light-emitting device **40** according to an embodiment. The organic light-emitting device **40** includes the first capping layer **210**, the first electrode **110**, the organic layer **150**, the second electrode **190**, and the second capping layer **220**, which are sequentially stacked in this stated order.

[0351] Regarding FIGS. 2, 3, and 4, the first electrode **110**, the organic layer **150**, and the second electrode **190** may be understood by referring to the description presented in connection with FIG. 1.

[0352] In the organic layer **150** of each of the organic light-emitting devices **20** and **40**, light generated in an emission layer may pass through the first electrode **110** and the first capping layer **210** toward the outside, wherein the first electrode **110** may be a semi-transmissive electrode or a transmissive electrode. In the organic layer **150** of each of the organic light-emitting devices **30** and **40**, light generated

in an emission layer may pass through the second to electrode **190** and the second capping layer **220** toward the outside, wherein the second electrode **190** may be a semi-transmissive electrode or a transmissive electrode.

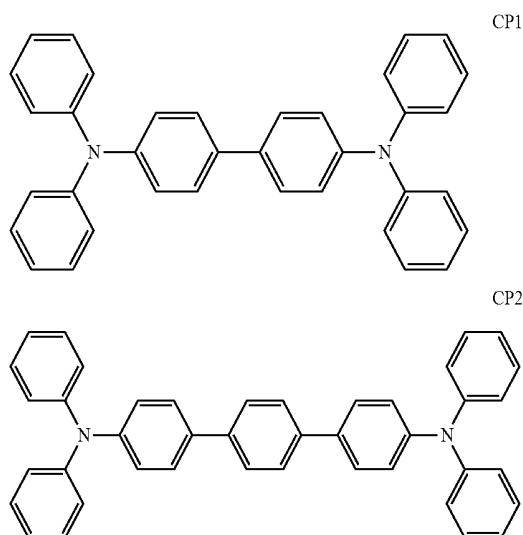
[0353] The first capping layer **210** and the second capping layer **220** may increase external luminescence efficiency according to the principle of constructive interference.

[0354] The first capping layer **210** and the second capping layer **220** may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or a composite capping layer including an organic material and an inorganic material.

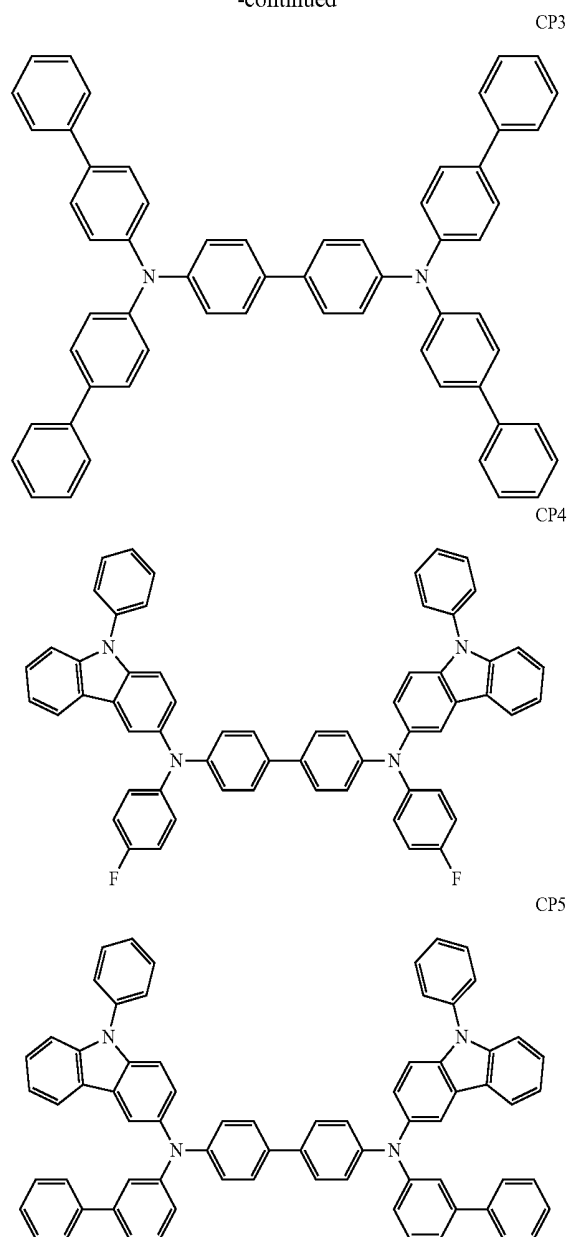
[0355] At least one selected from the first capping layer **210** and the second capping layer **220** may each independently include at least one material selected from carbocyclic compounds, heterocyclic compounds, amine-based compounds, porphyrine derivatives, phthalocyanine derivatives, a naphthalocyanine derivatives, alkali metal complexes, and alkaline earth-based complexes. The carbocyclic compound, the heterocyclic compound, and the amine-based compound may be optionally substituted with a substituent containing at least one element selected from O, N, S, Se, Si, F, Cl, Br, and I. In one embodiment, at least one selected from the first capping layer **210** and the second capping layer **220** may each independently include an amine-based compound.

[0356] In one embodiment, at least one selected from the first capping layer **210** and the second capping layer **220** may each independently include the compound represented by Formula 201 or the compound represented by Formula 202.

[0357] In one or more embodiments, at least one selected from the first capping layer **210** and the second capping layer **220** may each independently include a compound selected from Compounds HT28 to HT33 and Compounds CP1 to CP5, but embodiments of the inventive concepts are not limited thereto:



-continued



[0358] Hereinbefore, the organic light-emitting device according to an embodiment has been described in connection with FIGS. 1 to 4, but embodiments of the inventive concepts are not limited thereto.

[0359] Layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region may be formed in a certain region by using one or more suitable methods selected from vacuum deposition, spin coating, casting, Langmuir-Blodgett to (LB) deposition, ink-jet printing, laser-printing, and laser-induced thermal imaging.

[0360] When layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region are formed by vacuum deposition, the deposition may be performed at a deposition temperature of about 100° C. to about 500° C., a vacuum degree of about 10⁻⁸ torr to about 10⁻³ torr, and a deposition speed of about 0.01 Å/sec

to about 100 Å/sec is by taking into account a material to be included in a layer to be formed, and the structure of a layer to be formed.

[0361] When layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region are formed by spin coating, the spin coating may be performed at a coating speed of about 2,000 rpm to about 5,000 rpm and at a heat treatment temperature of about 80° C. to 200° C. by taking into account a material to be included in a layer to be formed, and the structure of a layer to be formed.

[0362] General Definition of Substituents:

[0363] 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 isobutyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an isooamyl 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.

[0364] The term “C₂-C₆₀ alkenyl group” as used herein refers to a hydrocarbon group having at least one carbon-carbon double bond in the middle or at the terminus of the C₂-C₆₀ alkyl group, and 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.

[0365] The term “C₂-C₆₀ alkynyl group” as used herein refers to a hydrocarbon group having at least one carbon-carbon triple bond in the middle or at the terminus of the C₂-C₆₀ alkyl group, and examples thereof include an ethynyl group, and a propynyl 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.

[0366] 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 isopropoxy group.

[0367] The term “C₃-C₁₀ cycloalkyl group” as used herein refers to a monovalent saturated hydrocarbon monocyclic group having 3 to 10 carbon atoms, and 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.

[0368] The term “C₁-C₁₀ heterocycloalkyl group” as used herein refers to a monovalent monocyclic group having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 10 carbon atoms, and examples thereof include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuranyl 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.

[0369] The term C₃-C₁₀ cycloalkenyl group 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 no aromaticity, and 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.

[0370] 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, Si, P, 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 4,5-dihydro-1,2,3,4-oxatriazolyl group, a 2,3-dihydrofuranyl 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.

[0371] The term “C₆-C₆₀ aryl group” as used herein refers to a monovalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms, and a C₆-C₆₀ arylene group used herein refers to a divalent group having a carbocyclic 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.

[0372] The term “C₁-C₆₀ heteroaryl group” as used herein refers to a monovalent group having a carbocyclic aromatic system that has at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, in addition to 1 to 60 carbon atoms. The term “C₁-C₆₀ heteroarylene group” as used herein refers to a divalent group having a carbocyclic aromatic system that has at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, in addition to 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 condensed with each other.

[0373] The term “C₆-C₆₀ aryloxy group” as used herein refers to —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).

[0374] The term “monovalent non-aromatic condensed polycyclic group” as used herein refers to a monovalent group (for example, having 8 to 60 carbon atoms) having two or more rings condensed with each other, only carbon atoms as ring-forming atoms, and no aromaticity in its entire molecular structure. A detailed example of the monovalent non-aromatic condensed polycyclic group is 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.

[0375] The term “monovalent non-aromatic condensed heteropolycyclic group” as used herein refers to a monovalent group (for example, having 1 to 60 carbon atoms) having two or is more rings condensed to each other, at least one heteroatom selected from N, O, Si, P, and S, other than carbon atoms, as a ring-forming atom, and no aromaticity in its entire molecular structure. An example of the monovalent non-aromatic condensed heteropolycyclic group is 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.

[0376] The term “C₄-C₆₀ carbocyclic group” as used herein refers to a monocyclic or polycyclic group having 4 to 60 carbon atoms in which a ring-forming atom is a carbon atom only. The term “C₄-C₆₀ carbocyclic group” as used herein refers to an aromatic carbocyclic group or a non-aromatic carbocyclic group. The C₄-C₆₀ carbocyclic group may be a ring, such as benzene, a monovalent group, such as a phenyl group, or a divalent group, such as a phenylene group. In one or more embodiments, depending on the number of substituents connected to the C₄-C₆₀ carbocyclic group, the C₄-C₆₀ carbocyclic group may be a trivalent group or a quadrivalent group.

[0377] The term “C₂-C₆₀ heterocyclic group” as used herein refers to a group having the same structure as the C₄-C₆₀ carbocyclic group, except that as a ring-forming atom, at least one heteroatom selected from N, O, Si, P, and S is used in addition to carbon (the number of carbon atoms may be in a range of 2 to 60).

[0378] In the present specification, at least one substituent of the substituted C₄-C₆₀ carbocyclic group, the substituted C₂-C₆₀ heterocyclic group, the substituted C₃-C₁₀ cycloalkylene group, the substituted C₁-C₁₀ heterocycloalkylene group, the substituted C₃-C₁₀ cycloalkenylene group, the substituted C₁-C₁₀ heterocycloalkenylene group, the substituted C₆-C₆₀ arylene group, the substituted C₁-C₆₀ heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C₁-C₆₀ alkyl group, the substituted C₂-C₆₀ alkenyl group, the substituted C₂-C₆₀ alkynyl group, the substituted C₁-C₆₀ alkoxy group, the substituted C₃-C₁₀ cycloalkyl group, the substituted C₁-C₁₀ heterocycloalkyl group, the substituted C₃-C₁₀ cycloalkenyl group, the substituted C₁-C₁₀ heterocycloalkenyl group, the substituted C₆-C₆₀ aryl group, the substituted C₆-C₆₀ aryloxy group, the substituted C₆-C₆₀ arylthio group, the substituted C₁-C₆₀ heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected is from:

[0379] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group;

[0380] 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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, —Si(Q₁₁)(Q₁₂)(Q₁₃), —N(Q₁₁)(Q₁₂), —B(Q₁₁)(Q₁₂), —C(=O)(Q₁₁), —S(=O)₂(Q₁₁), and —P(=O)(Q₁₁)(Q₁₂);

[0381] 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;

[0382] 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, —Si(Q₂₁)(Q₂₂)(Q₂₃), —N(Q₂₁)(Q₂₂), —B(Q₂₁)(Q₂₂), —C(=O)(Q₂₁), —S(=O)₂(Q₂₁), and —P(=O)(Q₂₁)(Q₂₂); and

[0383] —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂), and

[0384] Q₁₁ to Q₁₃, Q₂₁ to Q₂₃, and Q₃₁ to Q₃₃ may each independently be selected from is hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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 C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C₁-C₆₀ alkyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a C₆-C₆₀ aryl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a biphenyl group, and a terphenyl group.

