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

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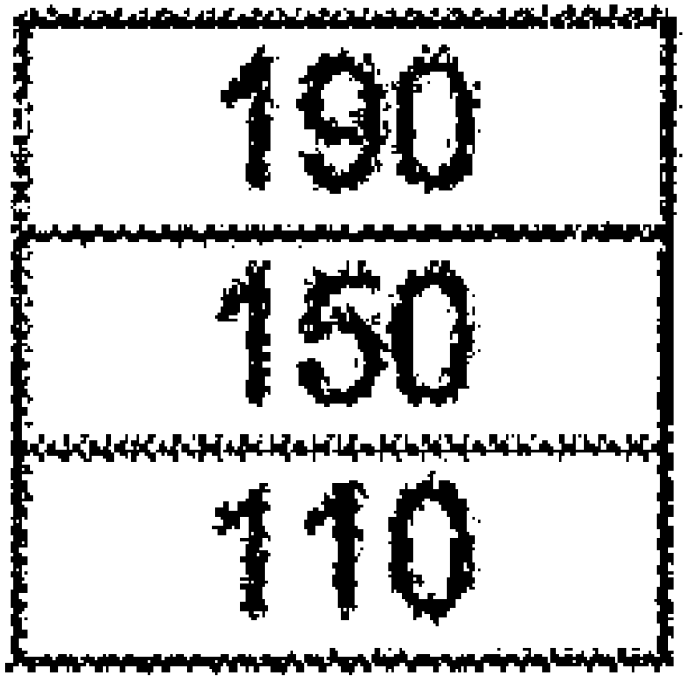
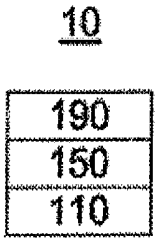
(57) **ABSTRACT**

Provided are an organometallic compound and an organic light-emitting device including the organometallic compound. The organometallic compound may be represented by Formula 1. In Formula 1, L_1 may be a ligand represented by Formula 2A or 2B, and L_2 may be a monovalent organic ligand or a divalent organic ligand.

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ORGANOMETALLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2017-0058095, filed on May 10, 2017, in the Korean Intellectual Property Office, the entire content of which is incorporated herein by reference.

BACKGROUND

1. Field

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

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 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.

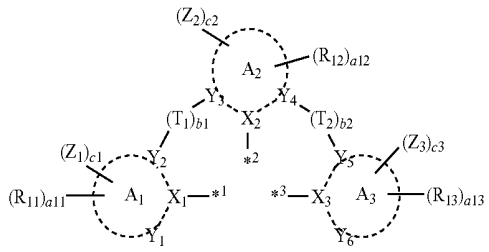
[0006] Additional aspects of embodiments will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

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

Formula 1

$$M(L_1)_{n1}(L_2)_{n2}$$

Formula 2A



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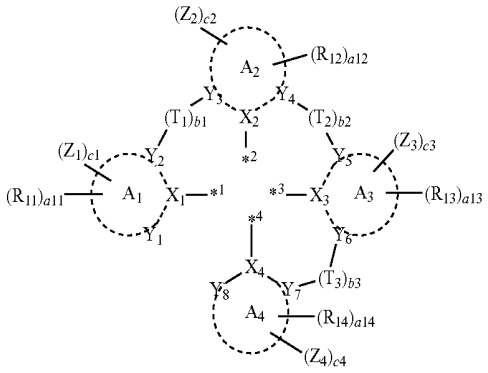
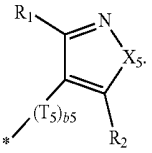
Formula 2B



Formula 3



[0008] M in Formula 1 may be Pt, Pd, Ir, or Os,

[0009] in Formula 1, L_1 may be a ligand represented by Formula 2A or 2B, and n1 may be 1 or 2, wherein, when n1 is two, two L_1(s) may be identical to or different from each other,

[0010] in Formula 1, L_2 may be a monovalent organic ligand or a divalent organic ligand, and n2 may be 1 or 2,

[0011] the sum of n1 and n2 in Formula 1 may be 1, 2, or 3,

[0012] $*^1$, $*^2$, and $*^3$ in Formula 2A and $*^1$, $*^2$, $*^3$, and $*^4$ in Formula 2B each indicate a binding site to M in Formula 1,

[0013] X_1 may be N or C, X_2 may be N or C, X_3 may be N or C, and X_4 may be N or C,

[0014] Y_1 to Y_8 may each independently be N or C,

[0015] a bond between X_1 and Y_1 may be a single bond or a double bond,

[0016] a bond between X_1 and Y_2 may be a single bond or a double bond,

[0017] a bond between X_2 and Y_3 may be a single bond or a double bond,

[0018] a bond between X_2 and Y_4 may be a single bond or a double bond,

[0019] a bond between X_3 and Y_5 may be a single bond or a double bond,

[0020] a bond between X_3 and Y_6 may be a single bond or a double bond,

[0021] rings A_1 to A_4 may each independently be a C_5-C_{30} carbocyclic group or a C_2-C_{60} heterocyclic group,

[0022] T_1 to T_3 may each independently be selected from $*—N[(L)_{a5}\text{-}(R_{15})]—*'$, $*—B(R_{15})—*'$, $*—P(R_{15})—*'$, $*—C(R_{15})(R_{15})—*'$, $*—Si(R_{15})(R_{15})—*'$, $*—Ge(R_{15})(R_{16})—*'$, $*—S—*'$, $*—Se—*'$, $*O—*'$, $*—C(=O)—*'$, $*—S(=O)—*'$, $*—S(=O)_2—*'$, $*—C(R_{15})=*'$, $*=C(R_{15})—*'$, $*—C(R_{15})=C(R_{16})—*'$, $C(=S)—*'$, and $*—C\equiv C—*'$,

[0023] a5 may be selected from 1 to 3, wherein, when a5 is two or more, two or more L_5(s) may be identical to or different from each other,

[0024] R_{15} and R_{16} may optionally be linked to a neighboring substituent selected from R_{11} to R_{14} to form a

substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

[0025] b1 to b4 may each independently be 0, 1, 2, or 3, wherein, when b1 is zero, *-$(T_1)_{b1}$-*' may be a single bond, when b2 is zero, *-$(T_2)_{b2}$-*' may be a single bond, when b3 is zero, *-$(T_3)_{b3}$-*' may be a single bond, and when b4 is 0, *-$(T_4)_{b4}$-*' may be a single bond,

[0026] *and *' each indicate a binding site to a neighboring atom,

[0027] Z_1 to Z_4 may each be represented by Formula 3,

[0028] c1 to c4 may each independently be 0, 1, 2, or 3,

[0029] the sum of c1, c2, and c3 in Formula 2A may be one or more,

[0030] the sum of c1, c2, c3, and c4 in Formula 2B may be one or more,

[0031] T_5 in Formula 3 may be a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{60} heterocyclic group,

[0032] b5 may be an integer from 0 to 5,

[0033] X_5 may be O, S, or $N(R_3)$,

[0034] R_1 to R_3 and R_{11} to R_{16} 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_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, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, and —$P(=O)(Q_1)(Q_2)$,

[0035] at least one substituent of 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, the substituted monovalent non-aromatic condensed heteropolycyclic group, the substituted C_4-C_{60} carbocyclic group, and the substituted C_2-C_{60} heterocyclic group may be selected from:

[0036] 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;

[0037] 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 —$P(=O)(Q_{11})(Q_{12})$;

[0038] 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;

[0039] 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

[0040] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0041] Q_1 to Q_3, 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 biphenyl group, and a terphenyl group.

[0042] Another aspect of an embodiment of the present disclosure provides an organic light-emitting device including: a first electrode; a second 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.

BRIEF DESCRIPTION OF THE DRAWING

[0043] These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accom-

panying drawing which is a schematic view of an organic light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0044] Reference will now be made in 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 present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects 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.

[0045] An organometallic compound according to an embodiment is represented by Formula 1 below:

$$M(L_1)_{n1}(L_2)_{n2}. \qquad \text{Formula 1}$$

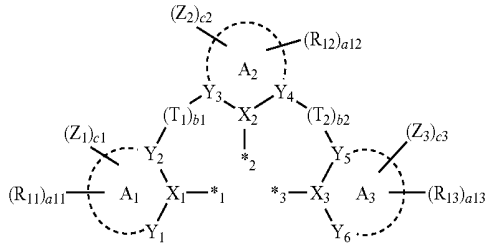
[0046] M in Formula 1 may be platinum (Pt), palladium (Pd), iridium (Ir), or osmium (Os).

[0047] In one embodiment, M may be platinum, but embodiments of the present disclosure are not limited thereto.

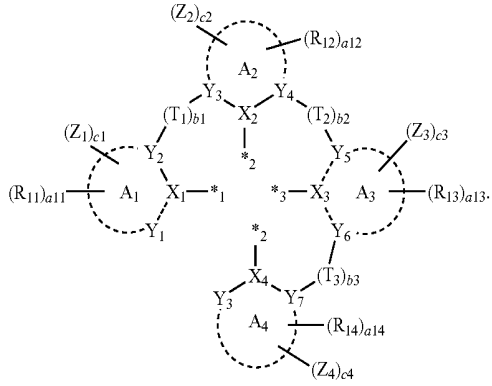
[0048] In Formula 1, L_1 may be a ligand represented by Formula 2A or 2B, and n1 may be 1 or 2, wherein, when n1 is two, two L_1(s) may be identical to or different from each other.

[0049] In one embodiment, n1 is 1, but embodiments of the present disclosure are not limited thereto.

Formula 2A



Formula 2B

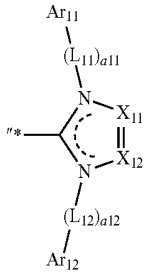


[0050] In Formula 1, L_2 may be a monovalent organic ligand or a divalent organic ligand, and n2 may be 0, 1, or 2.

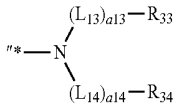
[0051] In one embodiment, L_2 may be a monovalent organic ligand, but embodiments of the present disclosure are not limited thereto.

[0052] In one or more embodiments, L_2 may be selected from ligands represented by Formulae 3A to 3F, but embodiments of the present disclosure are not limited thereto:

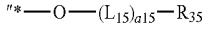
3A



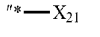
3B



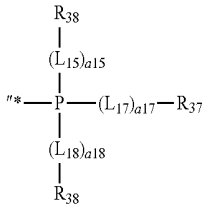
3C



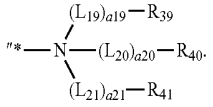
3D



3E



3F



[0053] In Formulae 3A to 3F,

[0054] X_{11} may be N or $C(R_{31})$, and X_{12} may be N or $C(R_{32})$,

[0055] L_{11} to L_{21} 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,

[0056] a11 to a21 may each independently be an integer from 0 to 3,

[0057] Ar_{11} and Ar_{12} 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,

[0058] R_{31} to R_{32} 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_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, $—Si(Q_{11})(Q_{12})(Q_{13})$, $—N(Q_{11})(Q_{12})$, $—B(Q_{11})(Q_{12})$, $—C(=O)(Q_{11})$, $—S(=O)_2(Q_{11})$, and $—P(=O)(Q_{11})(Q_{12})$,

[0059] R_{31} and R_{32} may optionally be linked to form a saturated or unsaturated ring, and R_{33} and R_{34} may optionally be linked to form a saturated or unsaturated ring,

[0060] X_{21} may be selected from —F, —Cl, —Br, and —I,

[0061] "*" indicates a binding site to M in Formula 1,

[0062] at least one substituent of 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:

[0063] 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;

[0064] 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 $—P(=O)(Q_{11})(Q_{12})$;

[0065] 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;

[0066] 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

[0067] $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$, and

[0068] Q_1 to Q_3, 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 biphenyl group, and a terphenyl group.

[0069] In one embodiment, L_2 may be selected from —F, —Cl, —Br, and a cyano group.

[0070] In one embodiment, n2 is 0, but embodiments of the present disclosure are not limited thereto.

[0071] The sum of n1 and n2 in Formula 1 may be 1, 2, or 3.

[0072] In one embodiment, the sum of n1 and n2 may be 1 or 2, but embodiments of the present disclosure are not limited thereto.

[0073] $*^1$, $*^2$, and $*^3$ in Formula 2A and $*^1$, $*^2$, $*^3$, and $*^4$ in Formula 2B each indicate a binding site to M in Formula 1.

[0074] In Formulae 2A and 2B, X_1 may be N or C, X_2 may be N or C, X_3 may be N or C, and X_4 may be N or C.

[0075] Y_1 to Y_8 in Formulae 2A and 2B may each independently be N or C.

[0076] In Formulae 2A and 2B,

[0077] a bond between X_1 and Y_1 may be a single bond or a double bond,

[0078] a bond between X_1 and Y_2 may be a single bond or a double bond,

[0079] a bond between X_2 and Y_3 may be a single bond or a double bond,

[0080] a bond between X_2 and Y_4 may be a single bond or a double bond,

[0081] a bond between X_3 and Y_5 may be a single bond or a double bond, and

[0082] a bond between X_3 and Y_6 may be a single bond or a double bond.

[0083] Rings A_1 to A_4 in Formulae 2A and 2B may each independently be a C_5-C_{30} carbocyclic group or a C_2-C_{60} heterocyclic group.

[0084] In one embodiment, rings A_1 to A_4 may each independently be selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a fluorene group, a phenalene group, a pyrene group, a fluoranthene group, a tetracene group, a chrysene group, a triphenylene group, a benzofluorene group, a perylene group, an indene group, an acenaphthene group, a biphenyl group, a terphenyl 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 pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazol group, a benzopyrazole group, a benzimidazole group, an imidazopyrazinyl group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazol group.

[0085] In one or more embodiments, rings A_1 to A_4 may each independently be selected from a benzene group, a pyridine group, a pyrimidine group, a triazine 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 thiadiazol group, a benzopyrazole group, a benzimidazole group, an imidazopyrazinyl group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazol group.

[0086] In one or more embodiments, rings A_1 to A_4 may each independently be selected from a benzene group, a pyridine group, a pyrimidine group, a triazine group, a pyrazole group, an imidazole group, a triazole group, a benzopyrazole group, a benzimidazole group, and an imidazopyrazinyl group, but embodiments of the present disclosure are not limited thereto.

[0087] T_1 to T_3 in Formulae 2A and 2B may each independently be selected from *—N[$(L)_{a5}$-(R_{15})]—*', *—B(R_{15})—*', *—P(R_{15})—*', *—C(R_{15})(R_{15})—*', *—Si(R_{15})(R_{15})—*', *—Ge(R_{15})(R_{16})—*', *—S—*', *—Se—*', *—O—*', *—C(=O)—*', *—S(=O)—*', *—S(=O)$_2$—*', *—C(R_{15})=*', *=C(R_{15})—*', *—C(R_{15})=C(R_{16})—*', *—C(=S)—*', and *—C≡C—*',

[0088] a5 may be selected from 1 to 3, wherein, when a5 is two or more, two or more L_5(s) may be identical to or different from each other, and

[0089] R_{15} and R_{16} may optionally be linked to a neighboring substituent selected from R_{11} to R_{14} to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group.

[0090] In one embodiment, when at least one of T_1 to T_3 is *—N[$(L_5)_{a5}$-(R_{15})]—*', R_{15} may be a substituted or unsubstituted C_1-C_{60} aryl group, or may optionally be linked to a neighboring substituent selected from R_{11} to R_{14} to form a substituted or unsubstituted C_1-C_{60} heterocyclic group.

[0091] In one or more embodiments, R_{15} may be a substituted or unsubstituted phenyl group, or may optionally be linked to one of L_1 to L_4 to form a substituted or unsubstituted carbazole ring or a substituted or unsubstituted azacarbazole ring, but embodiments of the present disclosure are not limited thereto.

[0092] b1 to b4 in Formulae 2A and 2B may each independently be 0, 1, 2, or 3. When b1 is zero, *-$(T_1)_{b1}$-*' may be a single bond, when b2 is zero, *-$(T_2)_{b2}$-*' may be a single bond, when b3 is zero, *-$(T_3)_{b3}$-*' may be a single bond, when b4 is zero, *-$(T_4)_{b4}$-*' may be a single bond, and * and *' each indicate a binding site to a neighboring atom.

[0093] In Formulae 2A and 2B, Z_1 to Z_4 may each be represented by Formula 3, and c1 to c4 may each independently be 0, 1, 2, or 3.

[0094] In Formulae 2A and 2B, the sum of c1, c2, and c3 in Formula 2A may be one or more, and the sum of c1, c2, c3, and c4 in Formula 2B may be one or more.

Formula 3

[0095] T_5 in Formula 3 may be a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{60} heterocyclic group.

[0096] In one embodiment, rings A_1 to A_4 may each independently be selected from:

[0097] a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a fluorene group, a phenalene group, a pyrene group, a fluoranthene group, a tetracene group, a chrysene group, a triphenylene group, a benzofluorene group, a perylene group, an indene group, an acenaphthene group, a biphenyl group, a terphenyl 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 pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazol group, a benzopyrazole group, a benzimidazole group, an imidazopyrazinyl group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazol group; and

[0098] a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a fluorene group, a phenalene group, a pyrene group, a fluoranthene group, a tetracene group, a chrysene group, a triphenylene group, a benzofluorene group, a perylene group, an indene group, an acenaphthene group, a biphenyl group, a terphenyl 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 pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazol group, a benzopyrazole group, a benzimidazole group, an imidazopyrazinyl group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazol group, each substituted with at least one substituent selected from deuterium, —CD_3, —CD_2H, —CDH_2, —F, —Cl, —Br, a cyano group, —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, an anthracenyl group, a phenanthrenyl group, a fluorenyl group, a phenalenyl group, a pyrenyl group, a fluoranthenyl group, a tetracenyl group, a chrysenyl group, a triperylenyl group, a benzofluorenyl group, a perylenyl group, an indenyl group, an acenaphthylene group, a biphenyl group, a terphenyl group, a pyridyl group, a pyrimidyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a phenanthrolinyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, an oxazolyl group, an isoxazolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, an imidazopyrazinyl group, a benzoxazolyl group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazolyl group,

[0099] but embodiments of the present disclosure are not limited thereto.

[0100] b5 in Formula 3 may be an integer from 0 to 5.

[0101] In one embodiment, b5 may be 0, 1, or 2.

[0102] In one or more embodiments, b5 may be 0.

[0103] X_5 in Formula 3 may be O, S, or $N(R_3)$.

[0104] R_1 to R_3 and R_{11} to R_{16} in Formula 3 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted 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, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, and —$P(=O)(Q_1)(Q_2)$,

[0105] at least one substituent of 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, the substituted monovalent non-aromatic condensed heteropolycyclic group, the substituted C_4-C_{60} carbocyclic group, and the substituted C_2-C_{60} heterocyclic group may be selected from:

[0106] 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;

[0107] 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 —$P(=O)(Q_{11})(Q_{12})$;

[0108] 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;

[0109] 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

[0110] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0111] Q_1 to Q_3, 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 biphenyl group, and a terphenyl group, but embodiments of the present disclosure are not limited thereto.

[0112] In one embodiment, R_3 and R_{11} to R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a C_6-C_{60} aryl group, and a C_1-C_{60} heteroaryl group.

[0113] In one or more embodiments, R_3 and R_{11} to R_{16} may each independently be selected from:

[0114] 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 methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, a pentyl group, an iso-amyl group, a hexyl group, a phenyl group, a naphthyl group, a biphenyl group, a terphenyl group, a pyridyl group, a pyrimidyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a phenanthrolinyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, an oxazolyl group, an isoxazolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, a benzoxazolyl group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazolyl group, a 5,6,7,8-tetrahydroisoquinolinyl group, a 5,6,7,8-tetrahydroquinoline group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0115] a substituted methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, a pentyl group, an iso-amyl group, a hexyl group, a phenyl group, a naphthyl group, a biphenyl group, a terphenyl group, a pyridyl group, a pyrimidyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a phenanthrolinyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, an oxazolyl group, an isoxazolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, a benzoxazolyl group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazolyl group, a 5,6,7,8-tetrahydroisoquinolinyl group, a 5,6,7,8-tetrahydroquinoline group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a triazinyl 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 methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, a pentyl group, an iso-amyl group, a hexyl 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 naphthyl group, a fluorenyl group, a pyridyl group, a pyrimidyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, a benzonaphthofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group,

[0116] but embodiments of the present disclosure are not limited thereto.

