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

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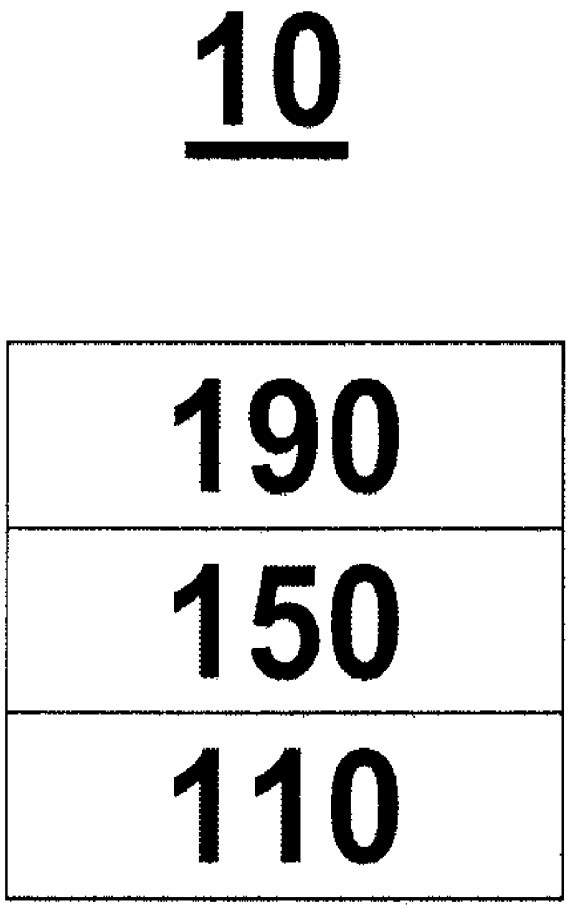
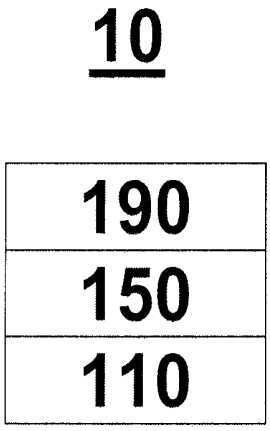
(57) **ABSTRACT**

Provided are an organometallic compound, an organic light-emitting device including the organometallic compound, and an organic light-emitting apparatus including the organic light-emitting device. The organic light-emitting device includes: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode and including an emission layer. The organic layer includes at least one of the organometallic compound.

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ORGANOMETALLIC COMPOUND, ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE ORGANOMETALLIC COMPOUND, AND ORGANIC LIGHT-EMITTING APPARATUS INCLUDING THE ORGANIC LIGHT-EMITTING DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2017-0117231, filed on Sep. 13, 2017, and Korean Patent Application No. 10-2018-0084765, filed on Jul. 20, 2018, in the Korean Intellectual Property Office, the entire content of each of which is incorporated herein by reference.

BACKGROUND

1. Field

[0002] One or more embodiments relate to an organometallic compound, an organic light-emitting device including the same, and an organic light-emitting apparatus including the organic light-emitting device.

2. Description of the Related Art

[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, as compared to other devices in the art.

[0004] An example of such organic light-emitting devices 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 (e.g., transition or relax) from an excited state to a ground state, thereby generating light.

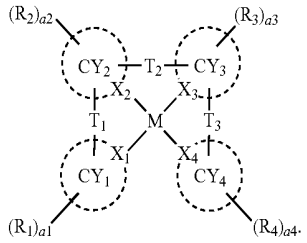
SUMMARY

[0005] Aspects of embodiments of the present disclosure provide a novel organometallic compound and an organic light-emitting device including the same.

[0006] Additional aspects of embodiments will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

[0007] An aspect of an embodiment provides an organometallic compound represented by Formula 1 below:

Formula 1



[0008] In Formula 1, M may be beryllium (Be), magnesium (Mg), aluminum (Al), calcium (Ca), titanium (Ti), manganese (Mn), cobalt (Co), copper (Cu), zinc (Zn), gallium (Ga), germanium (Ge), zirconium (Zr), ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), rhenium (Re), europium (Eu), platinum (Pt), or gold (Au),

[0009] two bonds selected from a bond between X_1 and M, a bond between X_2 and M, a bond between X_3 and M, and a bond between X_4 and M may each be a covalent bond, and the others thereof may each be a coordinate bond,

[0010] X_1 to X_4 may each independently be C or N,

[0011] ring CY_1 to ring CY_4 may each independently be selected from a C_5-C_{30} carbocyclic group and a C_1-C_{30} heterocyclic group,

[0012] T_1 to T_3 may each independently be selected from a single bond, a double bond, *—N(R_7)—*', *—B(R_7)—*', *—P(R_7)—*', *—C(R_7)(R_8)—*', *—Si(R_7)(R_8)—*', *—Ge(R_7)(R_8)—*', *—S—*', *—Se—*', *—O—*', *—C(=O)—*', *—S(=O)—*', *—S(=O)$_2$—*', *—C(R_7)=*', *=C(R_7)*', *—C(R_7)=C(R_8)—*', *—C(=S)—*', and *—C≡C—*', and * and *' each indicate a binding site to a neighboring atom,

[0013] R_7 and R_8 may optionally be linked via a single bond, a double bond, or a first linking group to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0014] R_1 to R_4, R_7, and R_8 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 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_6-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), —C(=O)(Q_1), —S(=O)$_2$(Q_1), —P(Q_1)(Q_2), and —P(=O)(Q_1)(Q_2),

[0015] a1 to a4 may each independently be an integer of 0 to 20,

[0016] two of a plurality of neighboring R_1(s) may optionally be linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0017] two of a plurality of neighboring R_2(s) may optionally be linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0018] two of a plurality of neighboring R_3(s) may optionally be linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0019] two of a plurality of neighboring R_4(s) may optionally be linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0020] two or more neighboring groups selected from R_1 to R_4 may optionally be linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0021] CY_1 and CY_4 may not be linked,

[0022] Formula 1 may satisfy at least one of a <first condition> to a <fourth condition>:

First Condition

[0023] at least one of T_1 and T_3 is not a single bond

Second Condition

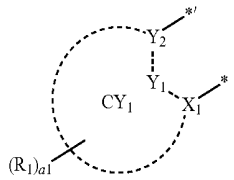
[0024] T_1 to T_3 are each a single bond, CY_1, M, and CY_2 form a cyclometalated 5-membered ring, and CY_2, M, and CY_3 form a cyclometalated 5-membered ring

Third Condition T_1 and T_3 are each a single bond, CY_1 is a group represented by $CY_1(1)$, and CY_4 is a group represented by $CY_4(1)$

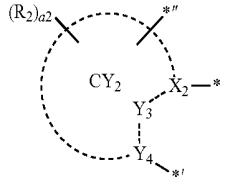
Fourth Condition

[0025] T_1 and T_3 are each a single bond, and CY_2 are each a group represented by $CY_2(1)$:

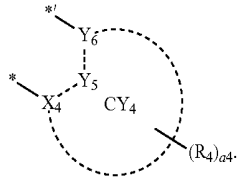
$CY_1(1)$



$CY_2(1)$



$CY_4(1)$



[0026] In Formulae $CY_1(1)$, $CY_2(1)$, and $CY_4(1)$, Y_1 to Y_6 may each independently be C or N,

[0027] in Formula $CY_1(1)$, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_1 in Formula 1,

[0028] in Formula $CY_2(1)$, * indicates a binding site to M in Formula 1, *' indicates a binding site to T_1 in Formula 1, and *'' indicates a binding site to T_2 in Formula 1,

[0029] in Formula $CY_4(1)$, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_3 in Formula 1,

[0030] at least one substituent of the substituted C_5-C_{30} carbocyclic group, the substituted C_1-C_{30} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0031] deuterium (-D), —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_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0032] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$;

[0033] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0034] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocy-

cloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0035] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0036] Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} 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_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C_1-C_{60} alkyl group substituted with at least one selected from deuterium, —F, and a cyano group, a C_6-C_{60} aryl group substituted with at least one selected from deuterium, —F, and a cyano group, a biphenyl group, and a terphenyl group.

[0037] Another aspect of an embodiment provides an organic light-emitting device including: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode and including an emission layer, wherein the organic layer includes at least one of the organometallic compound.

[0038] Another aspect of an embodiment provides an apparatus including the organic light-emitting device.

BRIEF DESCRIPTION OF THE DRAWING

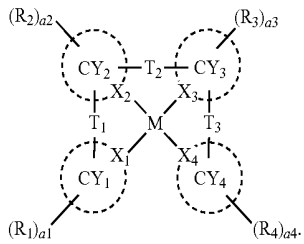
[0039] These and/or other aspects of embodiments will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawing which is a schematic view of an organic light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0040] Reference will now be made in more detail to embodiments, examples of which are illustrated in the accompanying drawing, wherein like reference numerals refer to like elements throughout. In this regard, the presented embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the accompanying drawing, to explain aspects of embodiments of the present description. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0041] An organometallic compound according to an embodiment is represented by Formula 1 below:

Formula 1



[0042] In Formula 1, M may be beryllium (Be), magnesium (Mg), aluminum (Al), calcium (Ca), titanium (Ti), manganese (Mn), cobalt (Co), copper (Cu), zinc (Zn), gallium (Ga), germanium (Ge), zirconium (Zr), ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), rhenium (Re), europium (Eu), platinum (Pt), or gold (Au).

[0043] In one embodiment, M may be Pt, but embodiments of the present disclosure are not limited thereto.

[0044] The organometallic compound represented by Formula 1 may not have a salt form consisting of a cation and an anion. Thus, the organometallic compound represented by Formula 1 may be neutral.

[0045] The organometallic compound represented by Formula 1 may be a near-infrared (NIR) light-emitting compound having a maximum emission wavelength of about 755 nm or more. The NIR light-emitting compound may have a maximum emission wavelength of about 755 nm or more, for example, in a range of about 755 nm to about 1,500 nm.

[0046] In Formula 1, two bonds selected from a bond between X_1 and M, a bond between X_2 and M, a bond between X_3 and M, and a bond between X_4 and M may each be a covalent bond, and the others thereof may each be a coordinate bond (e.g., a coordinate covalent bond). For example, i) the bond between the X_1 and M and the bond between X_4 and M may each be a covalent bond, and the bond between X_2 and M and the bond between X_3 and M may each be a coordinate bond (e.g., a coordinate covalent bond), or ii) the bond between the X_1 and M and the bond between X_4 and M may each be a coordinate bond (e.g., a coordinate covalent bond), and the bond between X_2 and M and the bond between X_3 and M may each be a covalent bond, but embodiments of the present disclosure are not limited thereto.

[0047] In one embodiment, at least one of ring CY_1 to ring CY_4 may be a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together),

[0048] at least one of ring CY_1 to ring CY_4 may be a condensed ring in which at least two 6-membered rings each including no nitrogen atom or one nitrogen atom are condensed with each other (e.g., combined together), or a condensed ring in which at least one 5-membered ring and at least one 6-membered ring are condensed with each other (e.g., combined together), wherein, in the condensed ring in which the at least one 5-membered ring and the at least one 6-membered ring are condensed with each other (e.g., combined together), a binding site to M is included in the 6-membered ring,

[0049] i) When ring CY_1 or CY_4 is a 6-membered ring including one nitrogen atom or a condensed ring in which at

least two 6-membered rings are condensed with each other (e.g., combined together), CY_1 and CY_4 have an asymmetric structure with respect to an inversion center axis passing through M, and

[0050] ii) when ring CY_2 or CY_3 is a 6-membered ring including one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), CY_2 and CY_3 may have an asymmetric structure with an inversion center axis passing through M.

[0051] In Formula 1, X_1 to X_4 may each independently be C or N. For example, i) X_1 and X_4 may each be N, or ii) X_2 and X_3 may each be N, but embodiments of the present disclosure are not limited thereto.

[0052] In one embodiment, i) when ring CY_1 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), X_1 may be N,

[0053] ii) when ring CY_2 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), X_2 may be N,

[0054] iii) when ring CY_3 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), X_3 may be N, and

[0055] iv) when ring CY_4 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), X_4 may be N.

[0056] In one embodiment, rings CY_1 to CY_4 may each independently be selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, and a benzocarbazole group, but embodiments of the present disclosure are not limited thereto.

[0057] For example, at least one of ring CY_1 to CY_4 may be a 6-membered ring including at least two nitrogen atoms or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), and

[0058] the 6-membered ring may be selected from a cyclohexane group, a cyclohexene group, a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, and a triazine group, but embodiments of the present disclosure are not limited thereto.

[0059] In one or more embodiments, i) rings CY_1 and CY_4 may each be a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), and rings CY_2 and CY_3 may each be a condensed ring in which at least two 6-membered rings each including no nitrogen atom or one nitrogen atom are condensed with each other (e.g., combined together), or a condensed ring in which at least one 5-membered ring and at least one 6-membered ring are condensed with each other (e.g., combined together), or

[0060] ii) rings CY_1 and CY_4 may each be a condensed ring in which at least two 6-membered rings each including no nitrogen atom 0 or one nitrogen atom are condensed with each other (e.g., combined together), or a condensed ring in which at least one 5-membered ring and at least one 6-membered ring are condensed with each other (e.g., combined together), and rings CY_2 and CY_3 may each be a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), but embodiments of the present disclosure are not limited thereto.

[0061] In one embodiment, in Formula 1, R_1 to R_4, R_7, and R_8 may each independently be selected from:

[0062] 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_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group;

[0063] a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$;

[0064] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl

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

[0065] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, 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_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cycloctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$; and

[0066] —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$P(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, and —$P(=O)(Q_1)(Q_2)$, and

[0067] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be selected from:

[0068] hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, a C_1-C_{20} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{20} aryl group, a C_1-C_{20} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0069] a C_1-C_{20} alkyl group substituted with at least one selected from deuterium, —F, and a cyano group;

[0070] a C_6-C_{20} aryl group substituted with at least one selected from deuterium, —F, and a cyano group; and

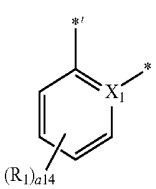
[0071] a biphenyl group and a terphenyl group.

[0072] 1) Two of a plurality of R_1(s) in Formula 1 may optionally be linked to form a substituted or unsubstituted C_4-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, 2) two of a plurality of R_2(s) in Formula 1 may optionally be linked to form a substituted or unsubstituted C_4-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, 3) two of a plurality of R_3(s) in Formula 1 may optionally be linked to form a substituted or unsubstituted C_4-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, 4) two of a plurality of R_4(s) in Formula 1 may optionally be linked to form a substituted or unsubstituted C_4-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, and 5) a least two neighboring groups selected from R_1 to R_4 in Formula 1 may optionally be linked to form a substituted or unsubstituted C_4-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group. The substituents of the substituted C_4-C_{60} carbocyclic group and the substituted C_1-C_{60} heterocyclic group may respectively be the same as described in connection with R_1 to R_4, the C_4-C_{60} carbocyclic group may be, for example, a cyclopentane group, a cyclohexane group, an adamantane group, a norbonane group, a benzene group, or a naphthalene group, and the C_1-C_{60} heterocyclic group may be, for example, a thiophene group, a furan group, a pyrrole group, a benzothiophene group, a benzofuran group, an indole group, or a pyridine group, but embodiments of the present disclosure are not limited thereto.

[0073] In Formula 1, a1 indicates the number of R_1(s) and may be an integer of 0 to 20, a2 indicates the number of R_2(s) and may be an integer of 0 to 20, a3 indicates the number of R_3(s) and may be an integer of 0 to 20, and a4 indicates the number of R_4(s) and may be an integer of 0 to 20. The plurality of R_1(s) may be identical to or different from each other, the plurality of R_2(s) may be identical to or different from each other, the plurality of R_3(s) may be identical to or different from each other, and the plurality of R_4(s) may be identical to or different from each other.

[0074] In one embodiment, CY_1 in Formula 1 may be represented by one selected from Formulae CY_1-1(1) to CY_1-1(18) and CY_1-2(1) to CY_1-2(12):

CY_1-1(1)



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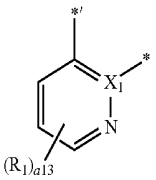
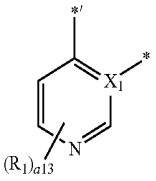
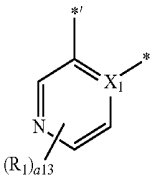
CY_1-1(2)



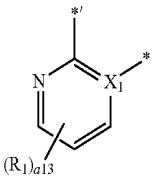
CY_1-1(3)



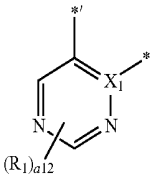
CY_1-1(4)



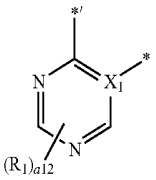
CY_1-1(5)



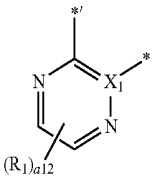
CY_1-1(6)



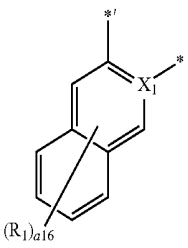
CY_1-1(7)



CY_1-1(8)



CY_1-1(9)



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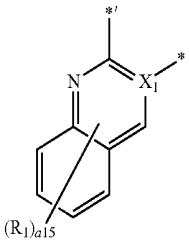
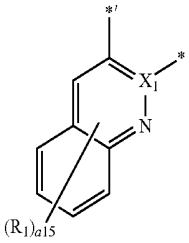
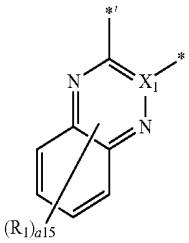
CY_1-1(10)



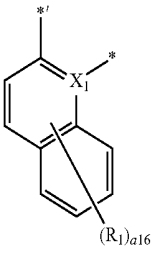
CY_1-1(11)



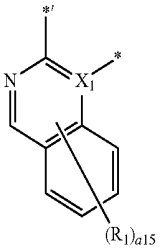
CY_1-1(12)



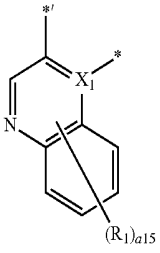
CY_1-1(13)



CY_1-1(14)



CY_1-1(15)



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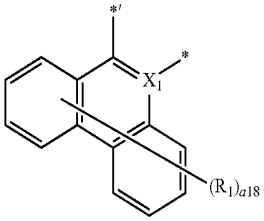
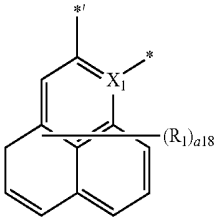
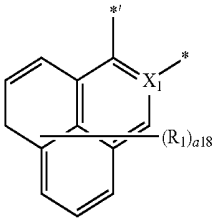
CY_1-1(16)



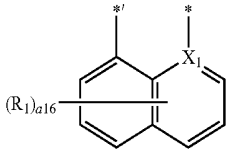
CY_1-1(17)



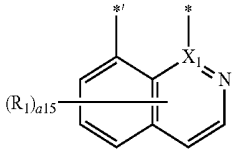
CY_1-1(18)



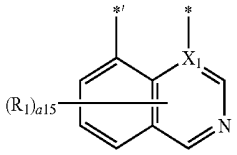
CY_1-2(1)



CY_1-2(2)



CY_1-2(3)



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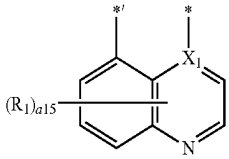
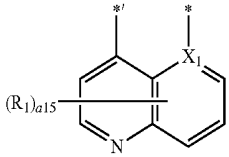


CY_1-2(5)



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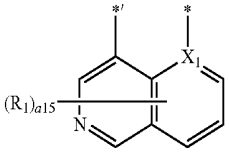
CY_1-2(6)



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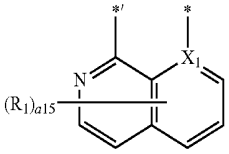

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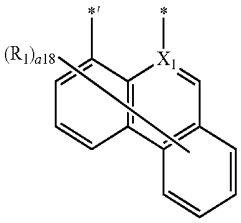
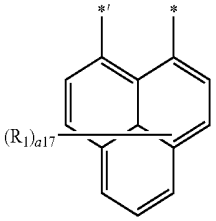
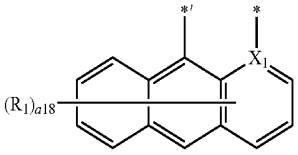


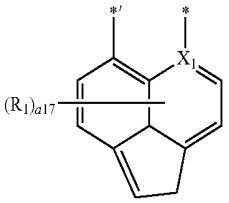
CY_1-2(9)



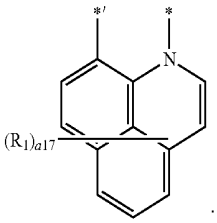
CY_1-2(10)



CY_1-2(11)



CY_1-2(12)



[0075] In Formulae CY_1-1(1) to CY_1-1(18) and CY_1-2(1) to CY_1-2(12),

[0076] X_1 and R_1 may respectively be the same as described herein,

[0077] a12 may be an integer of 0 to 2,

[0078] a13 may be an integer of 0 to 3,

[0079] a14 may be an integer of 0 to 4,

[0080] a15 may be an integer of 0 to 5,

[0081] a16 may be an integer of 0 to 6,

[0082] a17 may be an integer of 0 to 7,

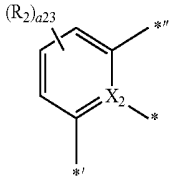
[0083] a18 may be an integer of 0 to 8,

[0084] * indicates a binding site to M in Formula 1, and

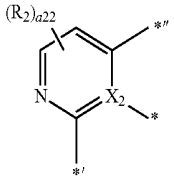
[0085] *' indicates a binding site to T_1 in Formula 1.

[0086] In one embodiment, CY_2 in Formula 1 may be represented by one selected from Formulae CY_1 CY_2-1(1) to CY_2-1(10), CY_2-2(1) to CY_2-2(2), and CY_2-3(1):

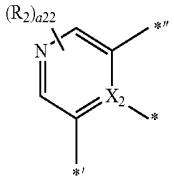
CY_2-1(1)



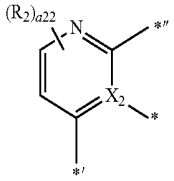
CY_2-1(2)



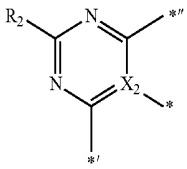
CY_2-1(3)



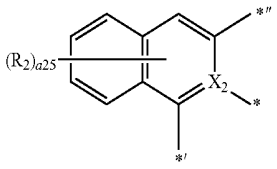
CY_2-1(4)



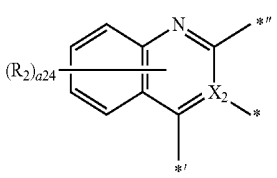
CY_2-1(5)



CY_2-1(6)



CY_2-1(7)



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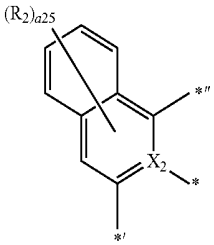
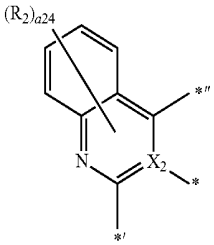
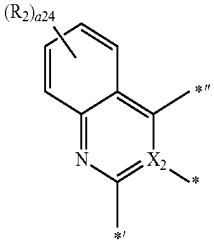
CY_2-1(8)



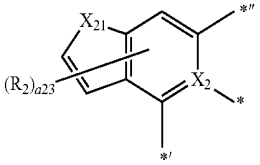
CY_2-1(9)



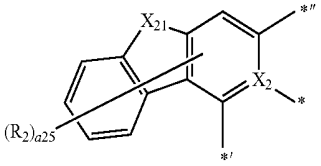
CY_2-1(10)



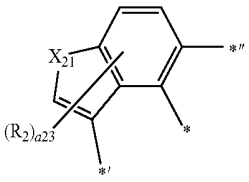
CY_2-1(11)



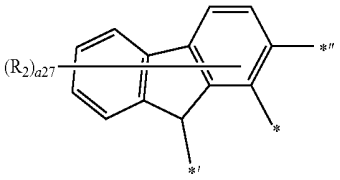
CY_2-1(12)



CY_2-2(1)



CY_2-2(2)



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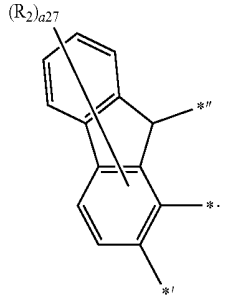
CY_2-3(1)



[0087] In Formulae CY_2-1(1) to CY_2-1 (10), CY_2-2(1) to CY_2-2(2), and CY_2-3(1),

[0088] X_2 and R_2 may respectively be the same as described herein,

[0089] X_{21} may be O, S, $N(R_{21})$, $C(R_{21})(R_{22})$, or $Si(R_{21})(R_{22})$,

[0090] R_{21} to R_{22} may respectively be the same as described in connection with R_2,

[0091] a22 may be an integer of 0 to 2,

[0092] a23 may be an integer of 0 to 3,

[0093] a24 may be an integer of 0 to 4,

[0094] a25 may be an integer of 0 to 5,

[0095] a26 may be an integer of 0 to 6,

[0096] a27 may be an integer of 0 to 7,

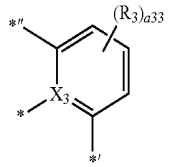
[0097] * indicates a binding site to M in Formula 1,

[0098] *' indicates a binding site to T_1 in Formula 1, and

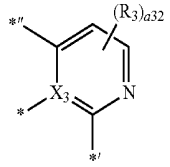
[0099] *" indicates a binding site to T_2 in Formula 1.

[0100] In one embodiment, CY_3 in Formula 1 may be represented by one selected from Formulae CY_3-1(1) to CY_3-1(10), CY_3-2(1) to CY_3-2(2), and CY_3-3(1):

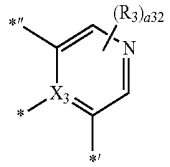
CY_3-1(1)



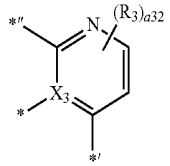
CY_3-1(2)



CY_3-1(3)



CY_3-1(4)



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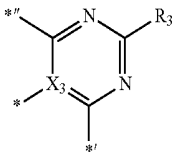
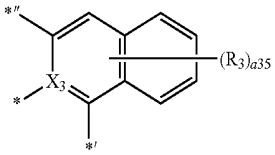
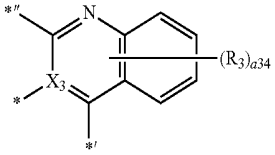
CY_3-1(5)



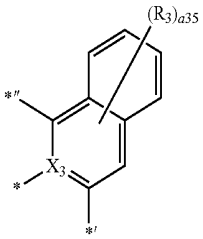
CY_3-1(6)



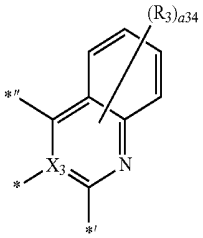
CY_3-1(7)



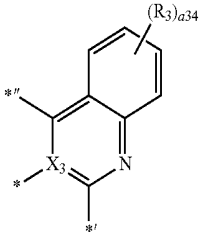
CY_3-1(8)



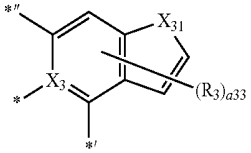
CY_3-1(9)



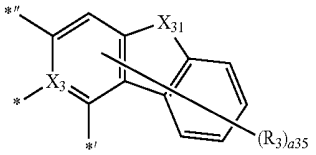
CY_3-1(10)



CY_3-1(11)



CY_3-1(12)



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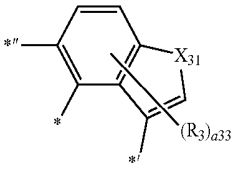
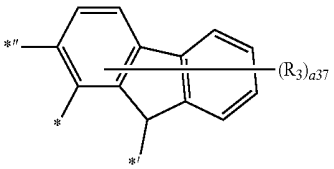
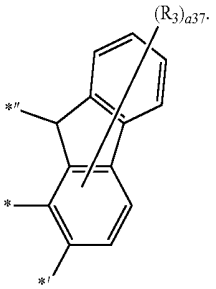
CY_3-2(1)



CY_3-2(2)



CY_3-3(1)



[0101] In Formulae CY_3-1(1) to CY_3-1 (10), CY_3-2(1) to CY_3-2(2), and CY_3-3(1),

[0102] X_3 and R_3 may respective be the same as described herein,

[0103] X_{31} may be O, S, $N(R_{31})$, $C(R_{31})(R_{32})$, Or $Si(R_{31})(R_{32})$,

[0104] R_{31} to R_{32} may respectively be the same as described in connection with R_3,

[0105] a32 may be an integer of 0 to 2,

[0106] a33 may be an integer of 0 to 3,

[0107] a34 may be an integer of 0 to 4,

[0108] a35 may be an integer of 0 to 5,

[0109] a36 may be an integer of 0 to 6,

[0110] a37 may be an integer of 0 to 7,

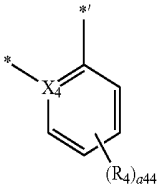
[0111] * indicates a binding site to M in Formula 1,

[0112] *" indicates a binding site to T_2 in Formula 1, and

[0113] *' indicates a binding site to T_3 in Formula 1.