[0385] The term “Ph” as used herein refers to a phenyl group, the term “Me” as used herein refers to a methyl group, the term “Et” as used herein refers to an ethyl group, the term “ter-Bu” or “Bu” as used herein refers to a tert-butyl group, and the term “OMe” as used herein refers to a methoxy group.

[0386] The term “biphenyl group” as used herein refers to “a phenyl group substituted with a phenyl group”. In other words, the “biphenyl group” is a substituted phenyl group having a C₆-C₆₀ aryl group as a substituent.

[0387] The term “terphenyl group” as used herein refers to “a phenyl group substituted with a biphenyl group”. In other words, the “terphenyl group” is a phenyl group having, as a substituent, a C₆-C₆₀ aryl group substituted with a C₆-C₆₀ aryl group.

[0388] *, *, and **, as used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

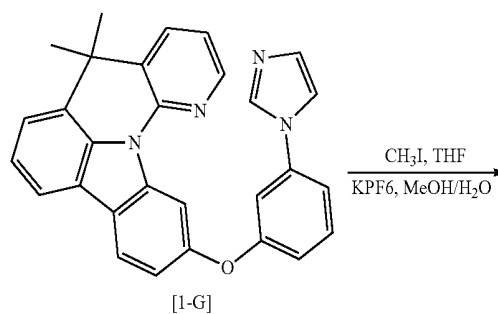
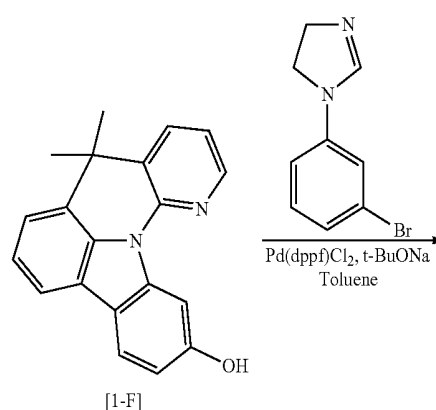
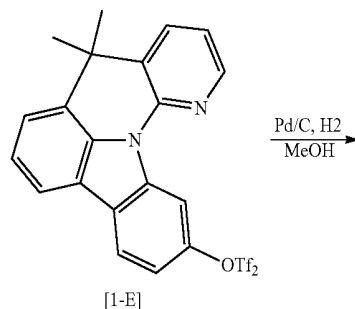
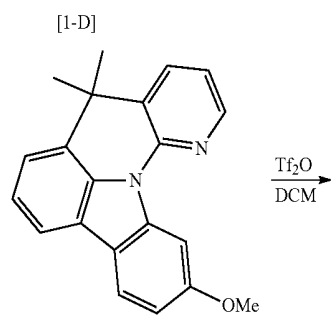
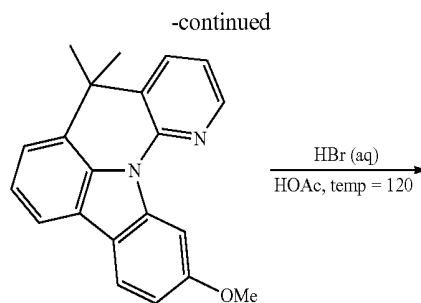
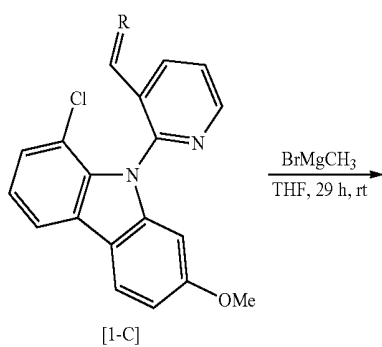
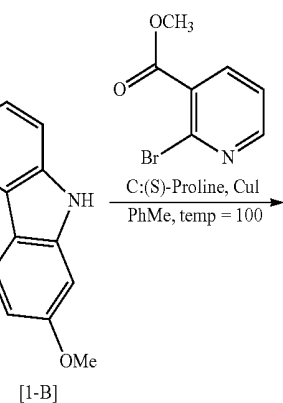
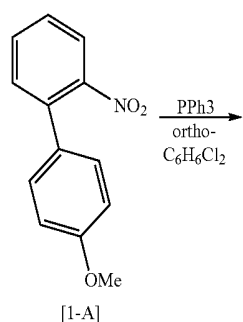
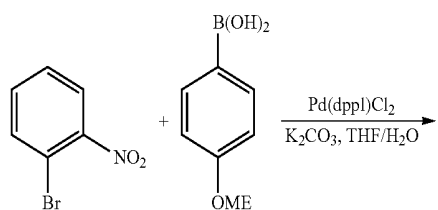
[0389] Hereinafter, a compound according to embodiments and an organic light-emitting device according to embodiments will be described in detail with reference to Synthesis Examples and Examples. The wording “B was

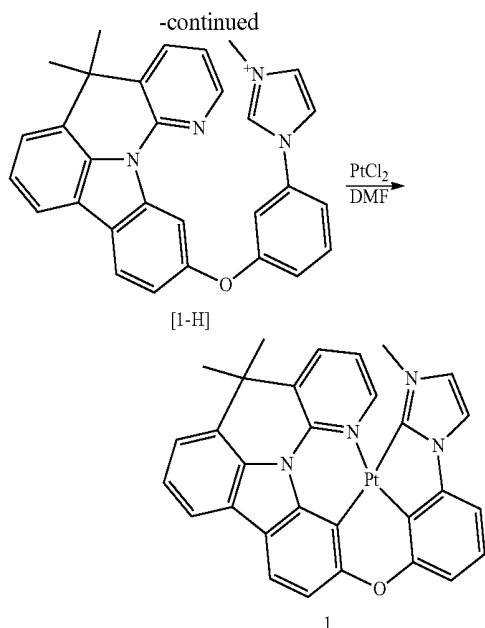
used instead of A” used in describing Synthesis Examples refers to that an identical molar equivalent of B was used in place of A.

SYNTHESIS EXAMPLES

Synthesis Example 1: Synthesis of Compound 1

[0390]





[0391] 1) Synthesis of Intermediate [1-A]

[0392] 1-bromo-2-nitrobenzene (1.0 eq), 4-methoxy phenylboronic acid (1.2 eq), K_2CO_3 (2.0 eq), and 0.01 g of $Pd(dppf)_2Cl_2$ catalyst were added, dissolved in a dimethyl sulfoxide (DMSO) solution, and then stirred at a temperature of 130 °C for 6 hours until the reactant was completely consumed. After the reaction mixture was cooled to room temperature, an organic layer was extracted therefrom three times by using ethyl acetate and water and separated from the reaction mixture. The obtained organic layer was dried by using magnesium sulfate and concentrated, and column chromatography was used to obtain Intermediate [1-A] (yield: 78%).

[0393] 2) Synthesis of Intermediate [1-B]

[0394] Intermediate [1-A] (1.2 eq) was dissolved in dichloromethane (0.1 M), and PPh_3 (2.0 eq) was slowly added thereto while stirring at a temperature of -78 °C. Then, the reaction mixture was stirred for 2 hours. After the reaction mixture was cooled to room temperature, an organic layer was extracted therefrom three times by using ethyl acetate and water and separated from the reaction mixture. The obtained organic layer was dried by using magnesium sulfate and concentrated to obtain Intermediate [1-B] (yield: 61%).

[0395] 3) Synthesis of Intermediate [1-C]

[0396] Intermediate [1-B] (1.5 eq), methyl-2-bromoicinate (1.1 eq), CuI (0.03 g), K_2CO_3 (2.0 eq), and L-Proline (0.04 eq) were dissolved in toluene (0.1 M) and stirred at a temperature of 130 °C for 12 hours. After the reaction mixture was cooled to room temperature, and an organic layer was dried by using magnesium sulfate and concentrate, and column chromatography was used to obtain Intermediate [1-C] (yield: 59%).

[0397] 4) Synthesis of Intermediate [1-D]

[0398] Intermediate [1-C] (1.3 eq) and Grignard reagent (1.3 eq) were dissolved in tetrahydrofuran (THF) and stirred at room temperature for 24 hours until the reactant was completely consumed. An organic layer was extracted therefrom three times by using dichloromethane and water. The obtained organic layer was dried by using magnesium sul-

fate and concentrated, and column chromatography was used to obtain Intermediate [1-D] (yield: 45%).

[0399] 5) Synthesis of Intermediate [1-E/1-F]

[0400] Intermediate [1-D] (1.0 eq), di-*p*-tolylidonium trifluoromethane sulfonate (1.5 eq), and CuOAc (0.1 eq) were dissolved in toluene (0.1 M) and stirred at a temperature of 100 °C for 10 hours until the reactant was completely consumed. A hydrogenation reaction was performed on obtained Intermediate [1-E] (1.0 eq) under Pd/C catalyst (0.02 g) at a high temperature (500K) and a high pressure (10 atm) to obtain Intermediate [1-F] (yield: 74%).