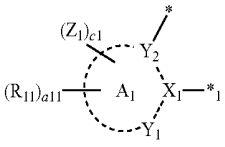
[0117] In one or more embodiments, R_3 and R_{11} to R_{16} may each independently be selected from:

[0118] hydrogen, deuterium, —F, —Cl, —Br, —I, a phenyl group, a naphthyl group, a biphenyl group, and a terphenyl group; and

[0119] a phenyl group, a naphthyl group, a biphenyl group, and a terphenyl 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 methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, a pentyl group, an iso-amyl group, a hexyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a pyridyl group, a pyrimidyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, a benzonaphthofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group,

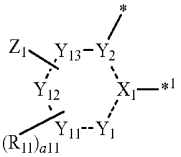
[0120] but embodiments of the present disclosure are not limited thereto.

[0121] In one embodiment, (i) c1 may be 1, and a moiety represented by



in Formula 2A or 2B may be represented by Formula 4A-1 or 4A-2:

Formula 4A-1



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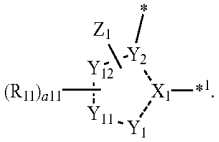
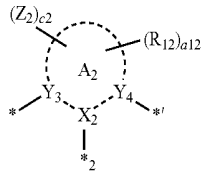
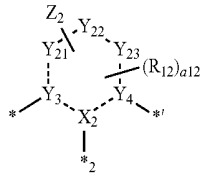


[0122] In one or more embodiments, c2 may be 1, and a moiety represented by

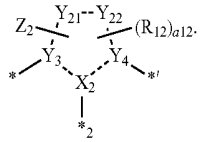


in Formula 2A or 2B may be represented by Formula 4B-1 or 4B-2:

Formula 4B-1



Formula 4B-2



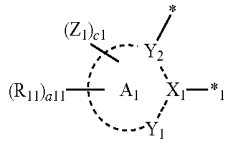
In Formulae 4A-1, 4A-2, 4B-1, and 4B-2,

[0123] Y_{11}, Y_{12}, Y_{13}, Y_{21}, Y_{22}, and Y_{23} may each independently be N or C,

[0124] *and *' each indicate a binding site to a neighboring atom, and

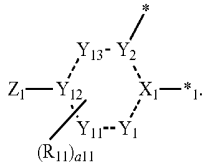
[0125] ^{*1} and ^{*2} each indicate a binding site to M in Formula 1.

[0126] In one embodiment, c1 may be 1, and a moiety represented by

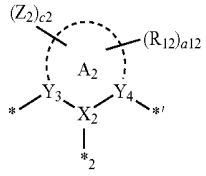


in Formula 2A or 2B may be represented by Formula 4A-1-1:

Formula 4A-1-1

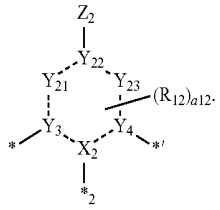


[0127] In one or more embodiments, (ii) c2 may be 1, and a moiety represented by



in Formula 2A or 2B may be represented by Formula 4B-1-1:

Formula 4B-1-1



[0128] In Formulae 4A-1-1 and 4B-1-1,

[0129] Y_{11}, Y_{12}, Y_{13}, Y_{21}, Y_{22}, and Y_{23} may each independently be N or C,

[0130] *and *' each indicate a binding site to a neighboring atom, and

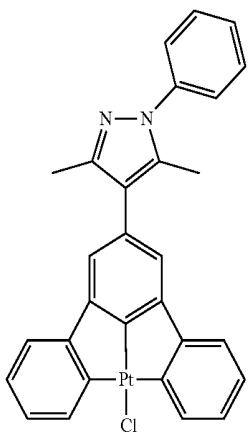
[0131] ^{*1} and ^{*2} each indicate a binding site to M in Formula 1.

[0132] In one embodiment, Y_{12} and Y_{22} in Formulae 4A-1-1 and 4B-1-1 may each be C, but embodiments of the present disclosure are not limited thereto.

[0133] two neighboring groups selected from Y_1, Y_2, Y_3, Y_4, Y_{11}, Y_{12}, Y_{13}, Y_{21}, Y_{22}, and Y_{23} in Formulae 4A-1, 4A-2, 4B-1, 4B-2, 4A-1-1, and 4B-1-1 may be a single bond or a double bond.

[0134] In one embodiment, the organometallic compound may be selected from Compounds 1 to 42, but embodiments of the present disclosure are not limited thereto:

1



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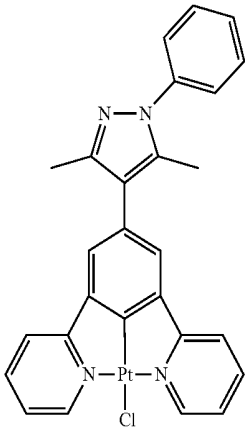

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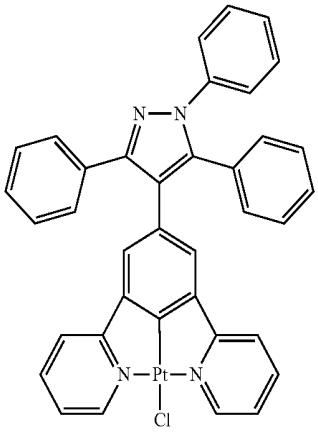

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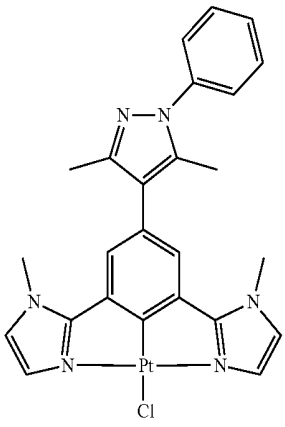

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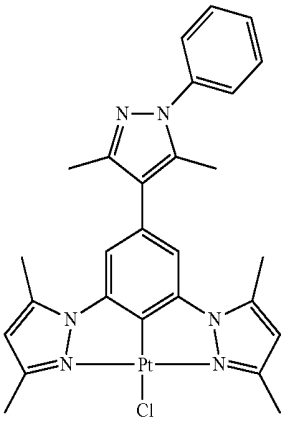

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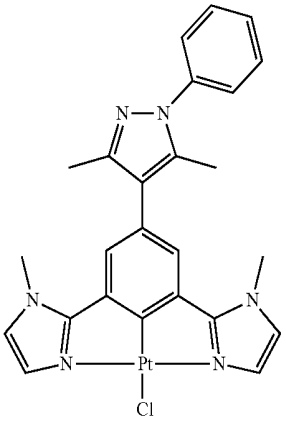

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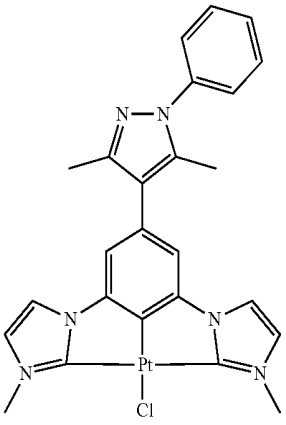

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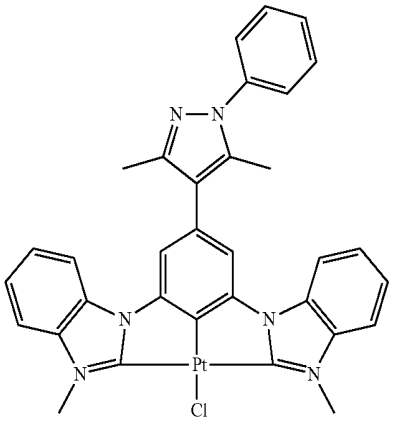

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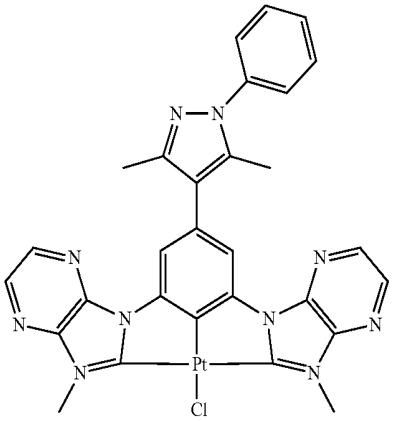

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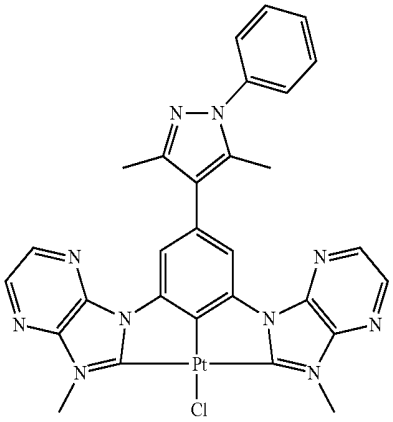

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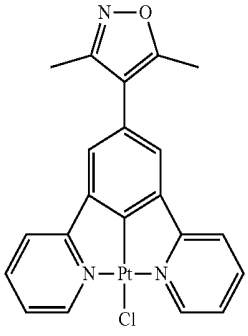

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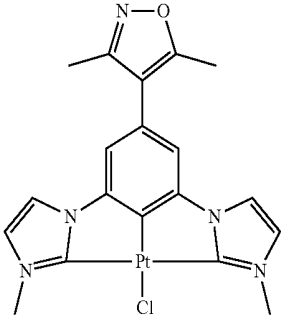

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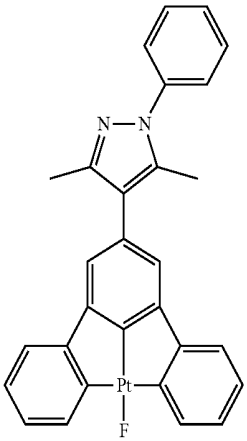

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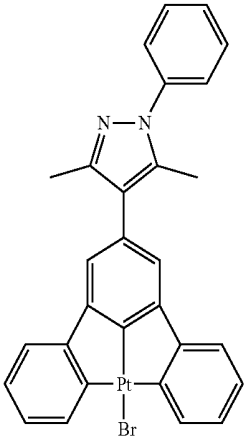

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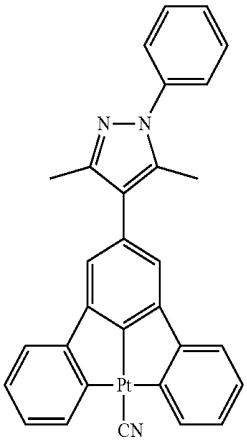

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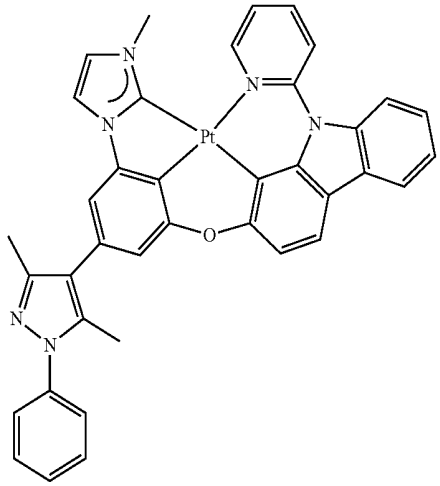

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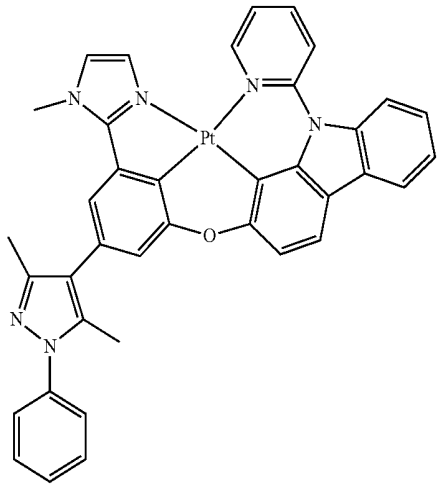

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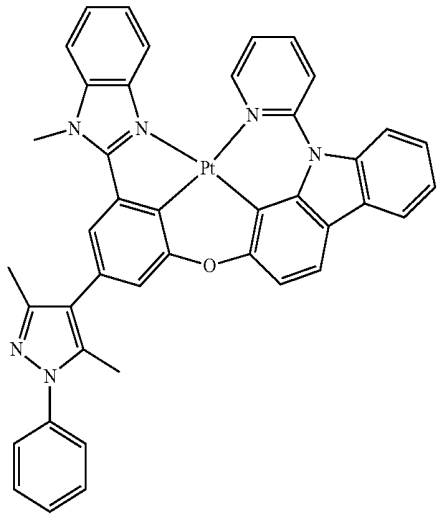

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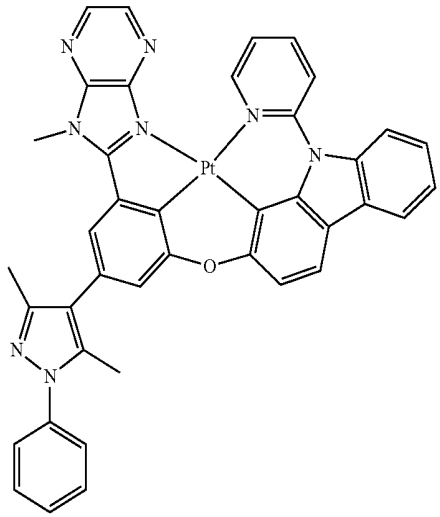

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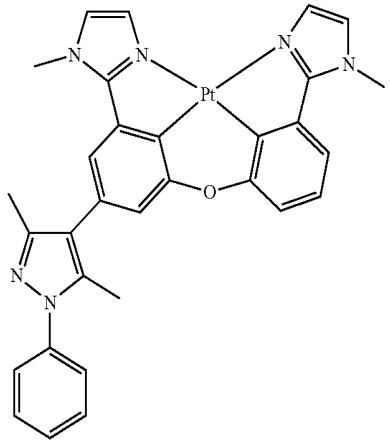

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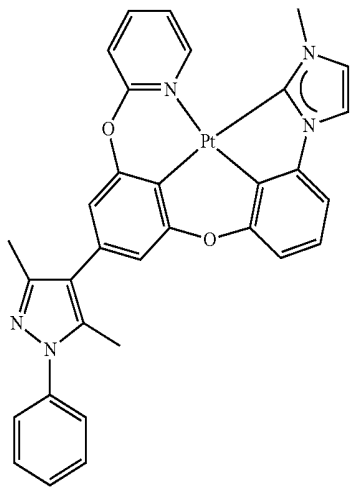

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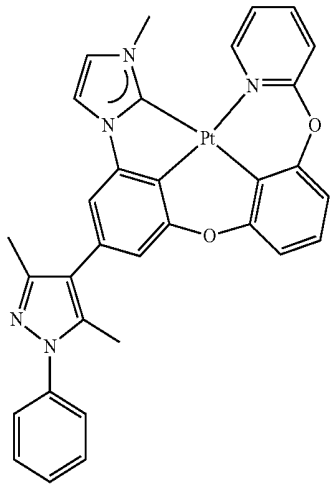

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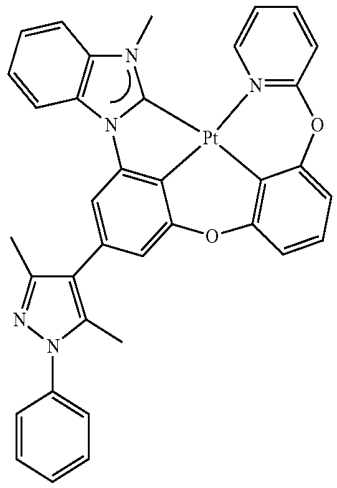

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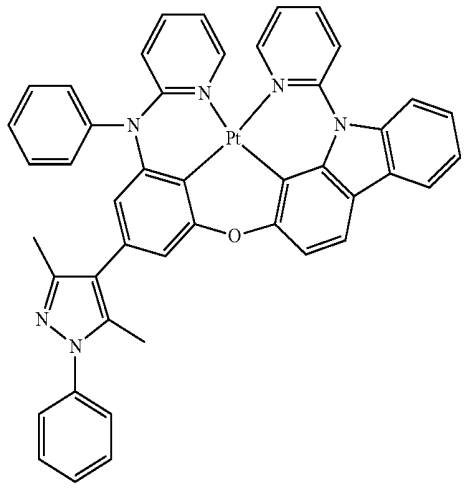

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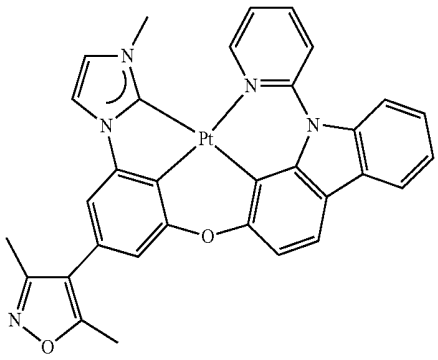

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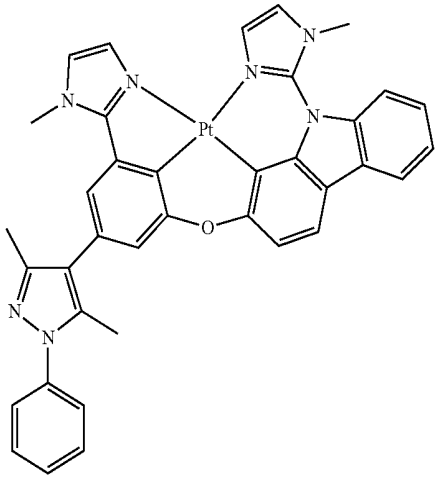

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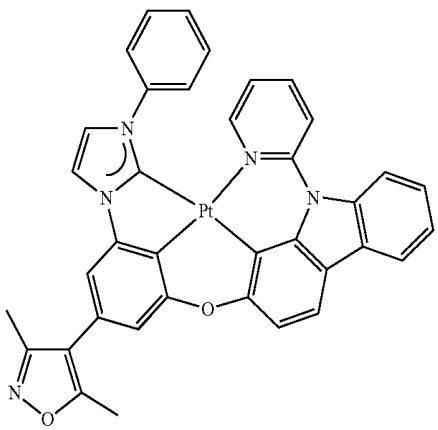

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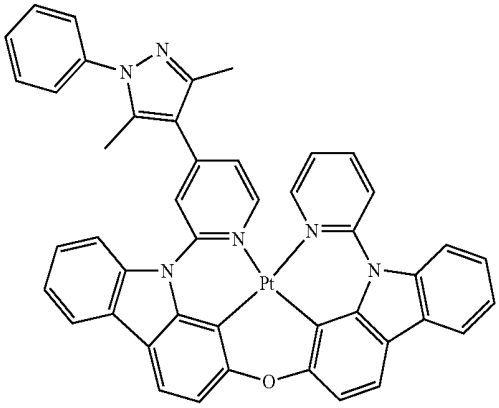

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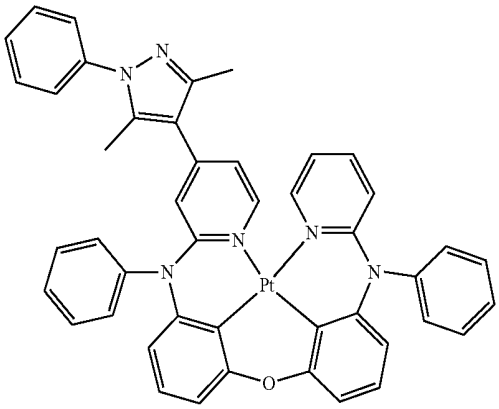

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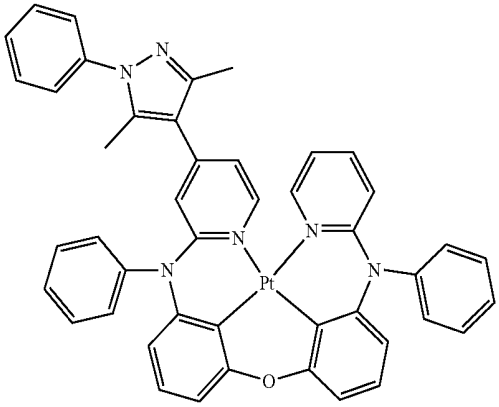