[0114] In one embodiment, CY_4 in Formula 1 may be represented by one selected from Formulae CY_4-1(1) to CY_4-1(18) and CY_4-2(1) to CY_4-2(12):

CY_4-1(1)



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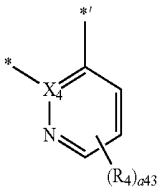
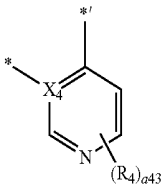
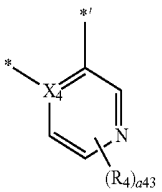
CY_4-1(2)



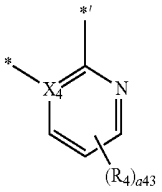
CY_4-1(3)



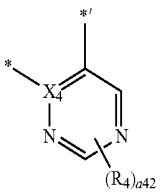
CY_4-1(4)



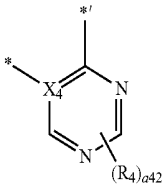
CY_4-1(5)



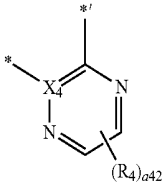
CY_4-1(6)



CY_4-1(7)



CY_4-1(8)



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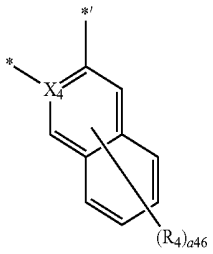
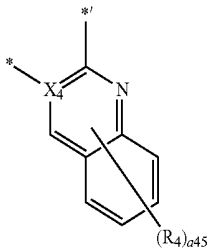
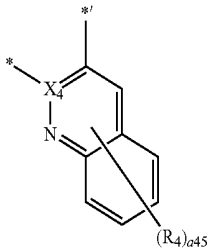
CY_4-1(9)



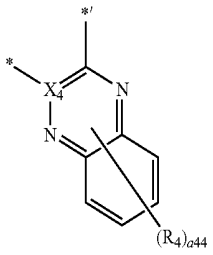
CY_4-1(10)



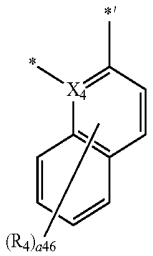
CY_4-1(11)



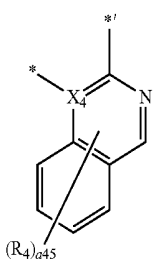
CY_4-1(12)



CY_4-1(13)



CY_4-1(14)



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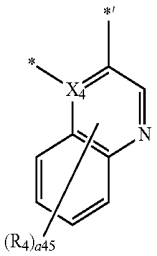
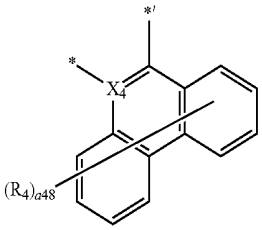
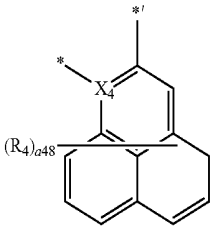
CY4-1(15)



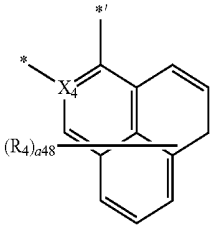
CY4-1(16)



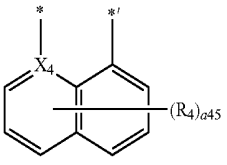
CY4-1(17)



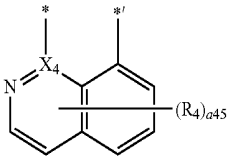
CY4-1(18)



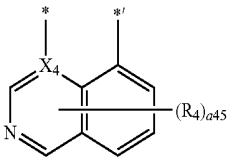
CY4-2(1)



CY4-2(2)



CY4-2(3)



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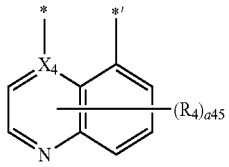
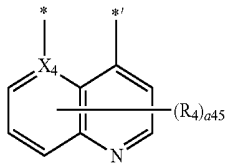
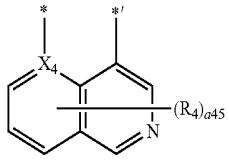
CY4-2(4)



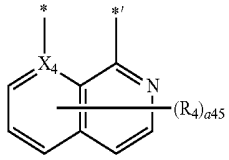
CY4-2(5)



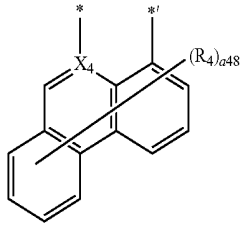
CY4-2(6)



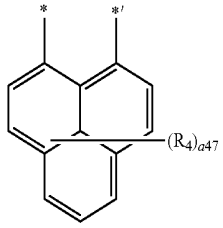
CY4-2(7)



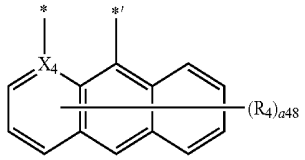
CY4-2(8)



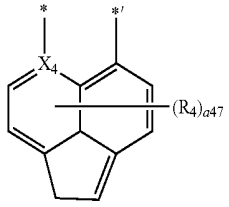
CY4-2(9)



CY4-2(10)



CY4-2(11)



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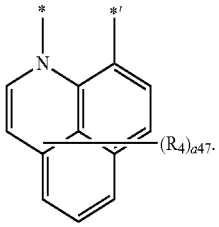
CY4-2(12)



[0115] In Formulae CY_4-1 (1) to CY_4-1 (18) and CY_4-2(1) to CY_4-2(12),

[0116] X_4 and R_4 may respectively be the same as described herein,

[0117] a42 may be an integer of 0 to 2,

[0118] a43 may be an integer of 0 to 3,

[0119] a44 may be an integer of 0 to 4,

[0120] a45 may be an integer of 0 to 5,

[0121] a46 may be an integer of 0 to 6,

[0122] a47 may be an integer of 0 to 7,

[0123] a48 may be an integer of 0 to 8,

[0124] * indicates a binding site to M in Formula 1, and

[0125] *' indicates a binding site to T_3 in Formula 1.

[0126] In one or more embodiments, in Formula 1,

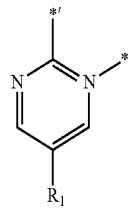
[0127] CY_1 may be represented by one selected from Formulae CY1-A to CY1-Q,

[0128] CY_2 may be represented by one selected from Formulae CY2-A to CY2-L,

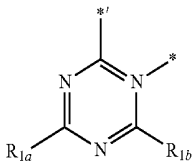
[0129] CY_3 may be represented by one selected from Formulae CY3-A to CY3-L, and

[0130] CY_4 may be represented by one selected from Formulae CY4-A to CY4-Q:

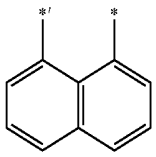
CY1-A



CY1-B



CY1-C



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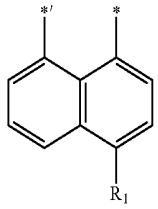
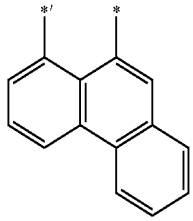
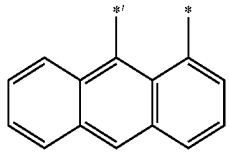
CY1-D



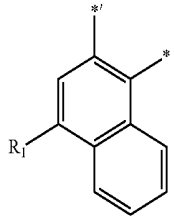
CY1-E



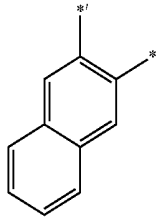
CY1-F



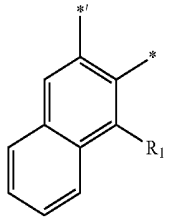
CY1-G



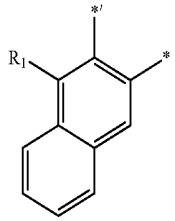
CY1-H



CY1-I



CY1-J



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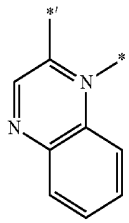
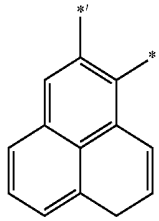
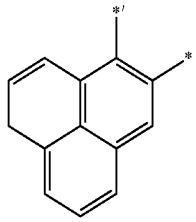
CY1-K



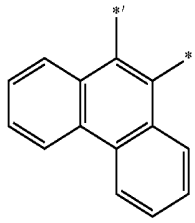
CY1-L



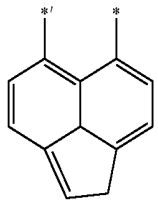
CY1-M



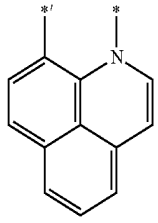
CY1-N



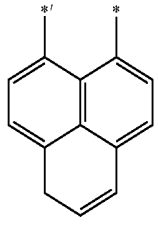
CY1-O



CY1-P



CY1-Q



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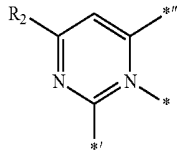
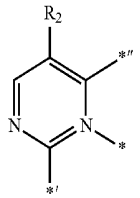
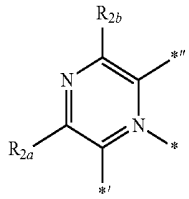
CY2-A



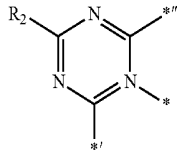
CY2-B



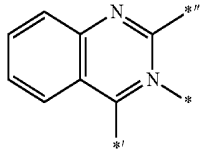
CY2-C



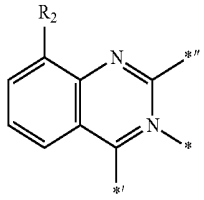
CY2-D



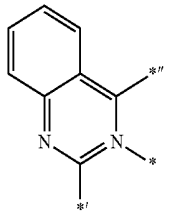
CY2-E



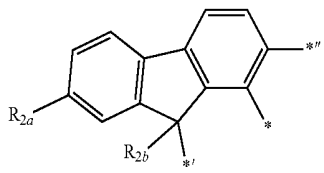
CY2-F



CY2-G



CY2-H



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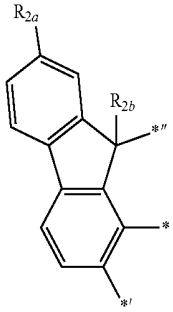
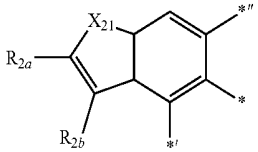
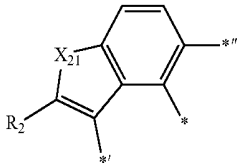
CY2-I



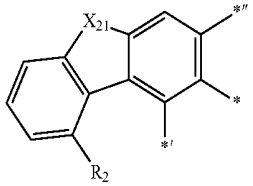
CY2-J



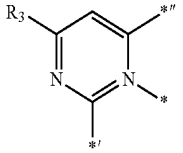
CY2-K



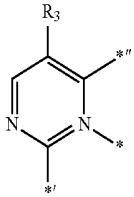
CY2-L



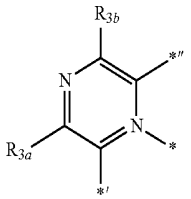
CY3-A



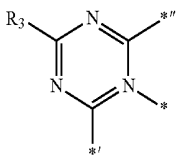
CY3-B



CY3-C



CY3-D



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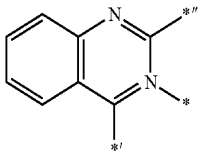
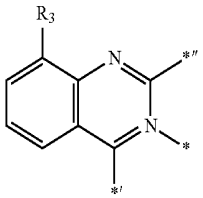
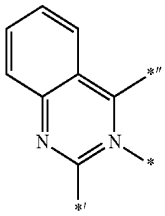
CY3-E



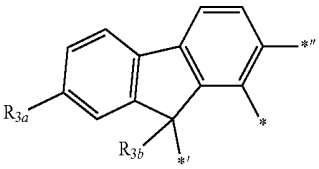
CY3-F



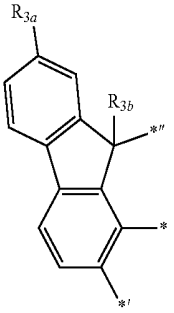
CY3-G



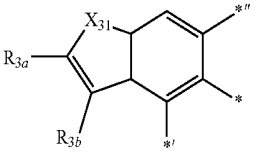
CY3-H



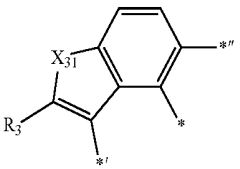
CY3-I



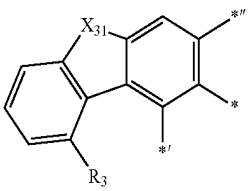
CY3-J



CY3-K



CY3-L



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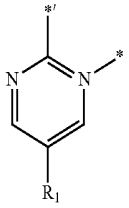
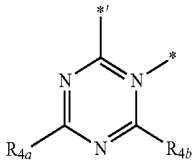
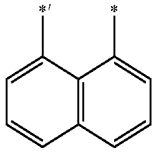
CY4-A



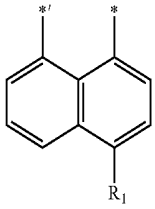
CY4-B



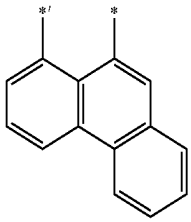
CY4-C



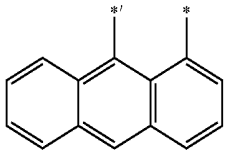
CY4-D



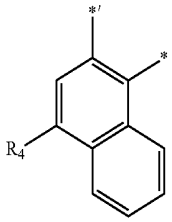
CY4-E



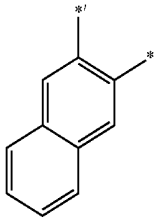
CY4-F



CY4-G



CY4-H



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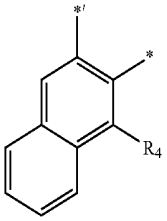
CY4-I



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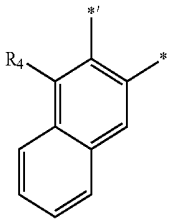

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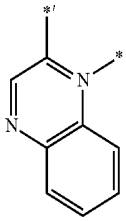
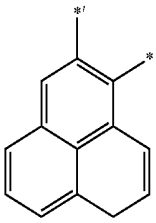


CY4-L



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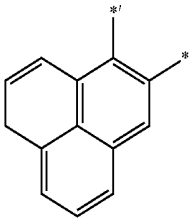
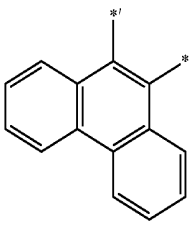
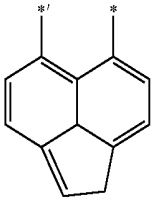


CY4-N



CY4-O



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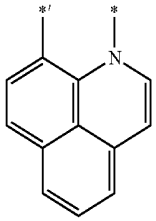
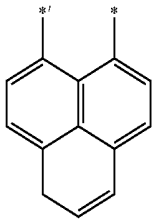
CY4-P



CY4-Q



[0131] In Formulae CY1-A to CY1-Q, CY2-A to CY2-L, CY3-A to CY3-L, and CY4-A to CY4-Q,

[0132] R_1 to R_4 may respectively be the same as described herein,

[0133] X_{21} may be O, S, $N(R_{21})$, $C(R_{21})(R_{22})$, or $Si(R_{21})(R_{22})$,

[0134] X_{31} may be O, S, $N(R_{31})$, $C(R_{31})(R_{32})$, or $Si(R_{31})(R_{32})$,

[0135] R_{2a}, R_{2b}, R_{21}, and R_{22} may respectively be the same as described in connection with R_2,

[0136] R_{3a}, R_{3b}, R_{31}, and R_{32} may respectively be the same as described in connection with R_3,

[0137] in Formulae CY1-A to CY1-Q, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_1 in Formula 1,

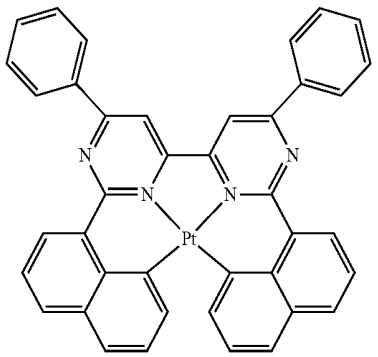
[0138] in Formulae CY2-A to CY2-L, * indicates a binding site to M in Formula 1, *' indicates a binding site to T_1 in Formula 1, and *" indicates a binding site to T_2 in Formula 1,

[0139] in Formulae CY3-A to CY3-L, * indicates a binding site to M in Formula 1, *" indicates a binding site to T_2 in Formula 1, and *' indicates a binding site to T_3 in Formula 1, and

[0140] in Formulae CY4-A to CY4-Q, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_3 in Formula 1.

[0141] The organometallic compound may be selected from Compounds 1 to 31:

1



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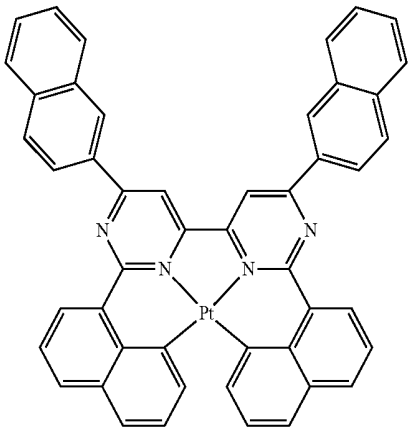

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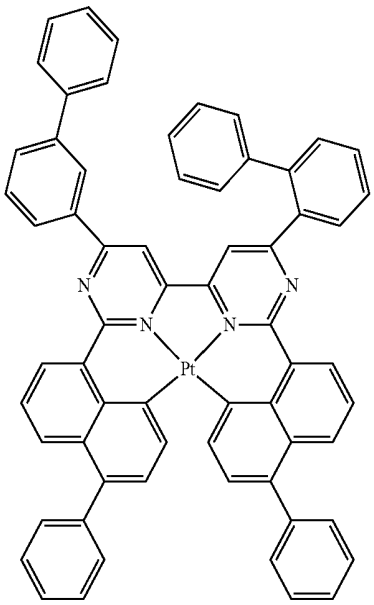

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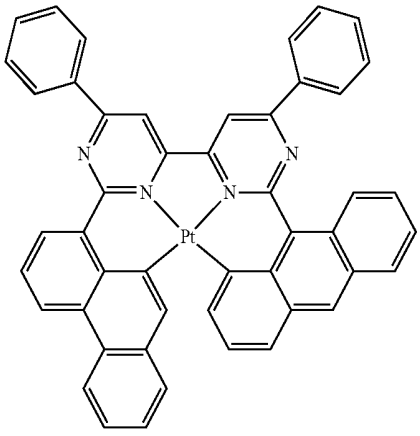

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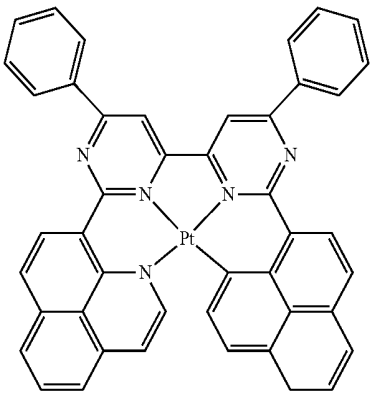

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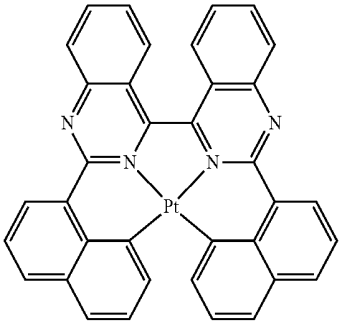

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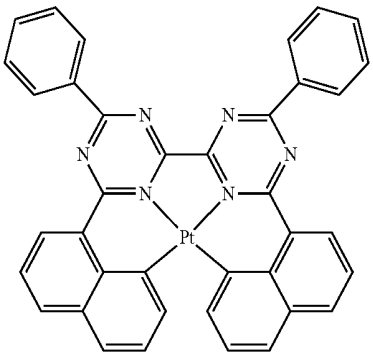

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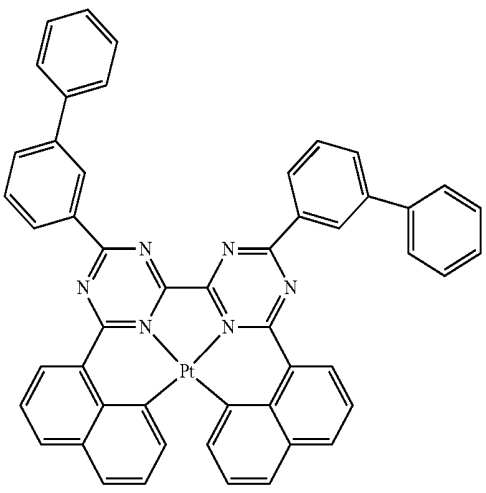

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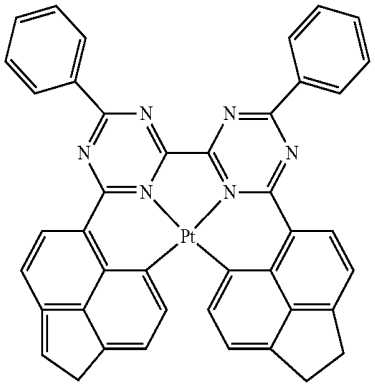

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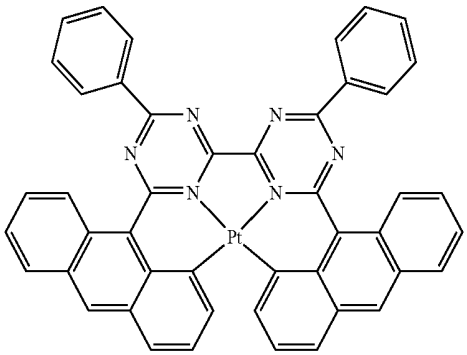

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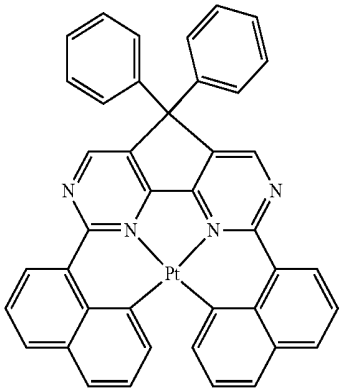

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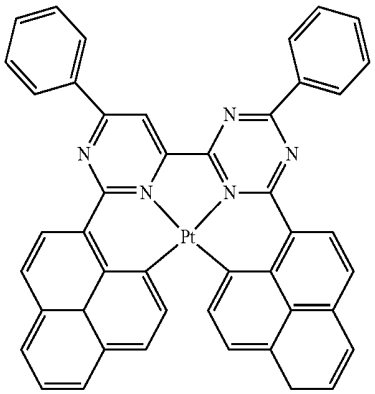

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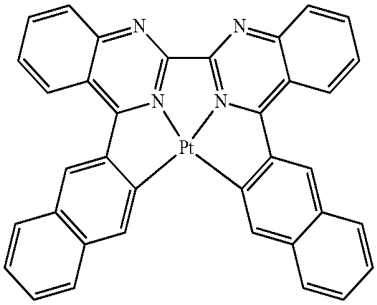

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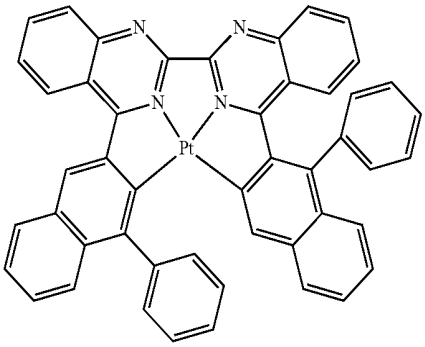

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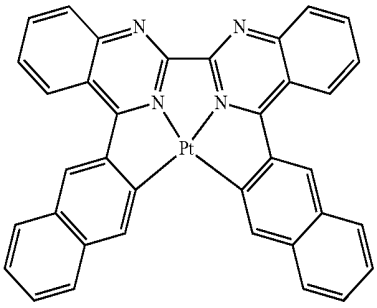

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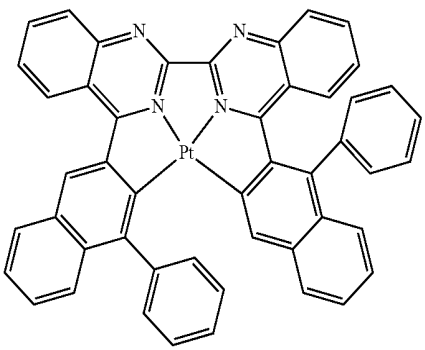

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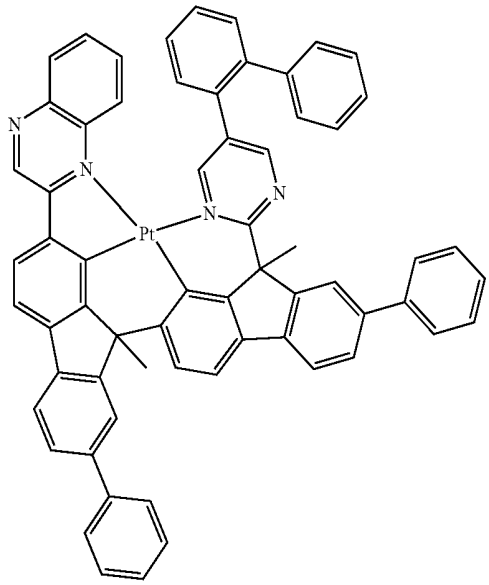

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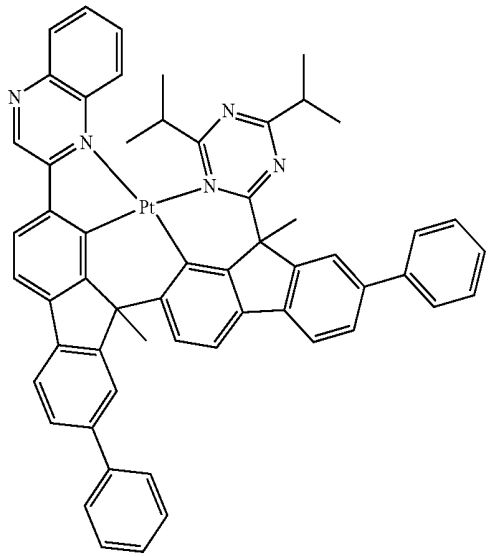

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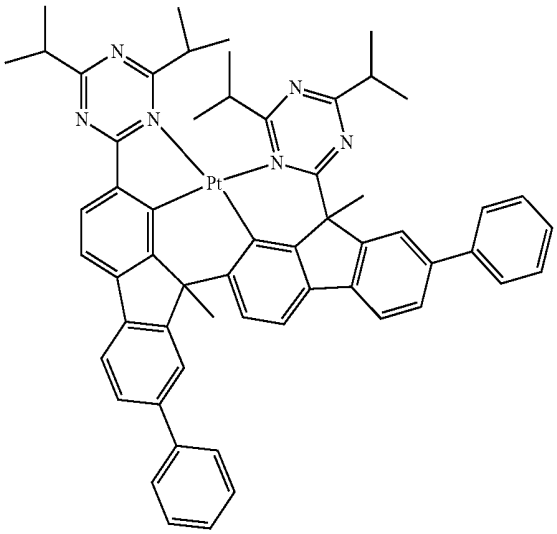

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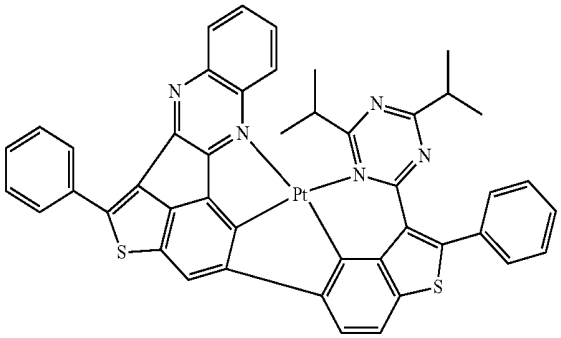

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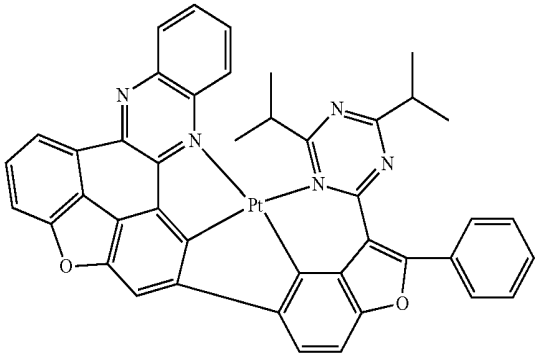

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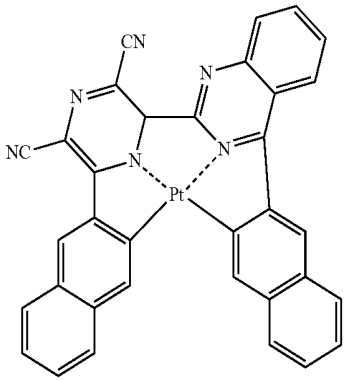

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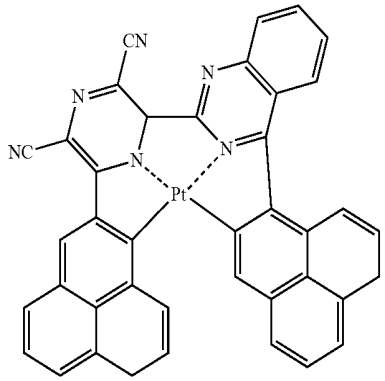

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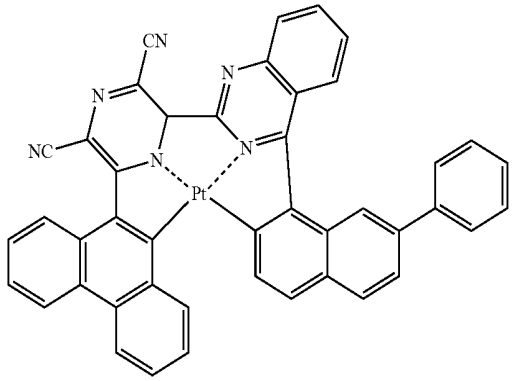

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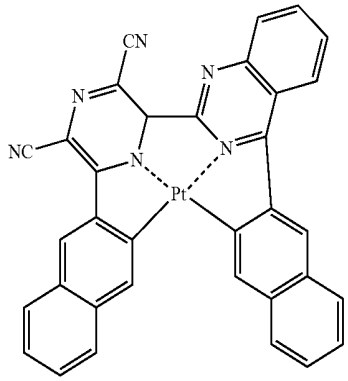

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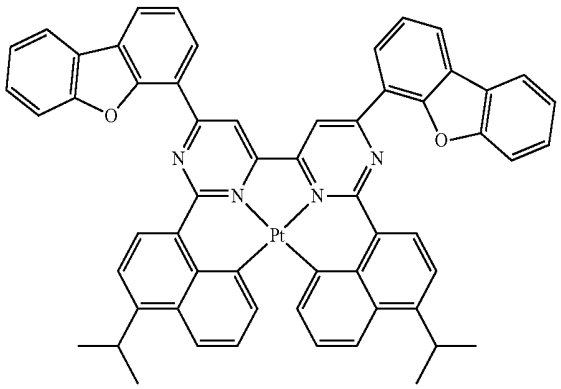

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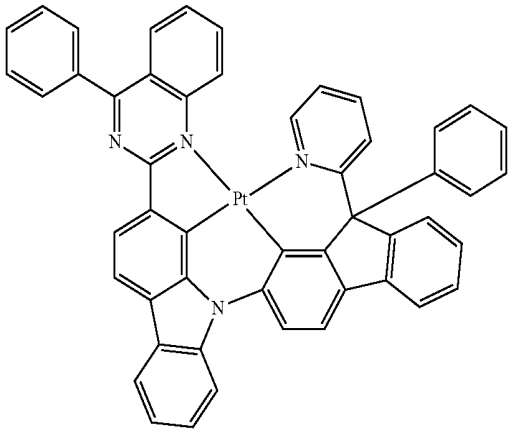

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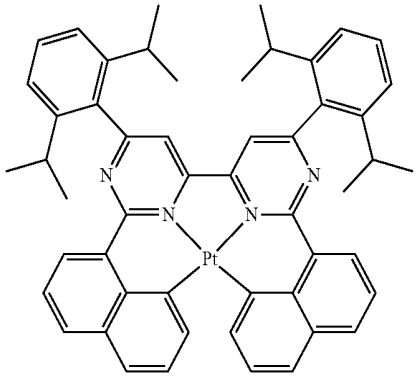

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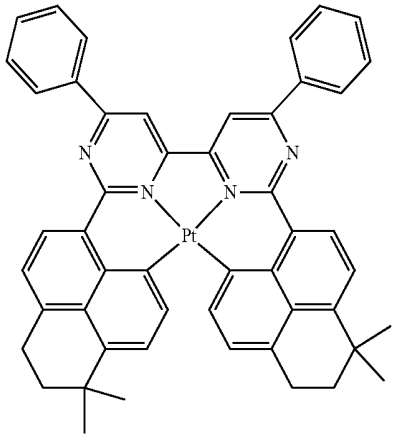

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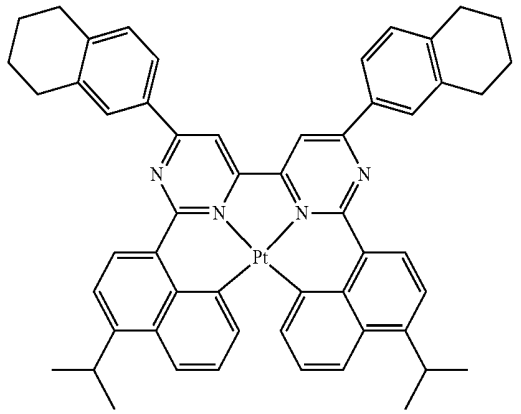

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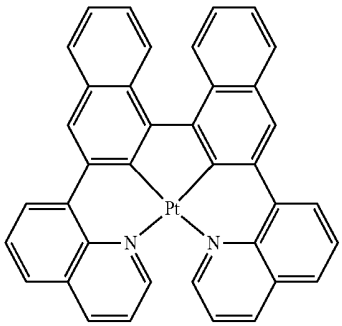


[0142] As described above, Formula 1 satisfies at least one of the <first condition> to the <fourth condition>.