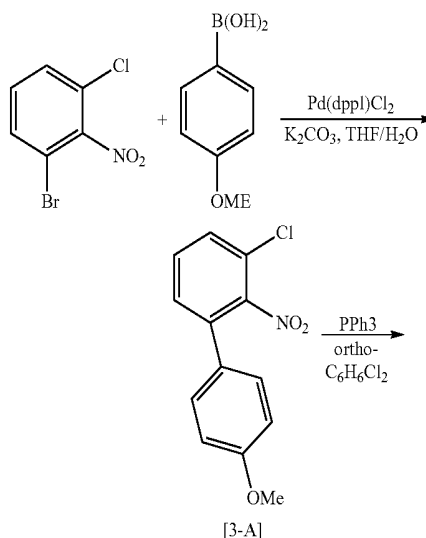
[0401] 6) Synthesis of Intermediate [1-G/1-H/1]

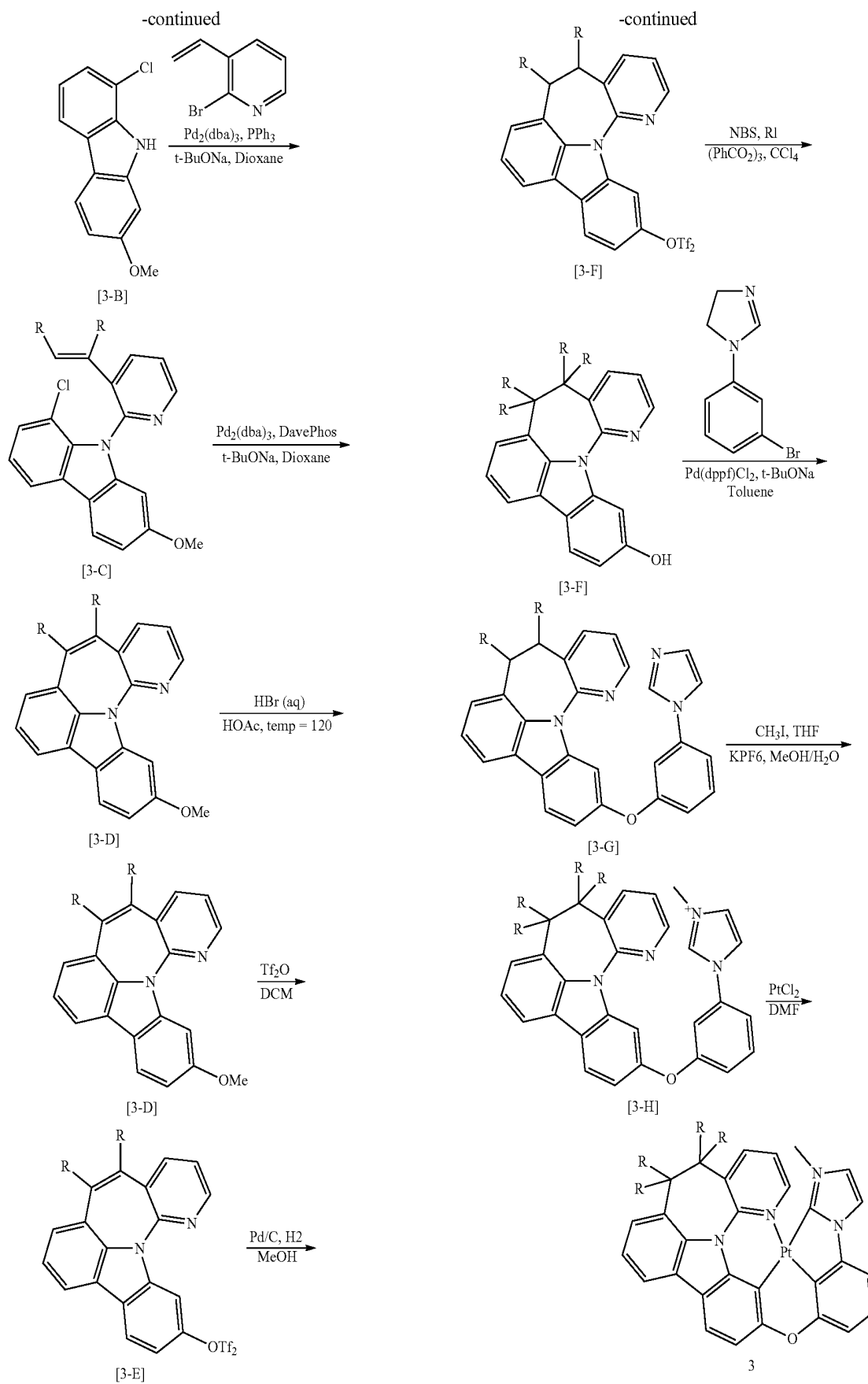
[0402] Intermediate [1-F] (1.2 eq), 1-(3-bromo-phenyl)-1H-imidazole (1.0 eq), CuI (0.02 eq), tBuONa (2.0 eq), and L-Proline (0.04 eq) were dissolved in toluene (0.1 M) and stirred at a temperature of 160 °C for 48 hours. Obtained Intermediate [1-G] was cooled to room temperature, and an organic layer was extracted therefrom three times by using CH_2Cl_2 and water. The obtained organic layer was dried by using Na_2SO_3 and concentrated, and chromatography was used to obtain Intermediate [1-H] ligand compound (yield: 85%). The obtained Intermediate [1-H] ligand compound (1.0 eq), dichloro(1,5-cyclooctadienyl) platinum (II) (1.05 eq), and sodium acetate (3.0 eq) were dissolved in THF (0.1 M) and stirred at a temperature of 120 °C for 72 hours in a nitrogen atmosphere. The reactant was cooled to room temperature, and a solvent was removed therefrom under reduced pressure. The concentrated reactant was dissolved in dichloromethane, and the remaining precipitate was filtered off. The filtrate was purified by column chromatography to obtain Compound 1 (yield: 20%).

[0403] MS cald. For $C_{30}H_{22}N_4O$ (MS+1), m/z 649.6; observed 649.6.

Synthesis Example 2: Synthesis of Compound 3

[0404]





[0405] 1) Synthesis of Intermediate [3-A]

[0406] 1-bromo-3-chloro-2-nitrobenzene (1.0 eq), 4-methoxy phenylboronic acid (1.2 eq), K_2CO_3 (2.0 eq), and 0.01 g of $Pd(dppf)_2Cl_2$ catalyst were added, dissolved in a DMSO solution, and then stirred at a temperature of 130 °C for 6 hours until the reactant was completely consumed. After the reaction mixture was cooled to room temperature, an organic layer was extracted therefrom three times by using ethyl acetate and water and separated from the reaction mixture. The obtained organic layer was dried by using magnesium sulfate and concentrate, and column chromatography was used to obtain Intermediate [3-A] (yield: 75%).

[0407] 2) Synthesis of Intermediate [3-B]

[0408] Intermediate [3-A] (1.2 eq) was dissolved in dichloromethane (0.1 M), and PPh_3 (2.0 eq) was slowly added thereto while stirring at a temperature of -78 °C. Then, the reaction mixture was stirred for 2 hours. After the reaction mixture was cooled to room temperature, an organic layer was extracted therefrom three times by using ethyl acetate and water and separated from the reaction mixture. The obtained organic layer was dried by using magnesium sulfate and concentrated to obtain Intermediate [3-B] (yield: 59%).

[0409] 3) Synthesis of Intermediate [3-C]

[0410] Intermediate [3-B] (1.5 eq), 2-bromo-3-vinylpyridine (1.1 eq), $Pd_2(dba)_3$ (0.03 g), PPh_3 (2 eq), and t-BuONa (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 130 °C for 12 hours. After the reaction mixture was cooled to room temperature, an organic layer was dried by using magnesium sulfate and concentrated, and column chromatography was used to obtain Intermediate [3-C] (yield: 51%).

[0411] 4) Synthesis of Intermediate [3-D]

[0412] Intermediate [3-C] (1.3 eq), $Pd_2(dba)_3$ (0.03 g), DavePhos (1.3 eq), and t-BuONa (0.02 eq) were dissolved in dioxane and stirred at room temperature for 24 hours until the reactant was completely consumed. An organic layer was extracted therefrom three times by using dichloromethane and water. The obtained organic layer was dried by using magnesium sulfate and concentrated, and column chromatography was used to obtain Intermediate [3-D] (yield: 41%).

[0413] 5) Synthesis of Intermediate [3-E/3-F]

[0414] Intermediate [3-D] (1.0 eq), di-p-tolylidonium trifluoromethane sulfonate (1.5 eq), and CuOAc (0.1 eq) were dissolved in toluene (0.1 M) and stirred at a temperature of 100 °C for 10 hours until the reactant was completely consumed. A hydrogenation reaction was performed on obtained Intermediate [3-E] (1.0 eq) under Pd/C catalyst (0.02 g) at a high temperature (500K) and a high pressure (10 atm) to obtain Intermediate [3-F] (yield: 42%).

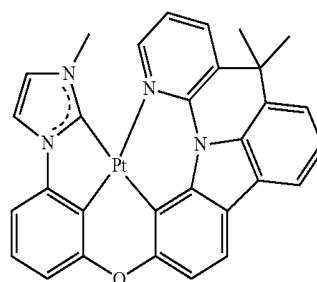
[0415] 7) Synthesis of Intermediate and Final Compound [3-G/3-H/3]

[0416] Intermediate [3-F] (1.2 eq), 1-(3-bromo-phenyl)-1H-imidazole (1.0 eq), CuI (0.02 eq), tBuONa (2.0 eq), and L-Proline (0.04 eq) were dissolved in toluene (0.1 M) and stirred at a temperature of 160 °C for 48 hours. Obtained Intermediate [3-G] was cooled to room temperature, and an organic layer was extracted therefrom three times by using CH_2Cl_2 and water. The obtained organic layer was dried by using Na_2SO_3 and concentrated, and chromatography was

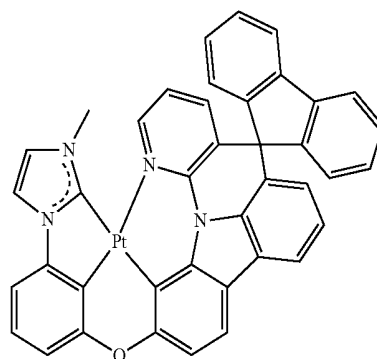
used to obtain Intermediate [3-H] ligand compound (yield: 80%). The obtained Intermediate [3-H] ligand compound (1.0 eq), dichloro(1,5-cyclooctadienyl) platinum to (II) (1.05 eq), and sodium acetate (3.0 eq) were dissolved in THF (0.1 M) and stirred at a temperature of 120 °C for 72 hours in a nitrogen atmosphere. The reaction was cooled to room temperature, and a solvent was removed therefrom under reduced pressure. The concentrated reactant was dissolved in dichloromethane, and the remaining precipitate was filtered out. The filtrate was purified by column chromatography to obtain Compound 3 (yield: 22%).

[0417] MS cald. For $C_{29}H_{20}N_4O$ (MS+1), m/z 635.6; observed 635.6.

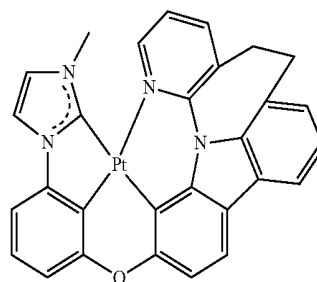
[0418] Compounds 2, 4, and 5 other than Compounds 1 and 3 were synthesized by referring to the methods provided in Synthesis Examples 1 and 2.