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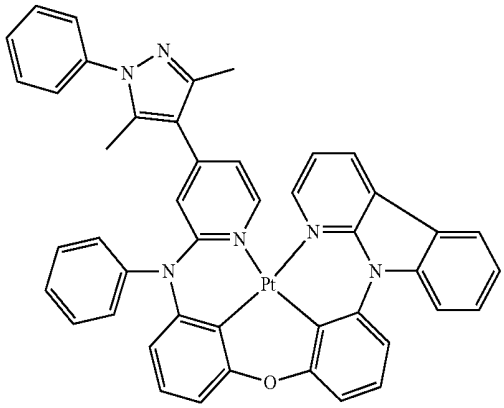

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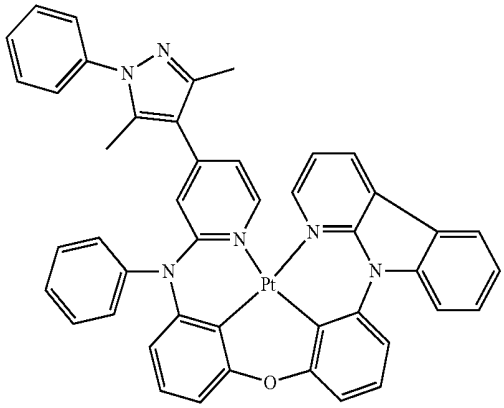

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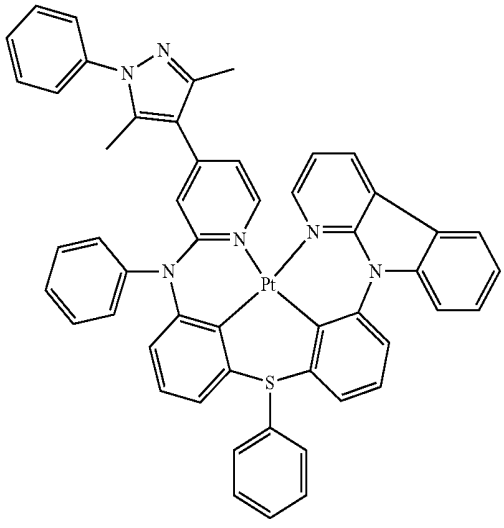

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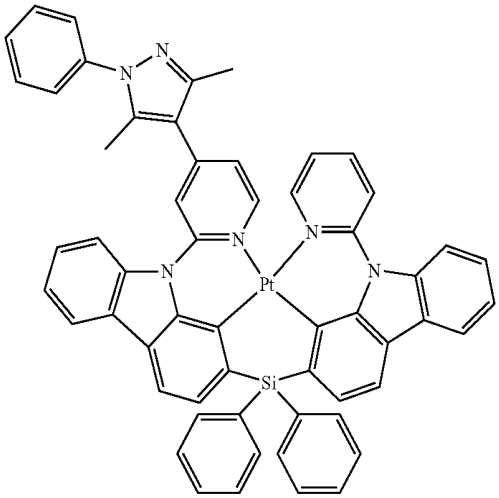

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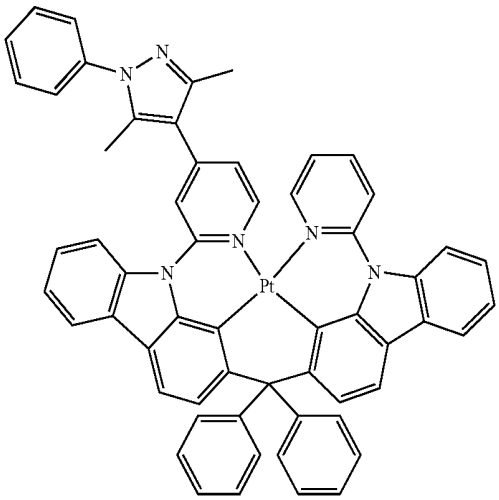

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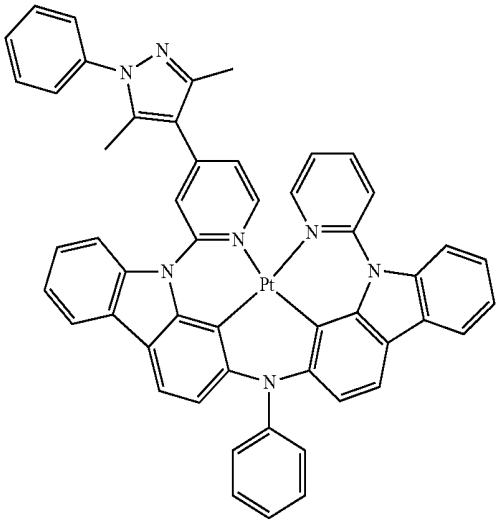

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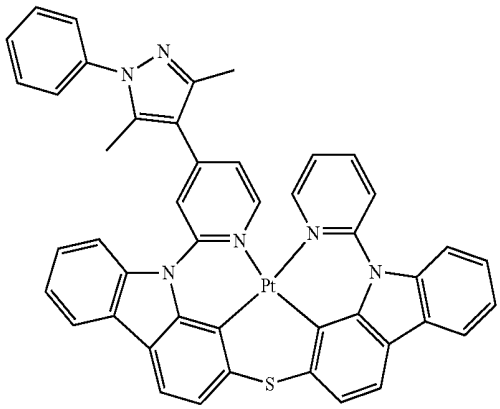

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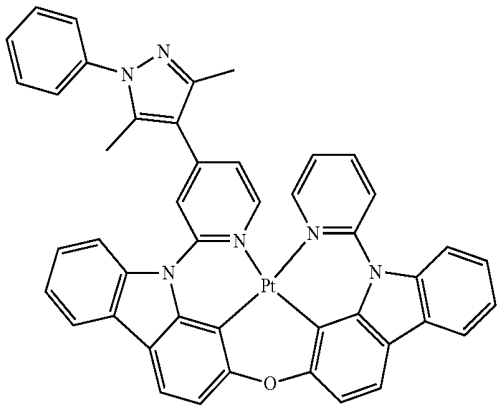

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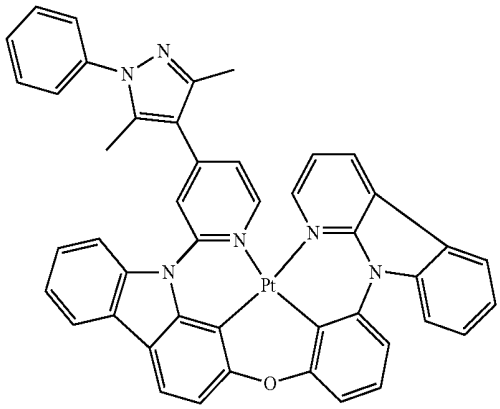

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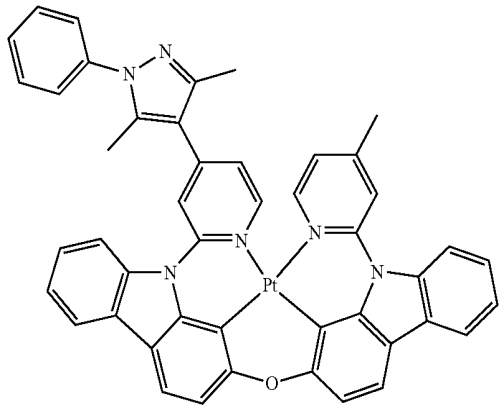

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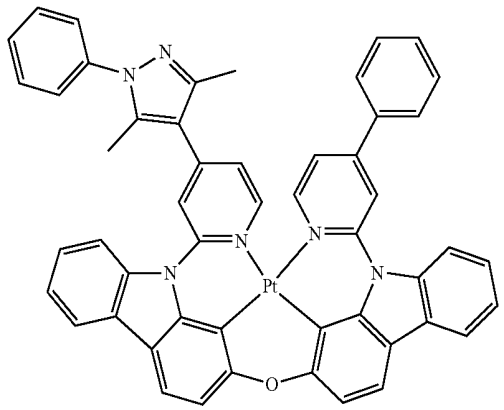

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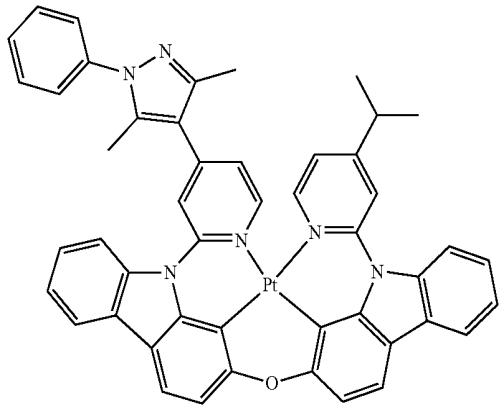


[0135] In general, an intermolecular aggregation easily occurs in a metal complex of a solid, for example, a d^8 planar metal complex such as Pt(II), due to a strong intermolecular interaction such as a ligand-ligand, metal-metal, and/or ligand-metal interaction. Due to such a phenomenon, when the degree of doping exceeds about 0.1%, which is the degree often used in the art, it is highly likely that an aggregation of complex units will be caused in an emission layer. Such aggregation causes formation what is referred to as an excimer (also referred to as exciplex) at the time of optical and/or electrical excitation. Since the excimer has a wide emission band without a regular system (e.g., the excimer does not emit light having a narrow band of wavelengths in an ordered system), it is difficult to implement pure basic colors (RGB) when the excimer is present.

[0136] In embodiments of the present disclosure, the ligand of the organometallic compound represented by Formula 1 is always substituted with the substituent represented by Formula 3, and thus is oriented in a way that an isoxazole or pyrazole substituent is perpendicular (e.g., substantially perpendicular) to the substituent represented by Formula 3. Therefore, as compared with the structure having no such substituent, steric hindrance occurs (or is increased) and the formation of an excimer is hindered by intermolecular stacking. Thus, it is possible to implement a light-emitting device having high efficiency and a long lifespan in a color region of deep blue light. For example, when the ligand and the substituent represented by Formula 3 are linked via a C—C bond, the effect of a distortion structure is increased and the effect of excimer formation suppression is increased (or maximized).

[0137] The organometallic compound according to embodiments of the present disclosure may emit blue light. For example, the organometallic compound may emit blue light having an upper (or a maximum) emission wavelength of 440 nm to 495 nm, for example, 450 nm to 465 nm (in the case of bottom emission, $CIE_{x,y}$ color coordinates (0.14, 0.06) to (0.14, 0.08)), but embodiments of the present disclosure are not limited thereto. Accordingly, the organometallic compound represented by Formula 1 may be suitably used to manufacture an organic light-emitting device that emits deep blue light.

[0138] A synthesis method for the organometallic compound represented by Formula 1 will be readily apparent to those of ordinary skill in the art by referring to the following examples.

[0139] At least one of the organometallic compound of Formula 1 may be used between a pair of electrodes of an organic light-emitting device. For example, the organometallic compound may be included in an emission layer. The organometallic compound may act as a dopant in the emission layer.

[0140] 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 compound represented by Formula 1.

[0141] The expression "(an organic layer) includes at least one organometallic compound" used herein may include a case in which "(an organic layer) includes identical compounds represented by Formula 1" and a case in which "(an organic layer) includes two or more different organometallic compounds represented by Formula 1."

[0142] 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).

[0143] According to one embodiment,

[0144] the first electrode of the organic light-emitting device may be an anode,

[0145] the second electrode of the organic light-emitting device may be a cathode,

[0146] 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,

[0147] 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

[0148] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0149] 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.

[0150] Description of the Accompanying Drawing

[0151] 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**.

[0152] 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.

[0153] [First Electrode **110**]

[0154] 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.

[0155] 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.

[0156] 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.

[0157] 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.

[0158] [Organic Layer **150**]

[0159] The organic layer **150** is disposed on the first electrode **110**. The organic layer **150** may include an emission layer.

[0160] 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**.

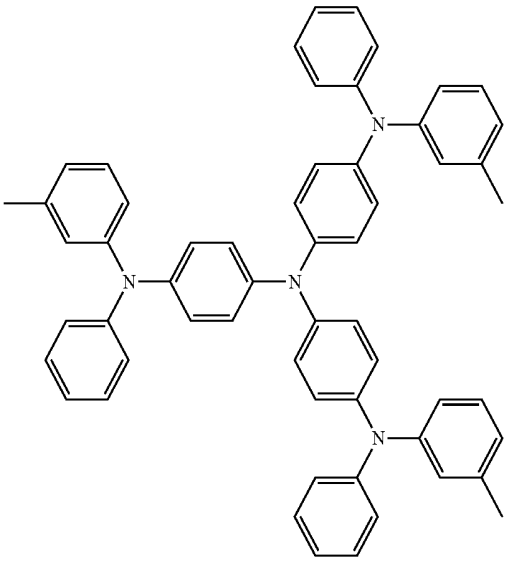
[0161] [Hole Transport Region in Organic Layer **150**]

[0162] 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.

[0163] 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.

[0164] 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.

[0165] 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

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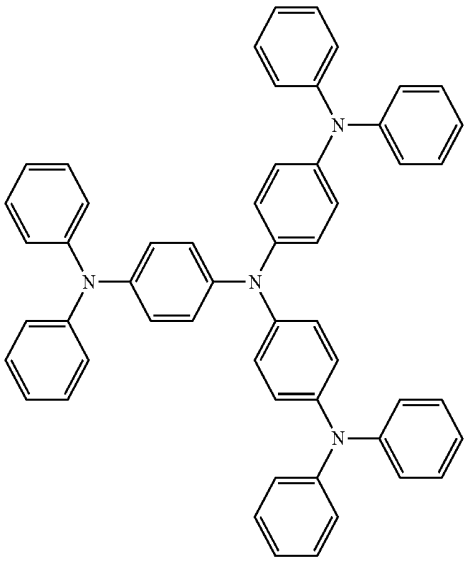
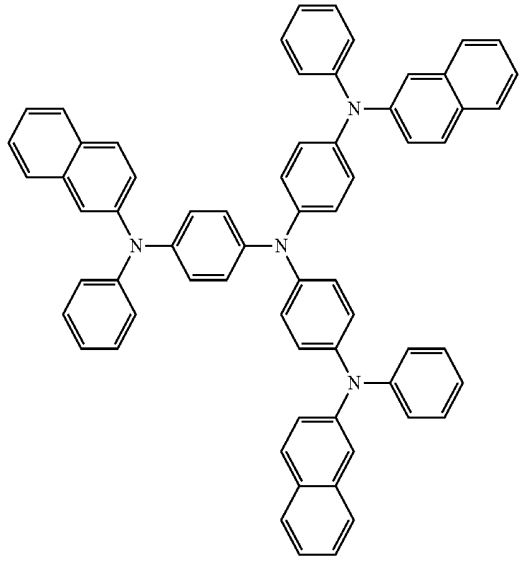
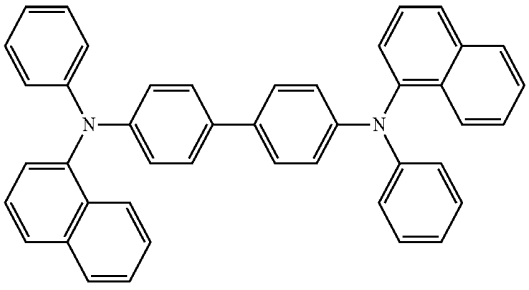


TDATA



3-TNATA



NPB

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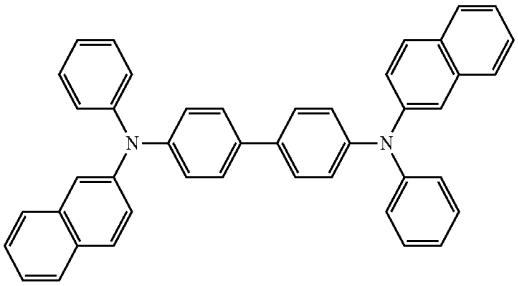
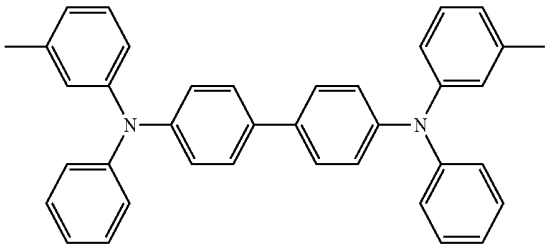
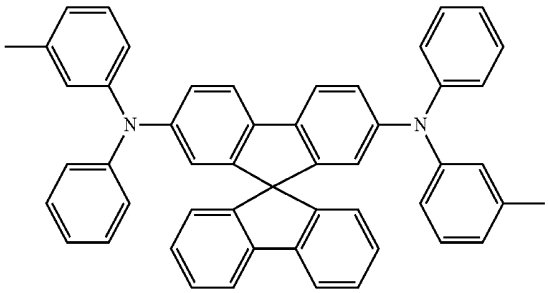


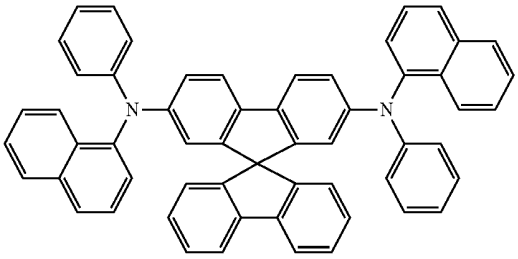
β-NPB



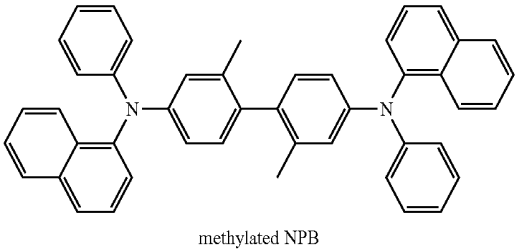
TPD



Spiro-TPD

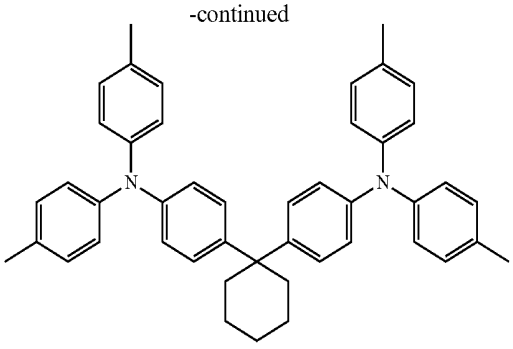


Spiro-NPS

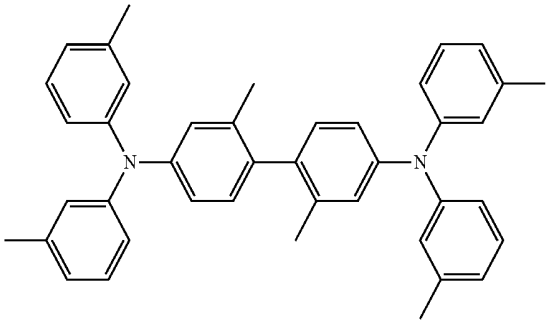


methylated NPB

-continued

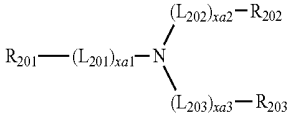


TAPC

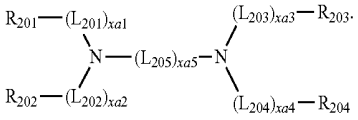


HMTPD

Formula 201



Formula 202



[0166] In Formulae 201 and 202,

[0167] 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,

[0168] 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,

[0169] xa1 to xa4 may each independently be an integer from 0 to 3,

[0170] xa5 may be an integer from 1 to 10, and

[0171] 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.

[0172] For example, in Formula 202, R_{201} and R_{202} may optionally be linked via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R_{203} and R_{204} may optionally be linked via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0173] In one embodiment, in Formulae 201 and 202,

[0174] L_{201} to L_{205} may each independently be selected from:

[0175] 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

[0176] 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

[0177] 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.

[0178] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0179] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0180] In one or more embodiments, R_{201} to R_{204} and Q_{201} may each independently be selected from:

[0181] 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

[0182] 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

[0183] Q_{31} to Q_{33} are the same as described above.

[0184] In one or more embodiments, at least one of R_{201} to R_{203} in Formula 201 may each independently be selected from:

[0185] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0186] 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,

[0187] but embodiments of the present disclosure are not limited thereto.

[0188] In one or more embodiments, in Formula 202, i) R_{201} and R_{202} may be linked via a single bond, and/or ii) R_{203} and R_{204} may be linked via a single bond.