[0143] Furthermore, in Formula 1, at least one of ring CY_1 to ring CY_4 may be a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together). In addition, in Formula 1, at least one of ring CY_1 to ring CY_4 may be a condensed ring in which at least two 6-membered rings each including no nitrogen atom or one nitrogen atom are condensed with each other (e.g., combined together) or a condensed ring in which at least one 5-membered ring and at least one 6-membered ring are condensed each other, wherein, in the condensed ring in which the at least one 5-membered ring and the at least one 6-membered ring are condensed with each other (e.g., combined together), a binding site to M is included in the 6-membered ring.

[0144] Therefore, since a ligand includes strong donor-acceptor, it is possible to obtain the effect of shifting a maximum emission wavelength to a long wavelength (e.g., a wavelength range of about 755 nm to about 1,500 nm).

[0145] In addition, in Formula 1, i) when ring CY_1 or CY_4 is a 6-membered ring including one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), CY_1 and CY_4 may have an asymmetric structure with respect to an inversion center axis passing through M, and ii) when ring CY_2 or CY_3 is a 6-membered including one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other (e.g., combined together), CY_2 and CY_3 may have an asymmetric structure with respect to an inversion center axis passing through M.

[0146] Therefore, since a ligand includes a strong donor-acceptor, it is possible to obtain the effect of shifting a maximum emission wavelength to a long wavelength (e.g., a wavelength range of about 755 nm to about 1,500 nm).

[0147] For example, the organometallic compound may emit NIR light having a maximum emission wavelength of about 755 nm or more, for example, in a range of about 755 nm to about 1,500 nm, but embodiments of the present disclosure 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 NIR light.

[0148] 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.

[0149] At least one of the organometallic compound of Formula 1 may be used between a pair of electrodes of an organic light-emitting device. Accordingly, provided is an organic light-emitting device including: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode, the organic layer including an emission layer, wherein the organic layer includes at least one organometallic cyclic compound represented by Formula 1.

[0150] 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."

[0151] For example, the organic layer may include, as the organometallic compound, only Compound 1. In this regard, Compound 1 may exist in an 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).

[0152] According to one embodiment,

[0153] the first electrode of the organic light-emitting device may be an anode,

[0154] the second electrode of the organic light-emitting device may be a cathode,

[0155] 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,

[0156] 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

[0157] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0158] For example, the emission layer may include the organometallic compound.

[0159] For example, the emission layer may further include a host, wherein an amount of the host may be greater than that of the organometallic compound.

[0160] The term "organic layer," as used herein, refers to a single layer and/or a plurality of layers disposed between

the first electrode and the second electrode of the organic light-emitting device. A material included in the "organic layer" is not limited to an organic material. For example, the organic layer may include an inorganic material in addition to an organic material.

[0161] Description of the Accompanying Drawing

[0162] The accompanying drawing is a schematic 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**.

[0163] 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 the accompanying drawing.

[0164] First Electrode **110**

[0165] In the accompanying drawing, 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.

[0166] 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 a first electrode may be selected from materials with a high work function to facilitate hole injection.

[0167] The first electrode **110** may be a reflective electrode, a semi-transmissive 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 (SnO_2), zinc oxide (ZnO), and any combinations thereof, but embodiments of the present disclosure are not limited thereto. In one or more embodiments, when the first electrode **110** is a semi-transmissive electrode or a reflectable 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 present disclosure are not limited thereto.

[0168] 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.

[0169] Organic Layer **150**

[0170] The organic layer **150** is disposed on the first electrode **110**. The organic layer **150** may include an emission layer.

[0171] 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**.

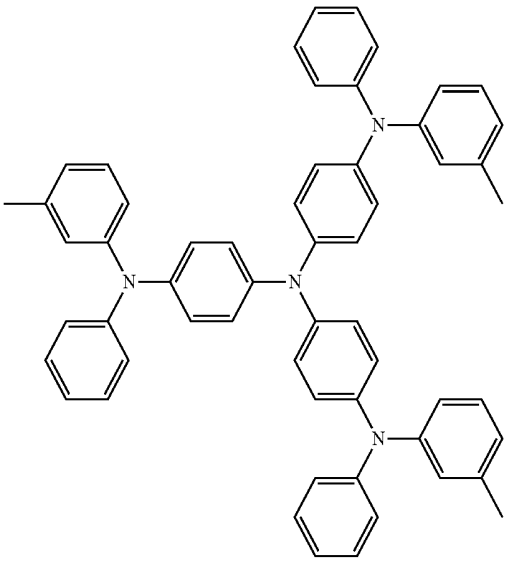
[0172] Hole Transport Region in Organic Layer **150**

[0173] The hole transport region 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.

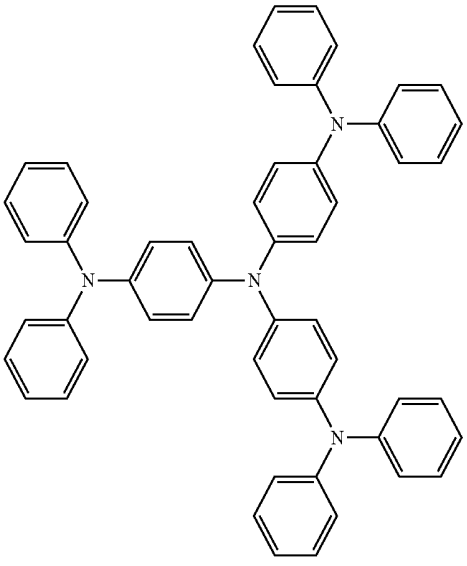
[0174] The hole transport region may include at least one layer selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

[0175] 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.

[0176] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB (NPD), 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:



m-MTDATA



TDATA

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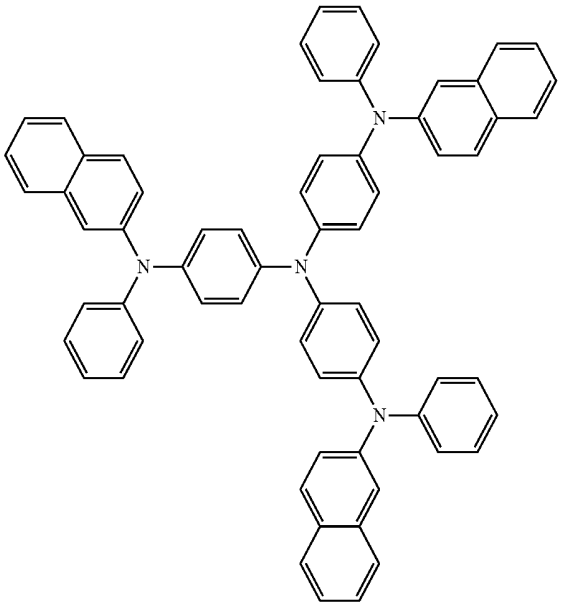
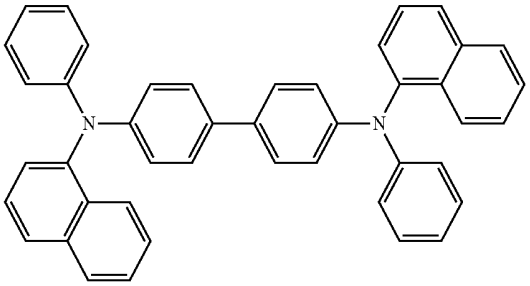
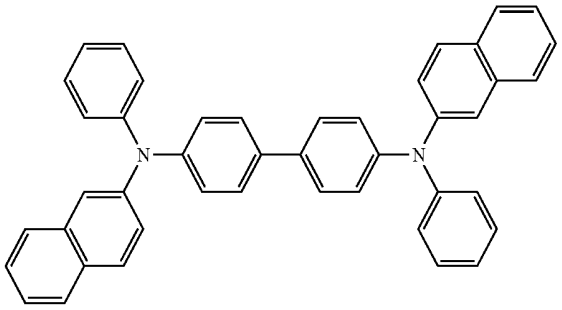


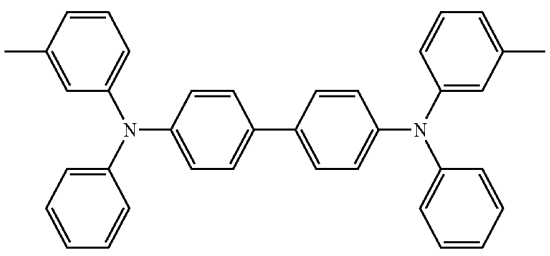
2-TNATA



NPB



β-NPB



TPD

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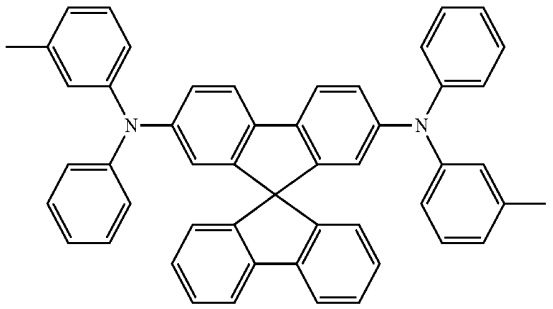
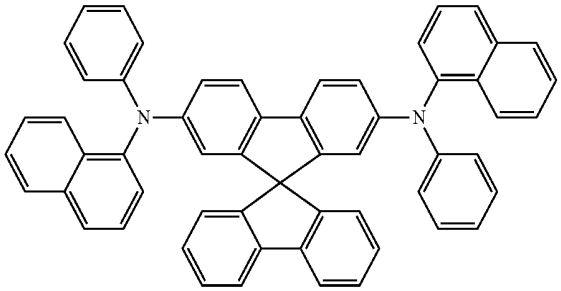
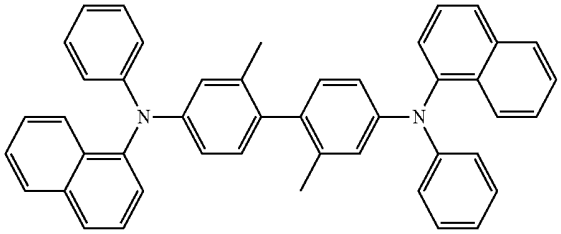


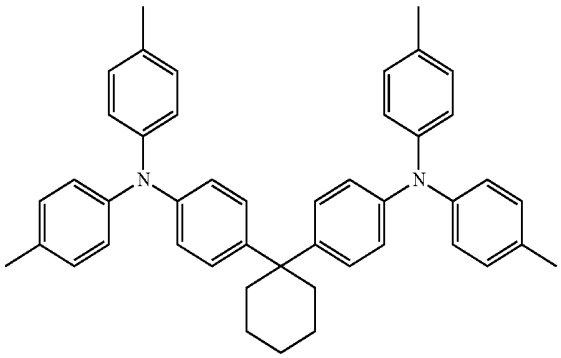
Spiro-TPD



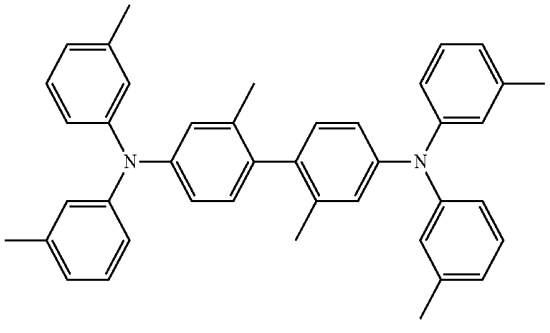
Spiro-NPB



methylated NPB



TAPC



HMTPD

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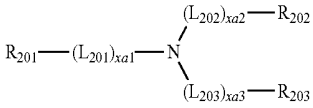
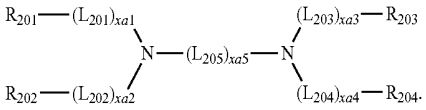
Formula 201



Formula 202



[0177] In Formulae 201 and 202,

[0178] 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,

[0179] L_{205} may be selected from *—O—*', *—S—*', *—N(Q_{201})-*', 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,

[0180] xa1 to xa4 may each independently be an integer of 0 to 3,

[0181] xa5 may be an integer of 1 to 10, and

[0182] R_{201} to R_{204} and Q_{201} 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.

[0183] For example, in Formula 202, R_{201} and R_{202} may optionally be linked each other via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R_{203} and R_{204} may optionally be linked each other via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0184] In one or more embodiments, in Formulae 201 and 202,

[0185] L_{201} to L_{205} may each independently be selected from:

[0186] 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 pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group; and

[0187] 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 pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene 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

[0188] 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.

[0189] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0190] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0191] In one or more embodiments, R_{201} to R_{204} and Q_{201} may each independently be selected from:

[0192] 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

[0193] 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

[0194] Q_{31} to Q_{33} may respectively be the same as described above.

[0195] In one or more embodiments, in Formula 201, at least one selected from R_{201} to R_{203} may each independently be selected from:

[0196] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0197] 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,

[0198] but embodiments of the present disclosure are not limited thereto.

[0199] In one or more embodiments, in Formula 202, i) R_{201} and R_{202} may be linked each other via a single bond, and/or ii) R_{203} and R_{204} may be linked each other via a single bond.

[0200] In one or more embodiments, in Formula 202, at least one selected from R_{201} to R_{204} may be selected from:

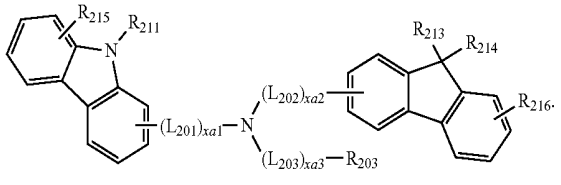
[0201] a carbazolyl group; and

[0202] 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,

[0203] but embodiments of the present disclosure are not limited thereto.

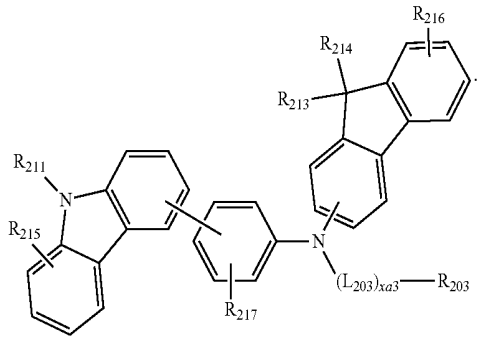
[0204] The compound represented by Formula 201 may be represented by Formula 201A:

Formua 201A



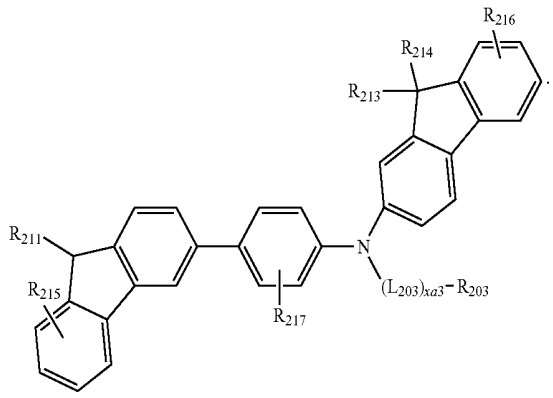
[0205] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A(1) below, but embodiments of the present disclosure are not limited thereto:

Formula 201A(1)



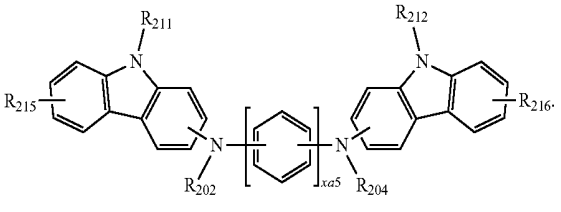
[0206] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A-1 below, but embodiments of the present disclosure are not limited thereto:

Formula 201A-1



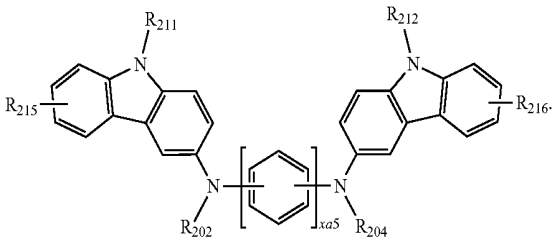
[0207] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A:

Formula 202A



[0208] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A-1:

Formula 202A-1



[0209] In Formulae 201A, 201A(1), 201A-1, 202A, and 202A-1,

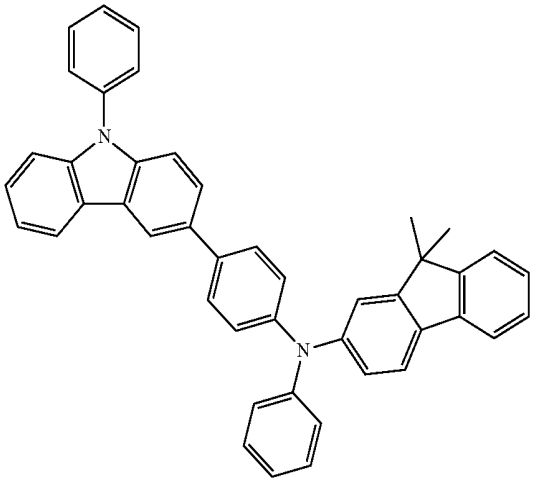
[0210] L_{201} to L_{203}, xa1 to xa3, xa5, and R_{202} to R_{204} are the same as described above,

[0211] R_{211} and R_{212} may be understood by referring to the description provided herein in connection with R_{203}, and

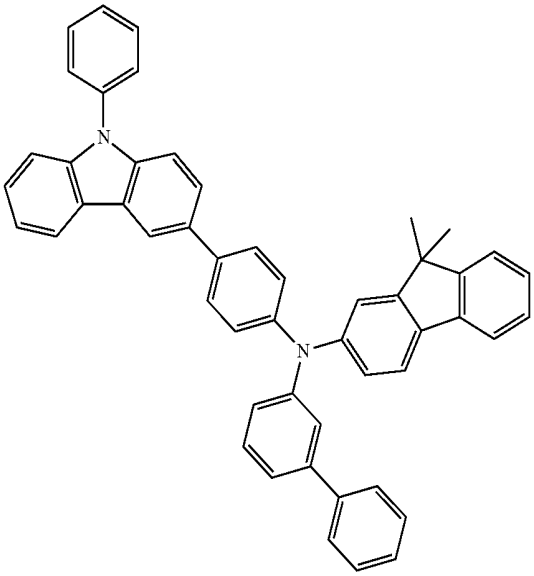
[0212] R_{213} to R_{217} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, 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 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.

[0213] The hole transport region may include at least one compound selected from Compounds HT1 to HT39, but embodiments of the present disclosure are not limited thereto:

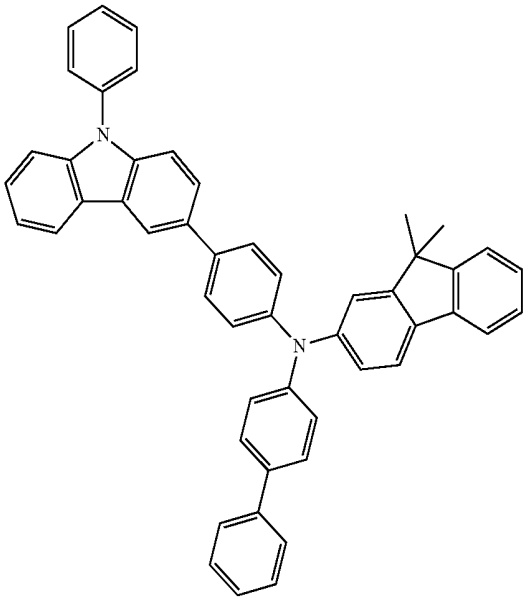
HT1



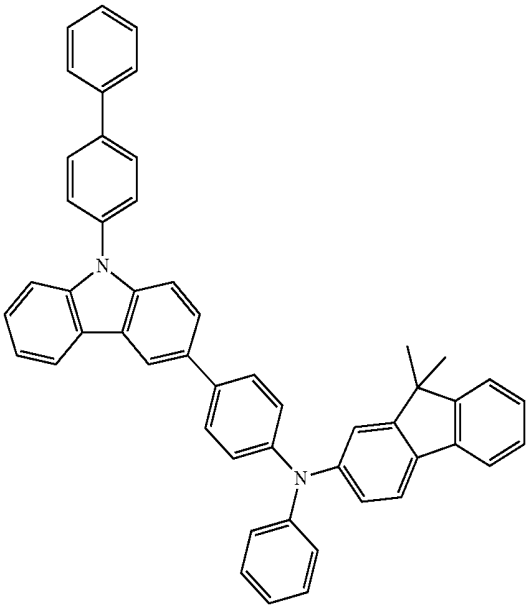
HT2



HT3



HT4



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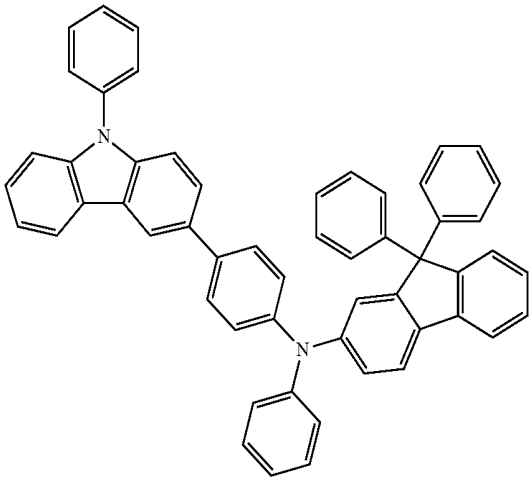
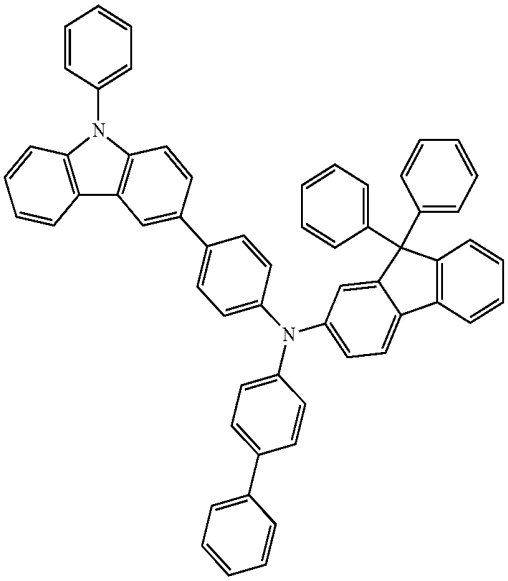
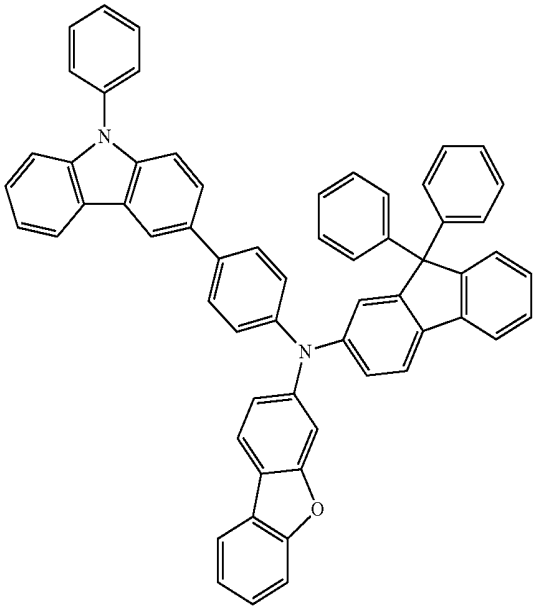
HT5



HT6



HT7



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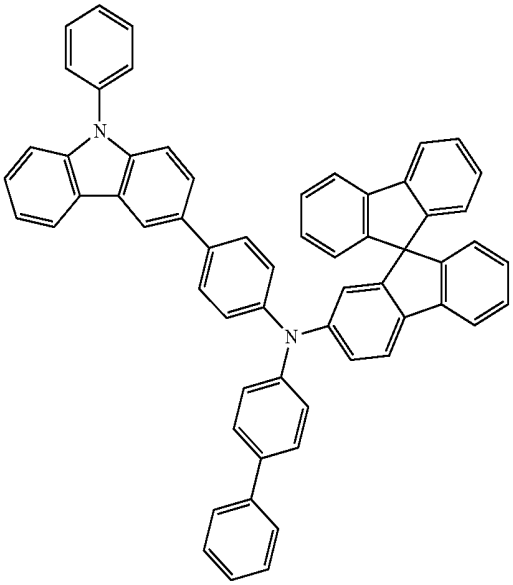

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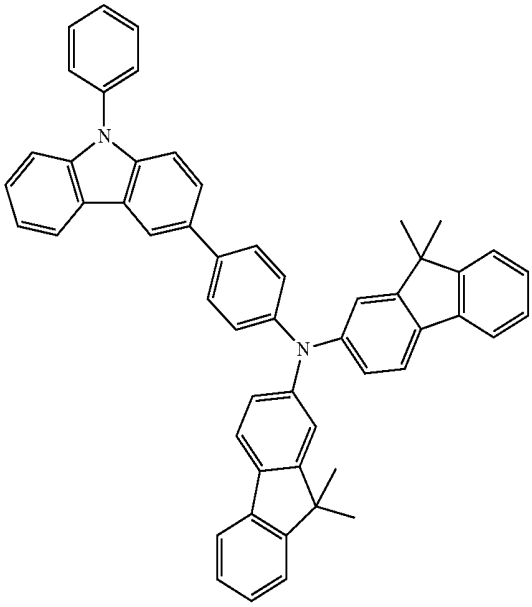

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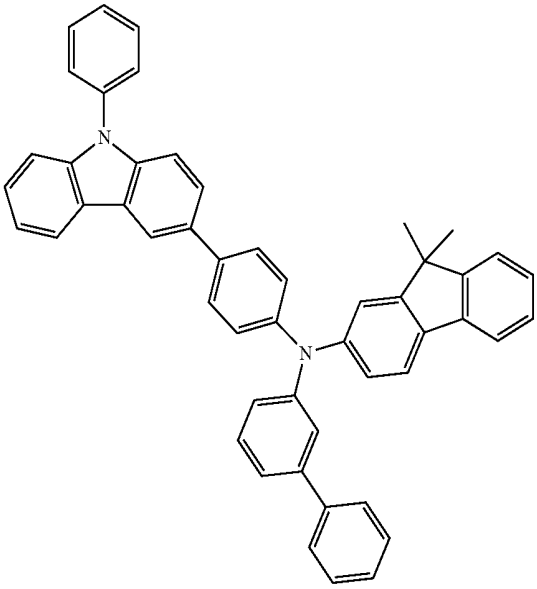

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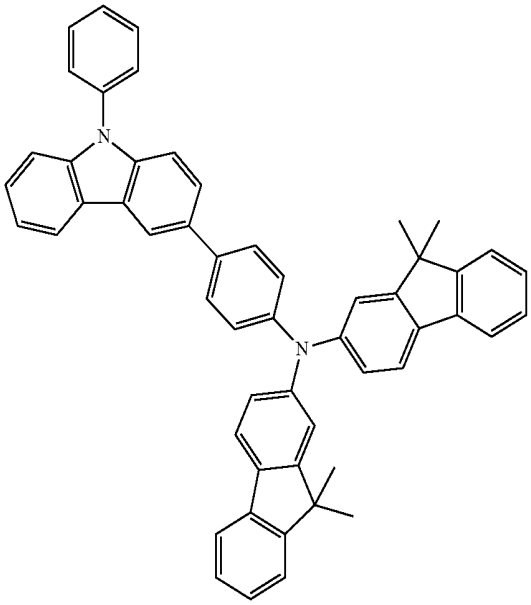

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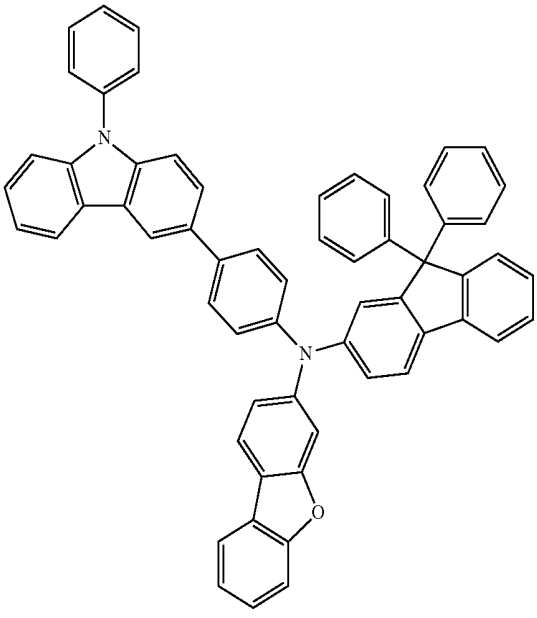

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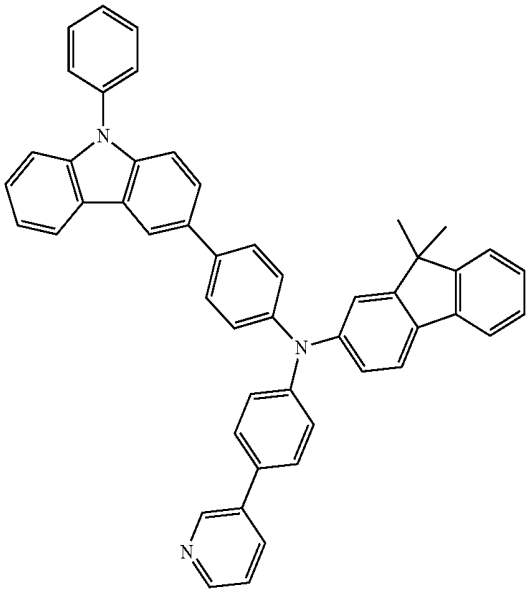