1



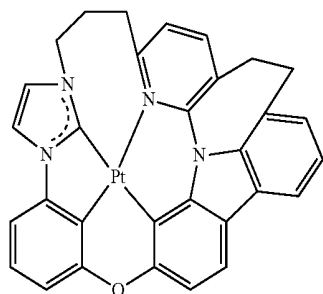
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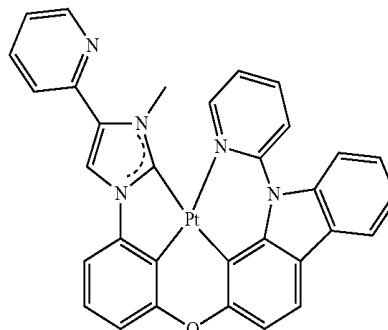
3

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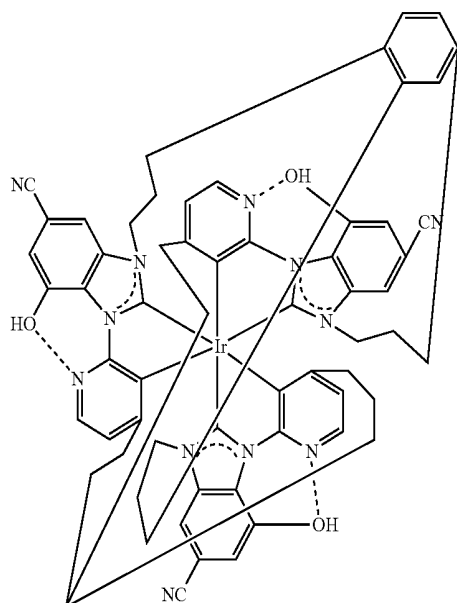
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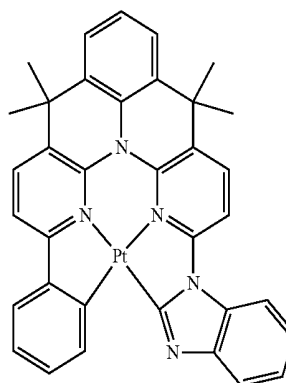
<Compound A>



5



<Compound B>



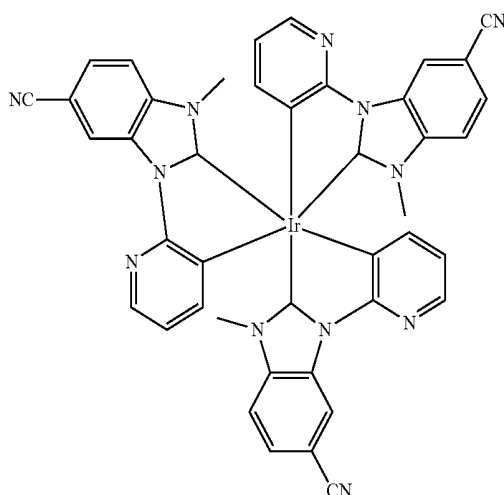
Evaluation Example 1: Quantum Simulation Analysis

[0419] Energy level values of $^3\text{MLCT}$ states of Compounds 1 to 5 and Compounds A to C as Comparative Examples were evaluated by using B3LYP functional. Pt and Ir were evaluated by using a density functional theory (DFT) method employing Gaussian program structurally optimized at a level of LANL2DZ basis set, and C, H, N, and O atoms were evaluated by using a DFT method employing Gaussian program structurally optimized at a level of 6-311G(d,p) basis set. The ground state energy and triplet energy were calculated based on the ^3MC state energy level values. E_3 was calculated by using Equation 1 as described above and is shown in Table 1.

TABLE 1

Compound	T_1 (eV)	^3MC (Kcal/mol)	$^3\text{MCLT}$	E_3 (kcal/mol)
Compound 1	2.68	27.4	12.11	27.4
Compound 2	2.65	27.2	12.32	27.2
Compound 3	2.65	27.4	12.24	27.4
Compound 4	2.61	—	19.50	—
Compound 5	2.79	31.0	24.08	31.0
Compound A	2.71	9.87	9.82	9.87
Compound B	2.14	22.45	15.32	6.08
Compound C	2.39	10.96	22.08	10.96

<Compound C>



[0420] From Table 1, the E_3 values of Compounds 1 to 5 were remarkably greater than the E_3 values of Compounds A to C. Therefore, since the probability that Compounds 1 to 5 transition from the $^3\text{MCLT}$ state to the non-emission state, that is, the ^3MC state decreases, the stability of Compounds 1 to 5 in the excited state may be excellent, and

the efficiency and lifespan of the organic light-emitting device including the organometallic compound may increase.

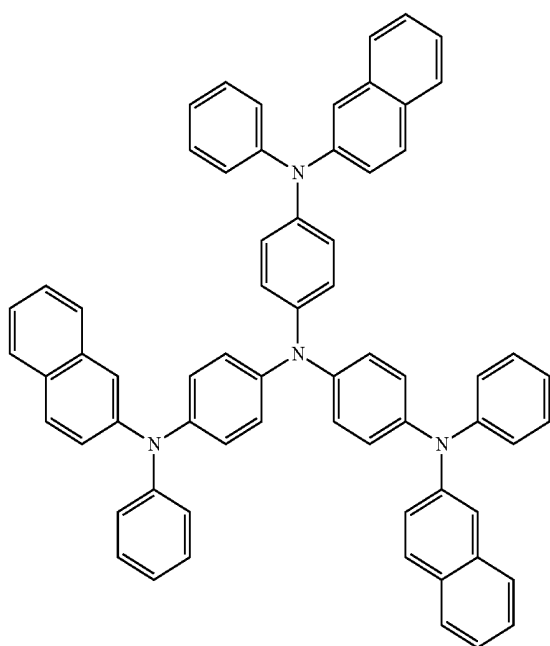
Example 1

[0421] As a substrate and an ITO anode, a 15 Ω/cm^2 (1,200 Å) ITO glass substrate from Corning was cut to a size of 50 mm×50 mm×0.7 mm, sonicated with isopropyl alcohol and pure water each for 5 minutes, and then cleaned by exposure to ultraviolet rays and ozone for 30 minutes. Then, the ITO glass substrate was provided to a vacuum deposition apparatus.

[0422] 2-TNATA was vacuum-deposited on the ITO anode formed on the ITO glass substrate to form a hole injection layer having a thickness of 600 Å, and NPB was vacuum-deposited on the hole injection layer to form a transport layer having a thickness of 300 Å.

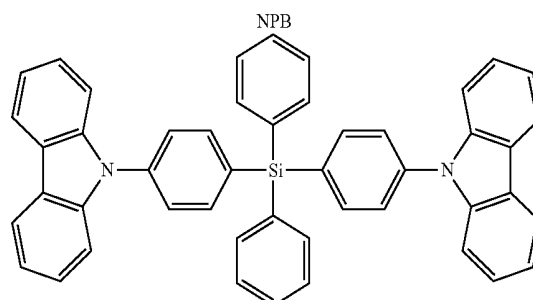
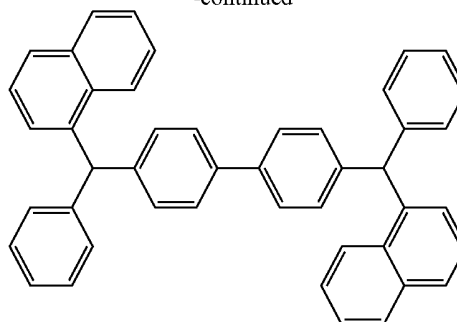
[0423] Co-hosts BCPDS (bis(4-(9H-carbazol-9-yl)phenyl)diphenylsilane) and POPCPA ((4-(1-(4-(diphenylamino)phenyl)cyclohexyl)phenyl)diphenyl-phosphine oxide) (a BCPDS to POPCPA weight ratio was 1:1) and a dopant Compound 1 were co-deposited on the hole transport layer at a co-host to dopant weight ratio of 90:10 to form an emission layer having a thickness of 300 Å.

[0424] TSPO1 (diphenyl(4-(triphenylsilyl)phenyl)-phosphine oxide) was deposited on the emission layer to form a hole blocking layer having a thickness of 50 Å, Alq₃ was deposited on the hole blocking layer to form an electron transport layer having a thickness of 300 Å, LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å, and Al was vacuum-deposited on the electron injection layer to form a cathode having a thickness of 3,000 Å, thereby completing the manufacture of an organic light-emitting device.

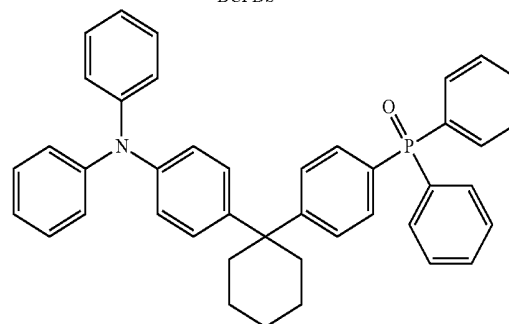


2-TNATA

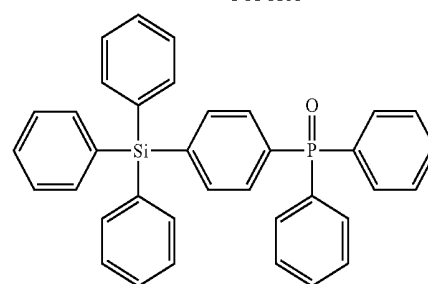
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BCPDS



POPCPA



TSPO1

Examples 2 and 3 and Comparative Example 1

[0425] Organic light-emitting devices were manufactured in the same manner as in Example 1, except that Compounds shown in Table 2 were each used instead of Compound 1 as is a dopant in forming an emission layer.

Evaluation Example 2

[0426] The driving voltage, current density, lifespan (LT₉₅), luminescence efficiency, emission color, and maximum emission wavelength of the organic light-emitting devices manufactured according to Examples 1 to 3 and

Comparative Example 1 were measured by using Keithley SMU 236 and a luminance meter PR650, and results thereof are shown in Table 2.

TABLE 2

	Dopant in emission layer	Driving voltage (V)	Current density (mA/cm ²)	Lifespan (LT ₉₅) (hr)	Emission color	Emission wavelength (nm)
Example 1	1	4.8	0.383	45	Blue color	464
Example 2	3	4.6	0.356	58	Blue color	468
Example 3	5	5.1	0.427	33	Blue color	445
Comparative Example 1	A	4.6	0.320	10	Blue color	467

[0427] Referring to Table 2, it is confirmed that the organic light-emitting devices manufactured according to Examples 1 to 3 have remarkably excellent current density and lifespan characteristics, as compared with the organic light-emitting device manufactured according to Comparative Example 1.

[0428] The organic light-emitting device including the organometallic compound may have a low driving voltage, high luminance, high efficiency, and a long lifespan.

[0429] Although certain exemplary embodiments and implementations have been described herein, other embodiments and modifications will be apparent from this description. Accordingly, the inventive concepts are not limited to such embodiments, but rather to the broader scope of the appended claims and various obvious modifications and equivalent arrangements as would be apparent to a person of ordinary skill in the art.