[0189] In one or more embodiments, at least one of R_{201} to R_{204} in Formula 202 may be selected from:

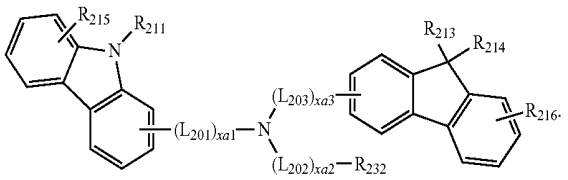
[0190] a carbazolyl group; and

[0191] 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,

[0192] but embodiments of the present disclosure are not limited thereto.

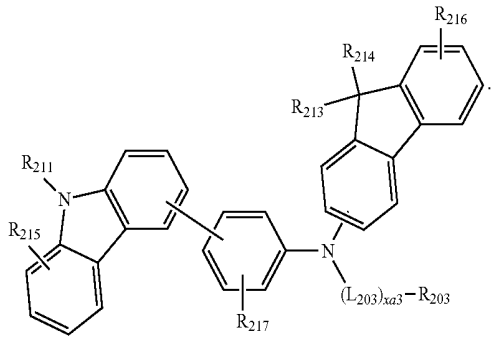
[0193] The compound represented by Formula 201 may be represented by Formula 201A:

Formula 201A



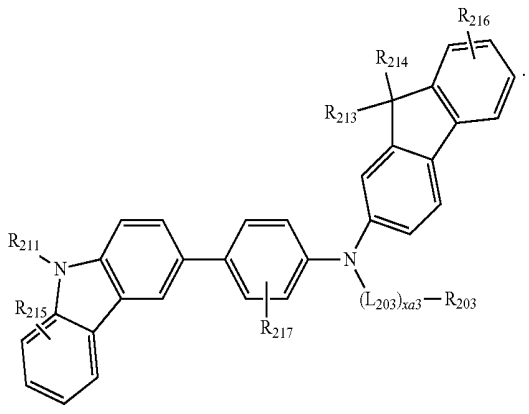
[0194] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A(1) below, but embodiments of the present disclosure are not limited thereto:

Formula 201A(1)



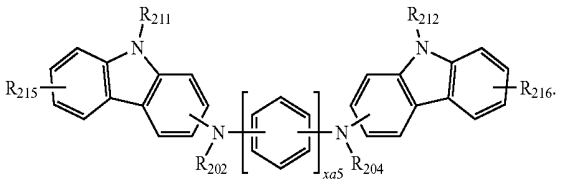
[0195] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A-1 below, but embodiments of the present disclosure are not limited thereto:

Formula 201A-1



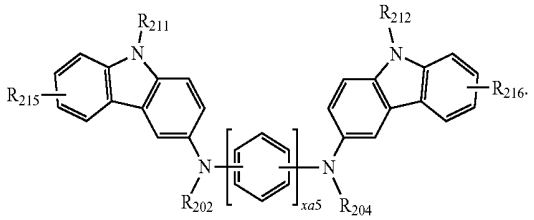
[0196] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A:

Formula 202A



[0197] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A-1:

Formula 202A-1



[0198] In Formulae 201A, 201A(1), 201A-1, 202A, and 202A-1,

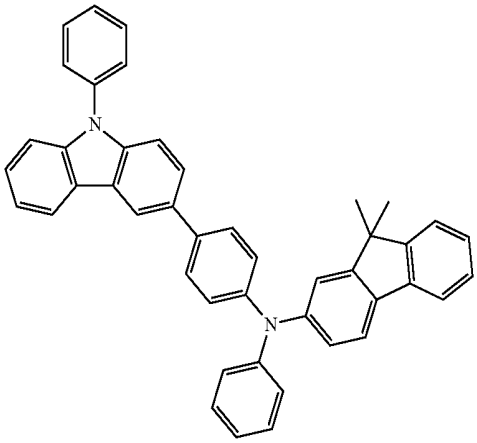
[0199] L_{201} to L_{203}, xa1 to xa3, xa5 and R_{202} to R_{204} are the same as described above,

[0200] R_{211} and R_{212} may be understood by referring to the description provided herein in connection with R_{203},

[0201] 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.

[0202] 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



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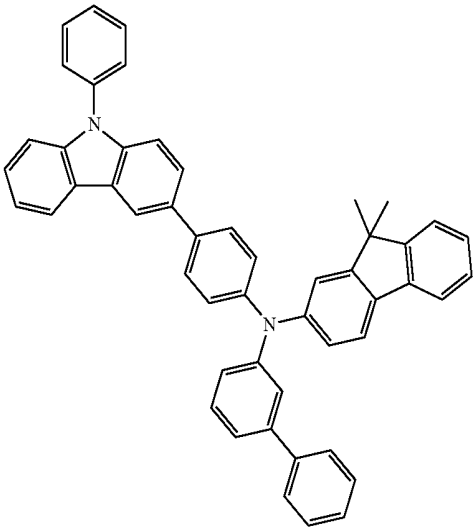

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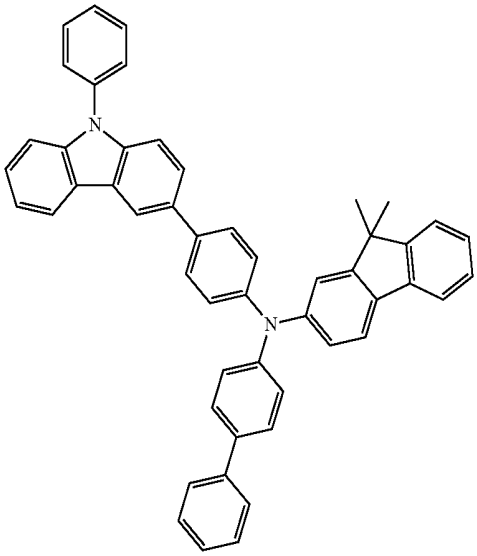

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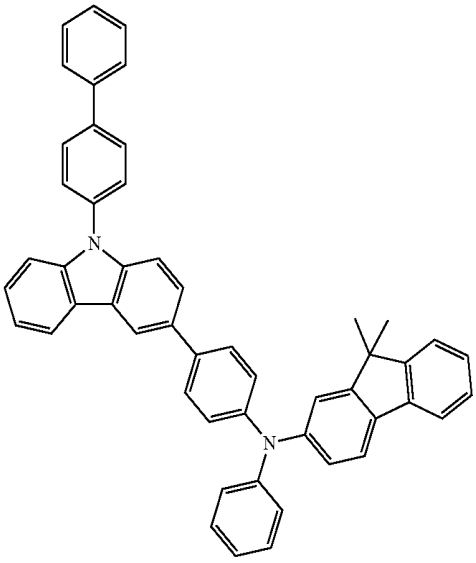

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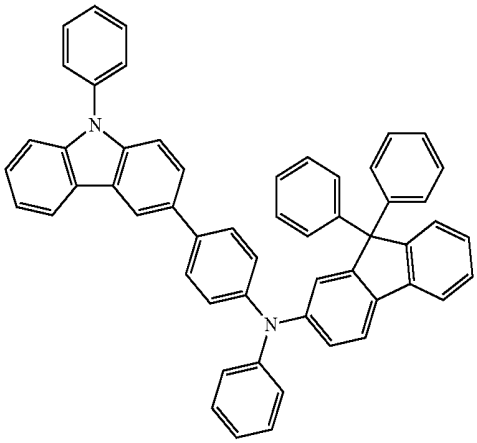

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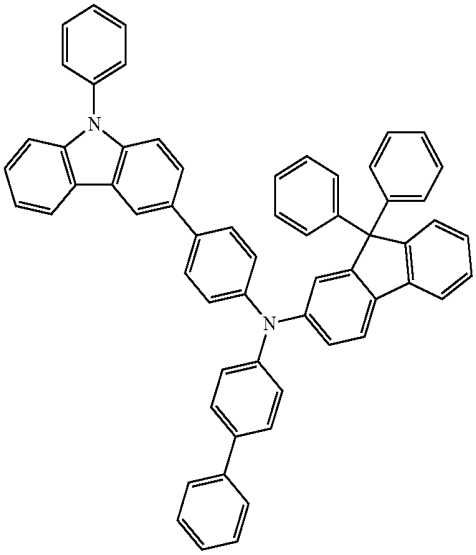

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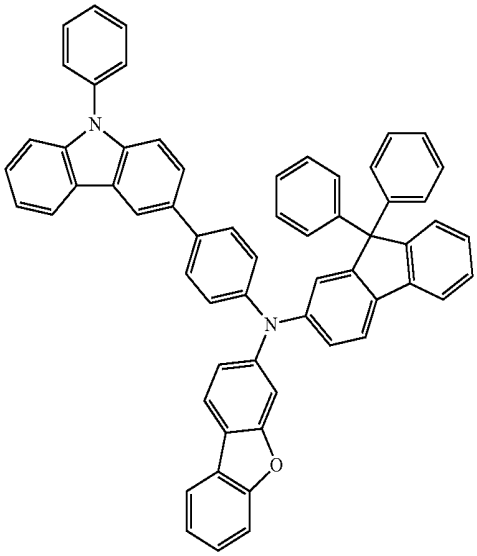

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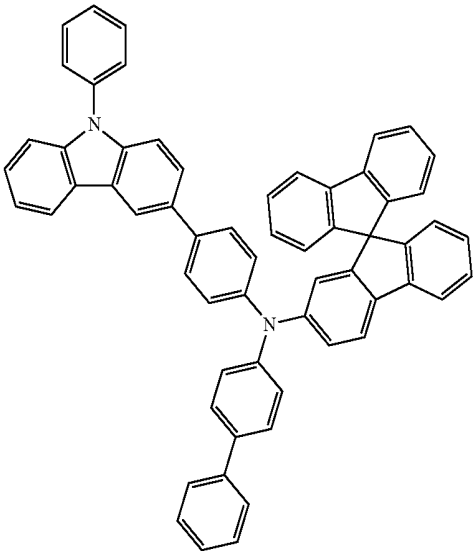

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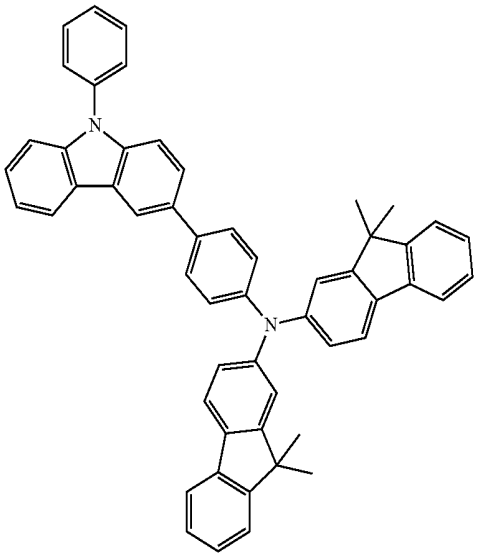

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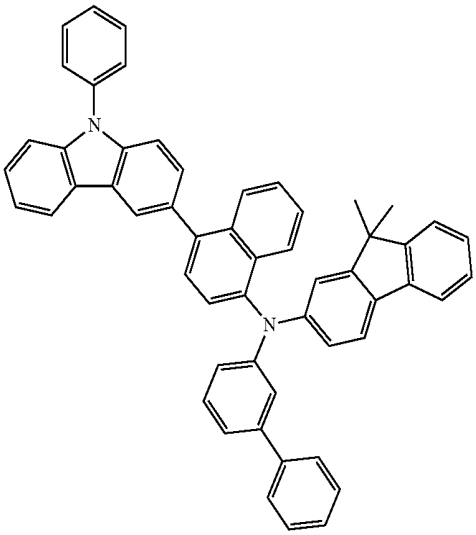

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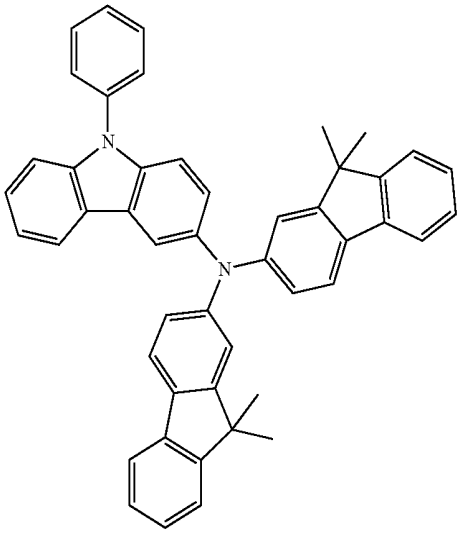

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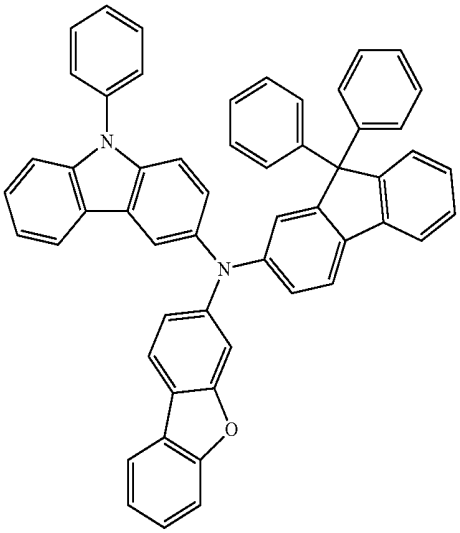

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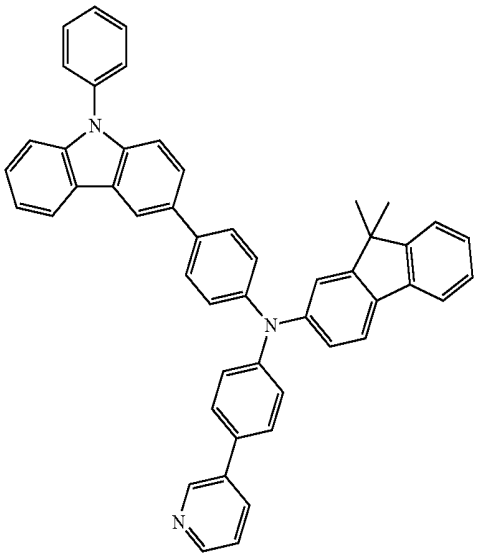

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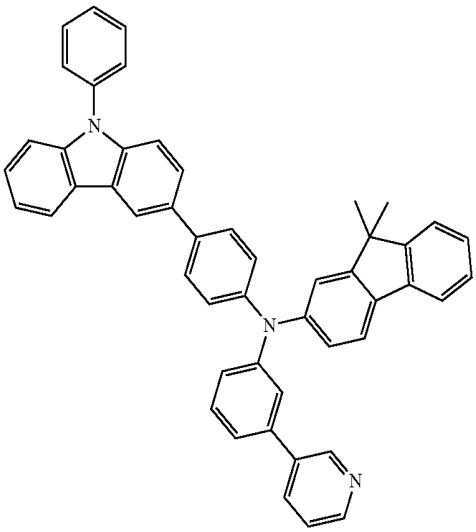

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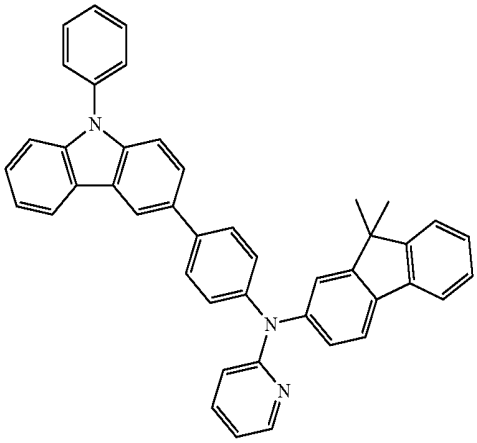

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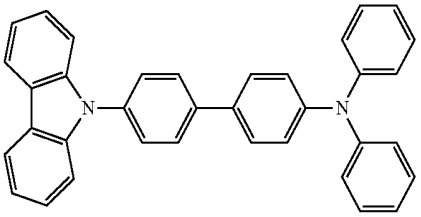

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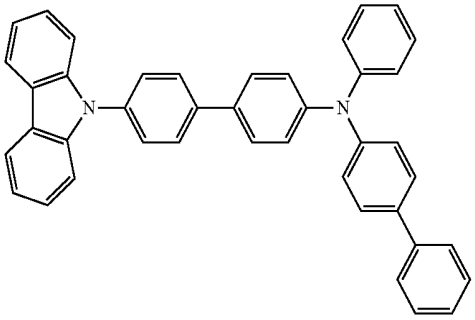

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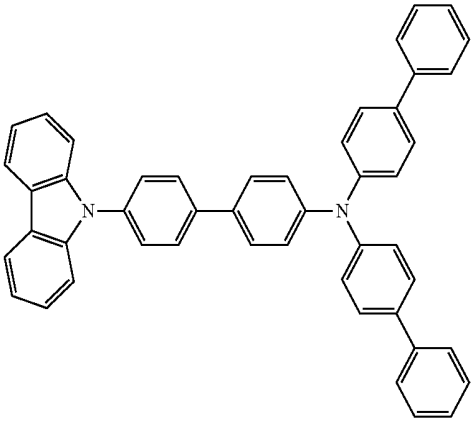

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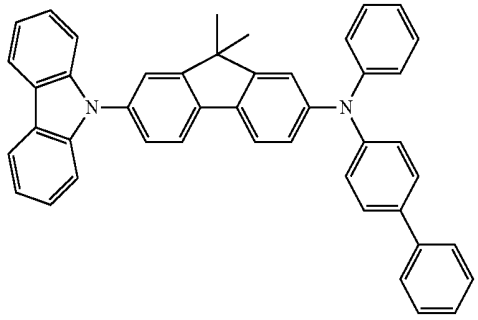

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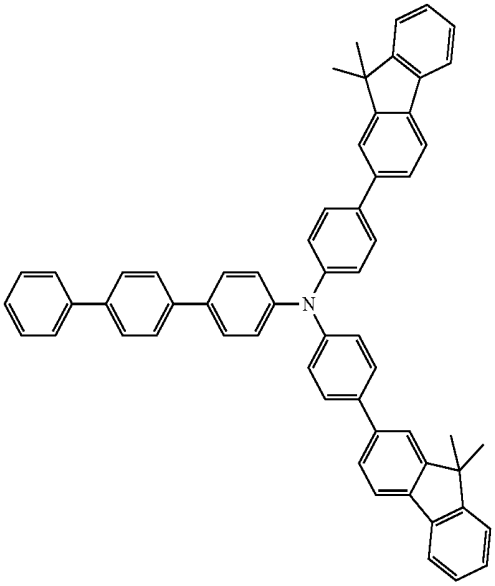

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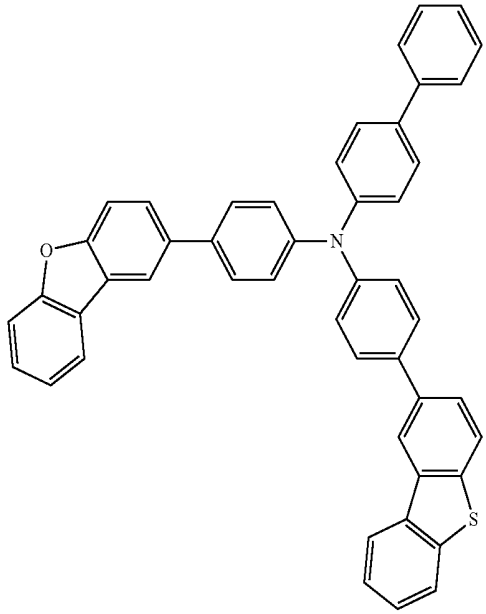

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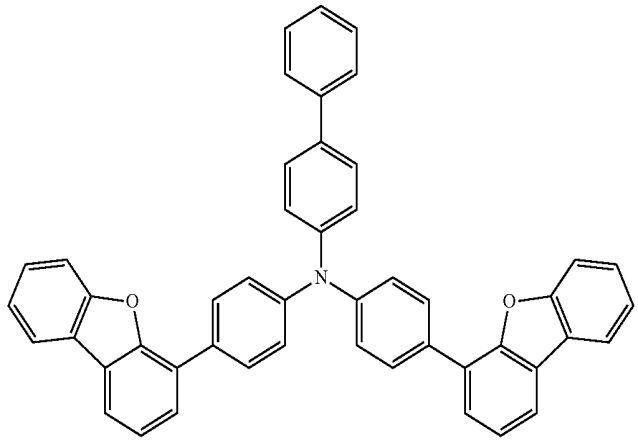