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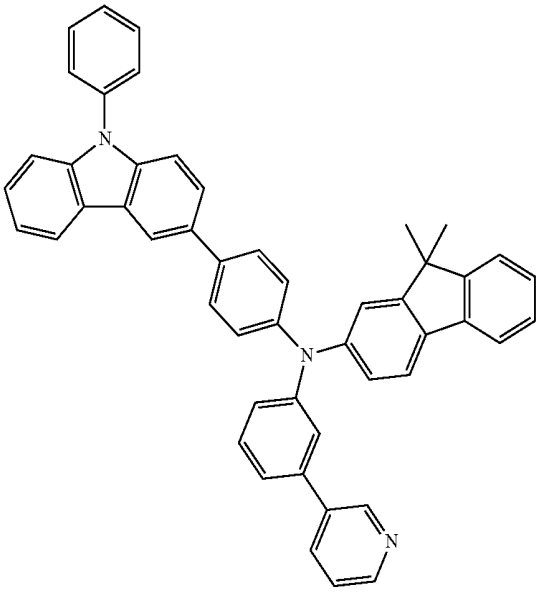

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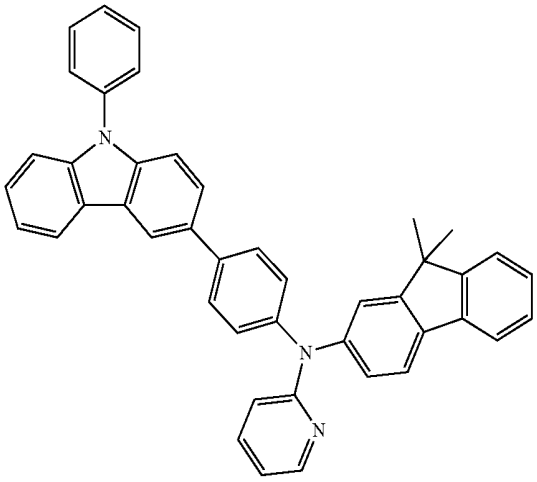

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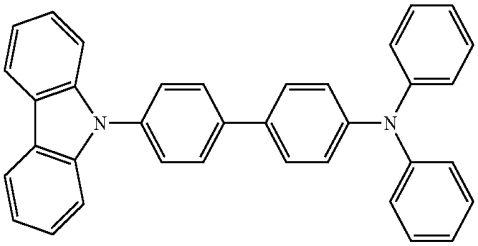

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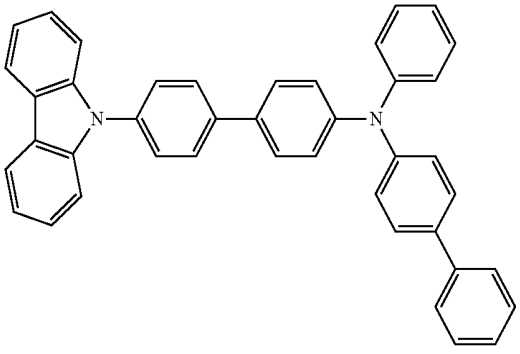

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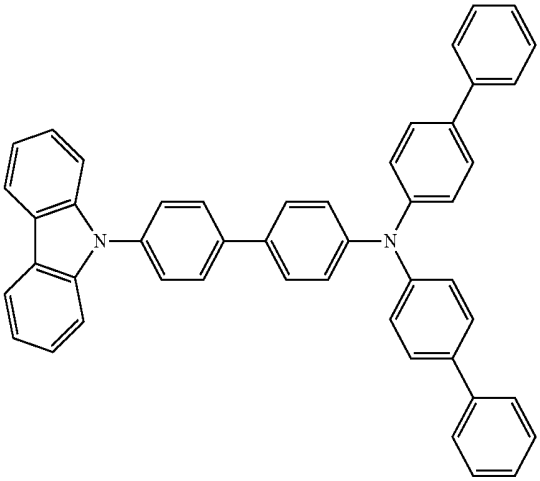

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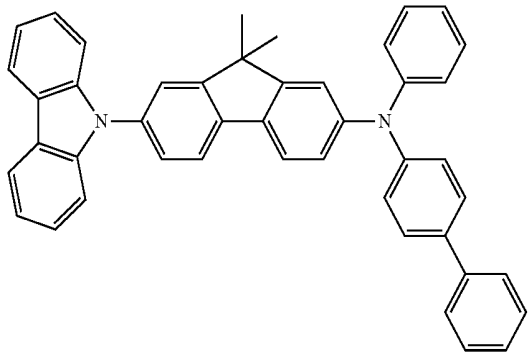

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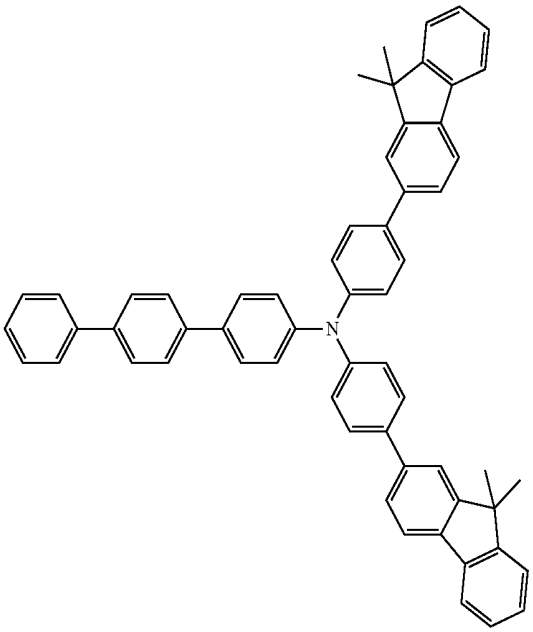

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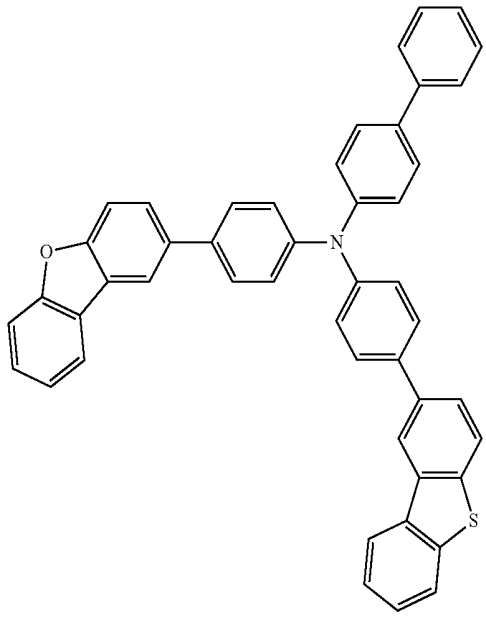

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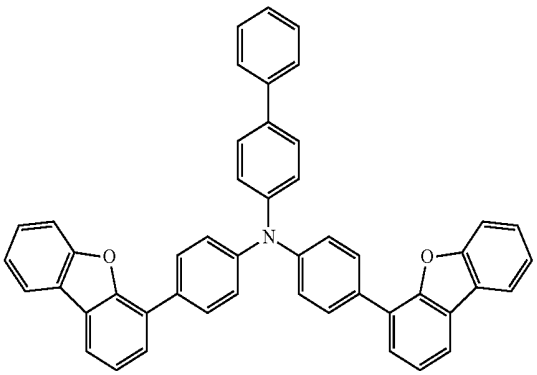

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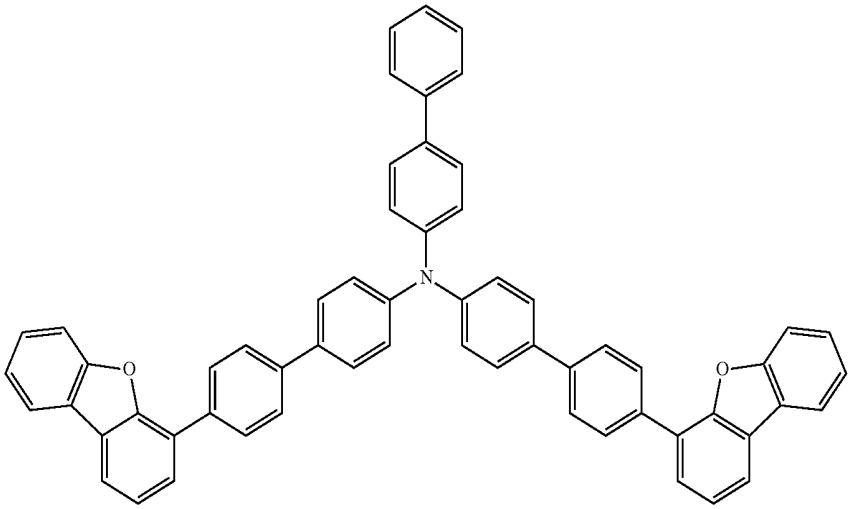

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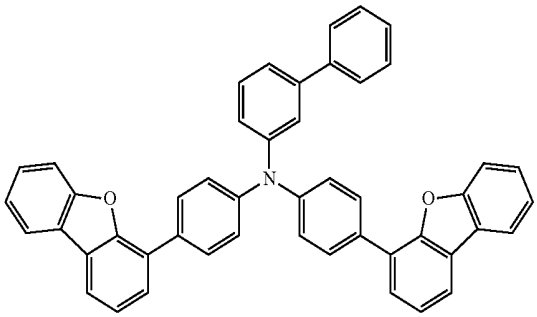

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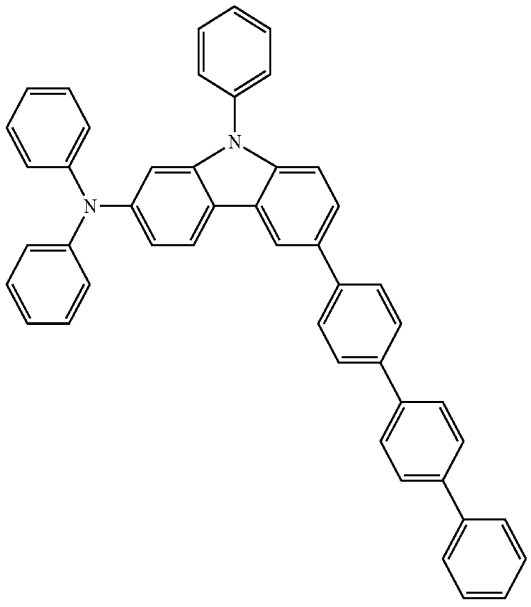

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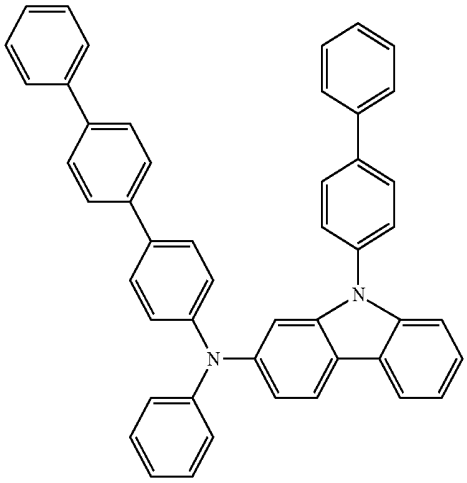

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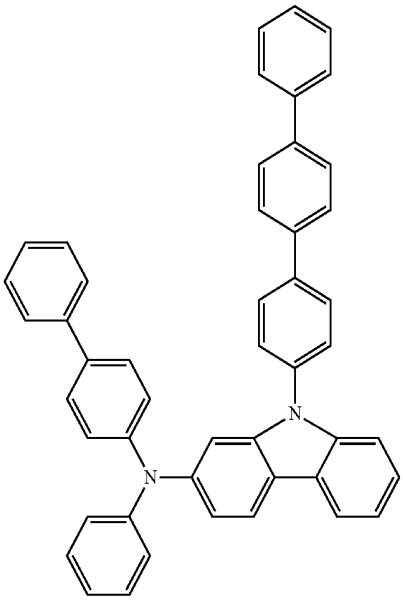

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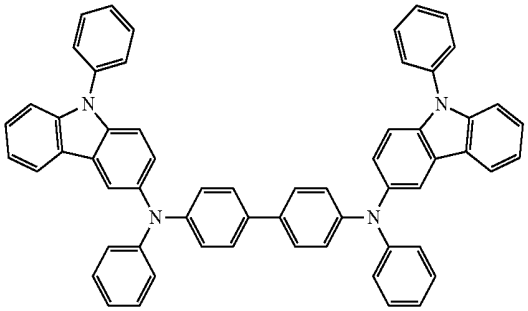

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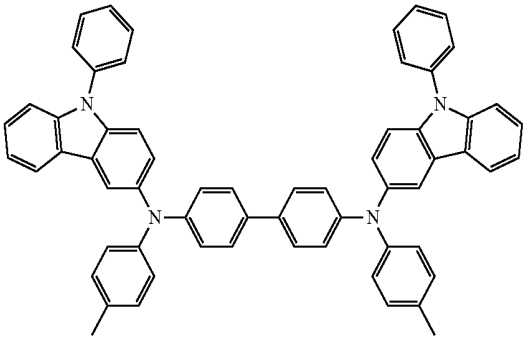

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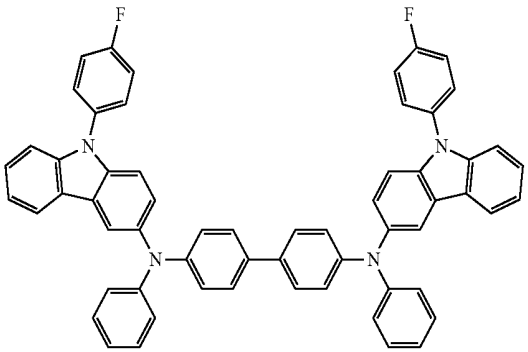

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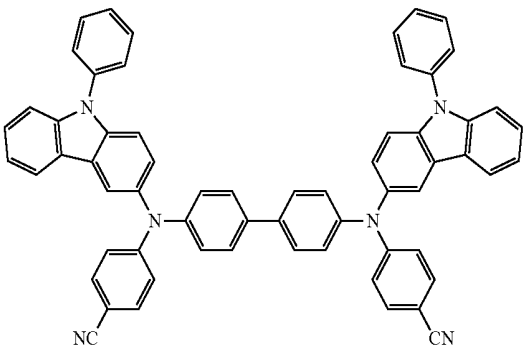

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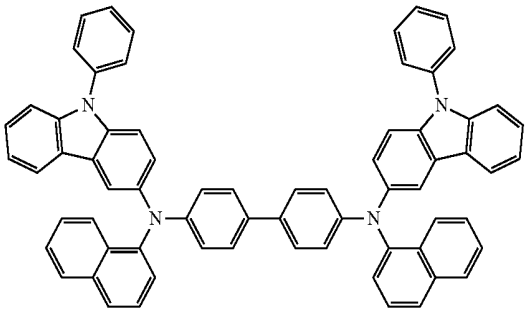

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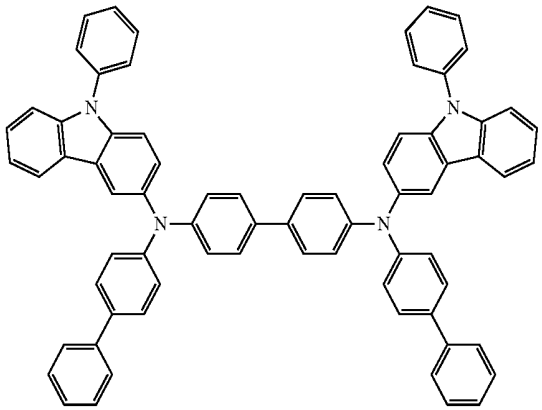

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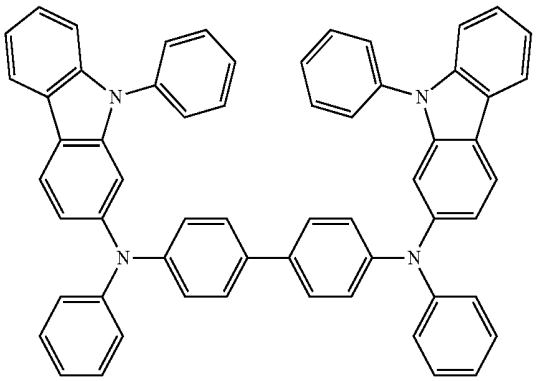

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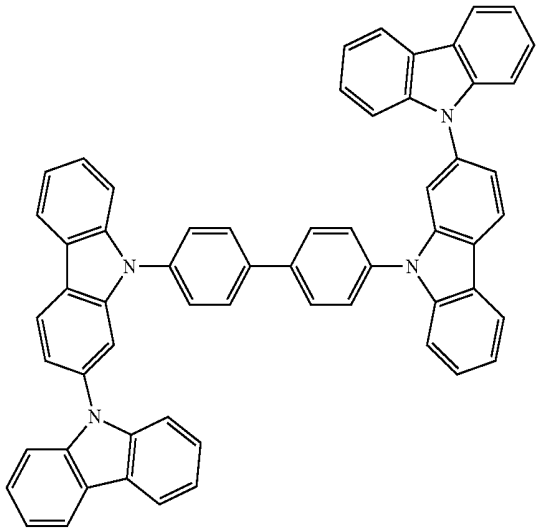

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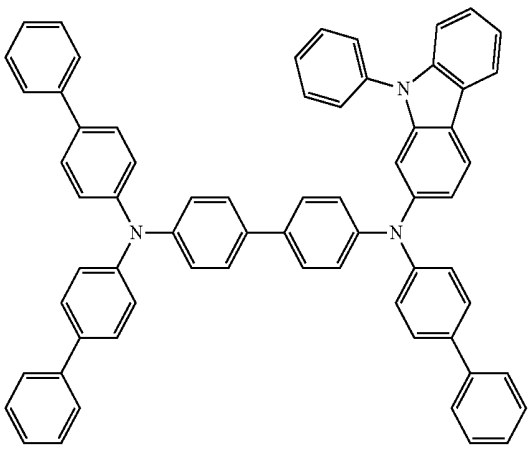

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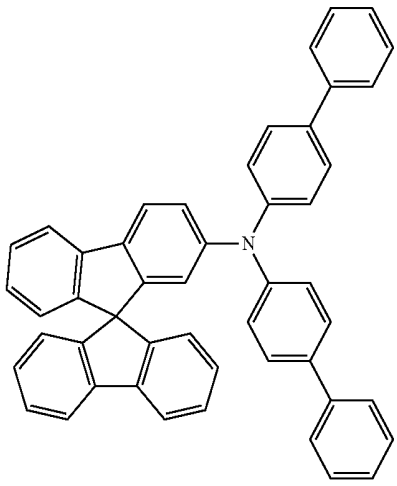

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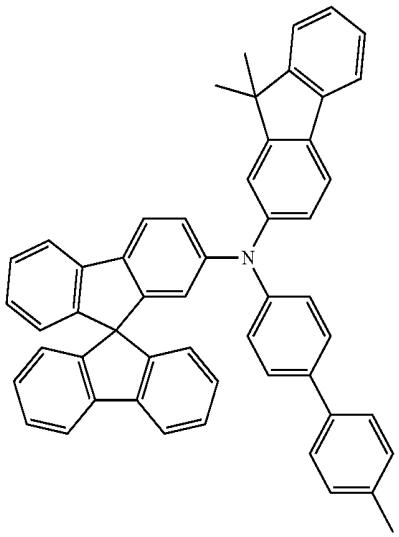

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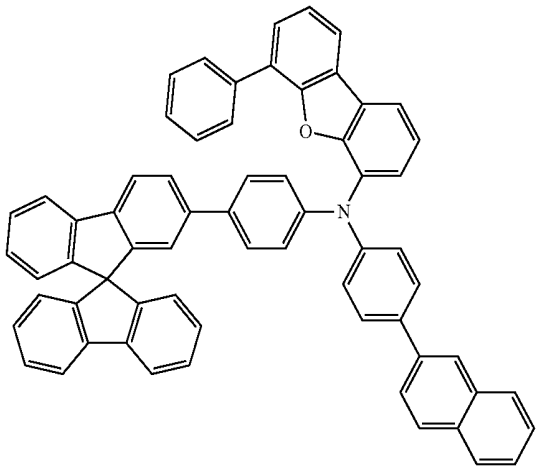


[0214] A thickness of the hole transport region may be in a range of about 100 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å. When the hole transport region includes at least one selected from a hole injection layer and a hole transport layer, the thickness of the hole injection layer 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 1500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within these ranges, suitable or satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

[0215] The emission auxiliary layer may increase light-emission efficiency by compensating for an optical resonance distance according to the wavelength of light emitted by 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.

[0216] p-Dopant

[0217] 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.

[0218] The charge-generation material may be, for example, a p-dopant.

[0219] In one embodiment, the p-dopant may have a lowest unoccupied molecular orbital (LUMO) level of about −3.5 eV or less.

[0220] 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 present disclosure are not limited thereto.

[0221] For example, the p-dopant may include at least one selected from:

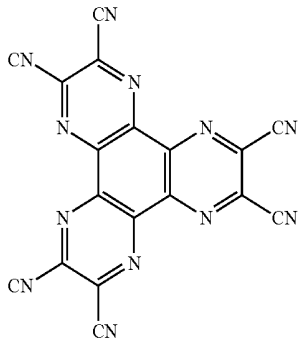
[0222] a quinone derivative, such as tetracyanoquinodimethane (TCNQ) or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ);

[0223] a metal oxide, such as tungsten oxide or molybdenum oxide;

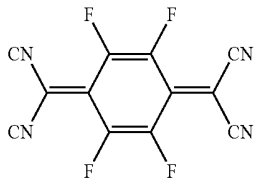
[0224] 1,4,5,8,9,12-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and

[0225] a compound represented by Formula 221 below:

[0226] but embodiments of the present disclosure are not limited thereto:



HAT-CN



F4-TCNQ

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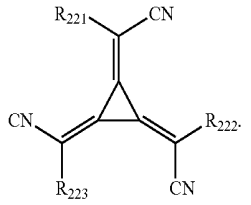
Formula 221



[0227] In Formula 221,

[0228] 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, provided that at least one selected from R_{221} to R_{223} has 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.

[0229] Emission Layer in Organic Layer **150**

[0230] When the organic light-emitting device **10** is a full-color organic light-emitting device, the emission layer 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.

[0231] 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.

[0232] An amount of the dopant in the emission layer 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 present disclosure are not limited thereto.

[0233] 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.

[0234] Host in Emission Layer

[0235] In one or more embodiments, the host may include a compound represented by Formula 301 below:

$$[Ar_{301}]_{xb11}-[(L_{301})_{xb1}-R_{301}]_{xb21}. \quad \text{Formula 301}$$

[0236] In Formula 301,

[0237] 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,

[0238] xb11 may be 1, 2, or 3,

[0239] L_{301} 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;

[0240] xb1 may be an integer from 0 to 5,

[0241] 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 —$P(=O)(Q_{301})(Q_{302})$,

[0242] xb21 may be an integer from 1 to 5, and

[0243] 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 present disclosure are not limited thereto.

[0244] In one embodiment, Ar_{301} in Formula 301 may be selected from:

[0245] a naphthalene group, a fluorene group, a spirobifluorene 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

[0246] a naphthalene group, a fluorene group, a spirobifluorene 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

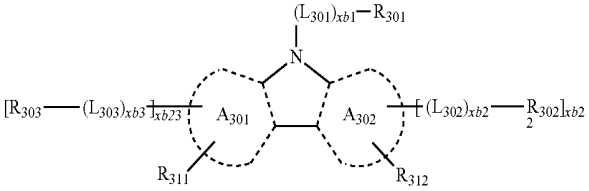
terphenyl group, a naphthyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0247] 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 present disclosure are not limited thereto.

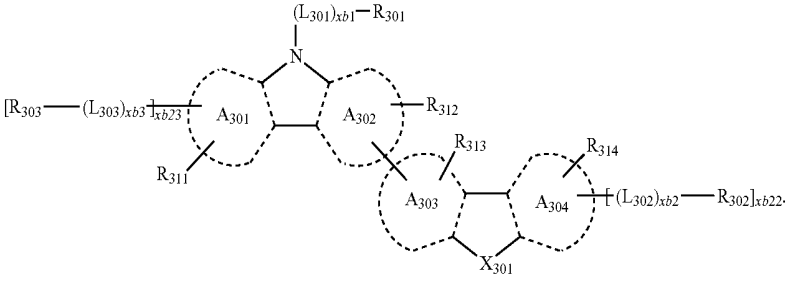
[0248] In Formula 301, when xb11 is two or more, two or more of Ar_{301}(s) may be linked via a single bond.

[0249] 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



[0250] In Formulae 301-1 and 301-2,

[0251] A_{301} to A_{304} may each independently be selected from a benzene, a naphthalene, a phenanthrene, a fluoranthene, a triphenylene, a pyrene, a chrysene, a pyridine, a pyrimidine, an indene, a fluorene, a spiro-bifluorene, a benzofluorene, a dibenzofluorene, an indole, a carbazole, benzocarbazole, dibenzocarbazole, a furan, a benzofuran, a dibenzofuran, a naphthofuran, a benzonaphthofuran, dinaphthofuran, a thiophene, a benzothiophene, a dibenzothiophene, a naphthothiophene, a benzonaphthothiophene, and a dinaphthothiophene,

[0252] X_{301} may be O, S, or N-[$(L_{304})_{xb4}$-R_{304}],

[0253] R_{311} to R_{314} 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 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 —$P(=O)(Q_{31})(Q_{32})$,

[0254] xb22 and xb23 may each independently be 0, 1, or 2,

[0255] L_{301}, xb1, R_{301}, and Q_{31} to Q_{33} may respectively be the same as described above,

[0256] L_{302} to L_{304} may respectively be same as described in connection with L_{301},

[0257] xb2 to xb4 may respectively be same as described in connection with xb1, and

[0258] R_{302} to R_{304} may respectively be same as described in connection with R_{301}.

[0259] For example, in Formulae 301, 301-1, and 301-2, L_{301} to L_{304} may each independently be selected from:

[0260] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene 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 benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0261] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a diben-

zofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene 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 benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene 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 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 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, an azacarbazolyl 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

[0262] Q_{31} and Q_{33} may respectively be the same as described above.

[0263] In one embodiment, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

[0264] 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 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

[0265] 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 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, 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 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 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 benzox-

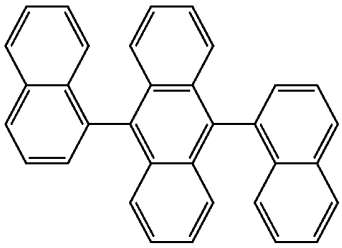
azolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0266] Q_{31} and Q_{33} may respectively be the same as described above.

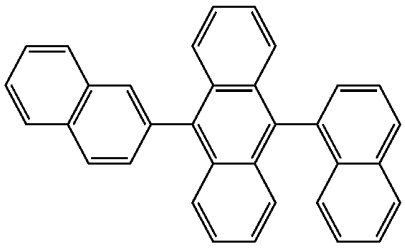
[0267] In one or more embodiments, the host may include an alkaline earth metal complex. For example, the host may be selected from a Be complex (for example, Compound H55), a Mg complex, and a Zn complex.