What is claimed is:

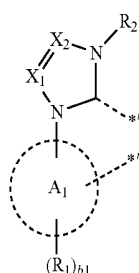
1. An organic light-emitting device comprising:

a first electrode;

a second electrode facing the first electrode;

an organic layer between the first electrode and the second electrode and comprising an emission layer; and

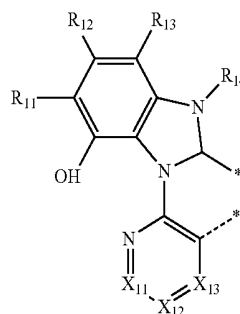
at least one of an organometallic compound represented by Formula 1:



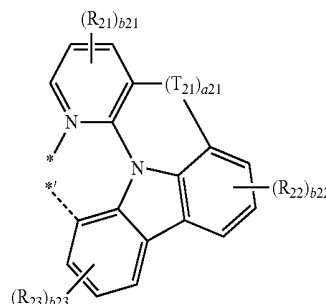
<Formula 2-1>

-continued

<Formula 2-2>



<Formula 3>



wherein, in Formula 1,

M is selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), and thulium (Tm),

in Formula 1, L₁ is a ligand represented by Formula 2-1 or 2-2, and n₁ is 1, 2, or 3, wherein, when n₁ is 2 or more, two or more L₁(s) are identical to or different from each other,

in Formula 1, L₂ is a ligand represented by Formula 3, and n₂ is 0, 1, or 2, wherein, when n₂ is 2 or more, two or more L₂(S) are identical to or different from each other, the sum of n₁ and n₂ in Formula 1 is 2 or 3,

in Formula 1, L₁(s) in the number of n₁ and L₂(S) in the number of n₂ are optionally linked to each other via a single bond, a first linking group, a substituted or unsubstituted C₅-C₆₀ carbocyclic group, or a substituted or unsubstituted C₁-C₆₀ heterocyclic group,

the first linking group is selected from *"-N(R₄)-*", *"-B(R₄)-*", *"-P(R₄)-*", *"-C(R₄)(R₅)-*", *"-Si(R₄)(R₅)-*", *"-Ge(R₄)(R₅)-*", *"-S-", *"-Se-", *"-O-", *"-C(=O)-*",

"-S(=O)-", *"-S(=O)₂-*", *"-C(R₄)=*",
 "-C(R₄)-", *"-C(R₄)=C(R₅)-*", *"-C(=S)
 *'", and *"-C≡C-*

A₁ in Formula 2-1 is selected from a C₅-C₆₀ carbocyclic group and a C₁-C₆₀ heterocyclic group,

X₁ and X₂ in Formula 2-1 are each independently N or C(R₃),

in Formula 2-2, X₁₁ and X₁₂ are each C(R₁₅), and X₁₃ is N or C(R₁₅),

T₂₁ in Formula 3 is selected from *"-N(R₂₄)-*",
 "-B(R₂₄)-", *"-P(R₂₄)-*", *"-C(R₂₄)
 (R₂₅)-*", *"-Si(R₂₄)(R₂₅)-*", *"-Ge(R₂₄)
 (R₂₅)-*", *"-S-*", *"-Se-*", *"-O-*",
 "-C(=O)-", *"-S(=O)-*", *"-S(=O)₂-*",
 "-C(R₂₄)=", *"-C(R₂₄)-*", *"-C(R₂₄)=C
 (R₂₅)-*", *"-C(=S)-*", and *"-C≡C-*

R₁ to R₅, R₁₁ to R₁₅, and R₂₁ to R₂₅ in Formulae 2-1, 2-2, and 3 are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, -Si(Q₁)(Q₂)(Q₃), -N(Q₁)(Q₂), -B(Q₁)(Q₂), -P(Q₁)(Q₂), -C(=O)(Q₁), -S(=O)₂(Q₁), and -P(=O)(Q₁)(Q₂),

b1 in Formula 2-1 is an integer from 1 to 6, wherein, when b1 is 2 or more, two or more R₁(s) are identical to or different from each other,

b21 to b23 in Formula 3 are each independently an integer from 1 to 3, wherein, when b21 is 2 or more, two or more R₂₁(s) are identical to or different from each other, when b22 is 2 or more, two or more R₂₂(s) are identical to or different from each other, and when b23 is 2 or more, two or more R₂₃(s) are identical to or different from each other,

in Formulae 2-1, 2-2, and 2-3, two neighboring substituents among R₁(s) in the number of b1, R₂, R₃, R₁₁ to R₁₄, R₁₅, R₂₁(S) in the number of b21, R₂₂(S) in the number of b22, R₂₃(S) in the number of b23, R₂₄, and R₂₅ are optionally linked to each other to form a substituted or unsubstituted C₅-C₃₀ carbocyclic group or a substituted or unsubstituted C₁-C₃₀ heterocyclic group,

a21 in Formula 3 is an integer from 1 to 3, wherein, when a21 is 2 or more, two or more T₂₁(s) are identical to or different from each other,

* and *' in Formulae 2-1 and 2-2 each indicate a binding site to M in Formula 1, and *'' and *''' in Formulae 1 and 3 each indicate a binding site to a neighboring atom,

at least one substituent of the substituted C₁-C₆₀ alkyl group, the substituted C₂-C₆₀ alkenyl group, the substituted C₂-C₆₀ alkynyl group, the substituted C₁-C₆₀ alkoxy group, the substituted C₃-C₁₀ cycloalkyl group, the substituted C₁-C₁₀ heterocycloalkyl group, the substituted C₃-C₁₀ cycloalkenyl group, the substituted C₁-C₁₀ heterocycloalkenyl group, the substituted C₆-C₆₀ aryl group, the substituted C₆-C₆₀ aryloxy group, the substituted C₆-C₆₀ arylthio group, the substituted C₁-C₆₀ heteroaryl group, the substituted C₁-C₆₀ heteroarylthio group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, and a C₁-C₆₀ alkoxy group;

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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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, -Si(Q₁₁)(Q₁₂)(Q₁₃), -N(Q₁₁)(Q₁₂), -B(Q₁₁)(Q₁₂), -C(=O)(Q₁₁), -S(=O)₂(Q₁₁), and -P(=O)(Q₁₁)(Q₁₂);

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;

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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, -Si(Q₂₁)(Q₂₂)(Q₂₃), -N(Q₂₁)(Q₂₂), -B(Q₂₁)(Q₂₂), -C(=O)(Q₂₁), -S(=O)₂(Q₂₁), and -P(=O)(Q₂₁)(Q₂₂); and

—Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂), and

Q₁ to Q₃, Q₁₁ to Q₁₃, Q₂₁ to Q₂₃, and Q₃₁ to Q₃₃ are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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 C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C₁-C₆₀ alkyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a C₆-C₆₀ aryl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a biphenyl group, and a terphenyl group.

2. The organic light-emitting device of claim 1, wherein the organometallic compound comprises a four-coordinate or six-coordinate ligand and a metal atom (M₁), and an energy level of a triplet metal centered state (³MC state) of the organometallic compound (E_{3MC}) is higher than an energy level of a triplet metal-to-ligand charge transfer state (³MLCT state) of the organometallic compound (E_{3MLCT}).

3. The organic light-emitting device of claim 1, wherein the organometallic compound satisfies E₃ ≥ 5 kcal/mol, and

E₃ is defined by Equation 1:

$$E_3 = |E_{3MLCT} - E_{3MC}| \quad \text{<Equation 1>}$$

4. The organic light-emitting device of claim 1, wherein the first electrode is an anode,

the second electrode is a cathode,

the organic layer comprises the at least one of the organometallic compound,

the organic layer further comprises a hole transport region between the first electrode and the emission layer and an electron transport region between the emission layer and the second electrode,

the hole transport region comprises at least one layer selected from a hole injection layer, a hole transport layer, a buffer layer, an emission auxiliary layer, and an electron blocking layer, and

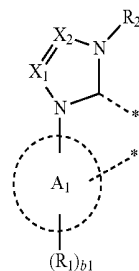
the electron transport region comprises at least one layer selected from a hole blocking layer, an electron transport layer, and an electron injection layer.

5. The organic light-emitting device of claim 4, wherein the emission layer comprises the at least one of the organometallic compound.

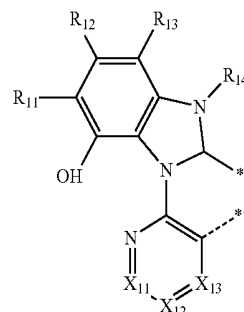
6. The organic light-emitting device of claim 1, wherein the emission layer emits blue light having a maximum emission wavelength of about 440 nm to about 490 nm.

7. The organic light-emitting device of claim 4, wherein the hole transport region comprises a p-dopant having a lowest unoccupied molecular orbital (LUMO) energy level of -3.5 eV or less.

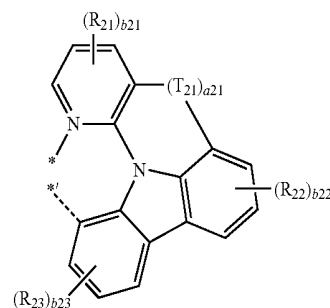
8. An organometallic compound represented by Formula 1:



<Formula 2-1>



<Formula 2-2>



<Formula 3>

wherein, in Formula 1,

M is selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), to rhodium (Rh), iridium (Ir), ruthenium (Ru), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), and thulium (Tm),

in Formula 1, L₁ is a ligand represented by Formula 2-1 or 2-2, and n₁ is 1, 2, or 3, wherein, when n₁ is 2 or more, two or more L₁(s) are identical to or different from each other,

in Formula 1, L₂ is a ligand represented by Formula 3, and n₂ is 0, 1, or 2, wherein, when n₂ is two or more, two or more L₂(s) are identical to or different from each other,

the sum of n₁ and n₂ in Formula 1 is 2 or 3,

L₁(s) in the number of n₁ and L₂(s) in the number of n₂ in Formula 1 are optionally linked to each other via a single bond or a first linking group,

the first linking group is selected from *—N(R₄)—*, *—B(R₄)—*, *—P(R₄)—*, *—C(R₄)(R₅)—*, *—Si(R₄)(R₅)—*, *—Ge(R₄)(R₅)—*, *—S—*, *—Se—*, *—O—*, *—C(=O)—*, *—S(=O)—*, *—S(=O)₂—*, *—C(R₄)=*,