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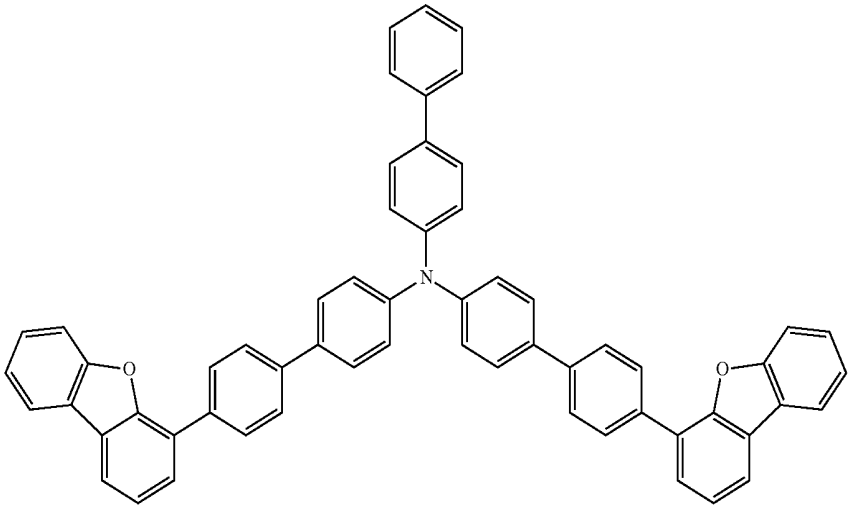

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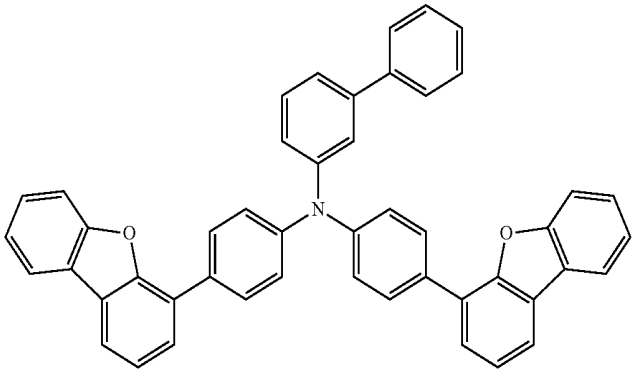

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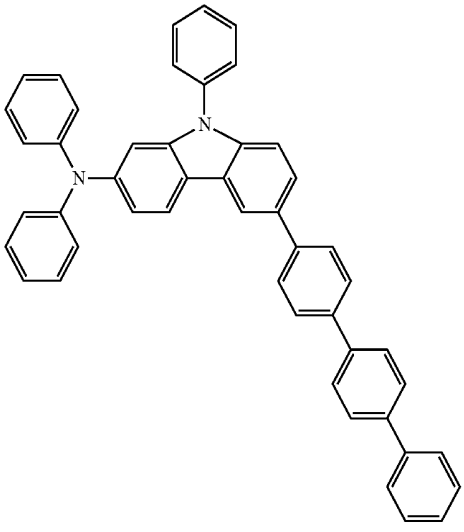

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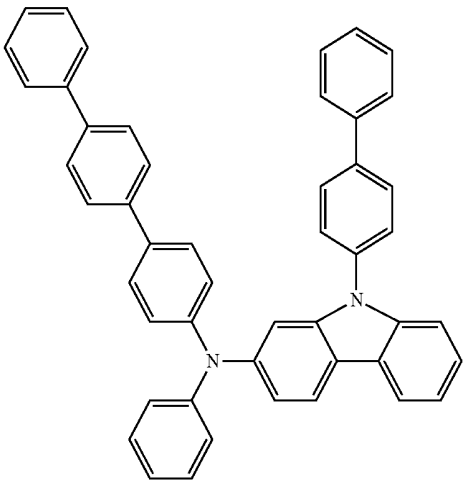

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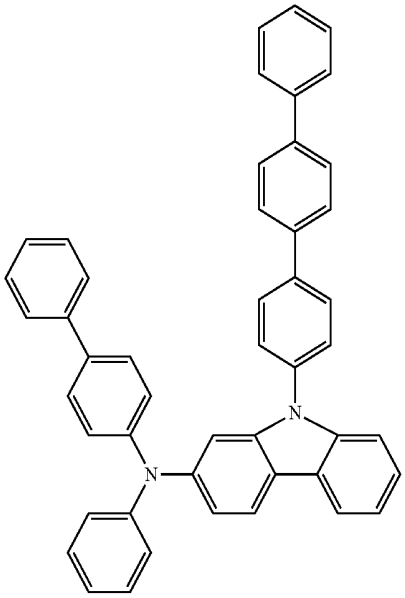

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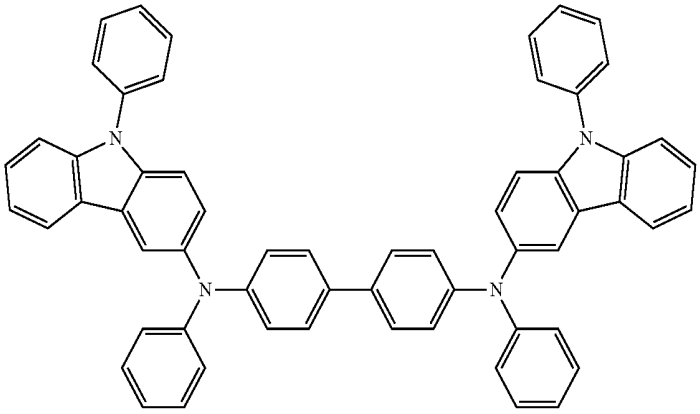

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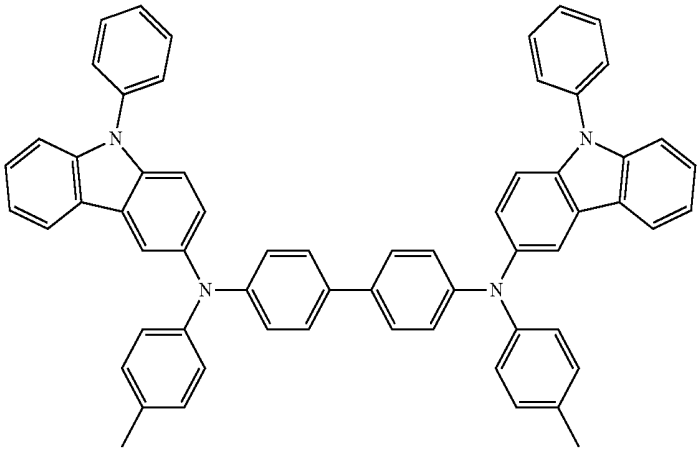

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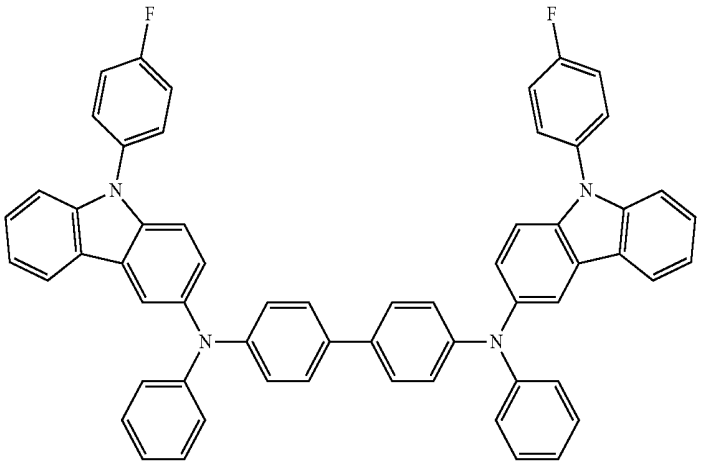

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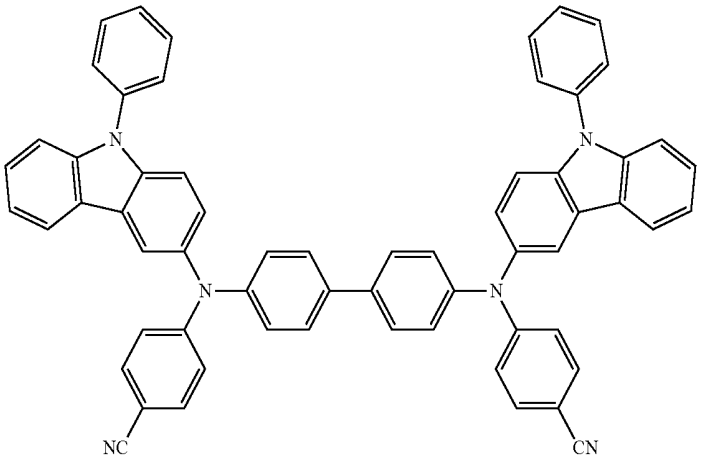

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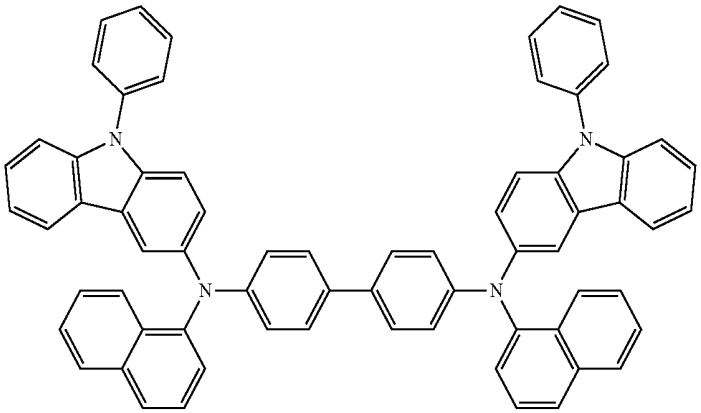

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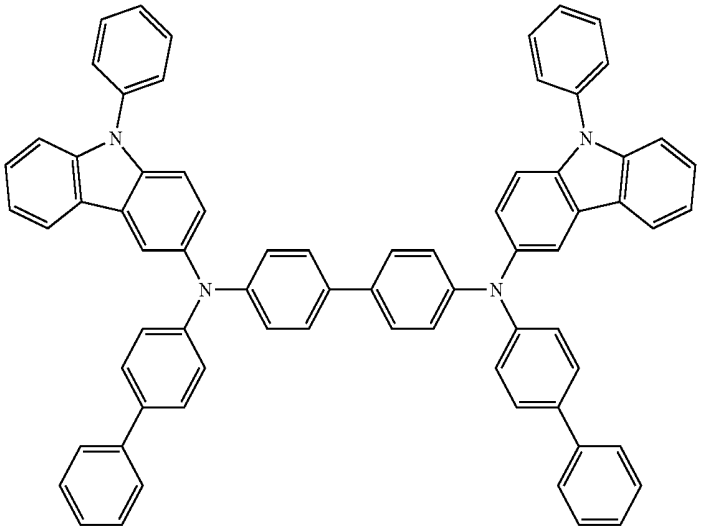

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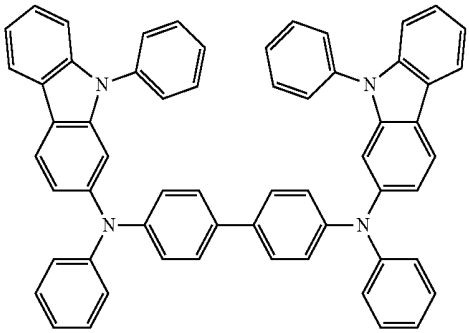

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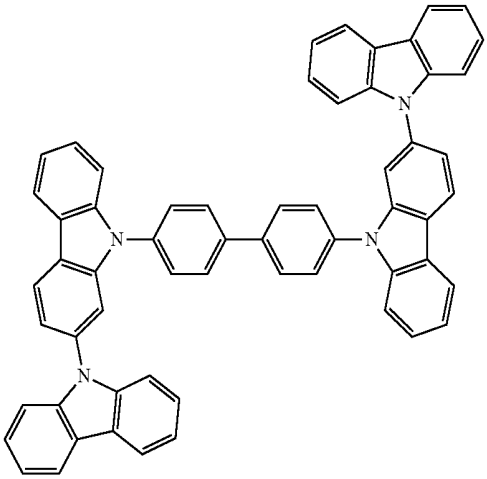

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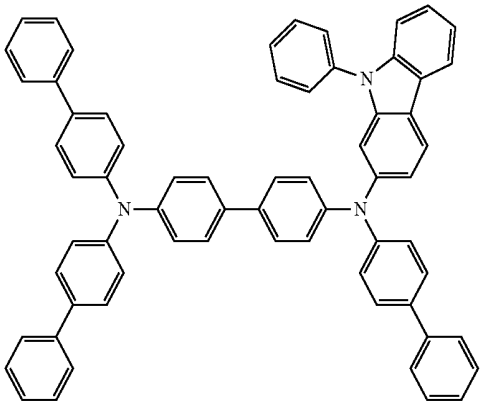

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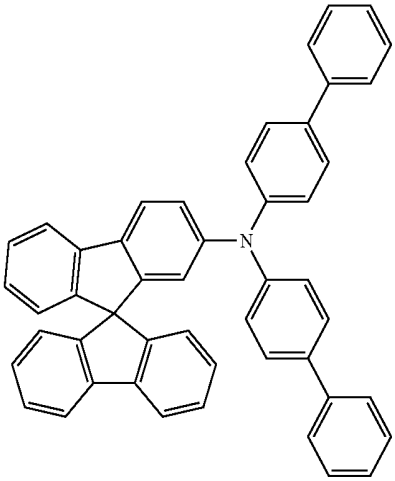

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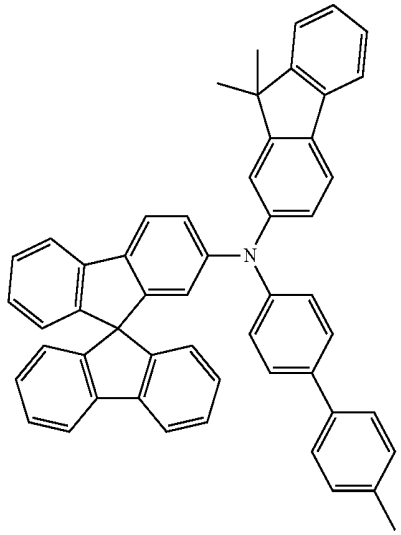
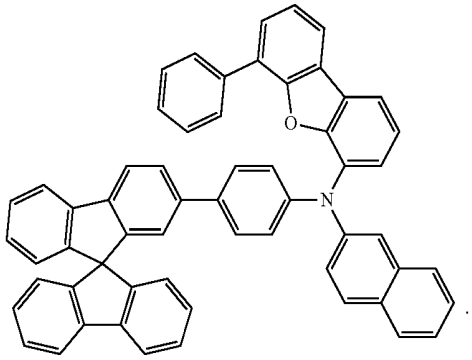
HT38



HT39



[0203] A thickness of the hole transport region may be in a range of about 100 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å. When the hole transport region includes at least one of a hole injection layer and a hole transport layer, a thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, for example, about 100 Å to about 1,000 Å, and a thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, for example about 100 Å to about 1,500 Å. 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.

[0204] 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.

[0205] [p-Dopant]

[0206] 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.

[0207] The charge-generation material may be, for example, a p-dopant.

[0208] In one embodiment, the p-dopant may have a lowest unoccupied molecular orbital of about −3.5 eV or less.

[0209] 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.

[0210] For example, the p-dopant may include at least one selected from:

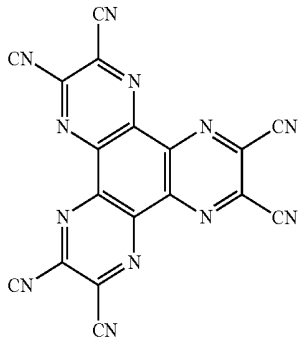
[0211] a quinone derivative, such as tetracyanoquinodimethane (TCNQ) or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ);

[0212] a metal oxide, such as tungsten oxide or molybdenum oxide;

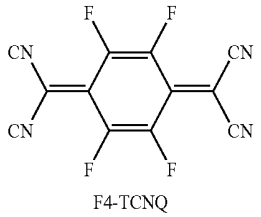
[0213] 1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and

[0214] a compound represented by Formula 221 below:

[0215] but embodiments of the present disclosure are not limited thereto:

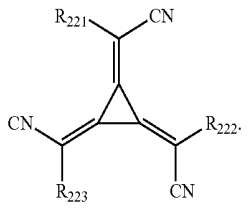


HAT-CN



F4-TCNQ

Formula 221



[0216] In Formula 221,

[0217] R_{221} to R_{223} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, wherein at least one selected from R_{221} to R_{223} may have at least one substituent selected from a cyano group, —F, —Cl, —Br, —I, a C_1-C_{20} alkyl group substituted with —F, a C_1-C_{20} alkyl group substituted with —Cl, a C_1-C_{20} alkyl group substituted with —Br and a C_1-C_{20} alkyl group substituted with —I.

[0218] [Emission Layer in Organic Layer **150**]

[0219] 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.

[0220] 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.

[0221] An amount of the dopant in the emission layer may be, for example, 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.

[0222] 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.

[0223] [Host in Emission Layer]

[0224] In one or more embodiments, the host may include a compound represented by Formula 301 below.

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

[0225] In Formula 301,

[0226] 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,

[0227] xb11 may be 1, 2, or 3,

[0228] L_{301} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0229] xb1 may be an integer from 0 to 5,

[0230] 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 —$P(=O)(Q_{301})(Q_{302})$,

[0231] xb21 may be an integer from 1 to 5, and

[0232] 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.

[0233] In one embodiment, Ar_{301} in Formula 301 may be selected from:

[0234] 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

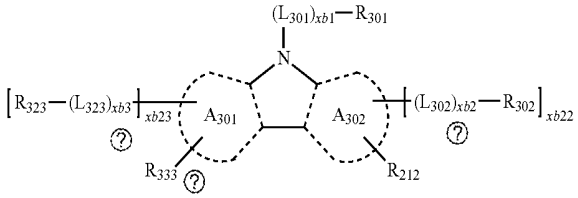
[0235] a naphthalene group, a fluorene group, a spirobifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene 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

[0236] 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.

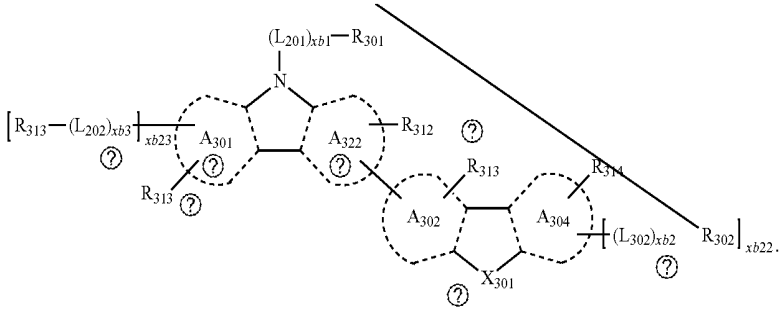
[0237] When xb11 in Formula 301 is two or more, two or more of Ar_{301}(s) may be linked via a single bond.

[0238] 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



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[0239] In Formulae 301-1 and 301-2,

[0240] A_{301} to A_{304} may each independently be selected from a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a pyridine group, a pyrimidine group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a carbazole group, a benzocarbazole group, a dibenzocarbazole group, a furan group, a benzofuran group, a dibenzofuran group, a naphthofuran group, a benzonaphthofuran group, a dinaphthofuran group, a thiophene group, a benzothiophene group, a dibenzothiophene group, a naphthothiophene group, a benzonaphthothiophene group, and a dinaphthothiophene group,

[0241] X_{301} may be O, S, or N-[$(L_{304})_{xb4}$-R_{304}],

[0242] 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 —$P(=O)(Q_{31})(Q_{32})$,

[0243] xb22 and xb23 may each independently be 0, 1, or 2,

[0244] L_{301}, xb1, R_{301}, and Q_{31} to Q_{33} are the same as described above,

[0245] L_{302} to L_{304} may each independently be the same as described in connection with L_{301},

[0246] xb2 to xb4 may each independently be the same as described in connection with xb1, and

[0247] R_{302} to R_{304} may each independently be the same as described in connection with R_{301}.