[0268] 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 present disclosure are not limited thereto:

H1



H2



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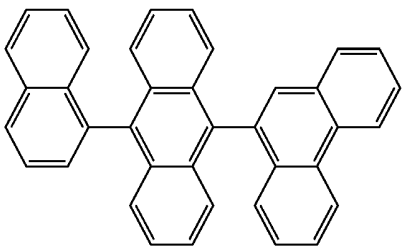

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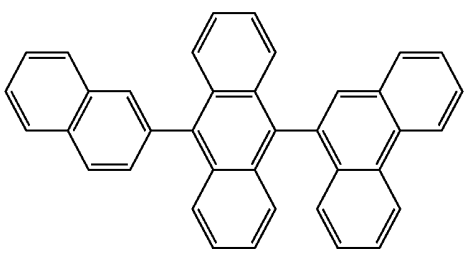

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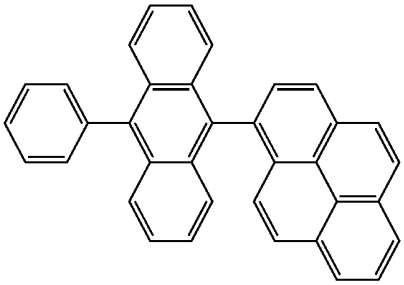
H5



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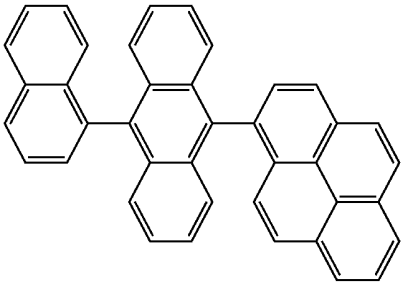

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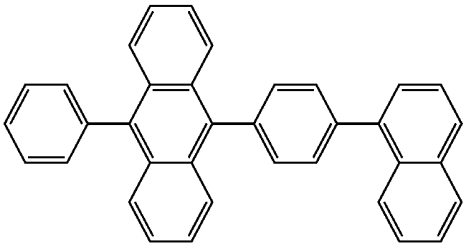

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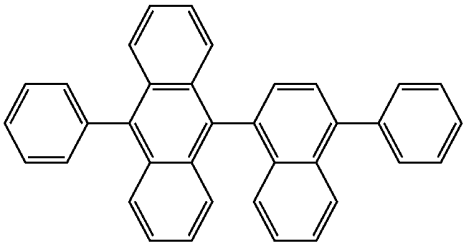

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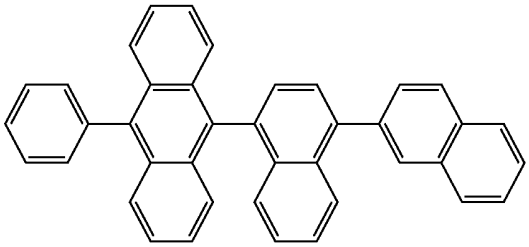

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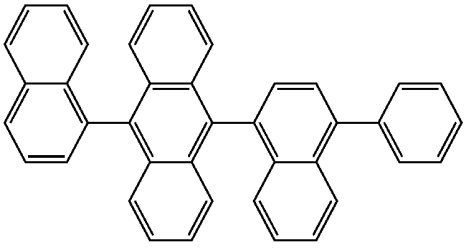

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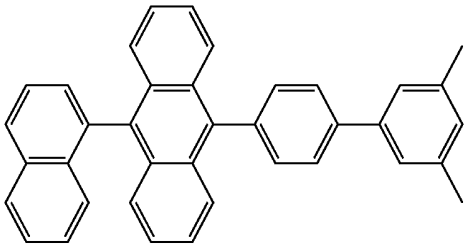

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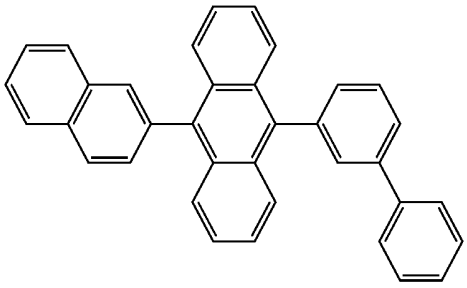

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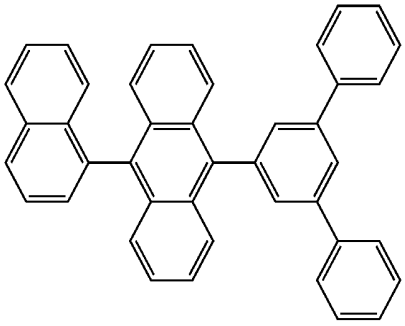

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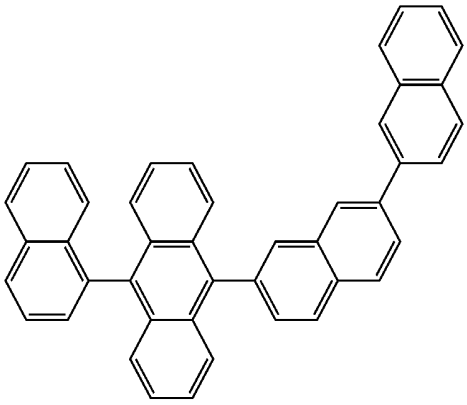

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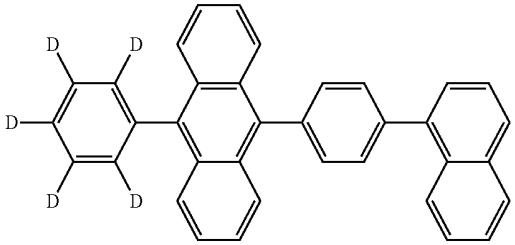

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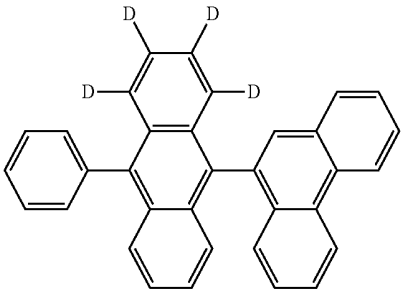

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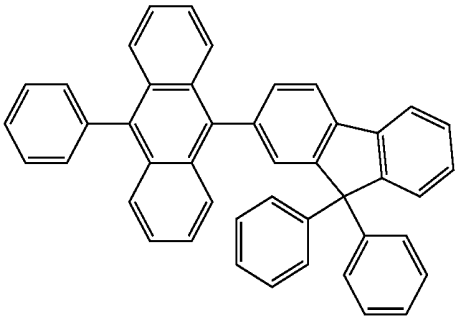

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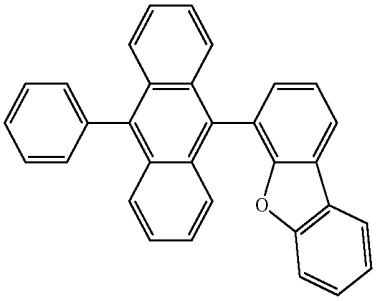

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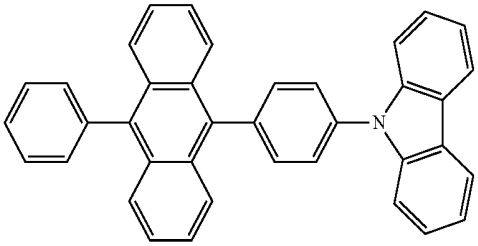

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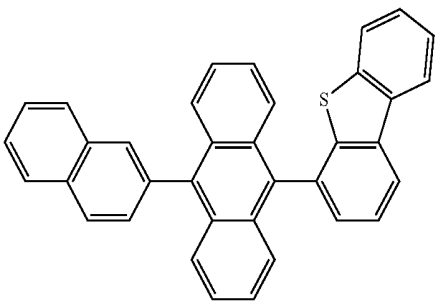

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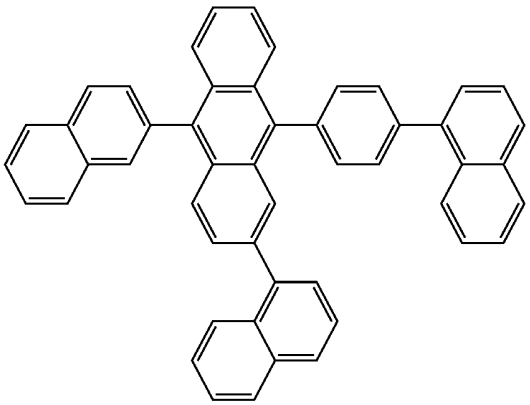
H21



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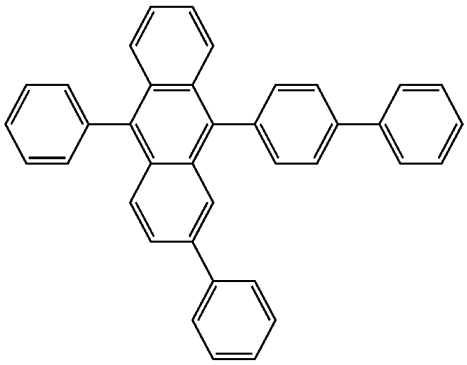

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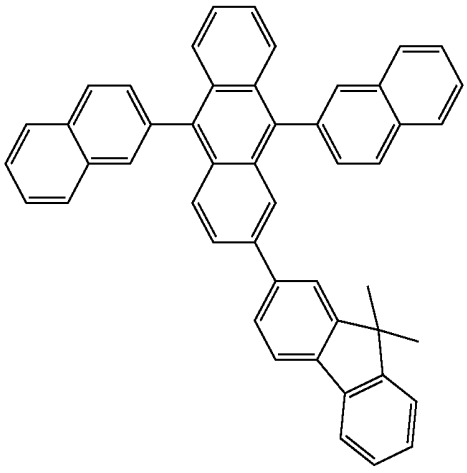

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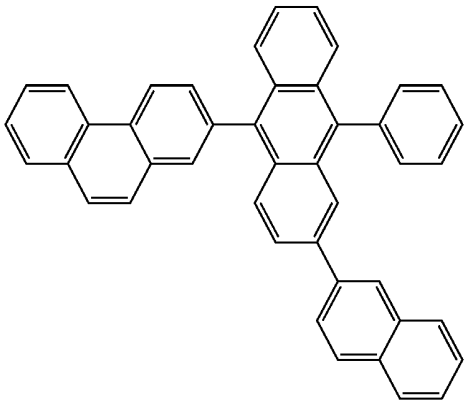

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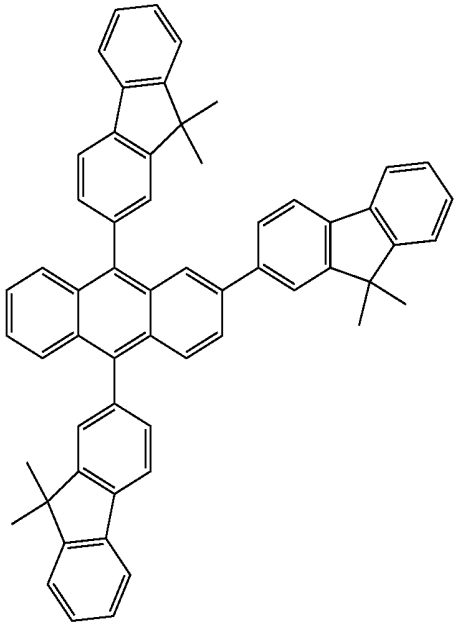
H25



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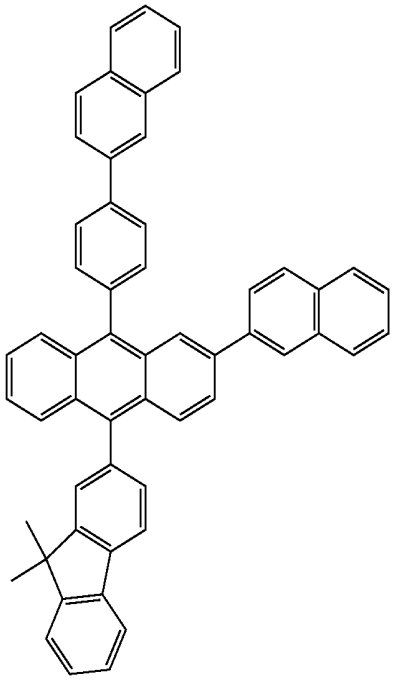

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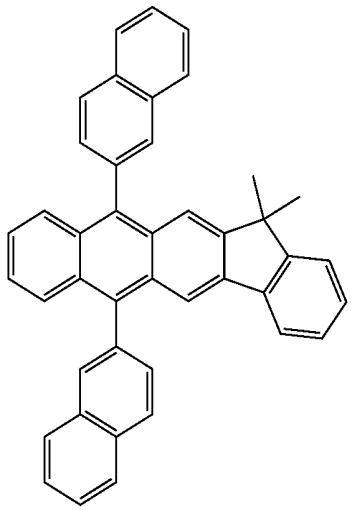
H27



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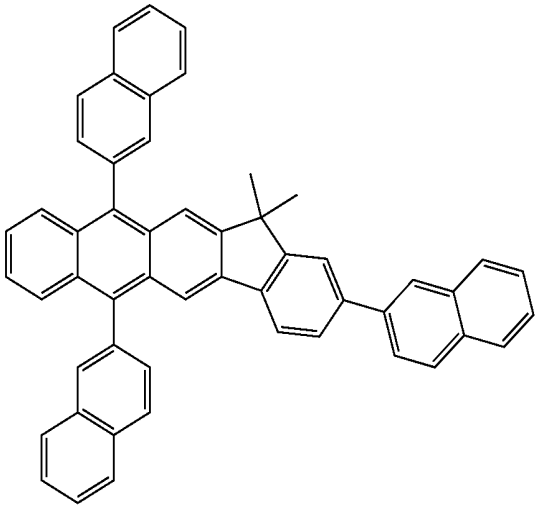

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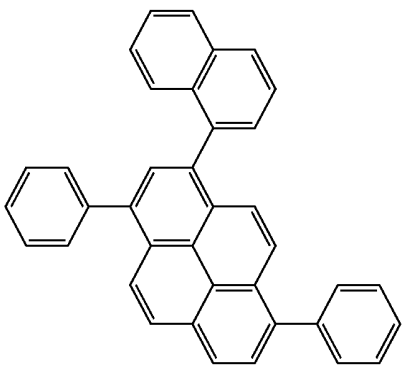

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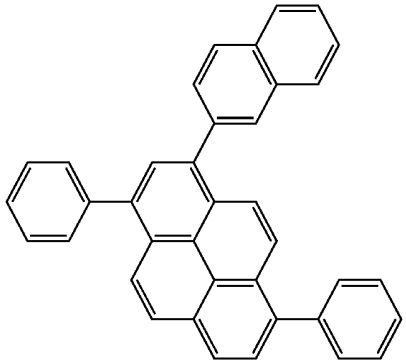
H30



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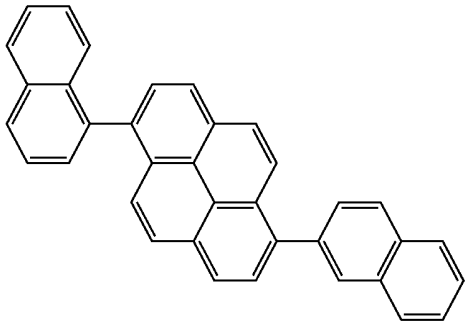

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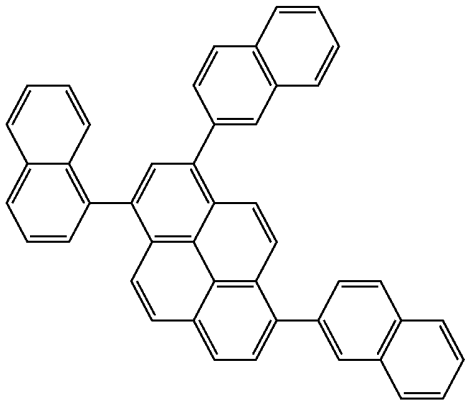

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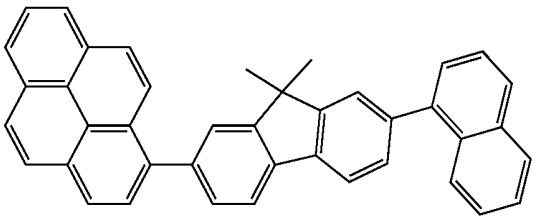

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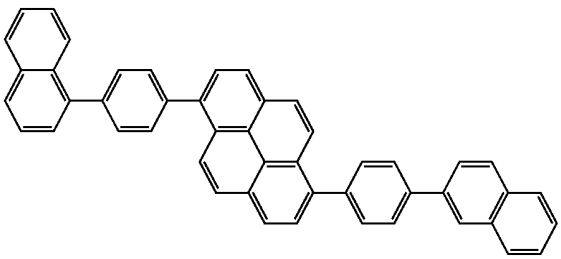

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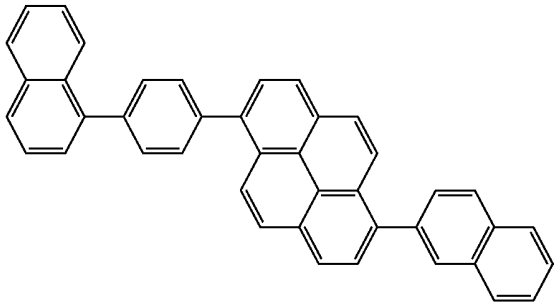

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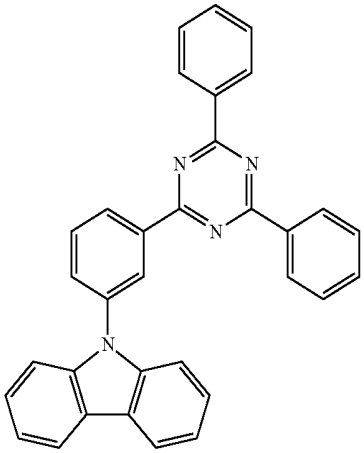

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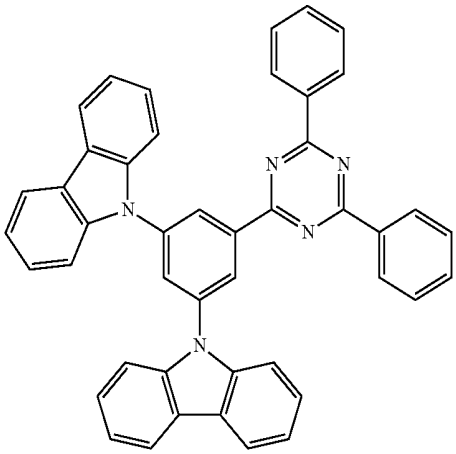

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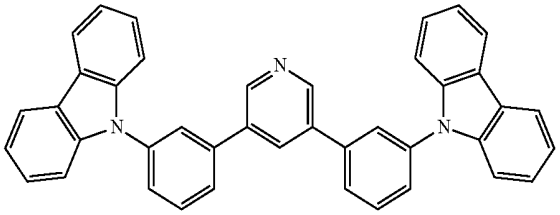

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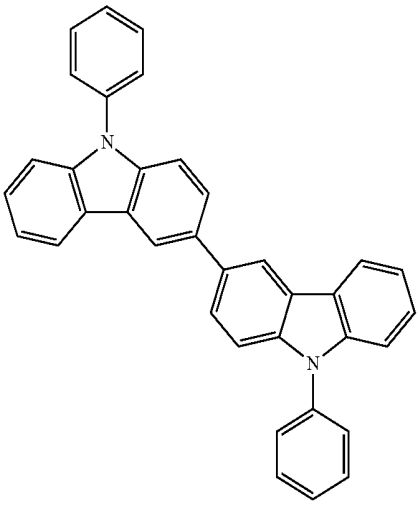

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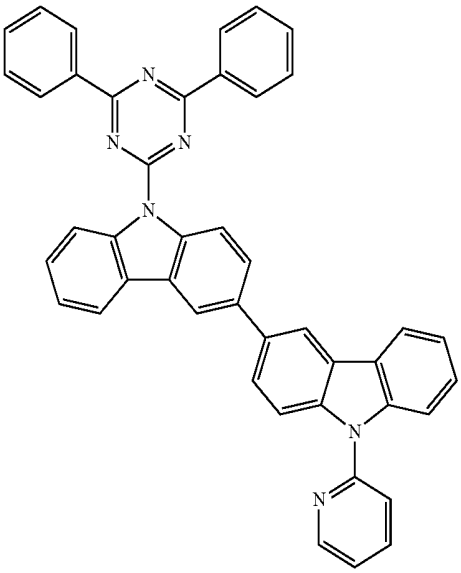

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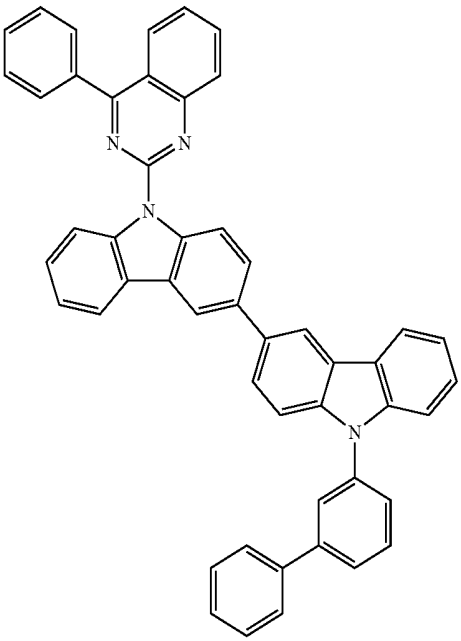

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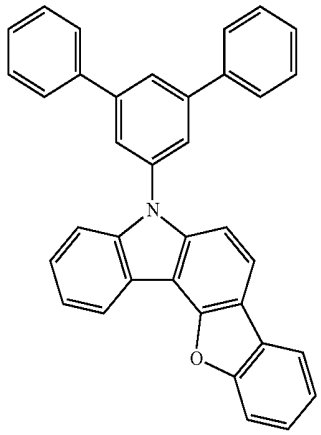

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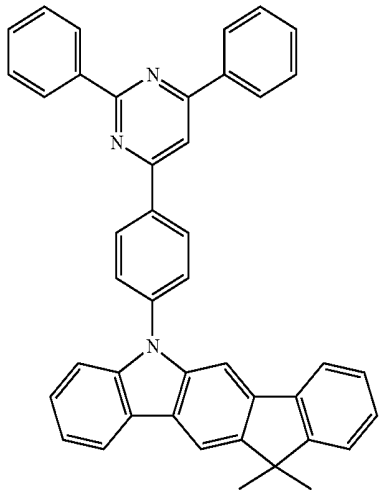

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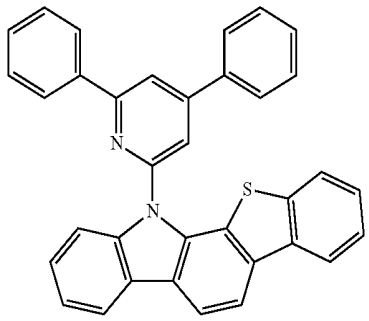

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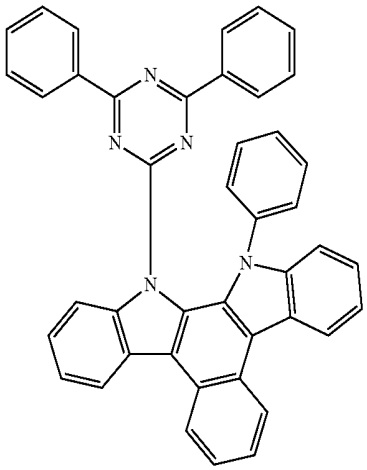

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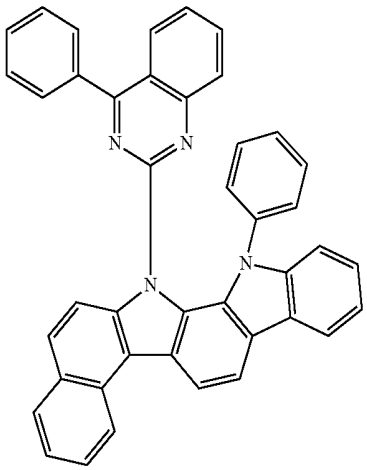

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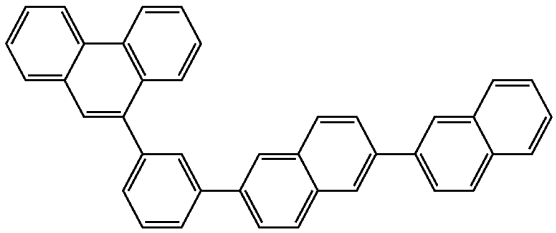

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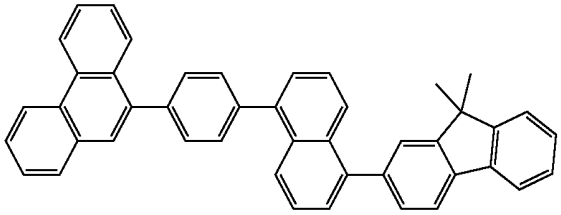

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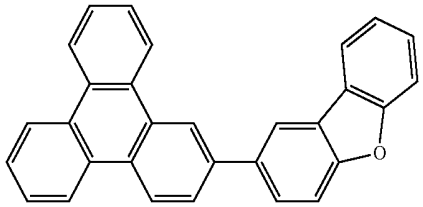

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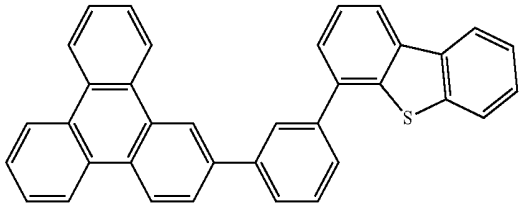

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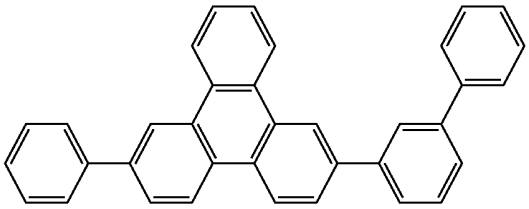

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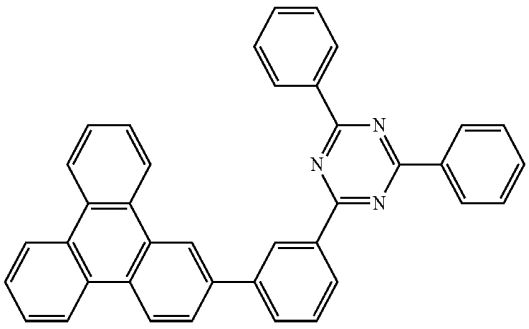

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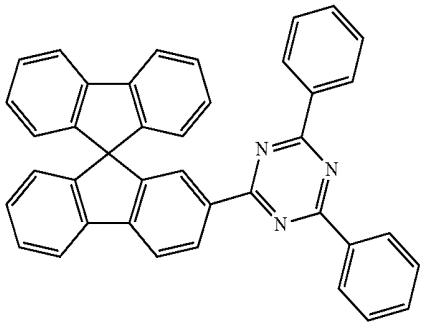

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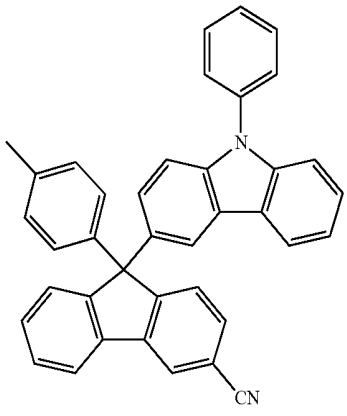

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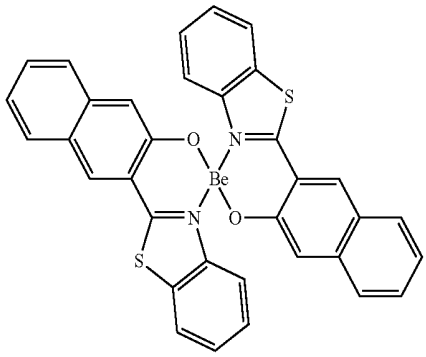
H55



[0269] 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).

[0270] However, embodiments of the present disclosure are not limited thereto. 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).

[0271] Phosphorescent Dopant Included in Emission Layer in Organic Layer **150**

[0272] The phosphorescent dopant may include an organometallic compound represented by Formula 1 below:

[0273] Electron Transport Region in Organic Layer **150**

[0274] The electron transport region 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.

[0275] The electron transport region may include at least one 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 present disclosure are not limited thereto.

[0276] For example, the electron transport region may have an electron transport 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.

[0277] 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.

[0278] As used herein, the term "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.

[0279] For example, the "π electron-depleted nitrogen-containing ring" may be i) a 60-membered to 7-membered heteromonocyclic group having at least one *—N=*' moi-

ety, 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 (e.g., combined together), 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 (e.g., combined together with) at least one C_5-C_{60} carbocyclic group.

[0280] Examples of the π electron-depleted nitrogen-containing ring include an imidazole, a pyrazole, a thiazole, an isothiazole, an oxazole, an isoxazole, a pyridine, a pyrazine, a pyrimidine, a pyridazine, an indazole, a purine, a quinoline, an isoquinoline, a benzoquinoline, a phthalazine, a naphthyridine, a quinoxaline, a quinazoline, a cinnoline, a phenanthridine, an acridine, a phenanthroline, a phenazine, a benzimidazole, an isobenzothiazole, a benzoxazole, an isobenzoxazole, a triazole, a tetrazole, an oxadiazole, a triazine, thiadiazol, an imidazopyridine, an imidazopyrimidine, and an azacarbazole, but are not limited thereto.

[0281] For example, the electron transport region may include a compound represented by Formula 601:

$$[Ar_{601}]_{xe11}\text{-}[(L_{601})_{xe1}\text{-}R_{601}]_{xe21}. \qquad \text{Formula 601}$$

[0282] In Formula 601,

[0283] 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,

[0284] xe11 may be 1, 2, or 3,

[0285] L_{601} 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;

[0286] xe1 may be an integer from 0 to 5,

[0287] 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 —$P(=O)(Q_{601})(Q_{602})$,

[0288] 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

[0289] xe21 may be an integer from 1 to 5.

[0290] 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.

[0291] In one embodiment, ring Ar_{601} in Formula 601 may be selected from:

[0292] 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

[0293] 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, 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, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

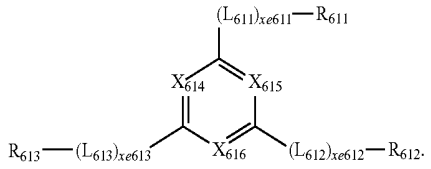
[0294] Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0295] When xe11 in Formula 601 is two or more, two or more Ar_{601}(s) may be linked via a single bond.

[0296] In one or more embodiments, Ar_{601} in Formula 601 may be an anthracene group.

[0297] In one or more embodiments, a compound represented by Formula 601 may be represented by Formula 601-1:

Formula 601-1



[0298] In Formula 601-1,

[0299] X_{614} may be N or $C(R_{614})$, X_{615} may be N or $C(R_{615})$, X_{616} may be N or $C(R_{616})$, and at least one selected from X_{614} to X_{616} may be N,

[0300] L_{611} to L_{613} may each independently be the same as described in connection with L_{601},

[0301] xe611 to xe613 may each independently be the same as described in connection with xe1,

[0302] R_{611} to R_{613} may each independently be the same as described in connection with R_{601}, and

[0303] R_{614} to R_{616} 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 phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0304] In one embodiment, L_{601} and L_{611} to L_{613} in Formulae 601 and 601-1 may each independently be selected from:

[0305] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene 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 benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0306] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene 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 benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene 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 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 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,

[0307] but embodiments of the present disclosure are not limited thereto.

[0308] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0309] In one or more embodiments, in Formulae 601 and 601-1, R_{601} and R_{611} to R_{613} may each independently be selected from:

[0310] 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 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;

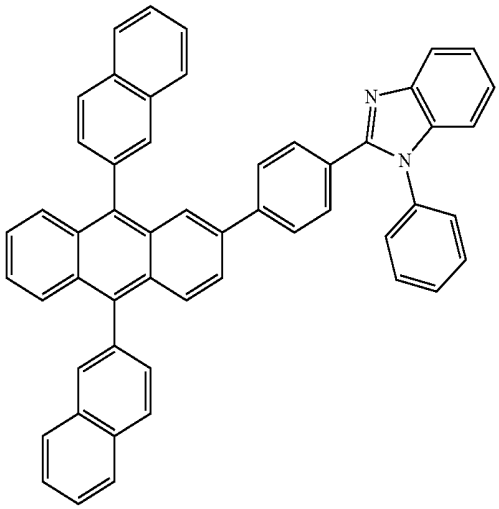
[0311] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a 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, 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 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 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

[0312] $—S(=O)_2(Q_{601})$ and $—P(=O)(Q_{601})(Q_{602})$, and

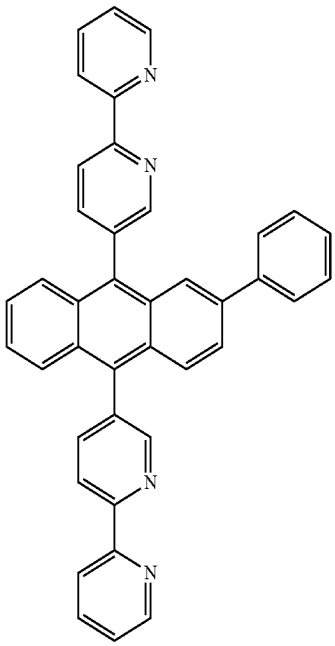
[0313] Q_{601} and Q_{602} may respectively be the same as described above.