$^{*''}=\text{C}(\text{R}_4)-^{*''}$, $^{*''}=\text{C}(\text{R}_4)=\text{C}(\text{R}_5)-^{*''}$, $^{*''}=\text{C}(\text{=S})-^{*''}$, and $^{*''}=\text{C}\equiv\text{C}-^{*''}$,
 A_1 in Formula 2-1 is selected from a $\text{C}_5\text{-C}_{60}$ carbocyclic group and a $\text{C}_1\text{-C}_{60}$ heterocyclic group,
 X_1 and X_2 in Formula 2-1 are each independently N or C(R_3),
 X_{11} and X_{12} in Formula 2-2 are each C(R_{15}), and X_{13} is N or C(R_{15}),
 T_{21} in Formula 3 is selected from $^{*''}=\text{N}(\text{R}_{24})-^{*''}$, $^{*''}=\text{B}(\text{R}_{24})-^{*''}$, $^{*''}=\text{P}(\text{R}_{24})-^{*''}$, $^{*''}=\text{C}(\text{R}_{24})(\text{R}_{25})-^{*''}$, $^{*''}=\text{Si}(\text{R}_{24})(\text{R}_{25})-^{*''}$, $^{*''}=\text{Ge}(\text{R}_{24})(\text{R}_{25})-^{*''}$, $^{*''}=\text{S}-^{*''}$, $^{*''}=\text{Se}-^{*''}$, $^{*''}=\text{O}-^{*''}$, $^{*''}=\text{C}(\text{=O})-^{*''}$, $^{*''}=\text{S}(\text{=O})-^{*''}$, $^{*''}=\text{S}(\text{=O})_2-^{*''}$, $^{*''}=\text{C}(\text{R}_{24})=^{*''}$, $^{*''}=\text{C}(\text{R}_{24})-^{*''}$, $^{*''}=\text{C}(\text{R}_{24})\equiv\text{C}(\text{R}_{25})-^{*''}$, $^{*''}=\text{C}(\text{=S})-^{*''}$, and $^{*''}=\text{C}\equiv\text{C}-^{*''}$,
 R_1 to R_5 , R_{11} to R_{15} , and R_{21} to R_{25} in Formulae 2-1, 2-2, and 3 are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted $\text{C}_1\text{-C}_{60}$ alkyl group, a substituted or unsubstituted $\text{C}_2\text{-C}_{60}$ alkenyl group, a substituted or unsubstituted $\text{C}_2\text{-C}_{60}$ alkynyl group, a substituted or unsubstituted $\text{C}_1\text{-C}_{60}$ alkoxy group, a substituted or unsubstituted $\text{C}_3\text{-C}_{10}$ cycloalkyl group, a substituted or unsubstituted $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, a substituted or unsubstituted $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, a substituted or unsubstituted $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, a substituted or unsubstituted $\text{C}_6\text{-C}_{60}$ aryl group, a substituted or unsubstituted $\text{C}_6\text{-C}_{60}$ aryloxy group, a substituted or unsubstituted $\text{C}_6\text{-C}_{60}$ arylthio group, a substituted or unsubstituted $\text{C}_1\text{-C}_{60}$ heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —Si(Q_1)(Q_2)(Q_3), —N(Q_1)(Q_2), —B(Q_1)(Q_2), —P(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)(Q_1), and —P(=O)(Q_1)(Q_2),
 b1 in Formula 2-1 is an integer from 1 to 6, wherein, when b1 is 2 or more, two or more $\text{R}_1(\text{s})$ are identical to or different from each other,
 b21 to b23 in Formula 3 are each independently an integer from 1 to 3, wherein, when b21 is 2 or more, two or more $\text{R}_{21}(\text{s})$ are identical to or different from each other, when b22 is 2 or more, two or more $\text{R}_{22}(\text{s})$ are identical to or different from each other, and when b23 is 2 or more, two or more $\text{R}_{23}(\text{s})$ are identical to or different from each other,
in Formulae 2-1, 2-2, and 2-3, two neighboring substituents among $\text{R}_1(\text{s})$ in the number of b1 , R_2 , R_3 , R_{11} to R_{14} , R_{15} , $\text{R}_{21}(\text{s})$ in the number of b21 , $\text{R}_{22}(\text{s})$ in the number of b22 , $\text{R}_{23}(\text{s})$ in the number of b23 , R_{24} , and R_{25} are optionally linked to each other to form a substituted or unsubstituted $\text{C}_5\text{-C}_{30}$ carbocyclic group or a substituted or unsubstituted $\text{C}_1\text{-C}_{30}$ heterocyclic group,
 a21 in Formula 3 is an integer from 1 to 3, wherein, when a21 is 2 or more, two or more $\text{T}_{21}(\text{s})$ are identical to or different from each other,
* and *' in Formulae 2-1 and 2-2 each indicate a binding site to M in Formula 1, and *'' and *''' in Formulae 1 and 3 each indicate a binding site to a neighboring atom,

at least one substituent of the substituted $\text{C}_5\text{-C}_{30}$ carbocyclic group, the substituted $\text{C}_1\text{-C}_{30}$ heterocyclic group, the substituted $\text{C}_1\text{-C}_{60}$ alkyl group, the substituted $\text{C}_2\text{-C}_{60}$ alkenyl group, the substituted $\text{C}_2\text{-C}_{60}$ alkynyl group, the substituted $\text{C}_1\text{-C}_{60}$ alkoxy group, the substituted $\text{C}_3\text{-C}_{10}$ cycloalkyl group, the substituted $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, the substituted $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, the substituted $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, the substituted $\text{C}_6\text{-C}_{60}$ aryl group, the substituted $\text{C}_6\text{-C}_{60}$ aryloxy group, the substituted $\text{C}_6\text{-C}_{60}$ arylthio group, the substituted $\text{C}_1\text{-C}_{60}$ heteroaryl group, the substituted $\text{C}_1\text{-C}_{60}$ heteroarylthio group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

- deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a $\text{C}_1\text{-C}_{60}$ alkyl group, a $\text{C}_2\text{-C}_{60}$ alkenyl group, a $\text{C}_2\text{-C}_{60}$ alkynyl group, and a $\text{C}_1\text{-C}_{60}$ alkoxy group;
- a $\text{C}_1\text{-C}_{60}$ alkyl group, a $\text{C}_2\text{-C}_{60}$ alkenyl group, a $\text{C}_2\text{-C}_{60}$ alkynyl group, and a $\text{C}_1\text{-C}_{60}$ 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 amidino group, a hydrazino group, a hydrazono group, a $\text{C}_3\text{-C}_{10}$ cycloalkyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, a $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, a $\text{C}_6\text{-C}_{60}$ aryl group, a $\text{C}_6\text{-C}_{60}$ aryloxy group, a $\text{C}_6\text{-C}_{60}$ arylthio group, a $\text{C}_1\text{-C}_{60}$ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q_{11})(Q_{12})(Q_{13}), —N(Q_{11})(Q_{12}), —B(Q_{11})(Q_{12}), —C(=O)(Q_{11}), —S(=O)(Q_{11}), and —P(=O)(Q_{11})(Q_{12});
- a $\text{C}_3\text{-C}_{10}$ cycloalkyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, a $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, a $\text{C}_6\text{-C}_{60}$ aryl group, a $\text{C}_6\text{-C}_{60}$ aryloxy group, a $\text{C}_6\text{-C}_{60}$ arylthio group, a $\text{C}_1\text{-C}_{60}$ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;
- a $\text{C}_3\text{-C}_{10}$ cycloalkyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, a $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, a $\text{C}_6\text{-C}_{60}$ aryl group, a $\text{C}_6\text{-C}_{60}$ aryloxy group, a $\text{C}_6\text{-C}_{60}$ arylthio group, a $\text{C}_1\text{-C}_{60}$ 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a $\text{C}_1\text{-C}_{60}$ alkyl group, a $\text{C}_2\text{-C}_{60}$ alkenyl group, a $\text{C}_2\text{-C}_{60}$ alkynyl group, a $\text{C}_1\text{-C}_{60}$ alkoxy group, a $\text{C}_3\text{-C}_{10}$ cycloalkyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkyl group, a $\text{C}_3\text{-C}_{10}$ cycloalkenyl group, a $\text{C}_1\text{-C}_{10}$ heterocycloalkenyl group, a $\text{C}_6\text{-C}_{60}$ aryl group, a $\text{C}_6\text{-C}_{60}$ aryloxy group, a $\text{C}_6\text{-C}_{60}$ arylthio group, a $\text{C}_1\text{-C}_{60}$ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q_{21})(Q_{22})(Q_{23}), —N(Q_{21})(Q_{22}), —B(Q_{21})(Q_{22}), —C(=O)(Q_{21}), —S(=O)(Q_{21}), and —P(=O)(Q_{21})(Q_{22}); and

—Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂), and

Q₁ to Q₃, Q₁₁ to Q₁₃, Q₂₁ to Q₂₃, and Q₃₁ to Q₃₃ are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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 C₁-C₆₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C₁-C₆₀ alkyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a C₆-C₆₀ aryl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a biphenyl group, and a terphenyl group.

9. The organometallic compound of claim 8, wherein M in Formula 1 is selected from Pt, Ir, Pd, Cu, Ag, and Au.

10. The organometallic compound of claim 8, wherein, in Formula 1, n1 is 1 and n2 is 1; or n1 is 3 and n2 is 0.

11. The organometallic compound of claim 8, wherein A₁ in Formula 2-1 is selected from:

a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a cyclopentane group, a cyclopentadiene group, a furan group, a thiophene group, a pyrrole group, a silole group, an oxazole group, an isoxazole group, an oxadiazole group, an isozadiazole group, an oxatriazole group, an isoxatriazole group, a thiazole group, an isothiazole group, a thiadiazole group, an isothiadiazole group, a thiatriazole group, an isothiatriazole group, a pyrazole group, an imidazole group, a triazole group, a 1,2,4-triazole group, a tetrazole group, an azasilole group, a diazasilole group, a triazasilole group, a cyclohexane group, and a cyclohexene group; and

a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a cyclopentane group, a cyclopentadiene group, a furan group, a thiophene group, a pyrrole group, a silole group, an oxazole group, an isoxazole group, an oxadiazole group, an isozadiazole group, an oxatriazole group, an isoxatriazole group, a thiazole is group, an isothiazole group, a thiadiazole group, an isothiadiazole group, a thiatriazole group, an isothiatriazole group, a pyrazole group, an imidazole group, a triazole group, a 1,2,4-triazole group, a tetrazole group, an azasilole group, a diazasilole group, a triazasilole group, a cyclohexane group, and a cyclohexene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluo-ranthenyl group, a triphenylenyl group, a pyrenyl

group, a chrysenyl group, a perylenyl group, a penta-cenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl 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 indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzo-quinoxalinyl group, a quinazolinyl group, a benzoqui-nazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzo-furanyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indeno carbazolyl group, an indolocarbazolyl group, —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)(Q₃₁), —S(=O)₂(Q₃₁), —P(=O)(Q₃₁)(Q₃₂), and —P(=S)(Q₃₁)(Q₃₂), and

Q₃₁ to Q₃₃ are each independently selected from hydrogen, deuterium, a C₆-C₆₀ aryl group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, a C₁-C₆₀ heteroaryl group, a C₁-C₆₀ heteroaryloxy group, a C₁-C₆₀ heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C₁-C₆₀ alkyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a C₆-C₆₀ aryl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group, a biphenyl group, and a terphenyl group.

12. The organometallic compound of claim 8, wherein X₁ and X₂ in Formula 2-1 are each C(R₃), and X₁₃ in Formula 2-2 is C(R₁₅).

13. The organometallic compound of claim 8, wherein, in Formula 3, T₂₁ is "*"—C(R₂₄)(R₂₅)—" and a21 is 1 or 2.

14. The organometallic compound of claim 8, wherein R₁ to R₅, R₁₁ to R₁₅, and R₂₁ to R₂₅ in Formulae 2-1, 2-2, and 3 are each independently selected from: hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, and C₁-C₂₀ alkoxy group;

a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a pyrrolyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolyl group, an isoquinolyl group, a quinoxalyl group, a quinazolyl group, a cinnolyl group, and a triazinyl group; and

a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolyl group, an isoquinolyl group, a quinoxalyl group, a quinazolyl group, a cinnolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a cyclopentyl group, a cyclohexyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a quinolyl group, an isoquinolyl group, a quinoxalyl group, a quinazolyl group, a cinnolyl group, and a triazinyl group, —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), and —P(=O)(Q₃₁)(Q₃₂); and

—Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), and —P(=O)(Q₁)(Q₂), and

Q₁ to Q₃ and Q₃₁ to Q₃₃ are each independently selected from

hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C₁-C₂₀ alkyl group, a C₂-C₂₀ alkenyl group, a C₂-C₂₀ alkynyl group, a C₁-C₂₀ alkoxy group, a C₃-C₁₀ cycloalkyl group, a C₁-C₁₀ heterocycloalkyl group, a C₃-C₁₀ cycloalkenyl group, a C₁-C₁₀ heterocycloalkenyl group, a C₆-C₂₀ aryl group, a C₁-C₂₀ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group.