[0248] For example, in Formulae 301, 301-1, and 301-2, L_{301} to L_{304} may each independently be selected from:

[0249] 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

[0250] 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, 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

[0251] Q_{31} to Q_{33} are the same as described above.

[0252] In one embodiment, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

[0253] 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

[0254] 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, 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

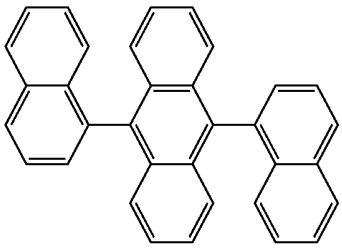
[0255] Q_{31} to Q_{33} are the same as described above.

[0256] In one or more embodiments, the host may include an alkaline earth metal complex. For example, the host may

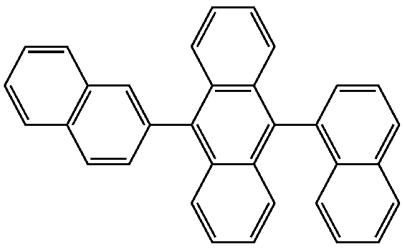
be selected from a Be complex (for example, Compound H55), a Mg complex, and a Zn complex.

[0257] 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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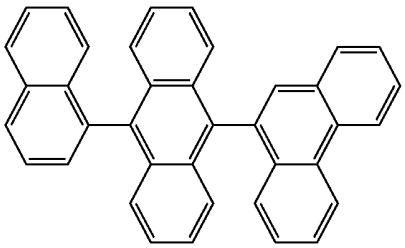

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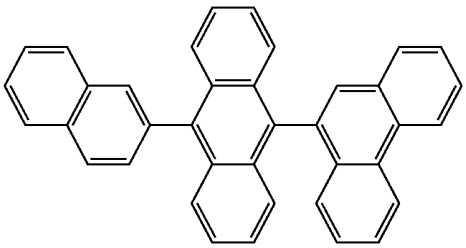

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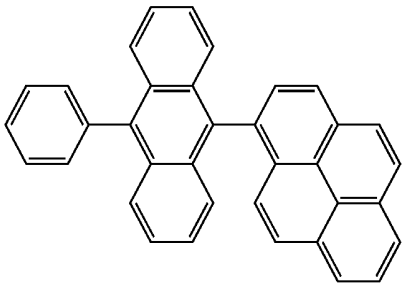

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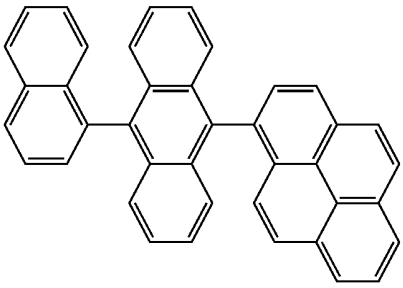

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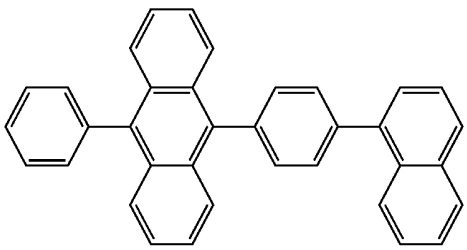

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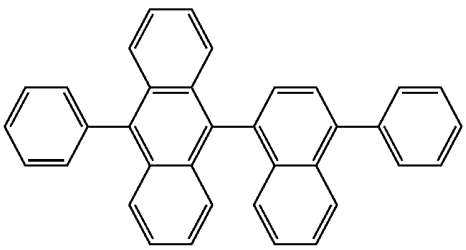
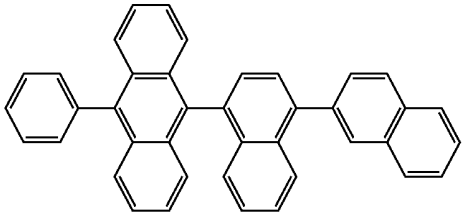


H9



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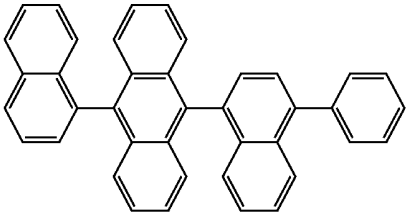

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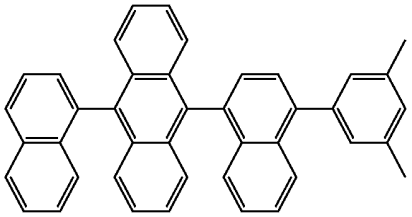
H11



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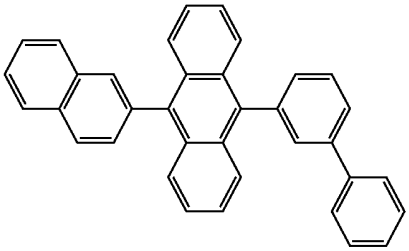

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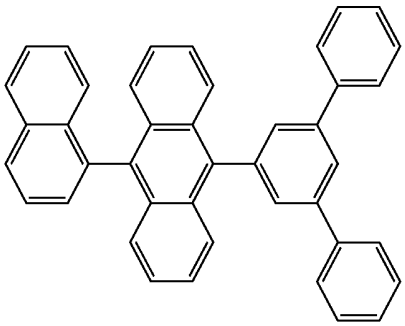

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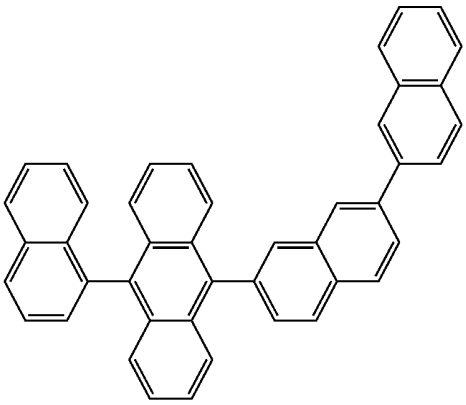

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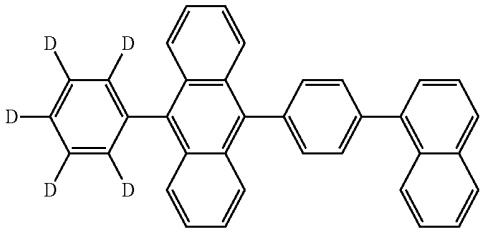

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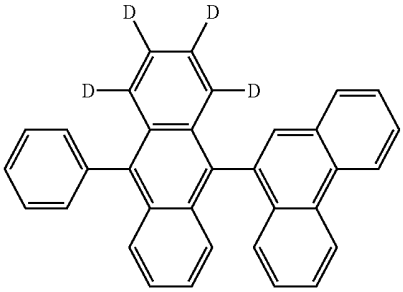

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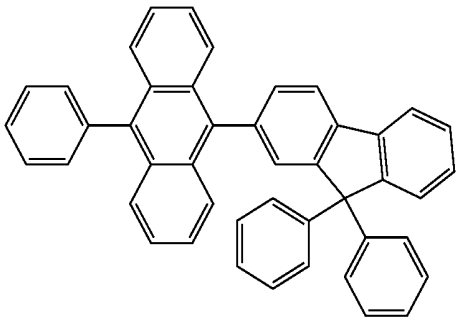

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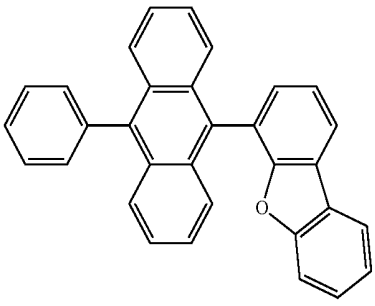
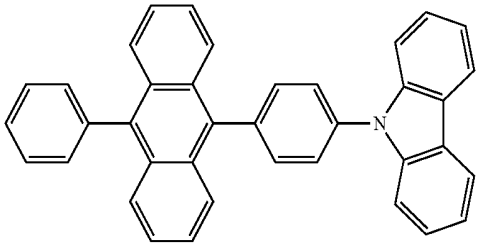


H19



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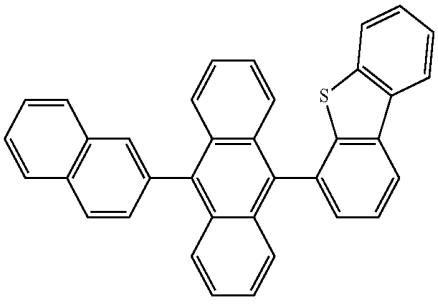

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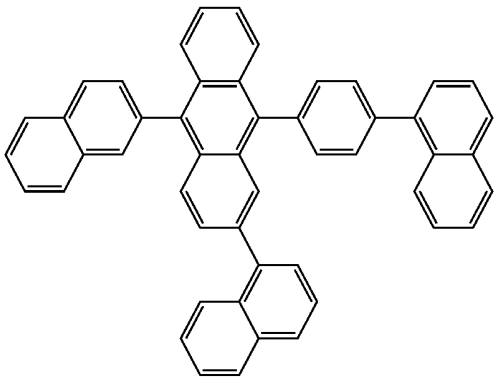

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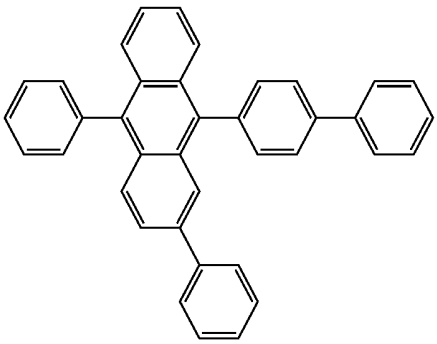

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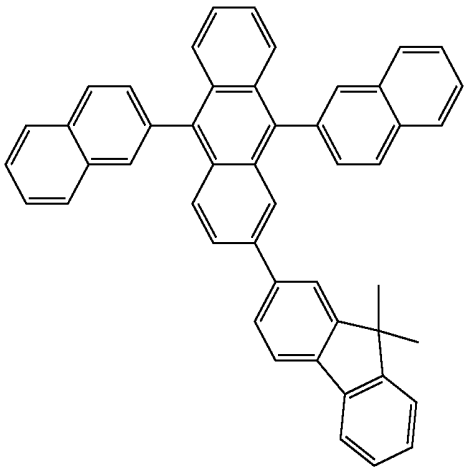

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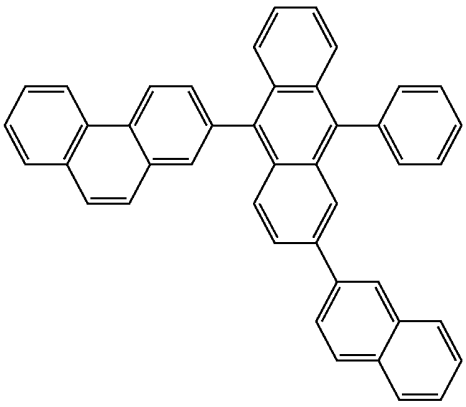

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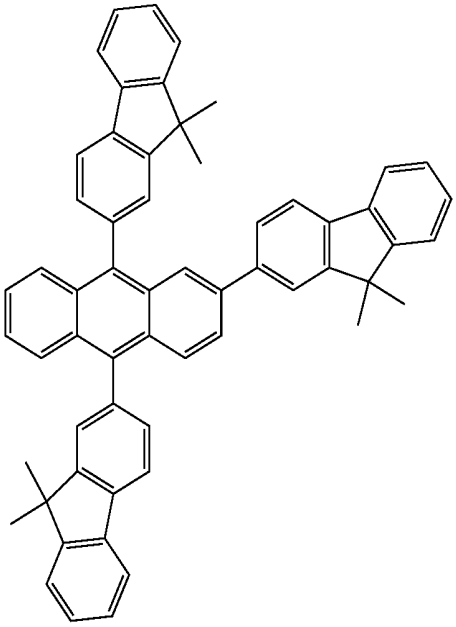

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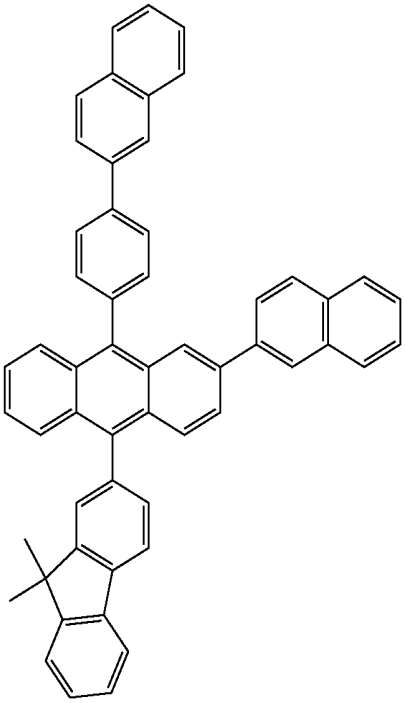

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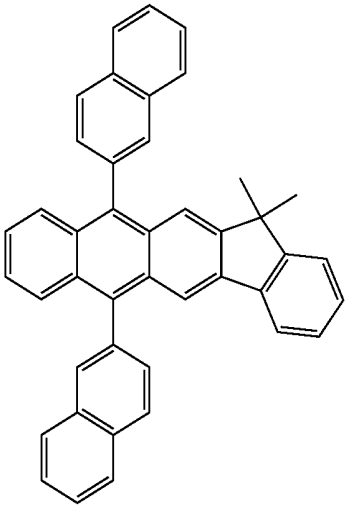

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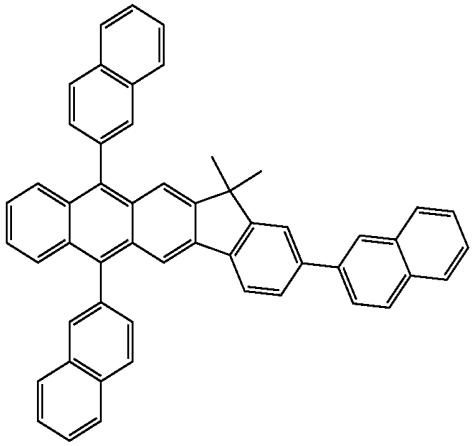

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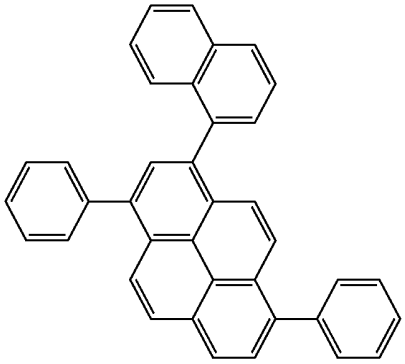

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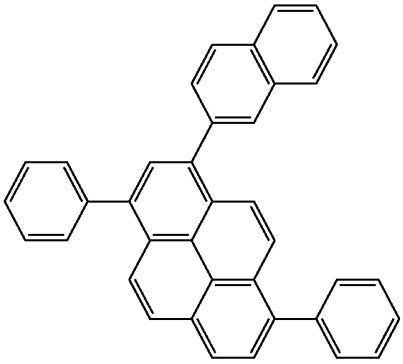

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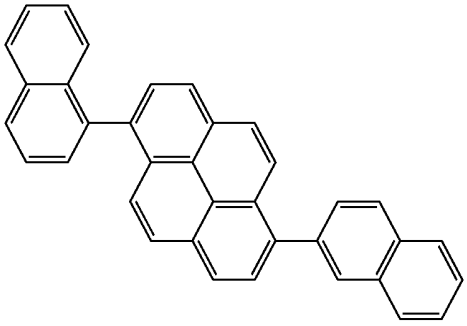

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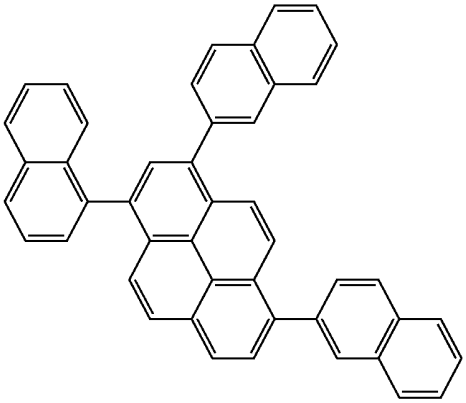

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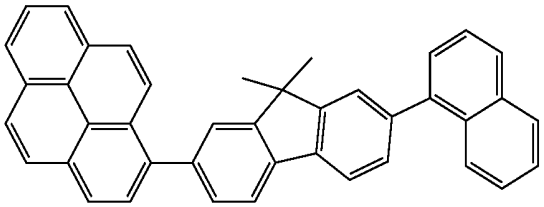

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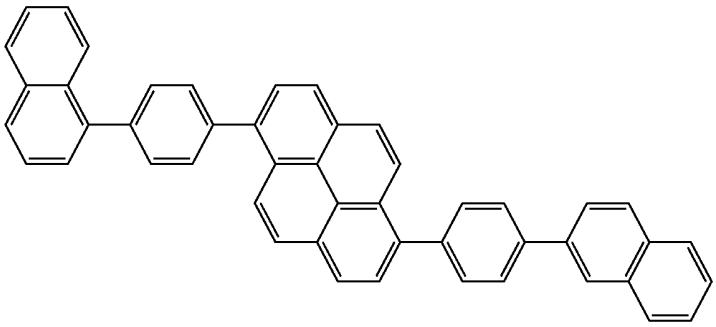

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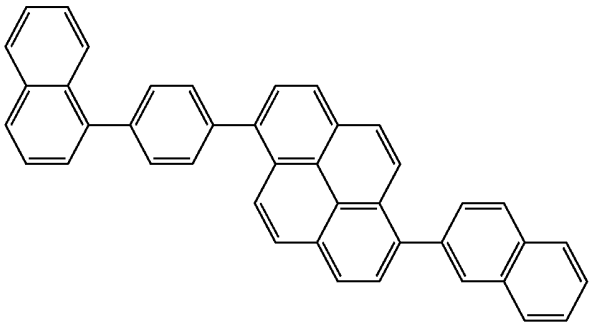

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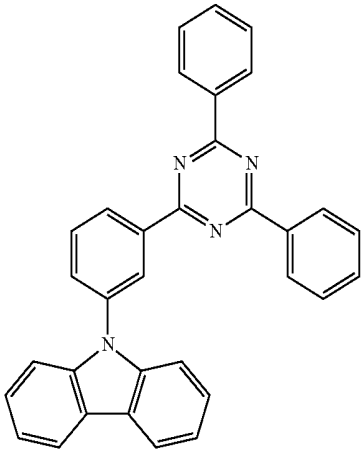

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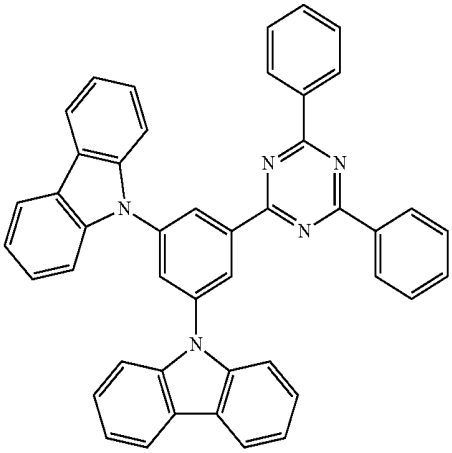

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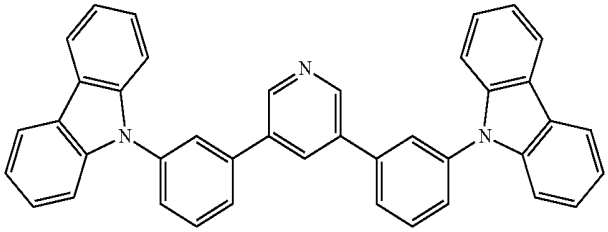

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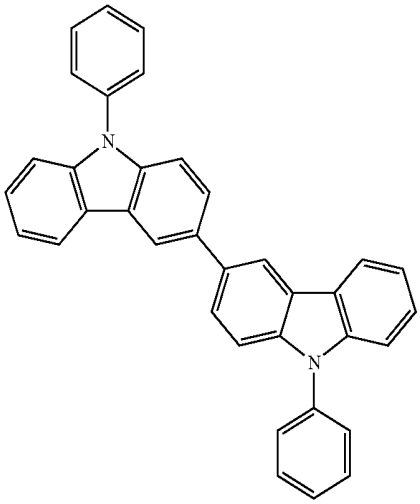