[0314] The electron transport region may include at least one compound selected from Compounds ET1 to ET36, but embodiments of the present disclosure are not limited thereto:

ET1



ET2



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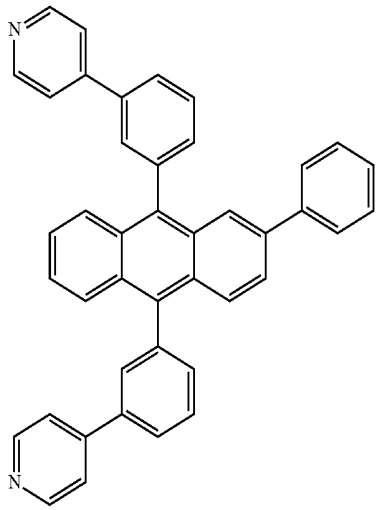
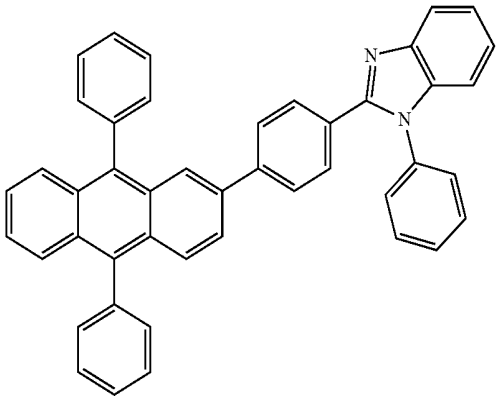
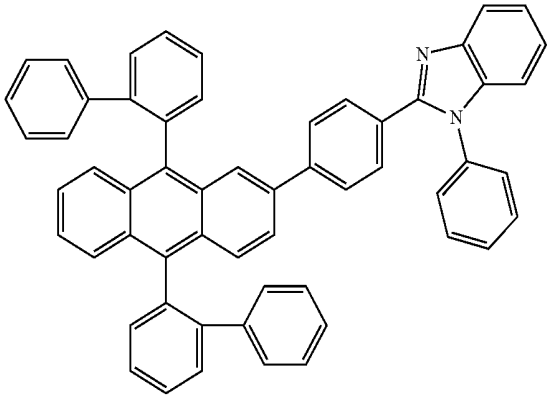
ET3



ET4



ET5



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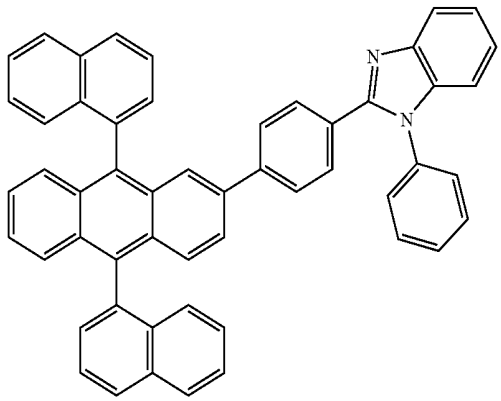
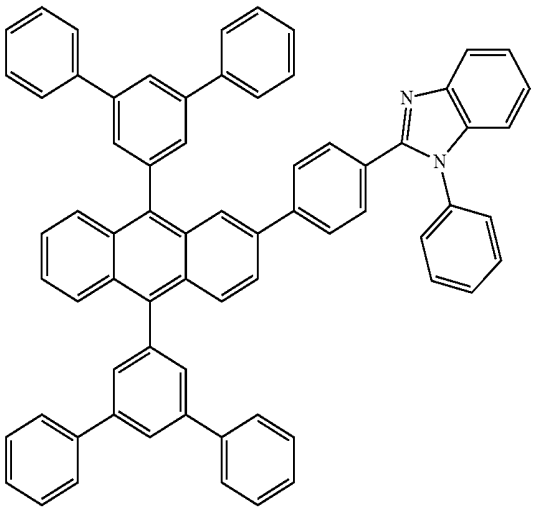
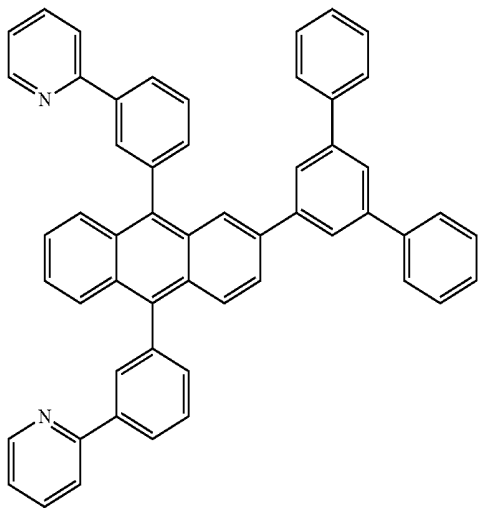
ET6



ET7



ET8



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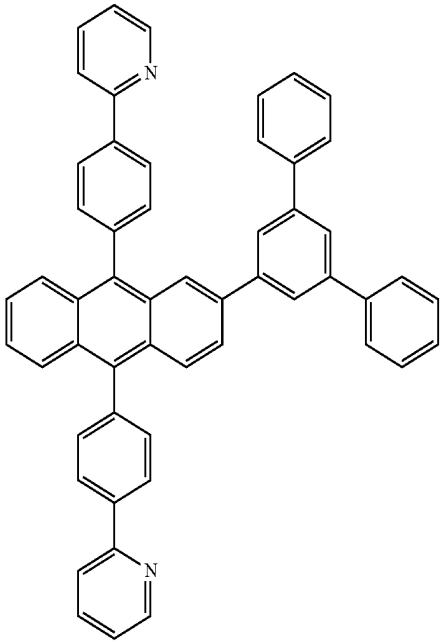
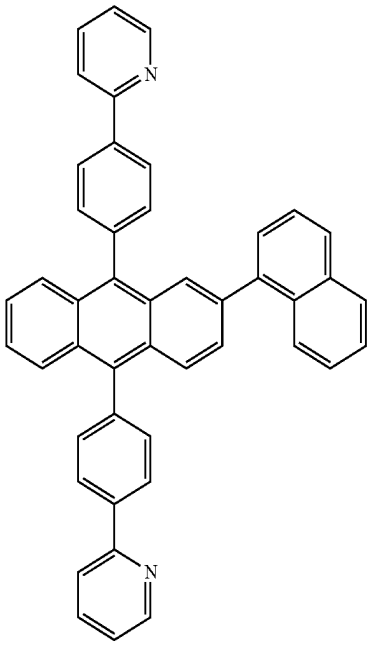
ET9



ET10



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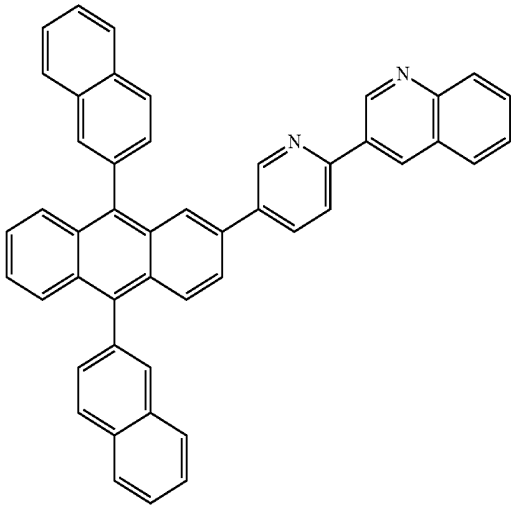
ET11



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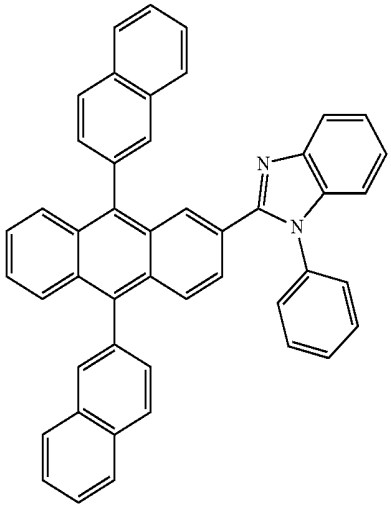

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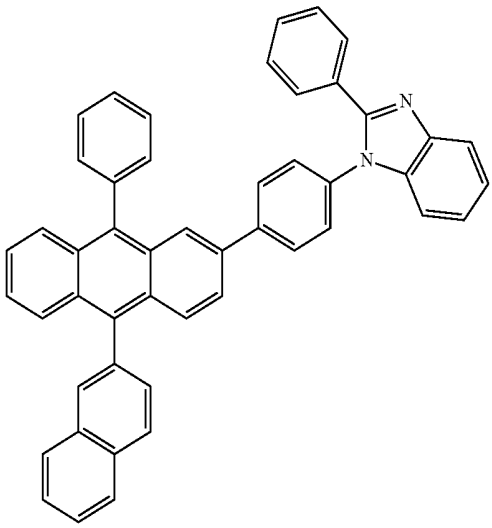

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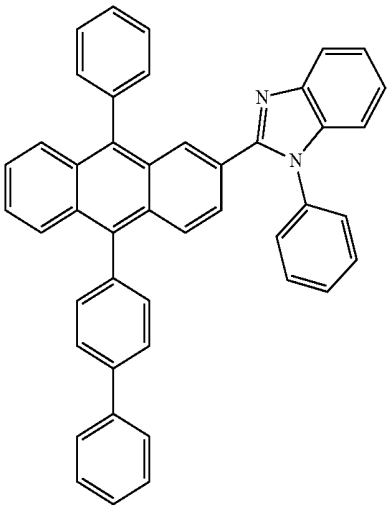
ET14



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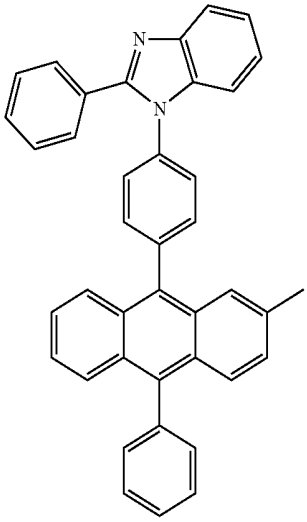
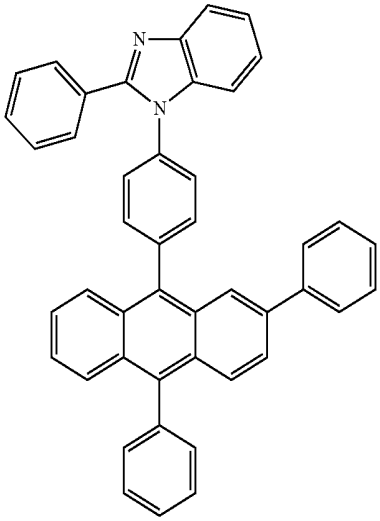


ET16



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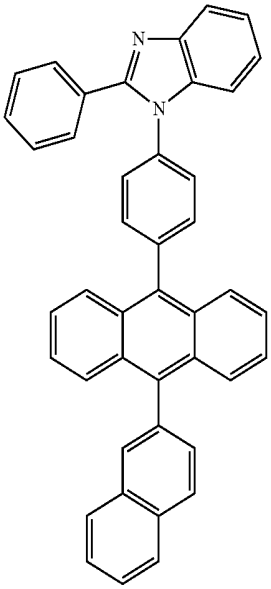
ET17



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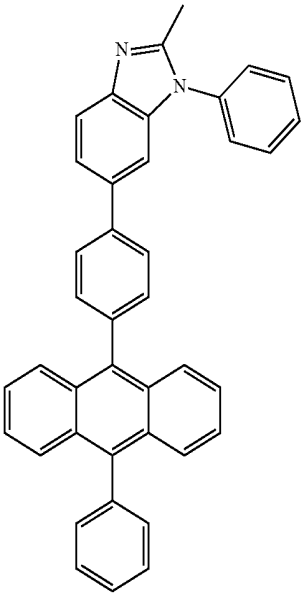

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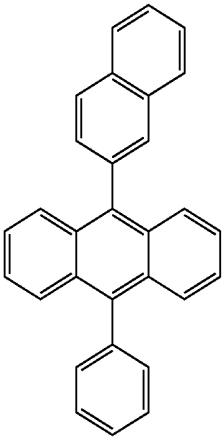

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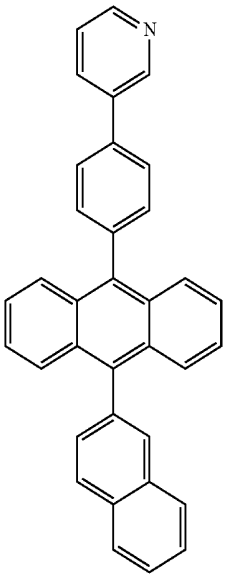
ET20



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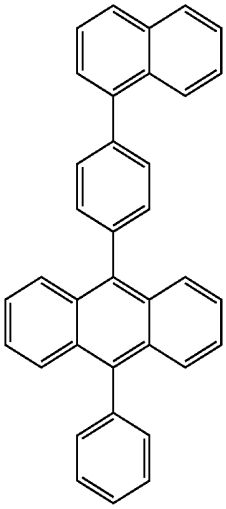

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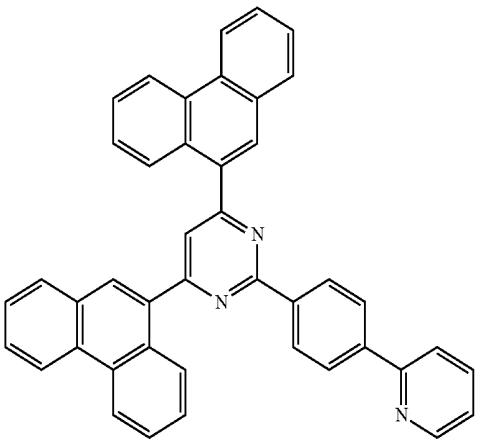

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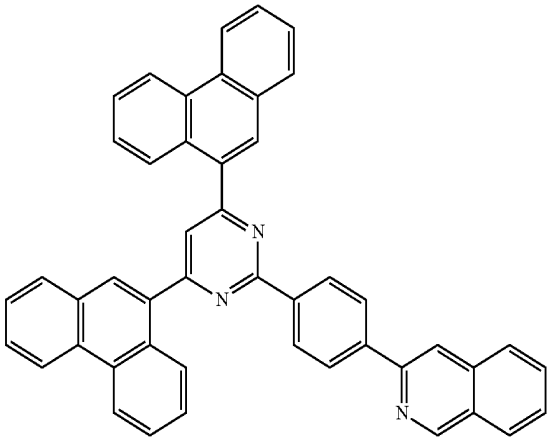
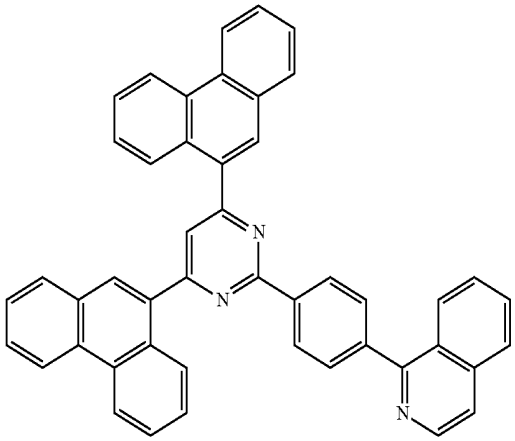
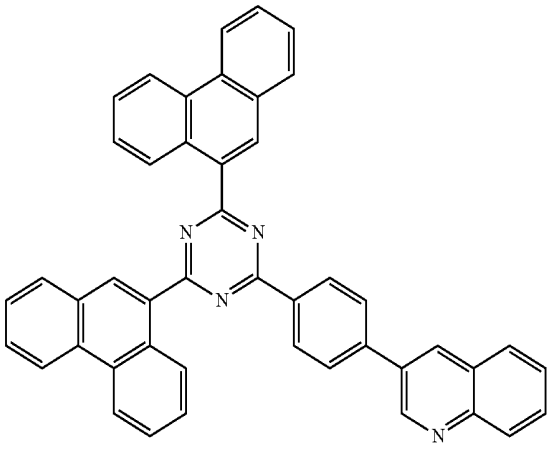


ET24



ET25



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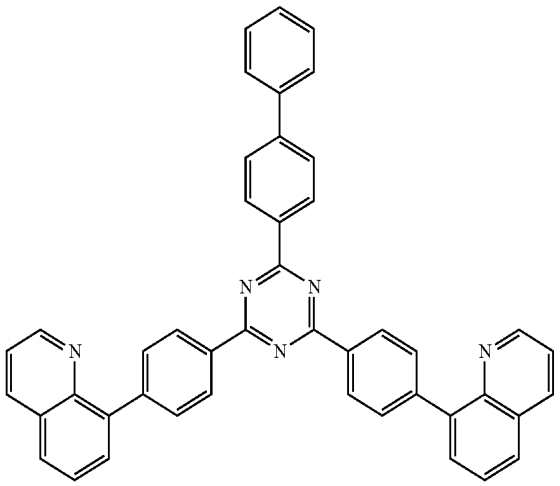

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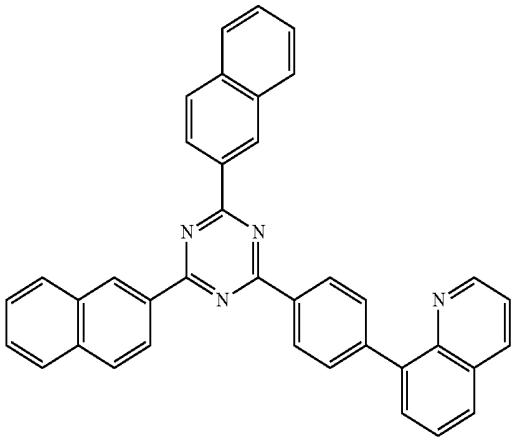
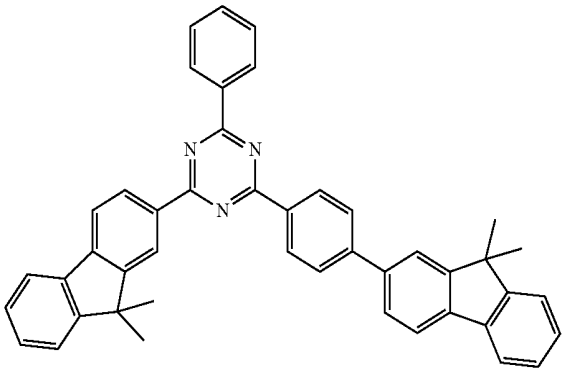


ET28



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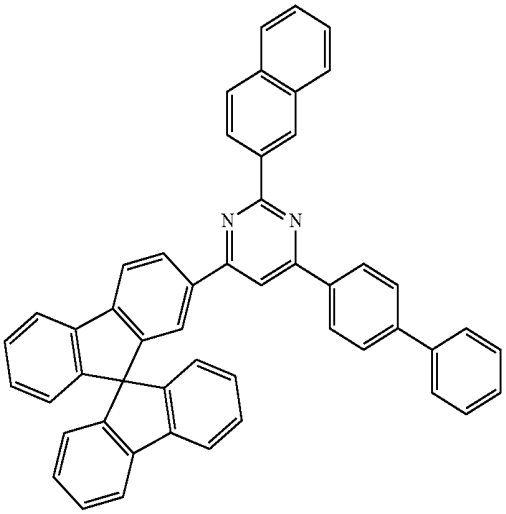

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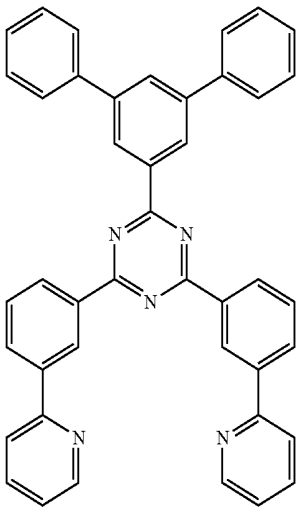
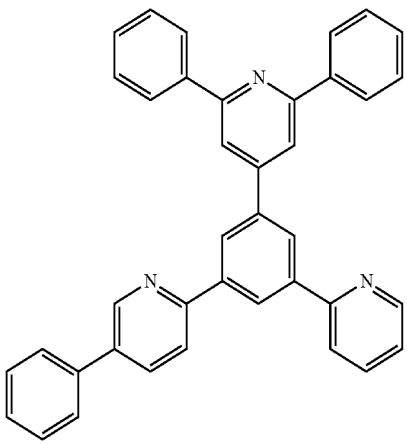


ET31



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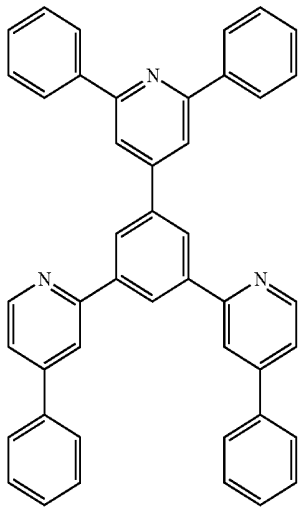
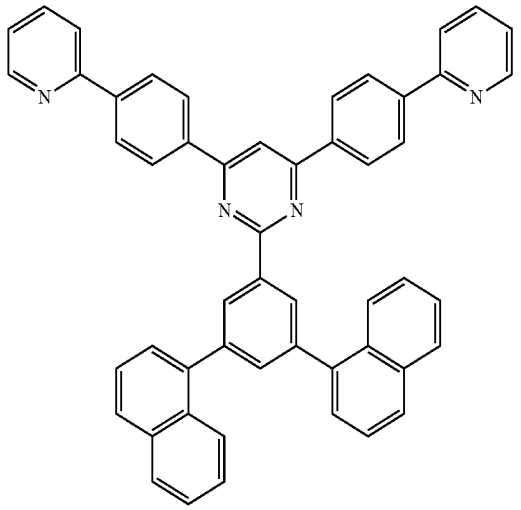
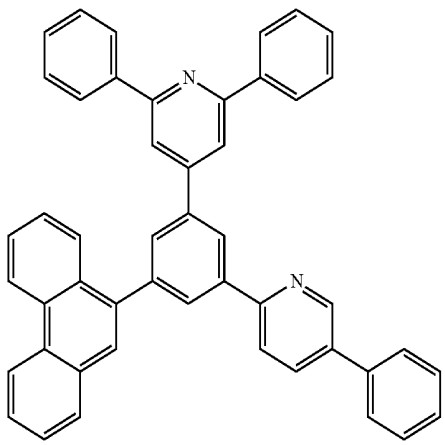
ET32



ET33



ET34



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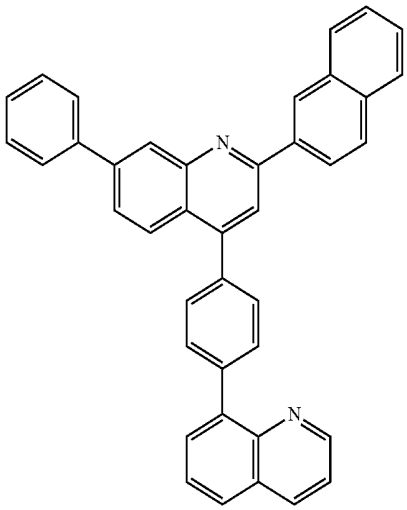
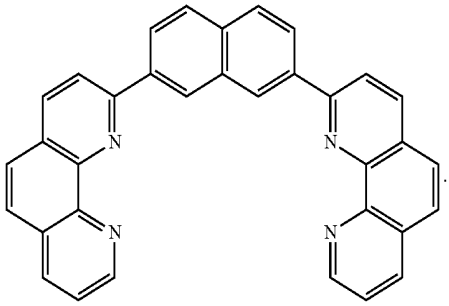
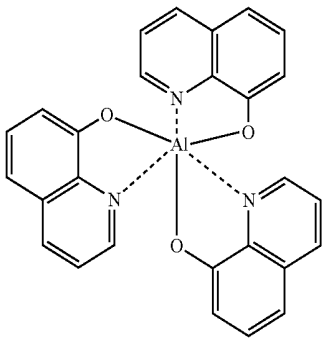
ET35



ET36



[0315] In one or more embodiments, 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), Alq_3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ:



Alq_3

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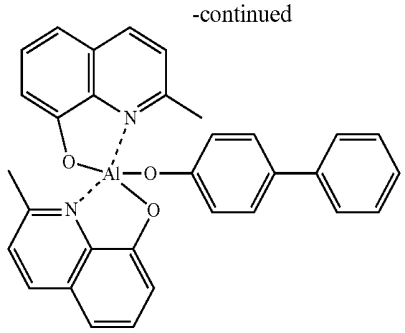
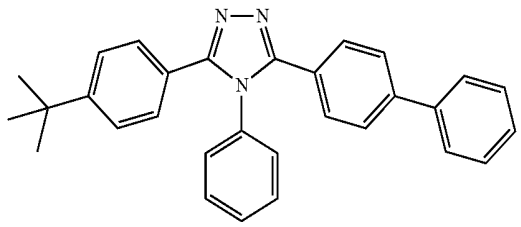
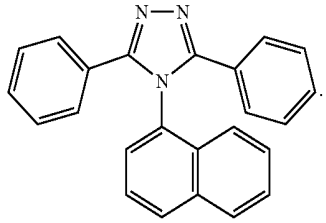


BAlq



TAZ



NTAZ

[0316] In one embodiment, the electron transport region may include a phosphine oxide-containing compound (for example, TSPO1 used in the following examples or the like), but embodiments of the present disclosure 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 present disclosure are not limited thereto.

[0317] 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.

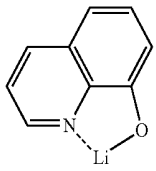
[0318] A thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within the range described above, the electron transport layer may have suitable or satisfactory electron transport characteristics without a substantial increase in driving voltage.

[0319] 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.

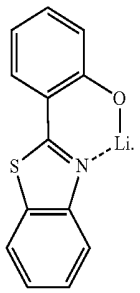
[0320] The metal-containing material may include at least one selected from alkali metal complex and alkaline earth-metal complex. The alkali metal complex may include a metal ion selected from a Li ion, a Na ion, a K ion, a Rb ion, and a Cs ion, and the alkaline earth-metal complex may include a metal 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 phenyloxazole, a hydroxy phenylthiazole, a hydroxy diphenyloxadiazole, a hydroxy diphenylthiadiazol, a hydroxy phenylpyridine, a hydroxy phenylbenzimidazole, a hydroxy phenylbenzothiazole, a bipyridine, a phenanthroline, and a cyclopentadiene, but embodiments of the present disclosure are not limited thereto.

[0321] 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



[0322] The electron transport region may include an electron injection layer that facilitates injection of electrons from the second electrode **190**. The electron injection layer may directly contact the second electrode **190**.

[0323] 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.

[0324] 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.

[0325] 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 present disclosure are not limited thereto.

[0326] The alkaline earth metal may be selected from Mg, Ca, Sr, and Ba.

[0327] The rare earth metal may be selected from Sc, Y, Ce, Tb, Yb, and Gd.

[0328] 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.

[0329] 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, and KI, but embodiments of the present disclosure are not limited thereto.

[0330] The alkaline earth-metal compound may be selected from alkaline earth-metal oxides, such as BaO, SrO, CaO, $Ba_xSr_{1-x}O$ ($0<x<1$), or $Ba_xCa_{1-x}O$ ($0<x<1$). In one embodiment, the alkaline earth-metal compound may be selected from BaO, SrO, and CaO, but embodiments of the present disclosure are not limited thereto.

[0331] The rare earth metal compound may be selected from YbF_3, ScF_3, ScO_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 TbI_3, but embodiments of the present disclosure are not limited thereto.

[0332] 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 diphenylthiadiazol, hydroxy phenylpyridine, hydroxy phenylbenzimidazole, hydroxy phenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments of the present disclosure are not limited thereto.

[0333] 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.

[0334] 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 suitable or satisfactory electron injection characteristics without a substantial increase in driving voltage.

[0335] Second Electrode **190**

[0336] 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.

[0337] 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 present disclosure are not limited thereto. The second electrode **190** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0338] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

[0339] 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 (LB) deposition, ink-jet printing, laser-printing, and laser-induced thermal imaging.

[0340] 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 by taking into account a material to be included in a layer to be formed, and the structure of a layer to be formed.

[0341] 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.

[0342] Apparatus

[0343] The organic light-emitting device may be included in various suitable apparatuses. For example, a light-emitting apparatus, an authentication apparatus, or an electronic apparatus, which includes the organic light-emitting device, may be provided.

[0344] The light-emitting apparatus may further include, in addition to the organic light-emitting device, a thin film transistor including a source electrode and a drain electrode. One of the source electrode and the drain electrode of the thin film transistor may be electrically coupled to (e.g., electrically connected to) one of the first electrode and the second electrode of the organic light-emitting device. The light-emitting apparatus may be used as various suitable displays, light sources, and the like.

[0345] The authentication apparatus may be, for example, a biometric authentication apparatus for authenticating an individual by using biometric information of a biometric body (for example, a fingertip, a pupil, or the like).

[0346] The authentication apparatus may further include, in addition to the organic light-emitting device, a biometric information collector.

[0347] The electronic apparatus may be applied to personal computers (for example, a mobile personal computer),

mobile phones, digital cameras, electronic organizers, electronic dictionaries, electronic game machines, medical instruments (for example, electronic thermometers, sphygmomanometers, blood glucose meters, pulse measurement devices, pulse wave measurement devices, electrocardiogram (ECG) displays, ultrasonic diagnostic devices, or endoscope displays), fish finders, various suitable measuring instruments, meters (for example, meters for a vehicle, an aircraft, and a vessel), projectors, and the like, but embodiments of the present disclosure are not limited thereto.

[0348] General Definition of Some of the Substituents

[0349] The term "C_1-C_{60} 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 isoamyl group, and a hexyl group. The term "C_1-C_{60} alkylene group," as used herein, refers to a divalent group having substantially the same structure as the C_1-C_{60} alkyl group.

[0350] The term "C_2-C_{60} alkenyl group," as used herein, refers to a hydrocarbon group having at least one carbon-carbon double bond in a main chain (e.g., in the middle) or at a terminus of the C_2-C_{60} alkyl group, and examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term "C_2-C_{60} alkenylene group," as used herein, refers to a divalent group having substantially the same structure as the C_2-C_{60} alkenyl group.

[0351] The term "C_2-C_{60} alkynyl group," as used herein, refers to a hydrocarbon group having at least one carbon-carbon triple bond in a main chain (e.g., in the middle) or at a terminus of the C_2-C_{60} alkyl group, and examples thereof include an ethynyl group, and a propynyl group. The term "C_2-C_{60} alkynylene group," as used herein, refers to a divalent group having substantially the same structure as the C_2-C_{60} alkynyl group.

[0352] The term "C_1-C_{60} alkoxy group," as used herein, refers to a monovalent group represented by $-OA_{101}$ (wherein A_{101} is the C_1-C_{60} alkyl group), and examples thereof include a methoxy group, an ethoxy group, and an isopropyloxy group.

[0353] The term "C_3-C_{10} 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 "C_3-C_{10} cycloalkylene group," as used herein, refers to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkyl group.

[0354] The term "C_1-C_{10} 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 "C_1-C_{10} heterocycloalkylene group," as used herein, refers to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkyl group.

[0355] The term "C_3-C_{10} cycloalkenyl group," as used herein, refers to a monovalent monocyclic group that has 3 to 10 carbon atoms and at least one carbon-carbon double bond in the ring thereof and no aromaticity (e.g., the ring is not aromatic), and examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group," as used herein, refers to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkenyl group.

[0356] The term "C_1-C_{10} 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 C_1-C_{10} 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 "C_1-C_{10} heterocycloalkenylene group," as used herein, refers to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkenyl group.

[0357] The term "C_6-C_{60} aryl group," as used herein, refers to a monovalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms, and a C_6-C_{60} 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 C_6-C_{60} aryl group include a phenyl group, a naphthyl group, an anthracenyl group, a phenanthrenyl group, a pyrenyl group, and a chrysenyl group. When the C_6-C_{60} aryl group and the C_6-C_{60} arylene group each include two or more rings, the rings may be fused to each other (e.g., combined together).

[0358] The term "C_1-C_{60} 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 "C_1-C_{60} 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 C_1-C_{60} 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 C_1-C_{60} heteroaryl group and the C_1-C_{60} heteroarylene group each include two or more rings, the rings may be condensed with each other (e.g., combined together).

[0359] The term "C_6-C_{60} aryloxy group," as used herein, refers to $-OA_{102}$ (wherein A_{102} is the C_6-C_{60} aryl group), and the term "C_6-C_{60} arylthio group," as used herein, indicates $-SA_{103}$ (wherein A_{103} is the C_6-C_{60} aryl group).

[0360] 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 (e.g., combined together), only carbon atoms as ring-forming atoms, and no aromaticity in its entire molecular structure (e.g., the entire group and/or molecule is not aromatic). An 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 substantially the same structure as the monovalent non-aromatic condensed polycyclic group.

[0361] 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 more rings condensed to each other (e.g., combined together), 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

(e.g., the entire group and/or molecule is not aromatic). 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 substantially the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0362] The term "C_4-C_{60} 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 C_4-C_{60} carbocyclic group may be an aromatic carbocyclic group or a non-aromatic carbocyclic group. The C_4-C_{60} 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 C_4-C_{60} carbocyclic group, the C_4-C_{60} carbocyclic group may be a trivalent group or a quadrivalent group.