15. The organometallic compound of claim 8, wherein R₂ in Formula 2-1 is selected from: a C₁-C₂₀ alkyl group, —N(Q₁)(Q₂), and a phenyl group; and a C₁-C₂₀ alkyl group, —N(Q₁)(Q₂), and a phenyl group, each substituted with a C₁-C₂₀ alkyl group, and

Q₁ and Q₂ are each independently a C₁-C₂₀ alkyl group.

16. The organometallic compound of claim 8, wherein R₁₁ and R₁₂ in Formula 2-2 are each independently selected from hydrogen, —F, —Cl, a cyano group, a C₁-C₂₀ alkyl group, and a phenyl group.

17. The organometallic compound of claim 8, wherein n₁ and n₂ are each 1, and L₁ is a group represented by Formula 2-1, and

one of R₁(s) in the number of b1 and one of neighboring R₂₃(s) in the number of b23 are linked to each other via a single bond or a first linking group.

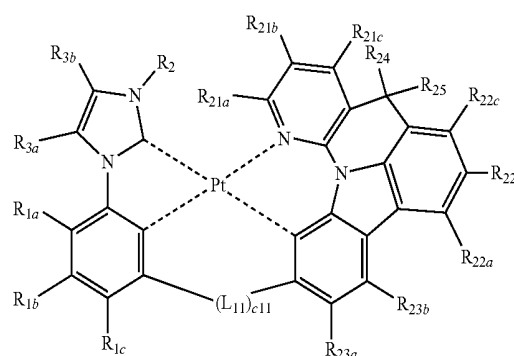
18. The organometallic compound of claim 8, wherein n₁ is 3, and L₁ is a group represented by Formula 2-2, X₁₃(s) in three L₁(s) are each C(R₁₅),

three R₁₄(s) in three L₁(s) are linked to each other via a substituted or unsubstituted C₅-C₆₀ carbocyclic group or a substituted or unsubstituted C₁-C₆₀ heterocyclic group, and

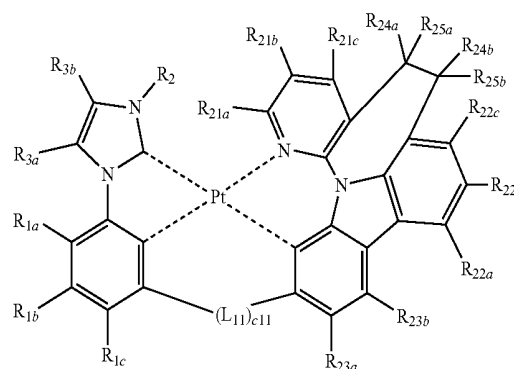
three R₁₅(s) in three L₁(s) are linked to each other via a substituted or unsubstituted C₅-C₆₀ carbocyclic group or a substituted or unsubstituted C₁-C₆₀ heterocyclic group.

19. The organometallic compound of claim 8, wherein the organometallic compound is a group represented by one of Formulae 1-1 to 1-5:

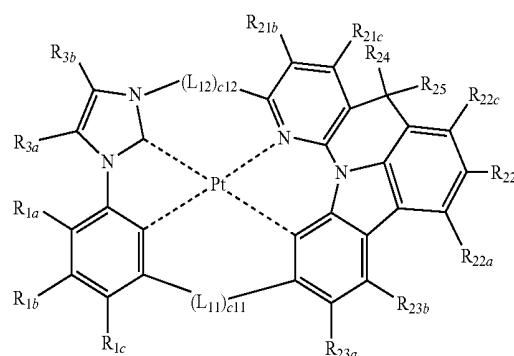
1-1



1-2

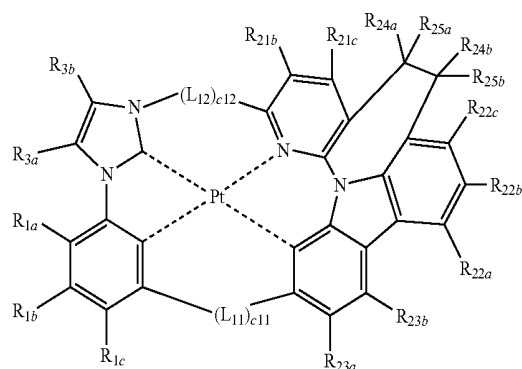


1-3

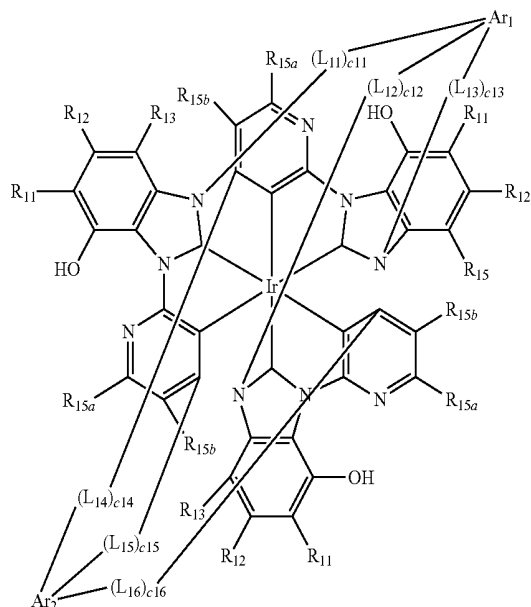


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1-4



1-5

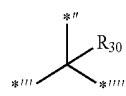


wherein, in Formulae 1-1 to 1-5,

L_{11} to L_{15} may each independently be selected from a single bond, $^{*''}-N(R_4)-^{*''}$, $^{*''}-B(R_4)-^{*''}$, $^{*''}-P(R_4)-^{*''}$, $^{*''}-C(R_4)(R_5)-^{*''}$, $^{*''}-Si(R_4)(R_5)-^{*''}$, $^{*''}-Ge(R_4)(R_5)-^{*''}$, $^{*''}-S-^{*''}$, $^{*''}-Se-^{*''}$, $^{*''}-O-^{*''}$, $^{*''}-C(=O)-^{*''}$, $^{*''}-S(=O)-^{*''}$, $^{*''}-S(=O)_2-^{*''}$, $^{*''}-C(R_4)=^{*''}$, $^{*''}-C(R_4)-^{*''}$, $^{*''}-C(R_4)=C(R_5)-^{*''}$, $^{*''}-C(=S)-^{*''}$, and $^{*''}-C\equiv C-^{*''}$,

c_{11} to c_{15} are each independently an integer from 1 to 3, wherein, when c_{11} is 2 or more, two or more $L_{11}(s)$ are identical to or different from each other, when c_{12} is 2 or more, two or more $L_{12}(s)$ are identical to or different from each other, when c_{13} is 2 or more, two or more $L_{13}(s)$ are identical to or different from each other, when c_{14} is 2 or more, two or more $L_{14}(s)$ are identical to or different from each other, and c_{15} is 2 or more, two or more $L_{15}(s)$ are identical to or different from each other,

Ar_1 and Ar_2 are each independently selected from a substituted or unsubstituted trivalent C_5 - C_{30} carbocyclic group, a substituted or unsubstituted trivalent C_1 - C_{30} heterocyclic group, or a group represented by



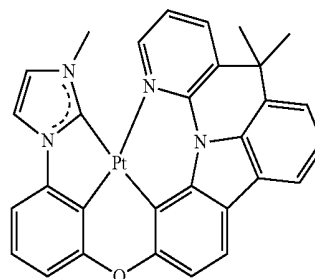
and $^{*''}$, $^{*''}$, and $^{*''}$ each indicate a binding site to a neighboring atom,

c_{11} and c_{12} are each independently an integer from 1 to 3, wherein, when c_{11} is 2 or more, two or more $L_{11}(s)$ are identical to or different from each other, and when c_{12} is 2 or more, two or more $L_{12}(s)$ are identical to or different from each other, and

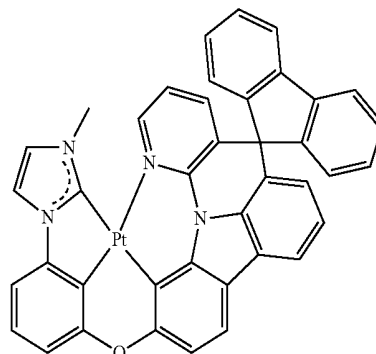
R_{1a} to R_{1c} , R_{3a} to R_{3b} , R_{15a} to R_{15b} , R_{21a} to R_{21c} , R_{22a} to R_{22c} , R_{23a} to R_{23b} , R_{24a} to R_{24b} , R_{25a} to R_{25b} , and R_{30} are each independently the same as defined in connection with R_1 , R_3 , R_{15} , and R_{21} to R_{25} in claim 1, and R_2 , R_4 , R_5 , and R_{11} to R_{13} are each independently the same as defined in connection with R_2 , R_4 , R_5 , and R_{11} to R_{13} in claim 1.

20. The organometallic compound of claim 8, wherein the organometallic compound represented by Formula 1 is selected from Compounds 1 to 14:

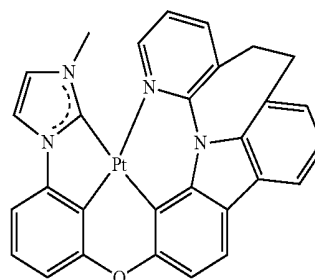
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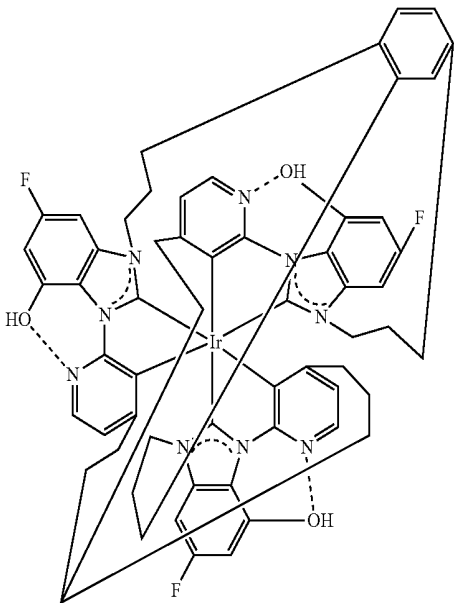
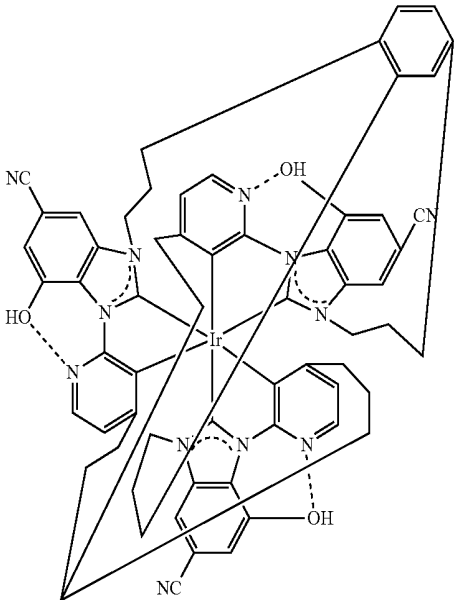
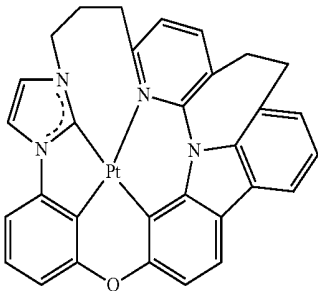
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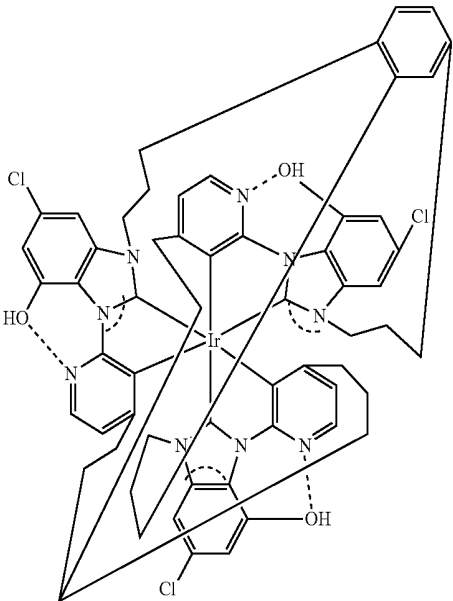
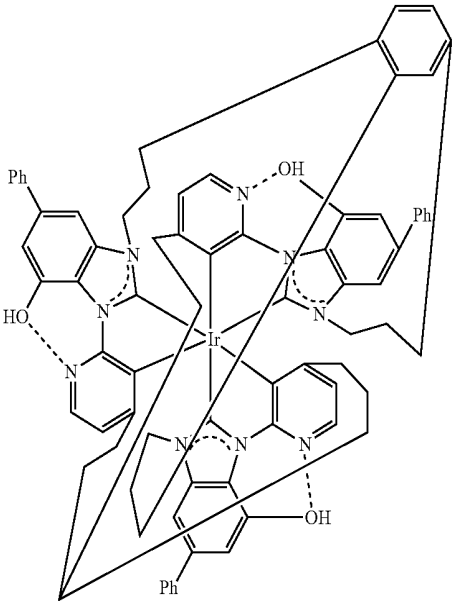
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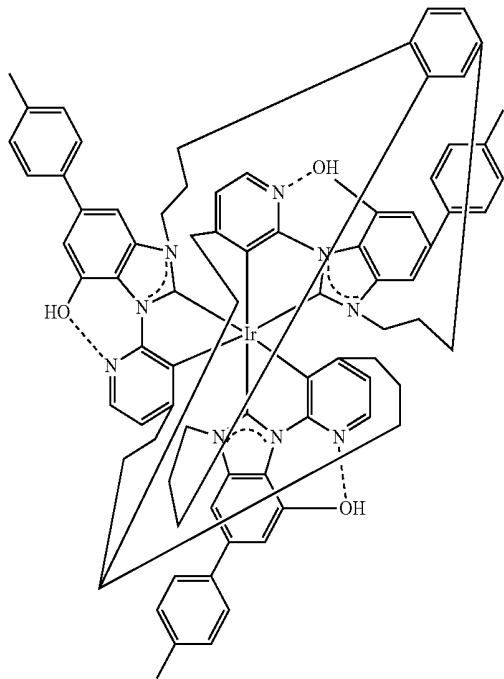


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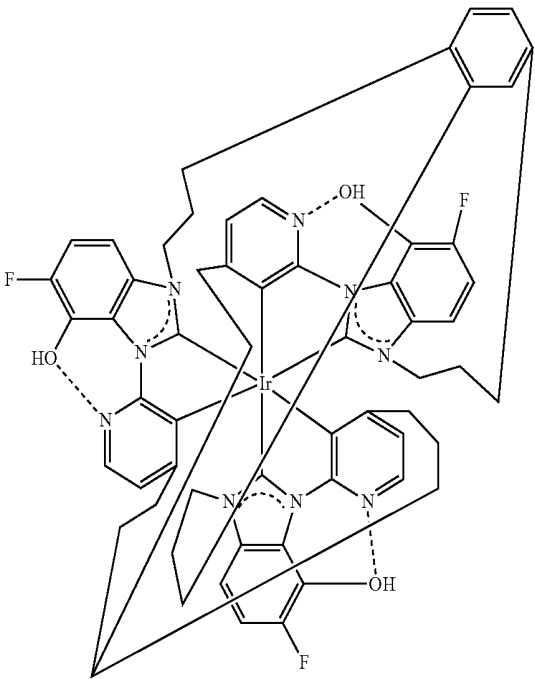
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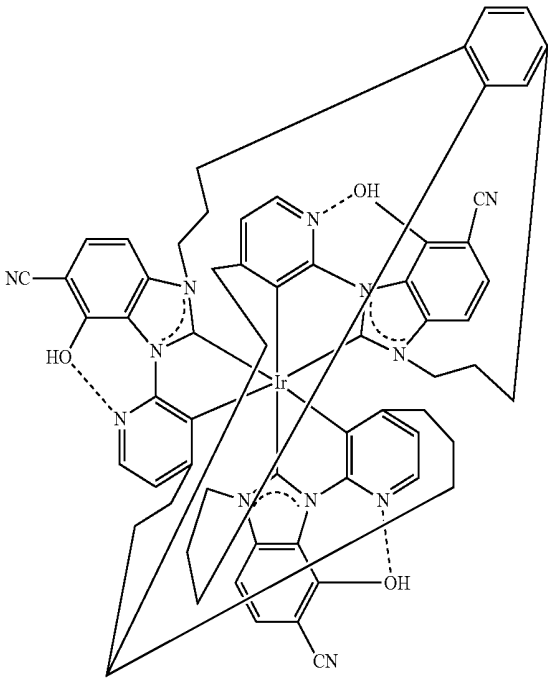


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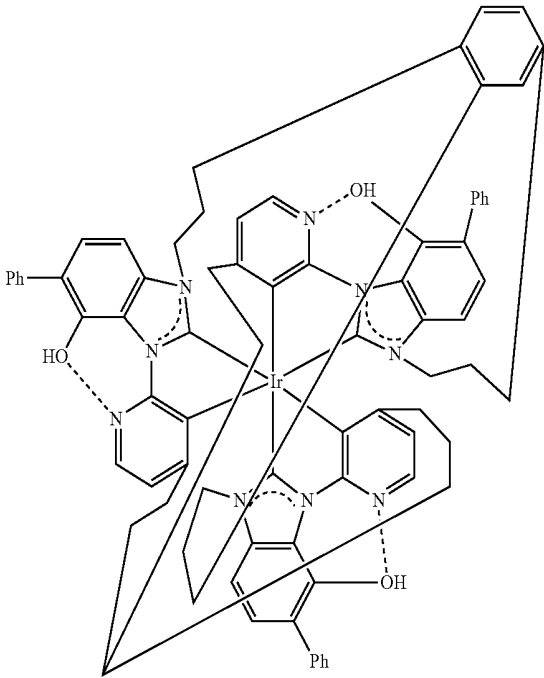
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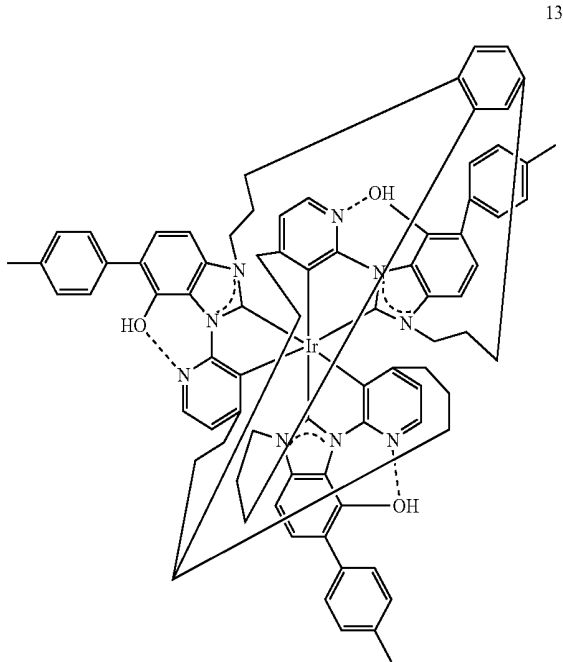
10



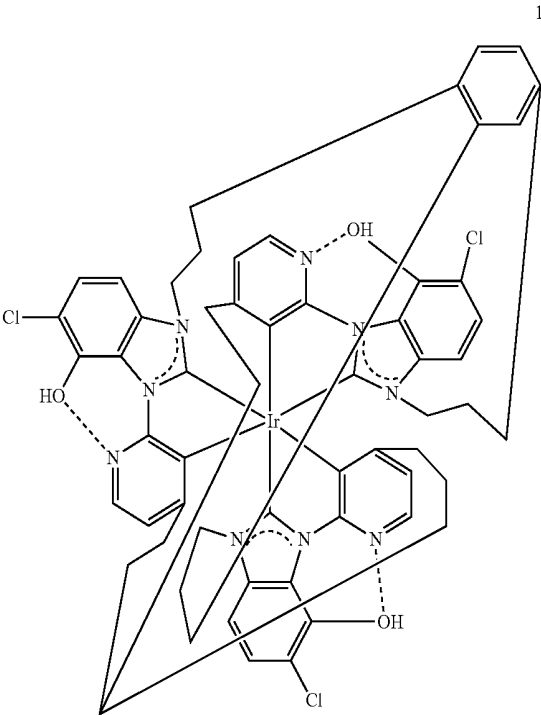
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专利名称(译)	有机金属化合物和包括该有机金属化合物的有机发光器件		
公开(公告)号	US20200168817A1	公开(公告)日	2020-05-28
申请号	US16/691532	申请日	2019-11-21
[标]申请(专利权)人(译)	三星显示有限公司		
申请(专利权)人(译)	三星DISPLAY CO. , LTD.		
当前申请(专利权)人(译)	三星DISPLAY CO. , LTD.		
[标]发明人	KANG SUNWOO JEON SANGHO CHO YOUNGMI		
发明人	KANG, SUNWOO JEON, SANGHO CHO, YOUNGMI		
IPC分类号	H01L51/00 C07F15/00 C09K11/06		
CPC分类号	C09K2211/185 H01L51/5012 C09K2211/1077 H01L51/0087 C09K11/06 H01L51/5016 C07F15/0086 C07F15/0033 H01L51/0072 H01L51/0085 H01L51/0094 H01L2251/5384		
优先权	1020180146767 2018-11-23 KR 1020190123360 2019-10-04 KR		
外部链接	Espacenet USPTO		

摘要(译)

有机金属化合物和包括该有机金属化合物的有机发光装置。

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220
190
150
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