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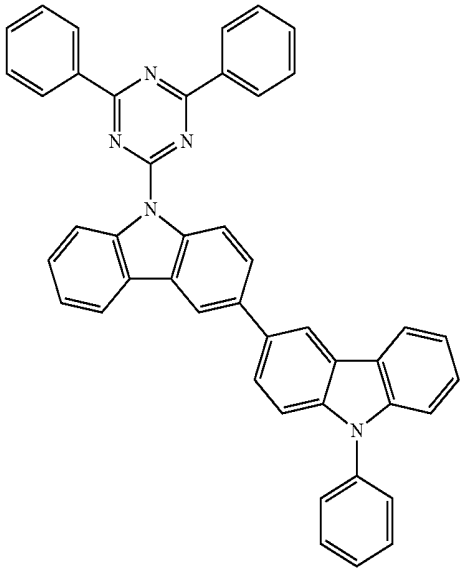

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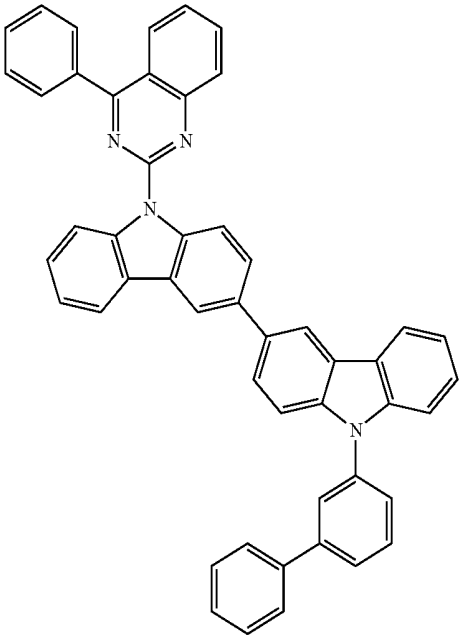

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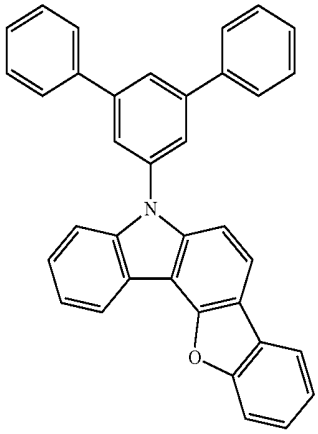

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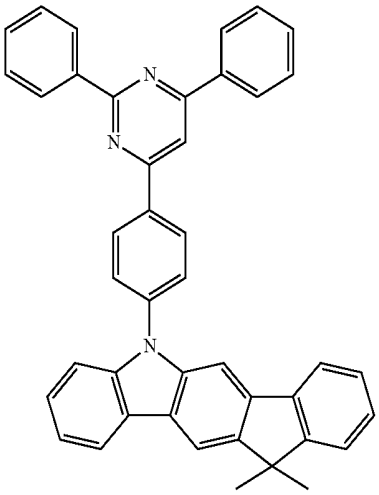

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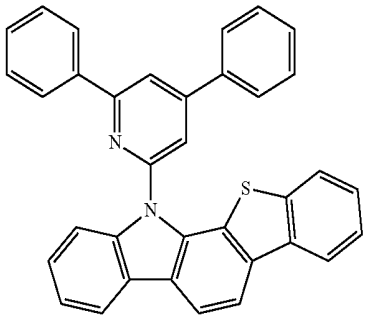

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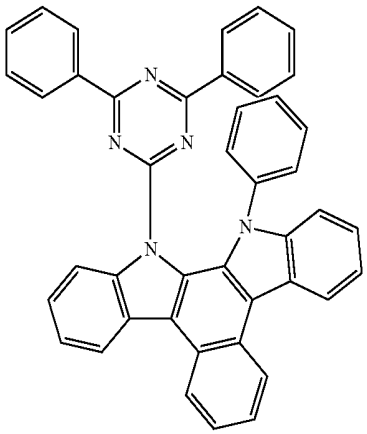

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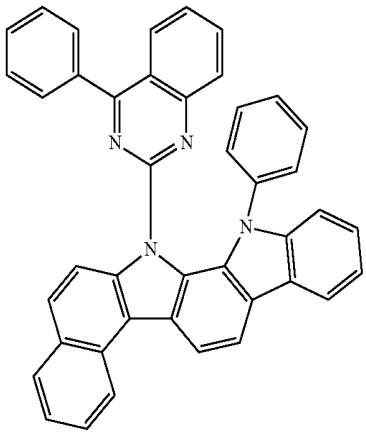

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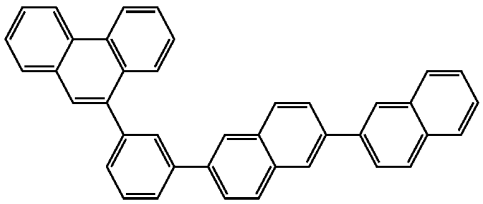

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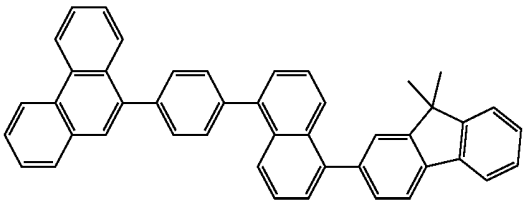

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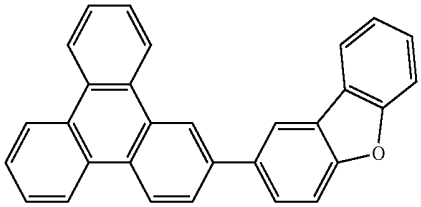

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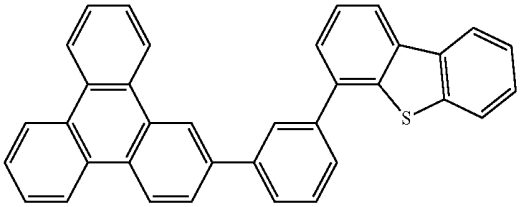

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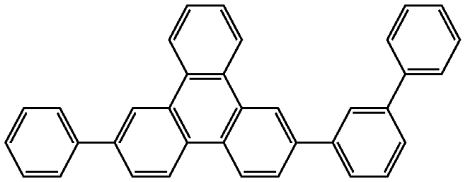

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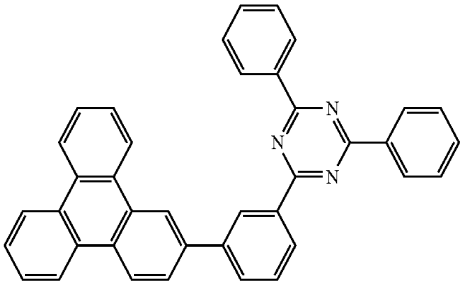

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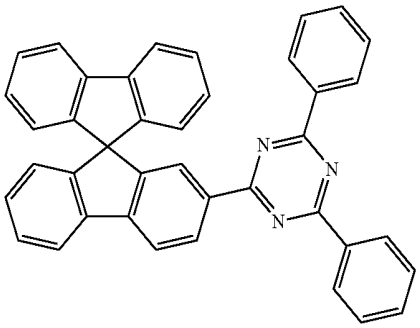

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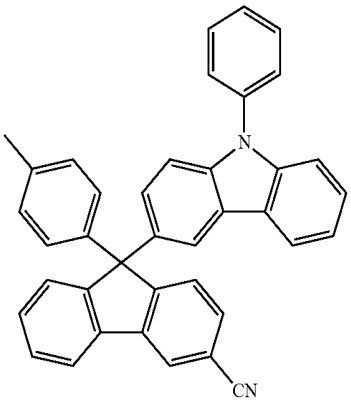

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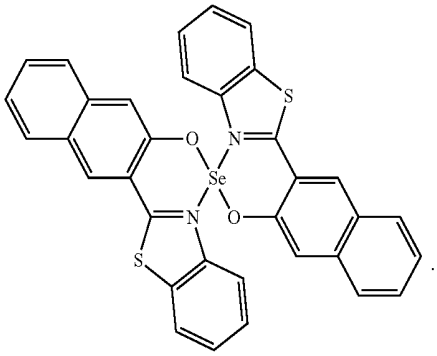


[0258] In one embodiment, the host may include at least one selected from a silicon-containing compound (for example, BCPDS used in the following examples or the like) and a phosphine oxide-containing compound (for example, POPCPA used in the following examples or the like).

[0259] 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).

[0260] [Phosphorescent Dopant Included in Emission Layer in Organic Layer **150**]

[0261] The phosphorescent dopant may include an organometallic compound represented by Formula 1 below:

[0262] [Electron Transport Region in Organic Layer **150**]

[0263] 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.

[0264] 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.

[0265] 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.

[0266] 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.

[0267] The "π electron-depleted nitrogen-containing ring" indicates a C_1-C_{60} heterocyclic group having at least one *—N=*' moiety as a ring-forming moiety.

[0268] 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=*' moiety, ii) a heteropolycyclic group in which two or more 5-membered to 7-membered heteromonocyclic groups each having at least one *—N=*' moiety are condensed with each other (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 at least one C_5-C_{60} carbocyclic group.

[0269] 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, thiadiazole, an imidazopyridine, an imidazopyrimidine, and an azacarbazole, but are not limited thereto.

[0270] For example, the electron transport region may include a compound represented by Formula 601:

$$Ar_{601}\text{-}[(L_{601})_{xe1}\text{-}E_{601}]_{xe2}. \qquad \text{Formula 601}$$

[0271] In Formula 601,

[0272] 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,

[0273] xe11 may be 1, 2, or 3,

[0274] L_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0275] xe1 may be an integer from 0 to 5,

[0276] 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 mon-

ovalent 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 —$P(=O)(Q_{601})(Q_{602})$, and

[0277] 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

[0278] xe21 may be an integer from 1 to 5.

[0279] 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.

[0280] In one embodiment, in Formula 601, ring Ar_{601} may be selected from:

[0281] 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, 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 thiadiazol group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group; and

[0282] 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, 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 thiadiazol 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

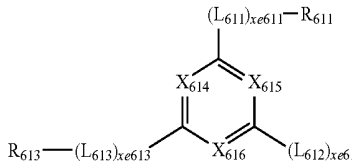
[0283] Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0284] When xe11 in Formula 601 is two or more, two or more Ar601(s) may be linked via a single bond.

[0285] In one or more embodiments, Ar_{601} in Formula 601 may be an anthracene group.

[0286] In one or more embodiments, a compound represented by Formula 601 may be represented by Formula 601-1:

Formula 601-1



[0287] In Formula 601-1,

[0288] X_{614} may be N or $C(R_{614})$, X_{615} may be N or $C(R_{615})$, and X_{616} may be N or $C(R_{616})$, wherein at least one selected from X_{614} to X_{616} may be N,

[0289] L_{611} to L_{613} may each independently be the same as described in connection with L_{601},

[0290] xe611 to xe613 may each independently be the same as described in connection with xe1,

[0291] R_{611} to R_{613} may each independently be the same as described in connection with R_{601}, and

[0292] 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.

[0293] In one embodiment, in Formulae 601 and 601-1, L_{601} and L_{611} to L_{613} may each independently be selected from:

[0294] 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

[0295] 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,

[0296] but embodiments of the present disclosure are not limited thereto.

[0297] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0298] 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:

[0299] 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;

[0300] 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 tetra-

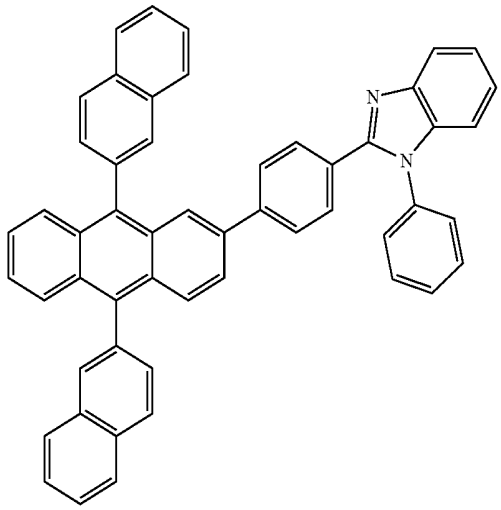
zolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, 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

[0301] —$S(=O)_2(Q_{601})$, and —$P(=O)(Q_{601})(Q_{602})$, and

[0302] Q_{601} and Q_{602} are the same as described above.

[0303] 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



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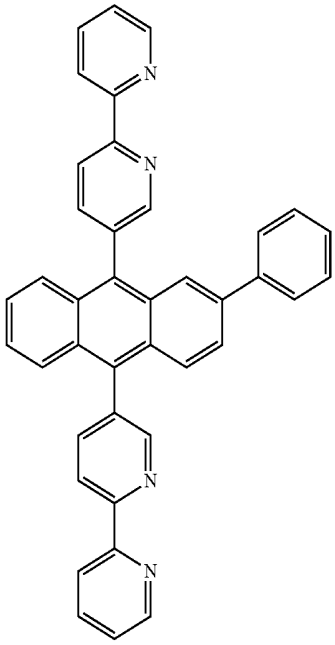
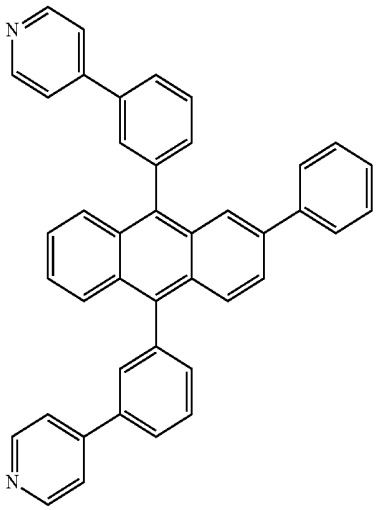
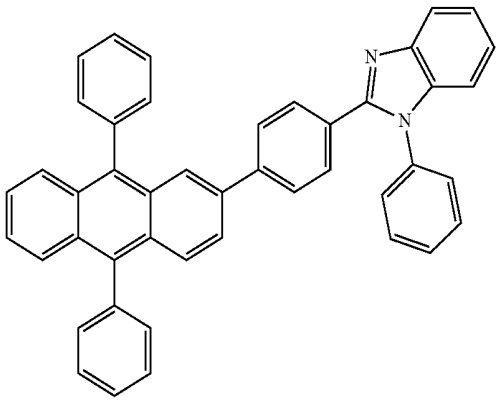
ET2



ET3



ET4



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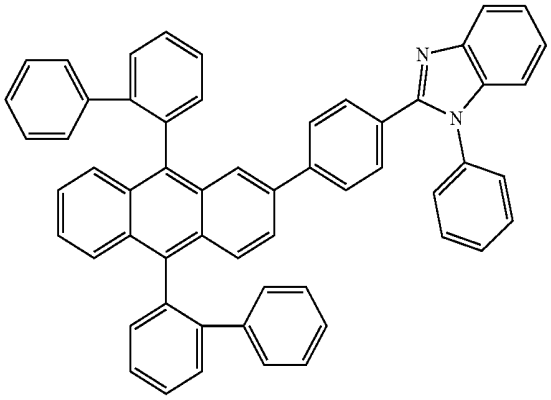
ET5



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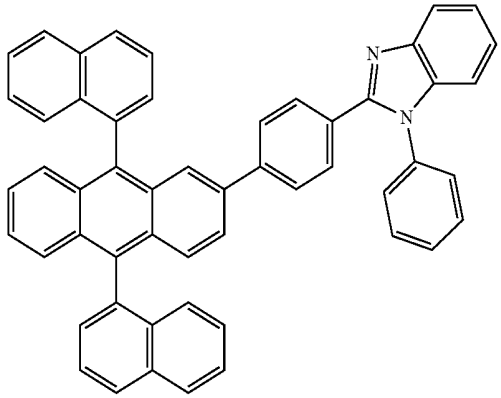

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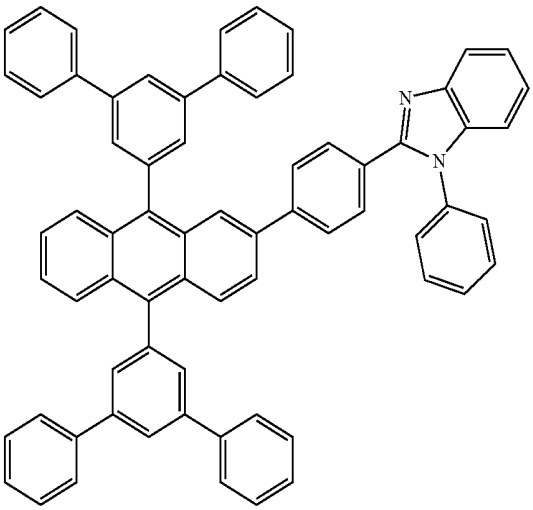

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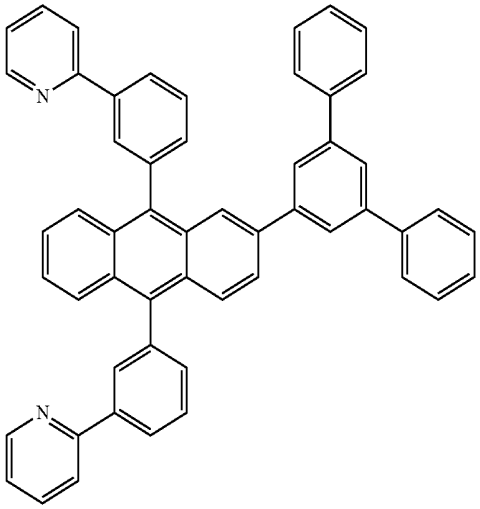
ET8



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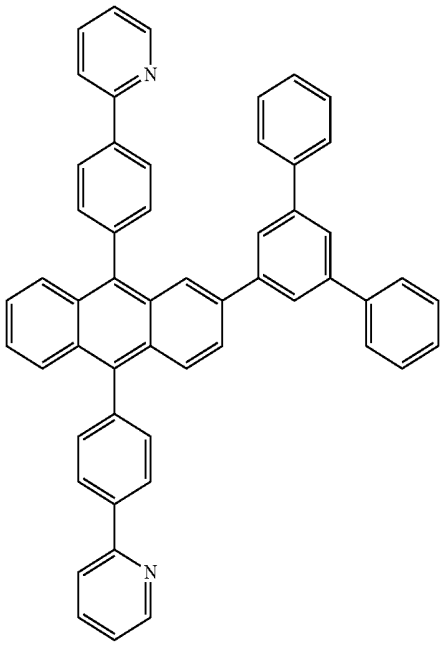

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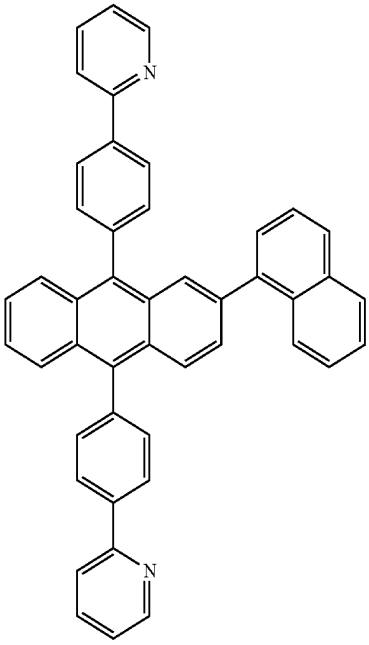
ET10



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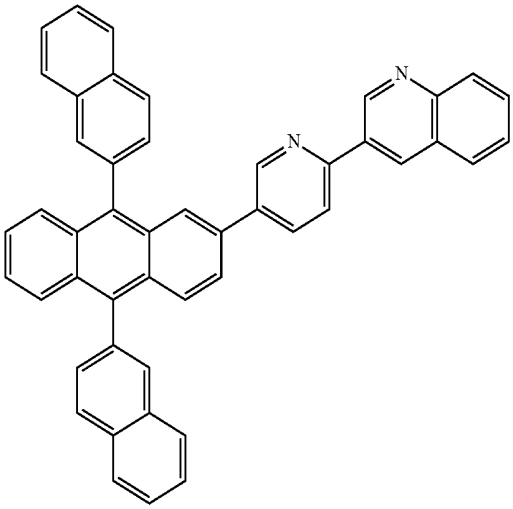