[0363] The term "C_1-C_{60} heterocyclic group," as used herein, refers to a group having substantially the same structure as the C_4-C_{60} 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 1 to 60).

[0364] At least one substituent of the substituted C_4-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_3-C_{10} cycloalkylene group, the substituted C_1-C_{10} heterocycloalkylene group, the substituted C_3-C_{10} cycloalkenylene group, the substituted C_1-C_{10} heterocycloalkenylene group, the substituted C_6-C_{60} arylene group, the substituted C_1-C_{60} heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0365] 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_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0366] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$;

[0367] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0368] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0369] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0370] Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} 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_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C_1-C_{60} alkyl group substituted with at least one selected from deuterium, —F, and a cyano group, a C_6-C_{60} aryl group substituted with at least one selected from deuterium, —F, and a cyano group, a biphenyl group, and a terphenyl group.

[0371] 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^t," as used herein, refers to a tert-butyl group, and the term "OMe," as used herein, refers to a methoxy group.

[0372] 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 C_6-C_{60} aryl group as a substituent.

[0373] 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 C_6-C_{60} aryl group substituted with a C_6-C_{60} aryl group.

[0374] * and *' used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

[0375] Hereinafter, a compound according to embodiments and an organic light-emitting device according to embodiments will be described in more detail with reference to Examples.

Example 1

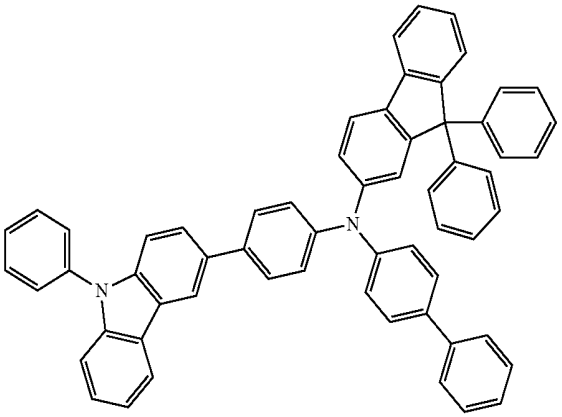
[0376] As a substrate and an ITO anode, a Corning 15 Ω/cm^2 (120 nm) ITO glass substrate was cut to a size of 50 mm×50 mm×0.7 mm, sonicated with isopropyl alcohol and pure water each for 5 minutes, and then cleaned by exposure to ultraviolet rays and ozone for 30 minutes. Then, the ITO glass substrate was provided to a vacuum deposition apparatus.

[0377] HT and HAT-CN were co-deposited on the ITO anode at a weight ratio of 99:1 to form a hole transport layer having a thickness of 120 nm.

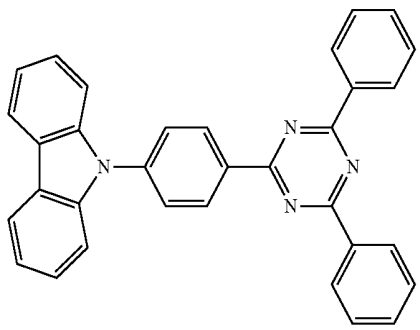
[0378] H-1 (host) and Compound 1 (dopant) were co-deposited on the hole transport layer at a host-to-dopant ratio of 99:1 to form an emission layer having a thickness of 300 Å.

[0379] ET1 was deposited on the emission layer to form a buffer having a thickness of 5 nm, ET2 was deposited on the buffer layer to form an electron transport layer having a thickness of 25 nm, LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 0.5 nm, 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.

HT

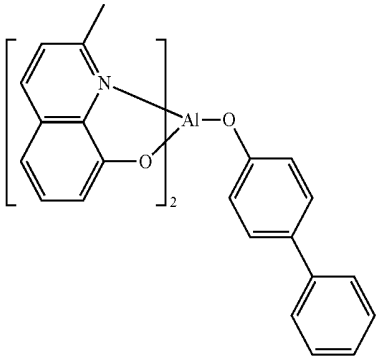


H-1

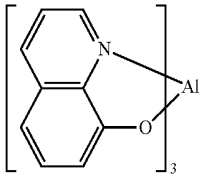


-continued

ET1



ET2



Example 2

[0380] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 3 was used instead of Compound 1 as a dopant in forming an emission layer.

Example 3

[0381] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 5 was used instead of Compound 1 as a dopant in forming an emission layer.

Example 4

[0382] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 7 was used instead of Compound 1 as a dopant in forming an emission layer.

Example 5

[0383] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 8 was used instead of Compound 1 as a dopant in forming an emission layer.

Example 6

[0384] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 18 was used instead of Compound 1 as a dopant in forming an emission layer.

Example 7

[0385] An organic light-emitting device was manufactured in substantially the same manner as in Example 1, except that Compound 24 was used instead of Compound 1 as a dopant in forming an emission layer.

Evaluation Example 1

[0386] The driving voltage, current density, luminance, external quantum efficiency (EQE), and maximum emission wavelength of the organic light-emitting devices manufactured according to Examples 1 to 7 were measured by using Keithley SMU 236 and a luminance meter PR740, and results thereof are shown in Table 1.

TABLE 1

	Dopant compound	HOMO (eV)	LUMO (eV)	T1 (eV)	EQE (%)	Maximum emission wavelength (nm)
Example 1	1	−4.8	−2.7	1.4	2.7	860
Example 2	3	−4.8	−2.7	1.4	2.9	860
Example 3	5	−4.7	−2.6	1.4	3.1	860
Example 4	7	−4.8	−2.6	1.4	3.0	844
Example 5	8	−4.8	−2.6	1.4	3.2	844
Example 6	18	−4.2	−2.1	1.5	2.9	827
Example 7	24	−4.6	−2.6	1.3	3.4	893

[0387] Referring to Table 1, it is confirmed that the organic light-emitting devices of Examples 1 to 7 have high external quantum efficiency and may shift the maximum emission wavelength to a long wavelength (e.g., a wavelength range of about 755 nm to about 1,500 nm), and thus is suitable for NIR light emission.

[0388] The organic light-emitting device may have a low driving voltage, high efficiency, and a long lifespan and may emit light in a near-infrared (NIR) range.

[0389] It should be understood that embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

[0390] It will be understood that, although the terms "first," "second," "third," etc., may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are used to distinguish one element, component, region, layer or section from another element, component, region, layer or section. Thus, a first element, component, region, layer or section described below could be termed a second element, component, region, layer or section, without departing from the spirit and scope of the present disclosure.

[0391] Spatially relative terms, such as "beneath," "below," "lower," "under," "above," "upper," and the like, may be used herein for ease of explanation to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the accompanying drawing. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or in operation, in addition to the orientation depicted in the accompanying drawing. For example, if the device in the accompanying drawing is turned over, elements described as "below" or "beneath" or "under" other elements or features would then be oriented "above" the other elements or features. Thus, the example terms "below" and "under" can encompass both an orientation of above and below. The device may be otherwise oriented (e.g., rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein should be interpreted accordingly.

[0392] It will be understood that when an element or layer is referred to as being "on," "connected to," or "coupled to" another element or layer, it can be directly on, connected to, or coupled to the other element or layer, or one or more intervening elements or layers may be present. In addition, it will also be understood that when an element or layer is referred to as being "between" two elements or layers, it can be the only element or layer between the two elements or layers, or one or more intervening elements or layers may also be present.

[0393] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a" and "an" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and "including," when used in this specification, specify the presence of the stated features, integers, acts, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, acts, operations, elements, components, and/or groups thereof.

[0394] As used herein, the terms "substantially," "about," and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent deviations in measured or calculated values that would be recognized by those of ordinary skill in the art. Further, the use of "may" when describing embodiments of the present disclosure refers to "one or more embodiments of the present disclosure." As used herein, the terms "use," "using," and "used" may be considered synonymous with the terms "utilize," "utilizing," and "utilized," respectively. Also, the term "exemplary" is intended to refer to an example or illustration.

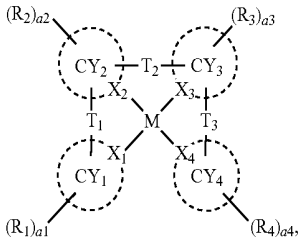
[0395] Also, any numerical range recited herein is intended to include all subranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein, and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein.

[0396] While one or more embodiments have been described with reference to the accompanying drawing, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the appended claims, and equivalents thereof.

What is claimed is:

1. An organometallic compound represented by Formula 1:

Formula 1



M in Formula 1 is beryllium (Be), magnesium (Mg), aluminum (Al), calcium (Ca), titanium (Ti), manganese (Mn), cobalt (Co), copper (Cu), zinc (Zn), gallium (Ga), germanium (Ge), zirconium (Zr), ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), rhenium (Re), europium (Eu), platinum (Pt), or gold (Au),

two bonds selected from a bond between X_1 and M, a bond between X_2 and M, a bond between X_3 and M, and a bond between X_4 and M are each a covalent bond, and the others thereof are each a coordinate bond,

X_1 to X_4 are each independently C or N,

ring CY_1 to ring CY_4 are each independently selected from a C_5-C_{30} carbocyclic group and a C_1-C_{30} heterocyclic group,

T_1 to T_3 are each independently selected from a single bond, a double bond, *—$N(R_7)$—*', *—$B(R_7)$—*', *—$P(R_7)$—*', *—$C(R_7)(R_8)$—*', *—$Si(R_7)(R_8)$—*', *—$Ge(R_7)(R_8)$—*', *—S—*', *—Se—*', *—O—*', *—C(=O)—*', *—S(=O)—*', *—$S(=O)_2$—*', *—$C(R_7)$=*', *=$C(R_7)$—*', *—$C(R_7)$=$C(R_8)$—*', *—C(=S)—*', and *—C≡C—*', and * and *' each indicate a binding site to a neighboring atom,

R_7 and R_8 are optionally linked via a single bond, a double bond, or a first linking group to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

R_1 to R_4, R_7, and R_8 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 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, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, —$P(Q_1)(Q_2)$, and —$P(=O)(Q_1)(Q_2)$,

a1 to a4 are each independently an integer of 0 to 20,

two of a plurality of neighboring R_1(s) are optionally linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

two of a plurality of neighboring R_2(s) are optionally linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

two of a plurality of neighboring R_3(s) are optionally linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

two of a plurality of neighboring R_4(s) are optionally linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

two or more neighboring groups selected from R_1 to R_4 are optionally linked to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

CY_1 and CY_4 are not linked, and

the organometallic compound represented by Formula 1 satisfies at least one of a <first condition> to a <fourth condition>,

<First condition>

at least one of T_1 and T_3 is not a single bond

<Second condition>

T_1 to T_3 are each a single bond, CY_1, M, and CY_2 form a cyclometalated 5-membered ring, and CY_2, M, and CY_3 form a cyclometalated 5-membered ring

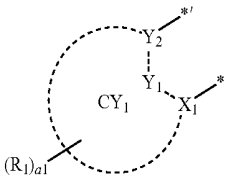
<Third condition>

T_1 and T_3 are each a single bond, CY_1 is a group represented by $CY_1(1)$, and CY_4 is a group represented by $CY_4(1)$

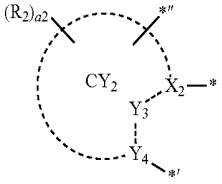
<Fourth condition>

T_1 and T_3 are each a single bond, and CY_2 is a group represented by $CY_2(1)$

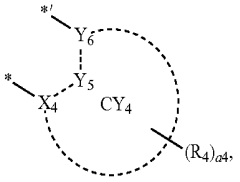
$CY_1(1)$



$CY_2(1)$



$CY_4(1)$



wherein, in Formulae $CY_1(1)$, $CY_2(1)$, and $CY_4(1)$, Y_1 to Y_6 are each independently C or N,

in Formula $CY_1(1)$, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_1 in Formula 1,

in Formula $CY_2(1)$, * indicates a binding site to M in Formula 1, *' indicates a binding site to T_1 in Formula 1, and *'' indicates a binding site to T_2 in Formula 1,

in Formula $CY_4(1)$, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_3 in Formula 1,

at least one substituent of the substituted C_5-C_{30} carbocyclic group, the substituted C_1-C_{30} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

deuterium (-D), —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_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_{11})(Q_{12})(Q_{13})$, $—N(Q_{11})(Q_{12})$, $—B(Q_{11})(Q_{12})$, $—C(=O)(Q_{11})$, $—S(=O)_2(Q_{11})$, and $—P(=O)(Q_{11})(Q_{12})$;

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

a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_{21})(Q_{22})(Q_{23})$, $—N(Q_{21})(Q_{22})$, $—B(Q_{21})(Q_{22})$, $—C(=O)(Q_{21})$, $—S(=O)_2(Q_{21})$, and $—P(=O)(Q_{21})(Q_{22})$; and

$—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$, and

Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} 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 C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a C_1-C_{60} alkyl group substituted with at least one selected from deuterium, —F, and a cyano group, a C_6-C_{60} aryl group substituted with at least one selected from deuterium, —F, and a cyano group, a biphenyl group, and a terphenyl group.

2. The organometallic compound of claim **1**, wherein:

the organometallic compound is a near-infrared (NIR) light-emitting compound having a maximum emission wavelength of about 755 nm or more.

3. The organometallic compound of claim **1**, wherein:

at least one of ring CY_1 to ring CY_4 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other,

at least one of ring CY_1 to ring CY_4 is a condensed ring in which at least two 6-membered rings including no nitrogen atom or one nitrogen atom are condensed with each other or a condensed ring in which at least one 5-membered ring and at least one 6-membered ring are condensed with each other, wherein, in the condensed ring in which the at least one 5-membered ring and the at least one 6-membered ring are condensed with each other, a binding site to M is included in the 6-membered ring,

i) when ring CY_1 or CY_4 is a 6-membered ring including one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, CY_1 and CY_4 have an asymmetric structure with respect to an inversion center axis passing through M, and

ii) when ring CY_2 or CY_3 is a 6-membered ring including one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, CY_2 and CY_3 have an asymmetric structure with respect to an inversion center axis passing through M.

4. The organometallic compound of claim **1**, wherein:

i) X_1 and X_4 are N, or

ii) X_2 and X_3 are N.

5. The organometallic compound of claim **1**, wherein:

i) when ring CY_1 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, X_1 is N,

ii) when ring CY_2 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, X_2 is N,

iii) when ring CY_3 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, X_3 is N, and

iv) when ring CY_4 is a 6-membered ring including at least one nitrogen atom or a condensed ring in which at least two 6-membered rings are condensed with each other, X_4 is N.

6. The organometallic compound of claim **1**, wherein:

ring CY_1 to CY_4 are each independently selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, and a benzocarbazole group.

7. The organometallic compound of claim **1**, wherein:

at least one of ring CY_1 to CY_4 is a 6-membered ring including at least two nitrogen or a condensed ring in which at least two 6-membered rings are condensed with each other, and

the 6-membered ring is selected from a cyclohexane group, a cyclohexene group, a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, and a triazine group.

8. The organometallic compound of claim **1**, wherein:

R_1 to R_4, R_7, and R_8 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 C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group;

a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, $-Si(Q_{31})(Q_{32})(Q_{33})$, $-N(Q_{31})(Q_{32})$, $-B(Q_{31})(Q_{32})$, $-P(Q_{31})(Q_{32})$, $-C(=O)(Q_{31})$, $-S(=O)_2(Q_{31})$, and $-P(=O)(Q_{31})(Q_{32})$;

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

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $-CD_3$, $-CD_2H$, $-CDH_2$, $-CF_3$, $-CF_2H$, $-CFH_2$, 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_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, a C_1-C_{20} alkoxy group,

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$; and

—$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$P(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, and —$P(=O)(Q_1)(Q_2)$, and

Q_1 to Q_3 and Q_{31} to Q_{33} are each independently selected from:

hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, a C_1-C_{20} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{20} aryl group, a C_1-C_{20} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

a C_1-C_{20} alkyl group substituted with at least one selected from deuterium, —F, and a cyano group;

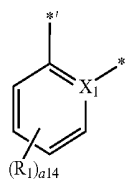
a C_6-C_{20} aryl group substituted with at least one selected from deuterium, —F, and a cyano group; and

a biphenyl group and a terphenyl group.

9. The organometallic compound of claim **1**, wherein:

CY_1 is represented by one selected from Formulae CY_1-1(1) to CY_1-1(18) and CY_1-2(1) to CY_1-2(12):

CY_1-1(1)



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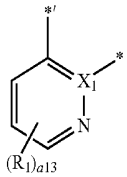
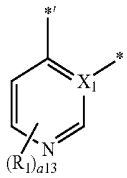
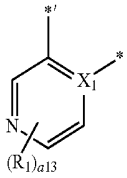
CY_1-1(2)



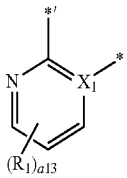
CY_1-1(3)



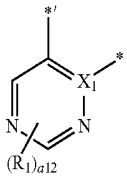
CY_1-1(4)



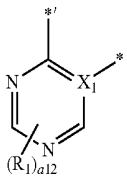
CY_1-1(5)



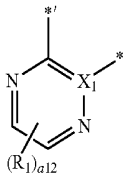
CY_1-1(6)



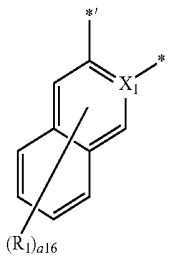
CY_1-1(7)



CY_1-1(8)



CY_1-1(9)



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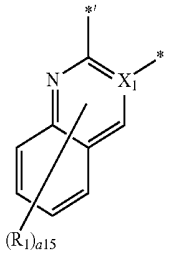
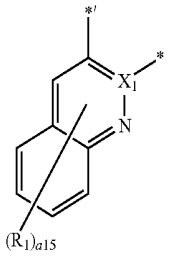
CY_1-1(10)



CY_1-1(11)



wherein, in Formulae CY_1-1(1) to CY_1-1(18) and CY_1-2(1) to CY_1-2(12),

X_1 and R_1 are respectively the same as described in claim **1**,

a12 is an integer of 0 to 2,

a13 is an integer of 0 to 3,

a14 is an integer of 0 to 4,

a15 is an integer of 0 to 5,

a16 is an integer of 0 to 6,

a17 is an integer of 0 to 7,

a18 is an integer of 0 to 8,

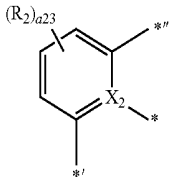
* indicates a binding site to M in Formula 1, and

*' indicates a binding site to T_1 in Formula 1.

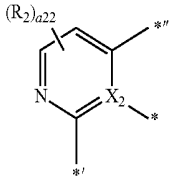
10. The organometallic compound of claim **1**, wherein:

CY_2 is represented by one selected from Formulae CY_2-1(1) to CY_2-1(10), CY_2-2(1) to CY_2-2(2), and CY_2-3(1):

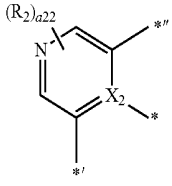
CY_2-1(1)



CY_2-1(2)



CY_2-1(3)



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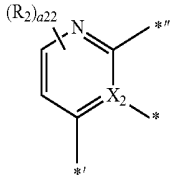
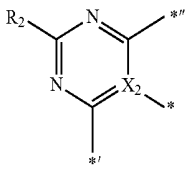
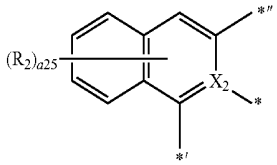
CY_2-1(4)



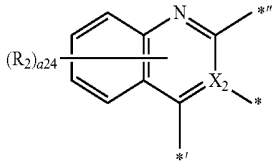
CY_2-1(5)



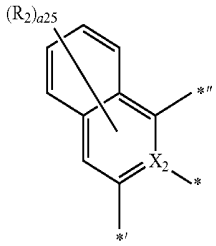
CY_2-1(6)



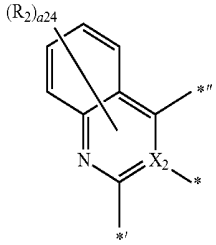
CY_2-1(7)



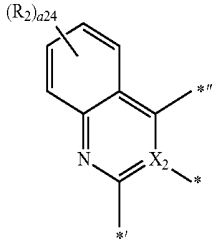
CY_2-1(8)



CY_2-1(9)



CY_2-1(10)



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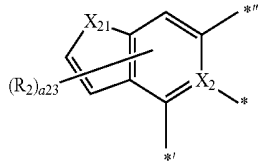
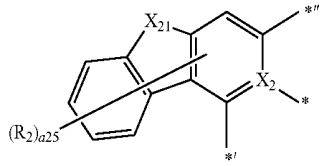
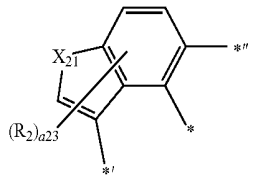
CY_2-1(11)



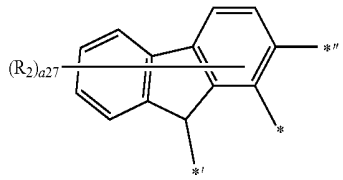
CY_2-1(12)



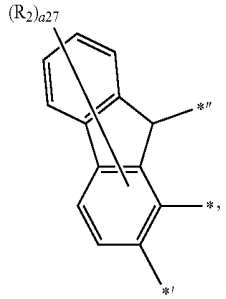
CY_2-2(1)



CY_2-2(2)



CY_2-3(1)



wherein, in Formulae CY_2-1 (1) to CY_2-1 (10), CY_2-2(1) to CY_2-2(2), and CY_2-3(1),

X_2 and R_2 are respectively the same as described in claim **1**,

X_{21} is O, S, $N(R_{21})$, $C(R_{21})(R_{22})$, or $Si(R_{21})(R_{22})$,

R_{21} to R_{22} are respectively the same as described in connection with R_2 in claim **1**,

a22 is an integer of 0 to 2,

a23 is an integer of 0 to 3,

a24 is an integer of 0 to 4,

a25 is an integer of 0 to 5,

a26 is an integer of 0 to 6,

a27 is an integer of 0 to 7,

* indicates a binding site to M in Formula 1,

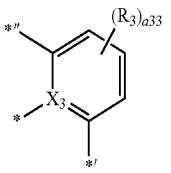
*' indicates a binding site to T_1 in Formula 1, and

*" indicates a binding site to T_2 in Formula 1.

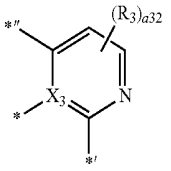
11. The organometallic compound of claim **1**, wherein:

CY_3 is represented by one selected from Formulae CY_3-1 (1) to CY_3-1(10), CY_3-2(1) to CY_3-2(2), and CY_3-3(1):

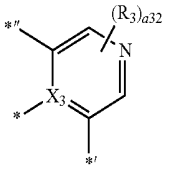
CY_3-1(1)



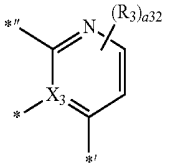
CY_3-1(2)



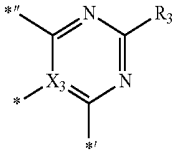
CY_3-1(3)



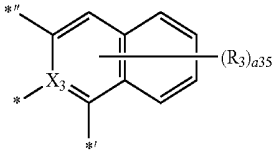
CY_3-1(4)



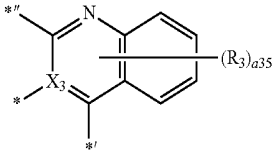
CY_3-1(5)



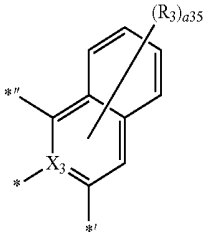
CY_3-1(6)



CY_3-1(7)



CY_3-1(8)



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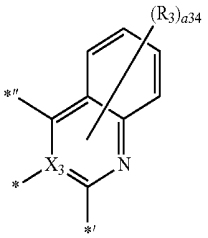
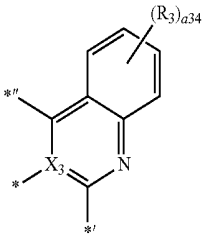
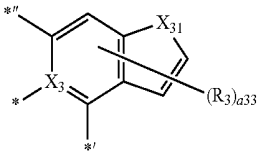
CY_3-1(9)



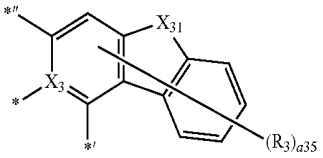
CY_3-1(10)



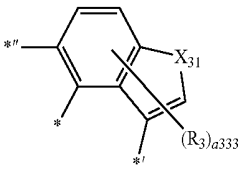
CY_3-1(11)



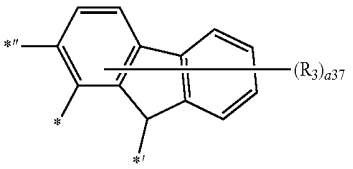
CY_3-1(12)



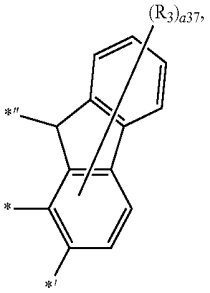
CY_3-2(1)



CY_3-2(2)



CY_3-3(1)



wherein, in Formulae CY_3-1(1) to CY_3-1(10), CY_3-2(1) to CY_3-2(2), and CY_3-3(1),

X_3 and R_3 are respectively the same as described in claim **1**,

X_{31} is O, S, $N(R_{31})$, $C(R_{31})(R_{32})$, or $Si(R_{31})(R_{32})$,

R_{31} to R_{32} are respectively the same as described in connection with R_3 in claim **1**,

a32 is an integer of 0 to 2,

a33 is an integer of 0 to 3,

a34 is an integer of 0 to 4,

a35 is an integer of 0 to 5,

a36 is an integer of 0 to 6,

a37 is an integer of 0 to 7,

* indicates a binding site to M in Formula 1,

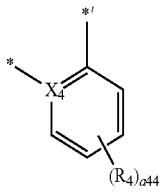
*" indicates a binding site to T_2 in Formula 1, and

*' indicates a binding site to T_3 in Formula 1.

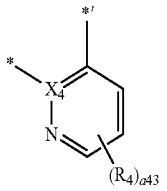
12. The organometallic compound of claim **1**, wherein:

CY_4 is represented by one selected from Formulae CY_4-1 (1) to CY_4-1 (18) and CY_4-2(1) to CY_4-2(12):

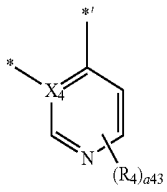
CY_4-1(1)



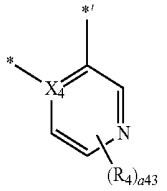
CY_4-1(2)



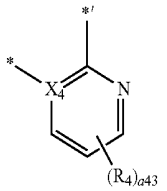
CY_4-1(3)



CY_4-1(4)



CY_4-1(5)



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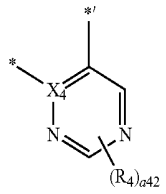
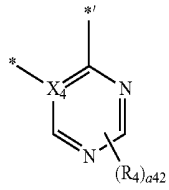
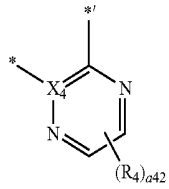
CY_4-1(6)



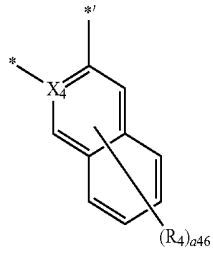
CY_4-1(7)



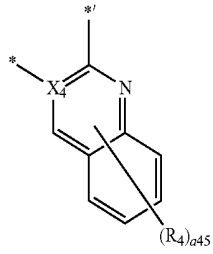
CY_4-1(8)



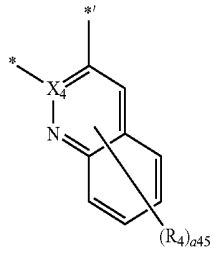
CY_4-1(9)



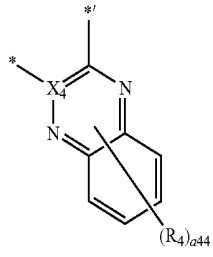
CY_4-1(10)



CY_4-1(11)



CY_4-1(12)



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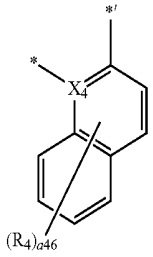
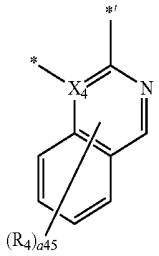
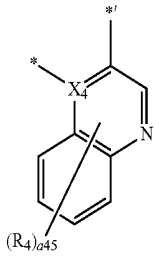
CY_4-1(13)



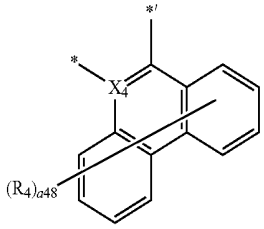
CY_4-1(14)



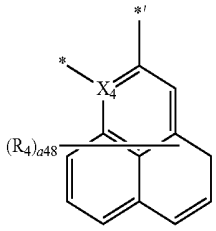
CY4-1(15)



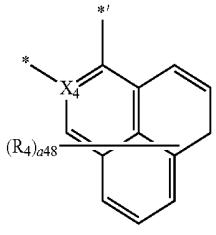
CY4-1(16)



CY4-1(17)



CY4-1(18)



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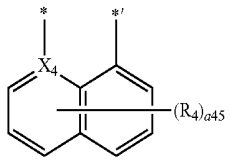
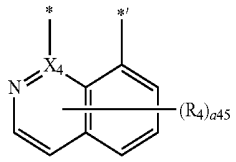
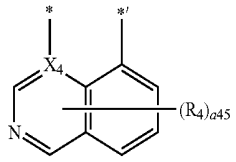
CY4-2(1)



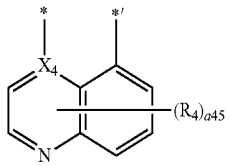
CY4-2(2)



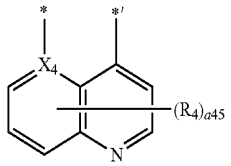
CY4-2(3)



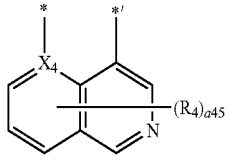
CY4-2(4)



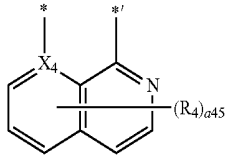
CY_4-2(5)



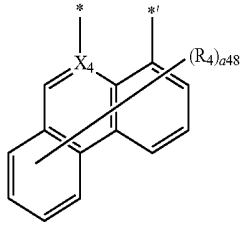
CY_4-2(6)



CY_4-2(7)



CY_4-2(8)



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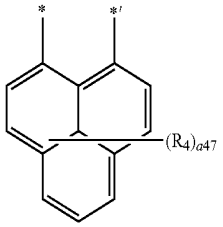
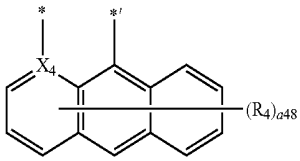
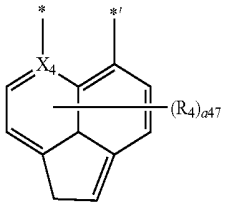
CY_4-2(9)



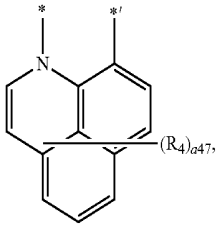
CY_4-2(10)



CY_4-2(11)



CY_4-2(12)



wherein, in Formulae CY_4-1(1) to CY_4-1(18) and CY_4-2(1) to CY_4-2(12),

X_4 and R_4 are respectively the same as described in claim **1**,

a42 is an integer of 0 to 2,

a43 is an integer of 0 to 3,

a44 is an integer of 0 to 4,

a45 is an integer of 0 to 5,

a46 is an integer of 0 to 6,

a47 is an integer of 0 to 7,

a48 is an integer of 0 to 8,

* indicates a binding site to M in Formula 1, and

*' indicates a binding site to T_3 in Formula 1.

13. The organometallic compound of claim **1**, wherein:

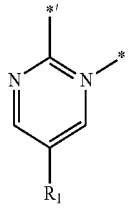
CY_1 is represented by one selected from Formulae CY1-A to CY1-Q,

CY_2 is represented by one selected from Formulae CY2-A to CY2-L,

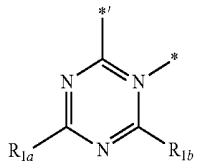
CY_3 is represented by one selected from Formulae CY3-A to CY3-L, and

CY_4 is represented by one selected from Formulae CY4-A to CY4-Q:

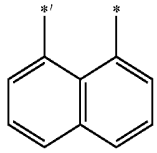
CY1-A



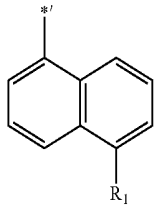
CY1-B



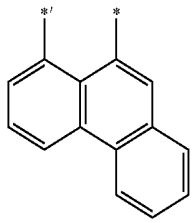
CY1-C



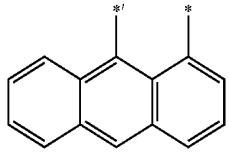
CY1-D



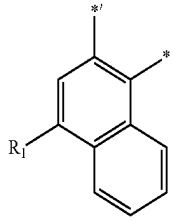
CY1-E



CY1-F



CY1-G



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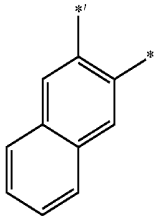
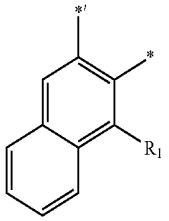
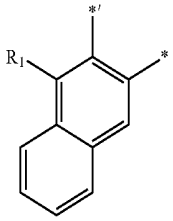
CY1-H



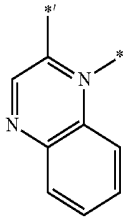
CY1-I



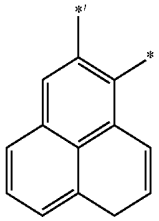
CY1-J



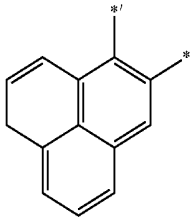
CY1-K



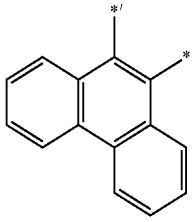
CY1-L



CY1-M



CY1-N



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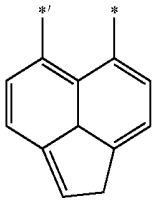
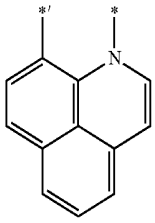
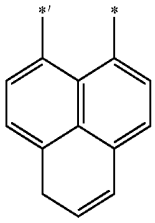
CY1-O



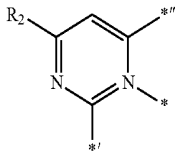
CY1-P



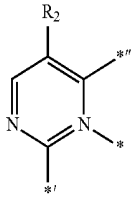
CY1-Q



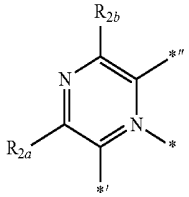
CY2-A



CY2-B



CY2-C



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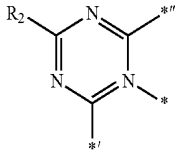

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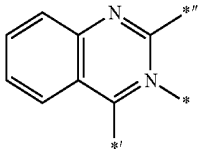

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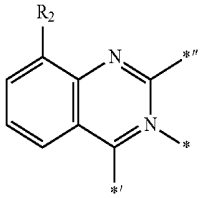
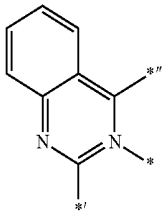
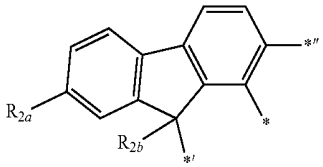
CY2-F



CY1-G



CY2-H



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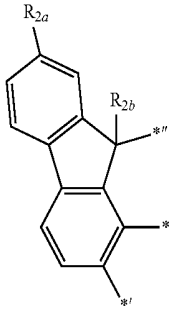

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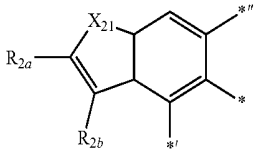

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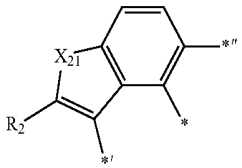

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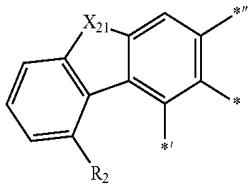
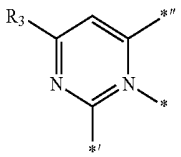


CY3-A



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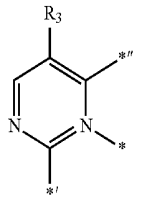
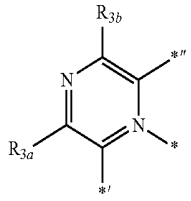
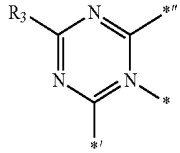


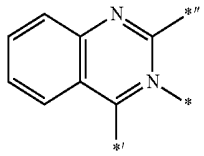
CY3-C



CY3-D



CY3-E



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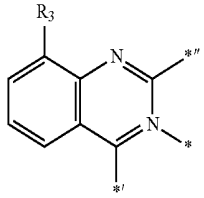
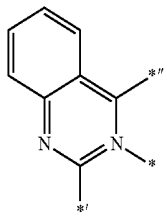


CY3-G



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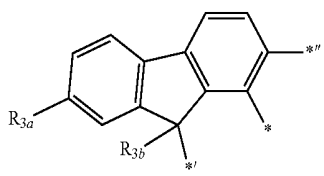

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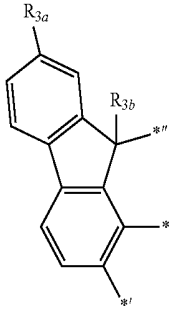

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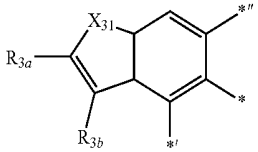

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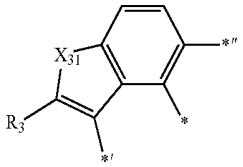
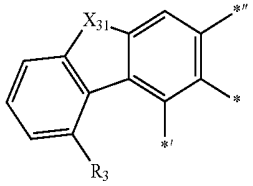
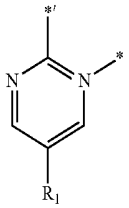


CY3-L



CY4-A



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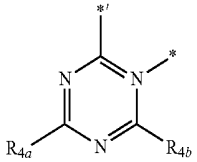
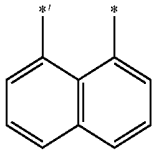


CY4-C



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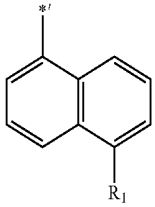

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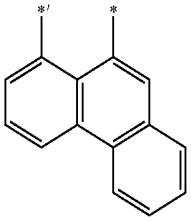

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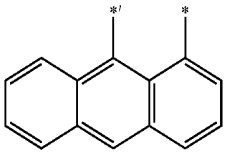

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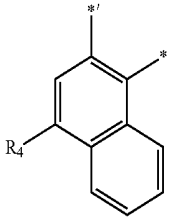

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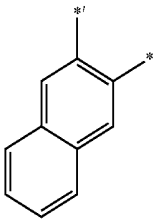

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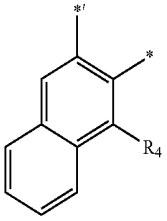

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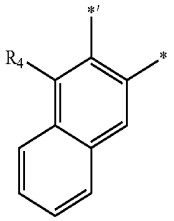

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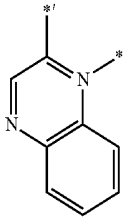

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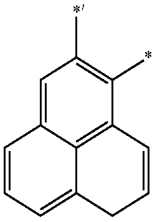

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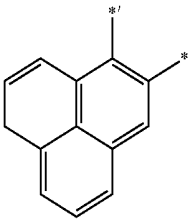

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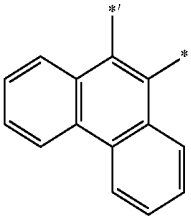
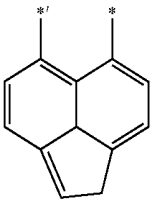


CY4-O



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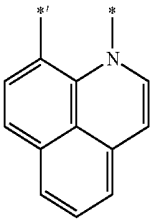
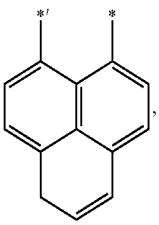


CY4-Q



wherein, in Formulae CY1-A to CY1-Q, CY2-A to CY2-L, CY3-A to CY3-L, and CY4-A to CY4-Q,

R_1 to R_4 are respectively the same as described in claim **1**,

X_{21} is O, S, $N(R_{21})$, $C(R_{21})(R_{22})$, or $Si(R_{21})(R_{22})$,

X_{31} is O, S, $N(R_{31})$, $C(R_{31})(R_{32})$, or $Si(R_{31})(R_{32})$,

R_{2a}, R_{2b}, R_{21}, and R_{22} are respectively the same as described in connection with R_2 in claim **1**,

R_{3a}, R_{3b}, R_{31}, and R_{32} are respectively the same as described in connection with R_3 in claim **1**,

in Formulae CY1-A to CY1-Q, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_1 in Formula 1,

in Formulae CY2-A to CY2-L, * indicates a binding site to M in Formula 1, *' indicates a binding site to T_1 in Formula 1, and *'' indicates a binding site to T_2 in Formula 1,

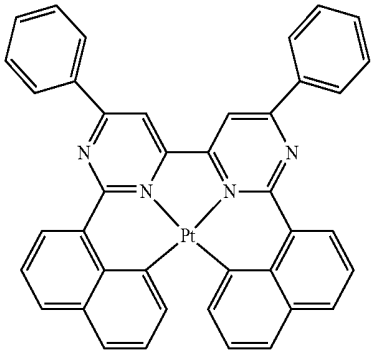
in Formulae CY3-A to CY3-L, * indicates a binding site to M in Formula 1, *'' indicates a binding site to T_2 in Formula 1, and *' indicates a binding site to T_3 in Formula 1, and

in Formulae CY4-A to CY4-Q, * indicates a binding site to M in Formula 1, and *' indicates a binding site to T_3 in Formula 1.

14. The organometallic compound of claim **1**, wherein:

the organometallic compound is one of Compounds 1 to 31:

1



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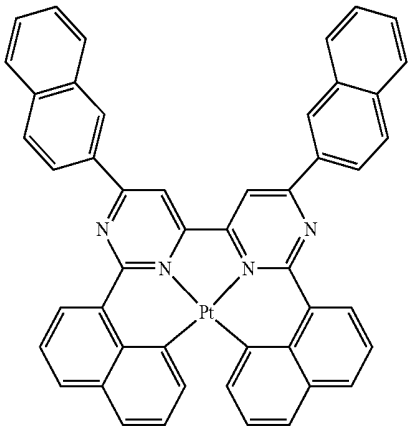

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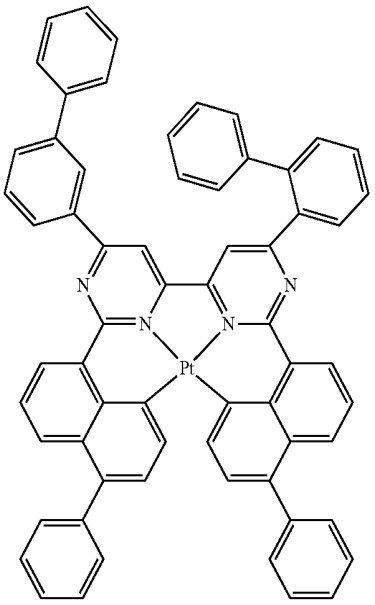

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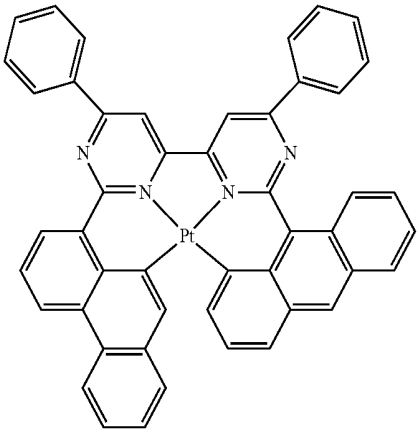

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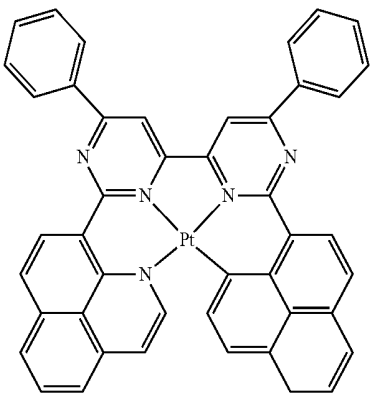

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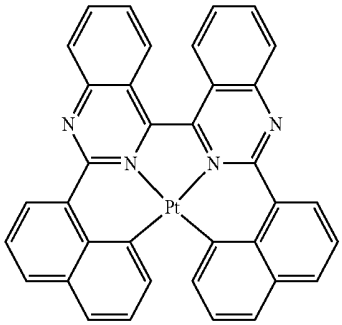

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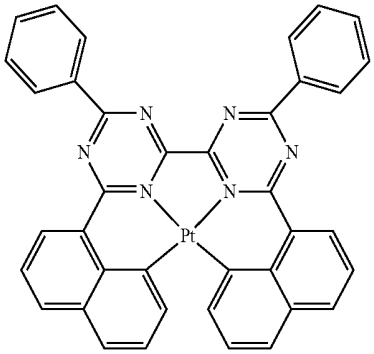

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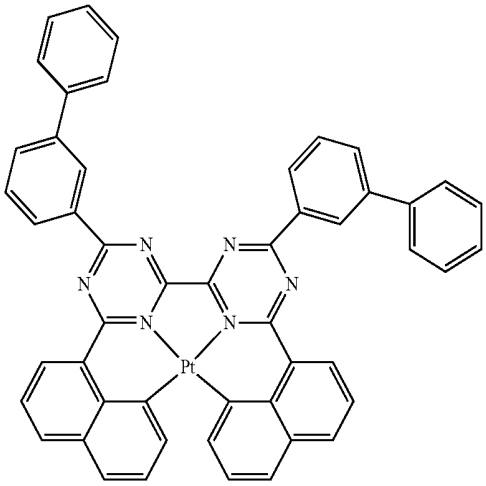

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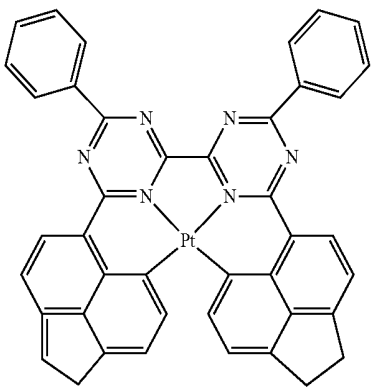

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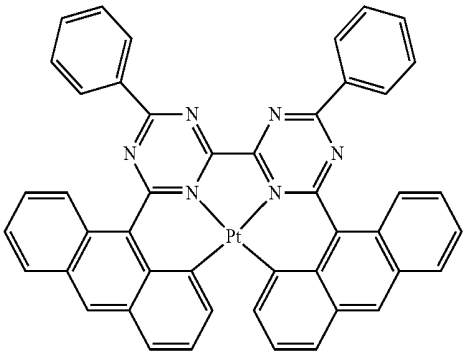
10



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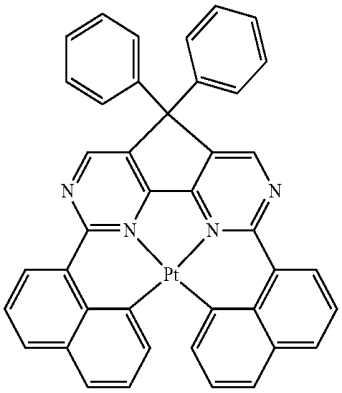

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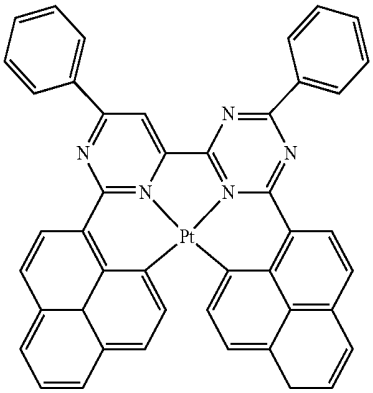

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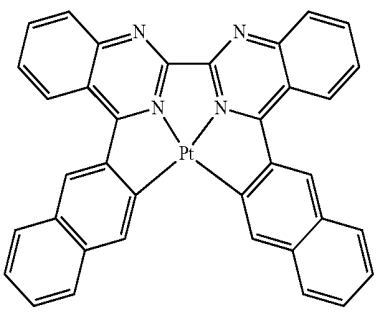

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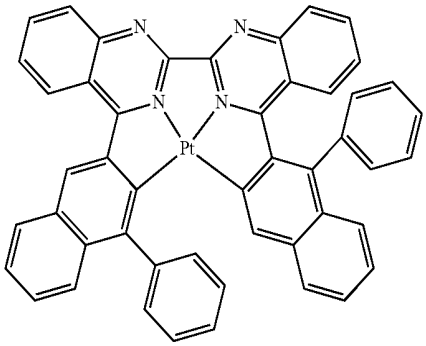

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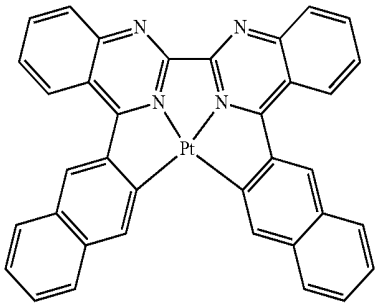

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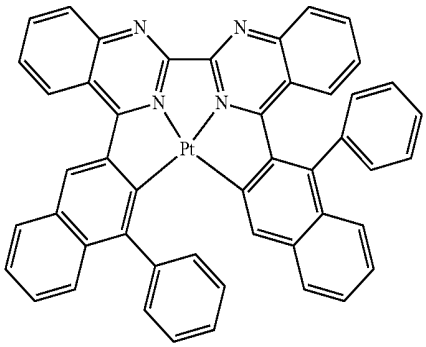

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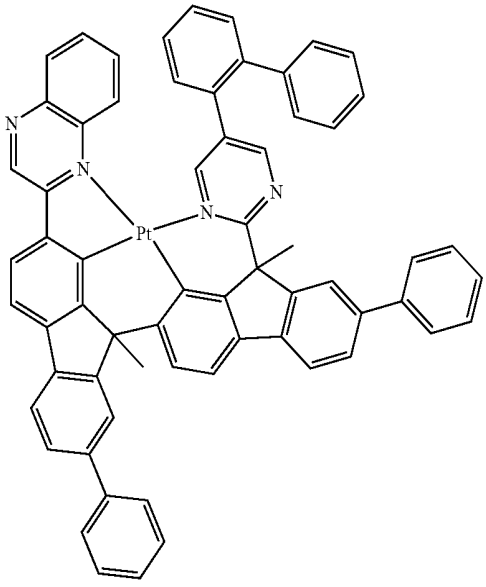

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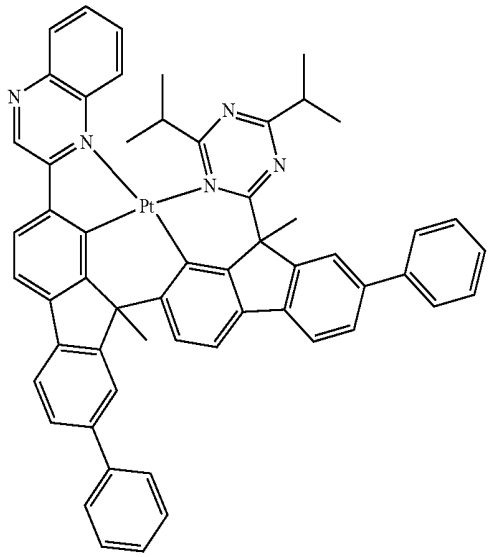

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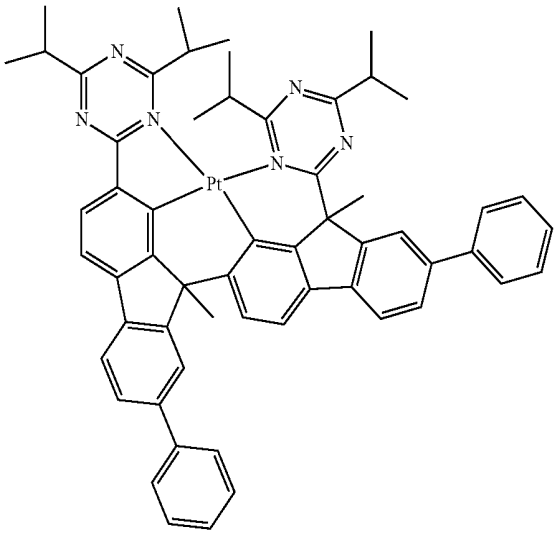

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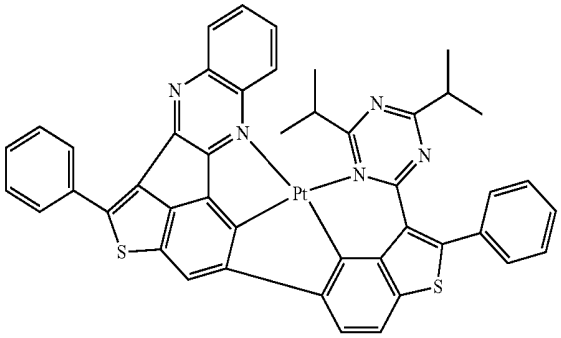

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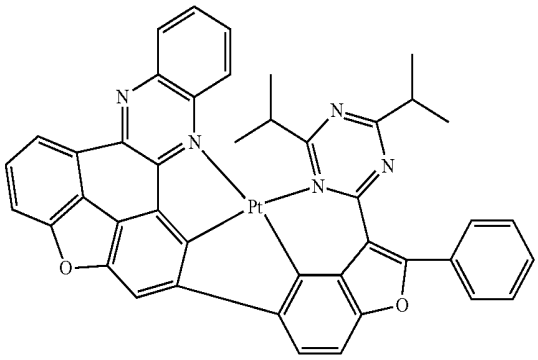

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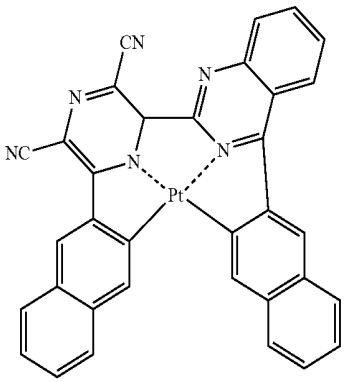

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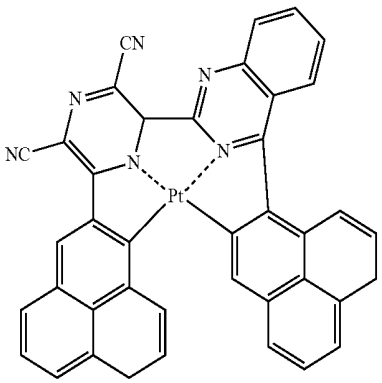

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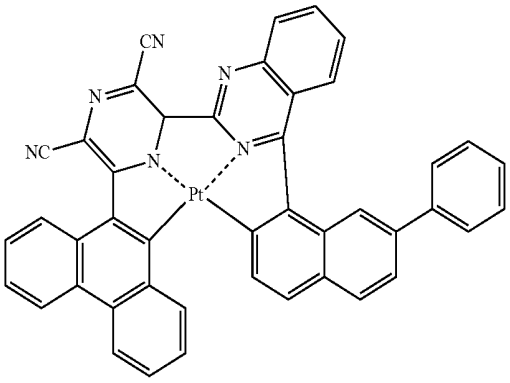

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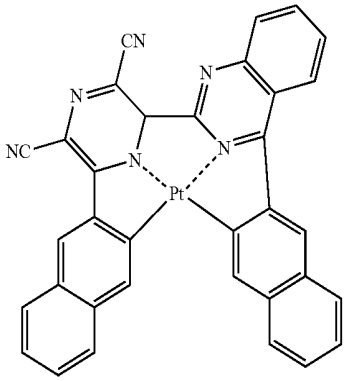

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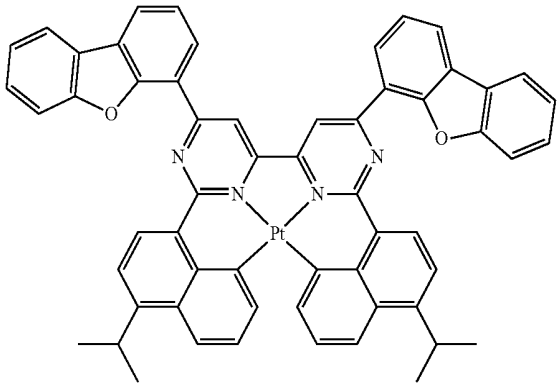

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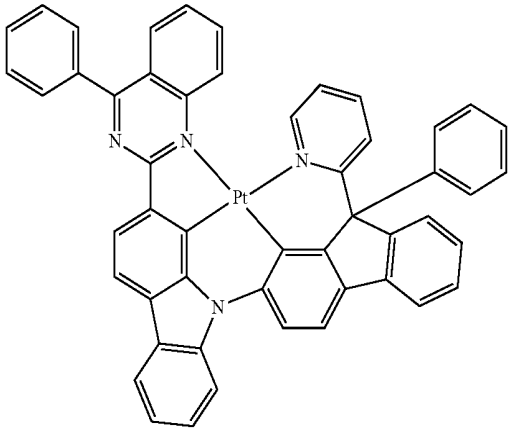

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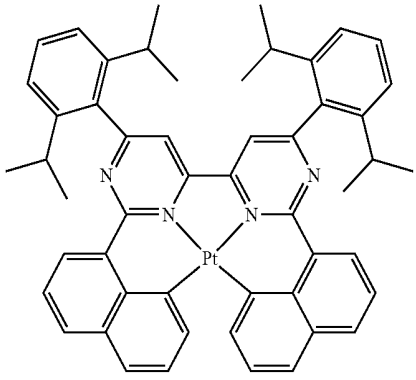

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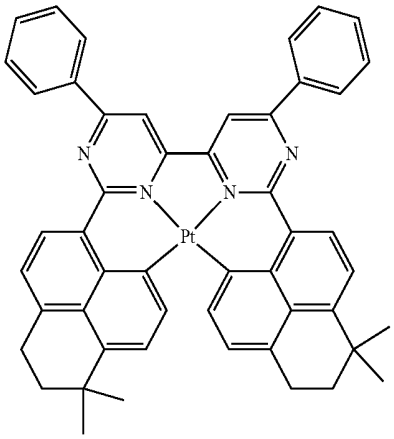

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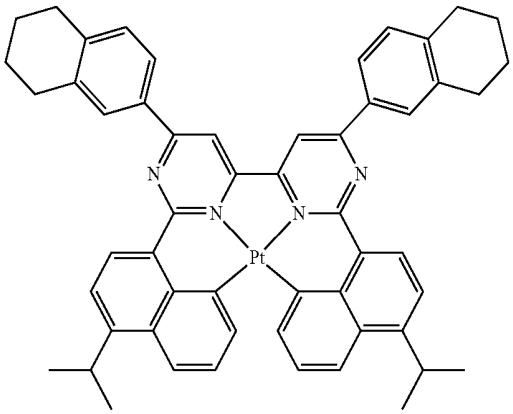

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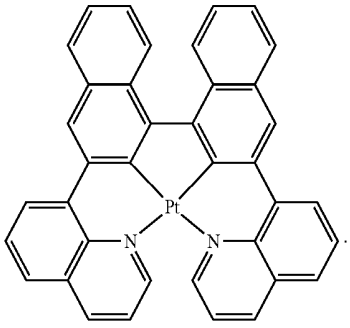

15. An organic light-emitting device comprising:

a first electrode;

a second electrode; and

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

wherein the organic layer comprises at least one of the organometallic compound of claim **1**.

16. The organic light-emitting device of claim **15**, wherein:

the first electrode is an anode,

the second electrode is a cathode,

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 a hole injection layer, a hole transport layer, an electron blocking layer, or any combination thereof, and

the electron transport region comprises a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

17. The organic light-emitting device of claim **15**, wherein:

the emission layer comprises the organometallic compound.

18. The organic light-emitting device of claim **17**, wherein:

the emission layer further comprises a host, and an amount of the host is larger than an amount of the organometallic compound.

19. An apparatus comprising the organic light-emitting device of claim **15**.

20. The apparatus of claim **19**, wherein:

the apparatus is a light-emitting apparatus, an authentication apparatus, and an electronic apparatus.

* * * * *

专利名称(译)	有机金属化合物，包括有机金属化合物的有机发光装置，以及包括有机发光装置的有机发光装置		
公开(公告)号	US20190081252A1	公开(公告)日	2019-03-14
申请号	US16/130396	申请日	2018-09-13
[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	KIM MYEONGSUK KIM SEULONG KO SOOBYUNG YE JIMYOUNG YOO BYEONGWOOK HWANG JAEHOON		
发明人	KIM, MYEONGSUK KIM, SEULONG KO, SOOBYUNG YE, JIMYOUNG YOO, BYEONGWOOK HWANG, JAEHOON		
IPC分类号	H01L51/00 H01L51/50 H01L51/52 C07F15/00		
CPC分类号	H01L51/0087 H01L51/5012 H01L51/5092 H01L51/5096 H01L51/5206 H01L51/5221 C07F15/0086 H01L51/506 H01L51/5072 H01L51/006 H01L51/0067 H01L51/0072 H01L51/0081 H01L51/5016		
优先权	1020180084765 2018-07-20 KR 1020170117231 2017-09-13 KR		
外部链接	Espacenet USPTO		

摘要(译)

本发明提供有机金属化合物，包含该有机金属化合物的有机发光装置，以及包含该有机发光装置的有机发光装置。有机发光装置包括：第一电极;面向第一电极的第二电极;第一电极和第二电极之间的有机层，包括发光层。有机层包括至少一种有机金属化合物。