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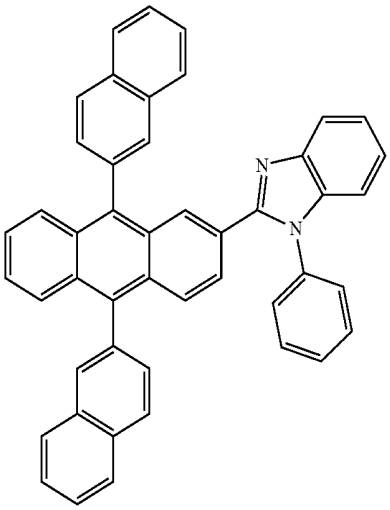

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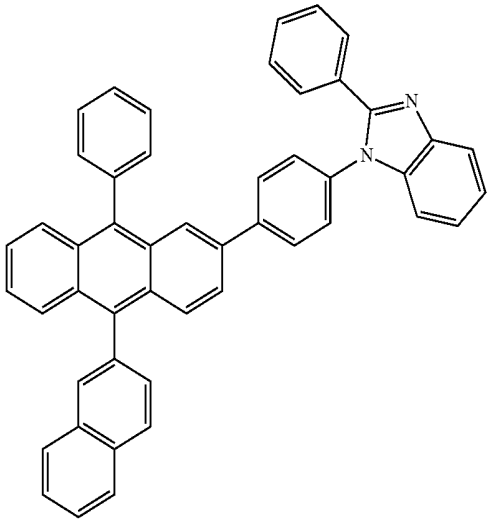

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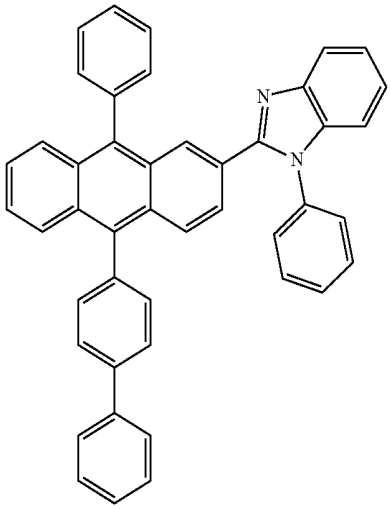

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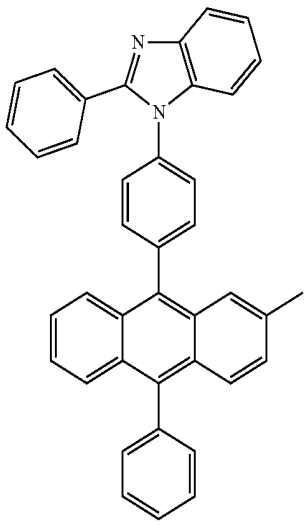

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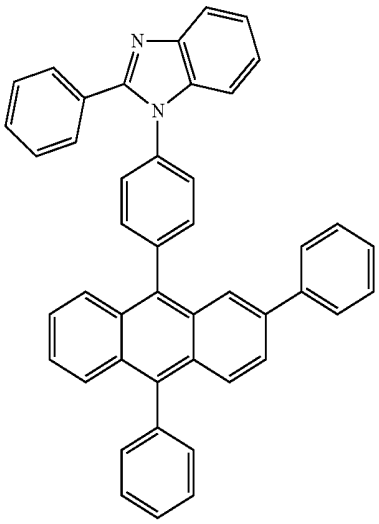
ET16



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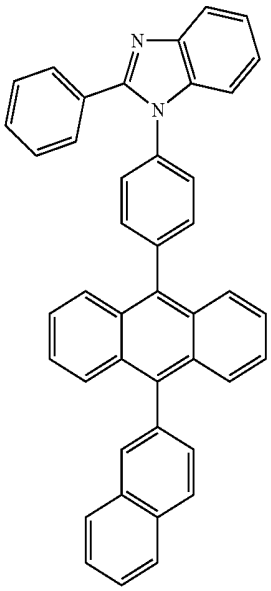

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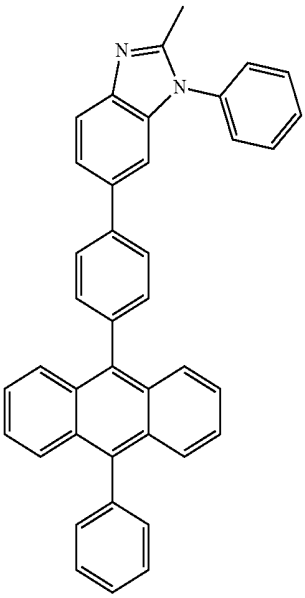
ET18



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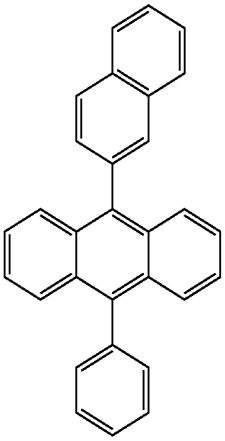

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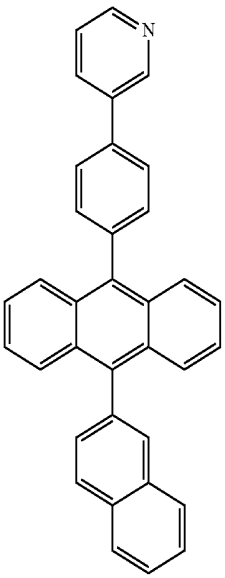

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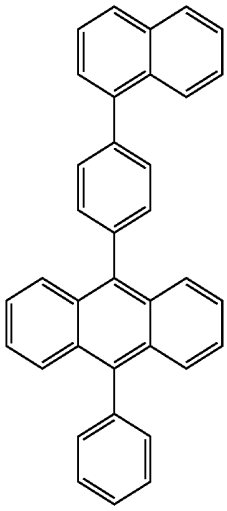
ET21



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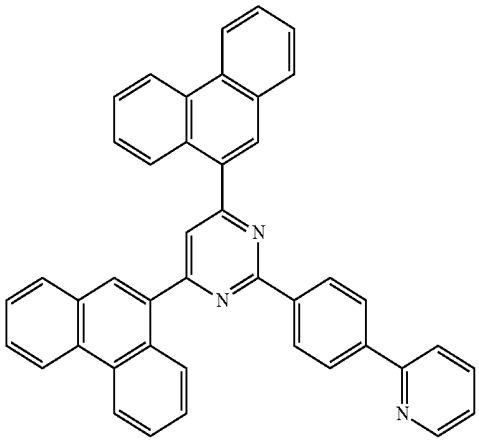

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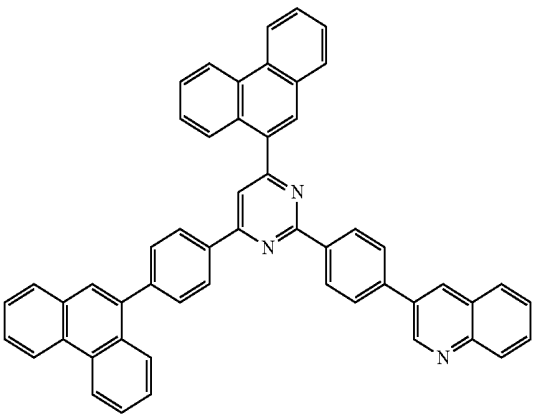

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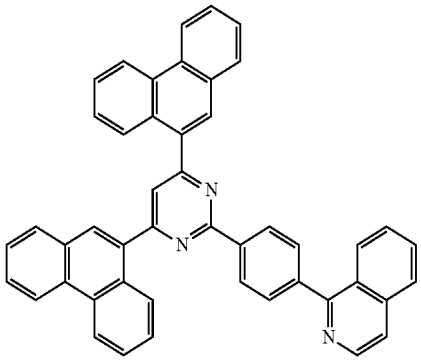

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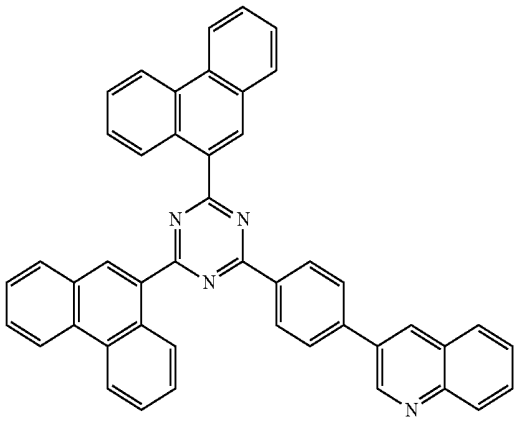

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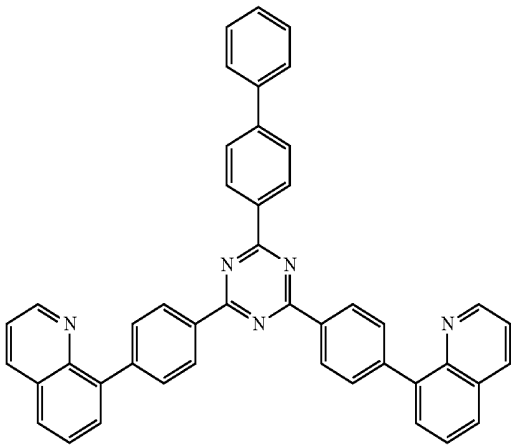

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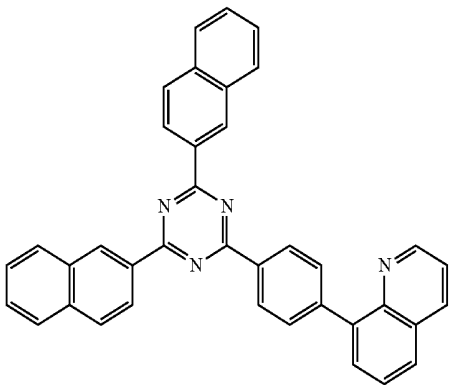

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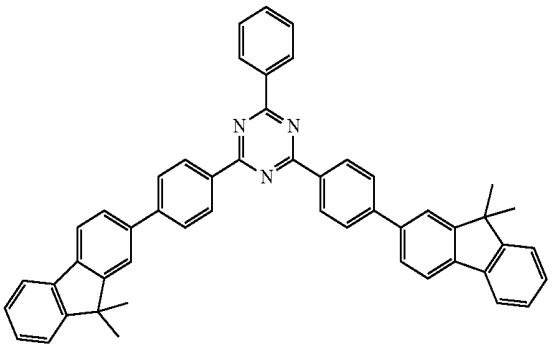
ET28



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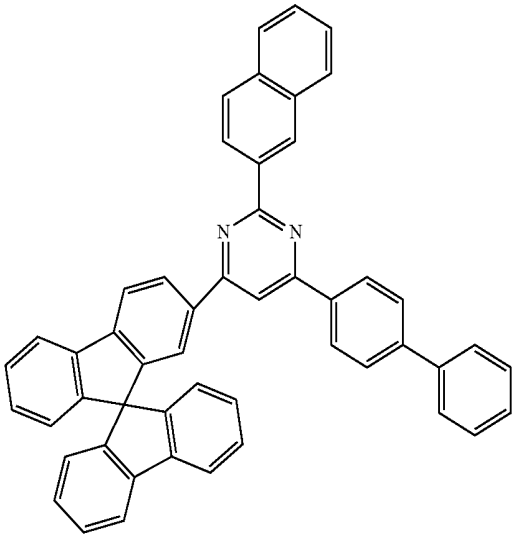

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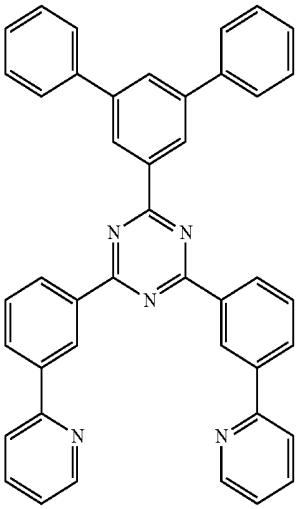

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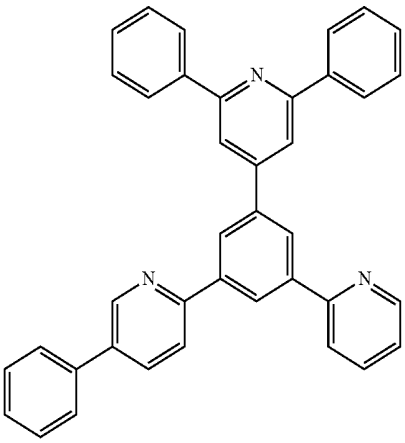
ET31



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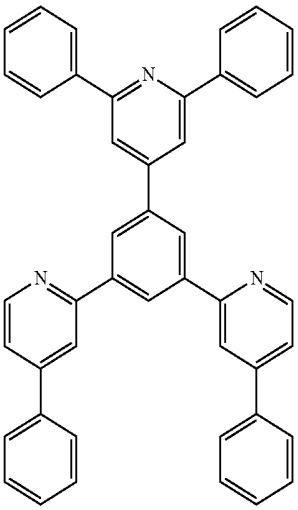

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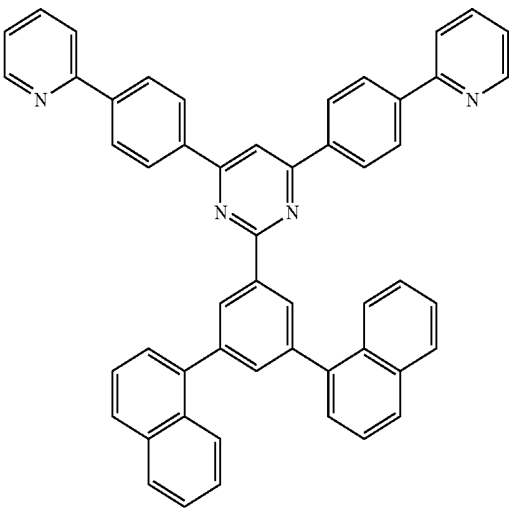

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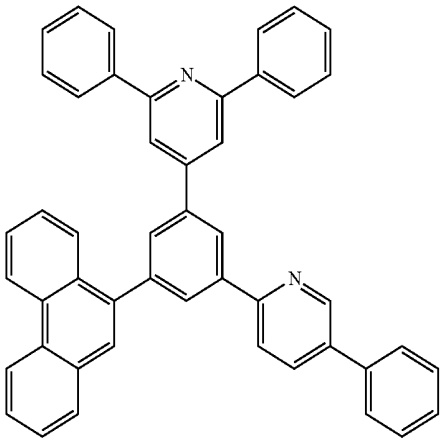
ET34



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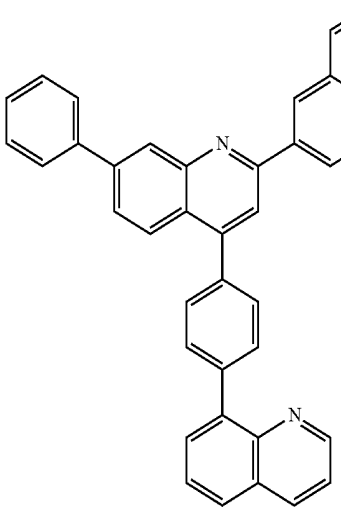
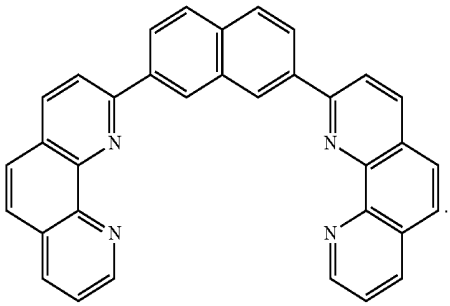
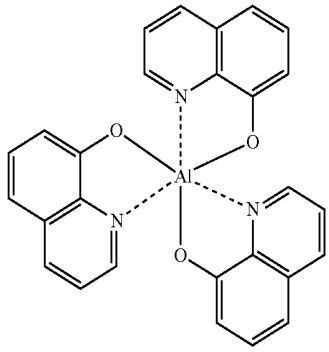


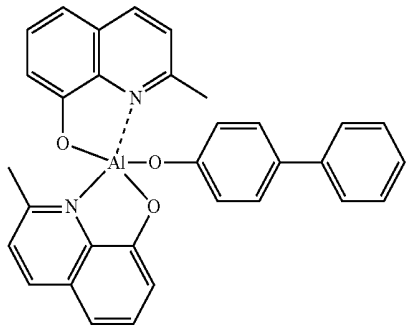
ET36



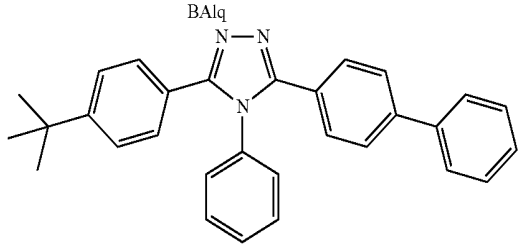
[0304] In one or more embodiments, the electron transport region may include at least one compound selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq_3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole(TAZ), and NTAZ:



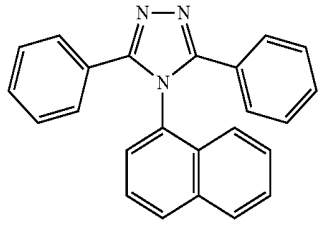
Alq_3



BAlq



TAZ



NTAZ

[0305] 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.

[0306] A thickness of the buffer layer, the hole blocking layer, and/or the electron control layer may 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/or 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.

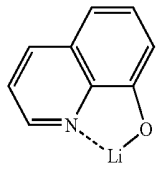
[0307] A thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within the range described above, the electron transport layer may have suitable or satisfactory electron transport characteristics without a substantial increase in driving voltage.

[0308] 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.

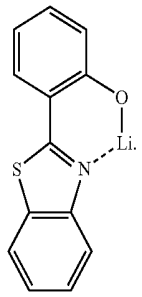
[0309] The metal-containing material may include at least one selected from alkali metal complex and alkaline earth-metal complex. The alkali metal complex may include a metal ion selected from a Li ion, a Na ion, a K ion, a Rb ion, and a Cs ion, and the alkaline earth-metal complex may include a metal 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 diphenylthiadiazole, 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.

[0310] For example, the metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (lithium quinolate, LiQ) and/or ET-D2:

ET-D1



ET-D2



[0311] 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**.

[0312] 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.

[0313] 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.

[0314] The alkali metal may be selected from Li, Na, K, Rb, and Cs. In one embodiment, the alkali metal may be Li, a 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.

[0315] The alkaline earth metal may be selected from Mg, Ca, Sr, and Ba.

[0316] The rare earth metal may be selected from Sc, Y, Ce, Tb, Yb, and Gd.

[0317] 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.

[0318] 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.

[0319] 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.

[0320] 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 YbF3, ScF_3, TbF_3, YbI_3, ScI_3, and TbI_3, but embodiments of the present disclosure are not limited thereto.

[0321] The alkali metal complex, the alkaline earth-metal complex, and the rare earth metal complex may include an ion of alkali metal, alkaline earth-metal, and rare earth metal as described above, and a ligand coordinated with a metal ion of the alkali metal complex, the alkaline earth-metal complex, or the rare earth metal complex may be selected from hydroxy quinoline, hydroxy isoquinoline, hydroxy benzoquinoline, hydroxy acridine, hydroxy phenanthridine, hydroxy phenyloxazole, hydroxy phenylthiazole, hydroxy diphenyloxadiazole, hydroxy diphenylthiadiazole, hydroxy phenylpyridine, hydroxy phenylbenzimidazole, hydroxy phenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments of the present disclosure are not limited thereto.

[0322] The electron injection layer may include (or 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.

[0323] 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.

[0324] [Second Electrode **190**]

[0325] 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.

[0326] 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.

[0327] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

[0328] 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.

[0329] When layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region may be formed by vacuum deposition, the vacuum deposition may be performed at a deposition temperature of about 100° C. to about 500° C., at a vacuum degree of about 10^{-8} torr to about 10^{-3} torr, and at 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.

[0330] 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 about 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.

[0331] [General Definitions of Substituents]

[0332] 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 iso-amyl 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, except that the C_1-C_{60} alkylene group is divalent.

[0333] 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., the middle) or at the 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, except that the C_2-C_{60} alkenylene group is divalent.

[0334] 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 the middle or at the 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, except that the C_2-C_{60} alkynylene group is divalent.

[0335] 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.

[0336] 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, except that the C_3-C_{10} cycloalkylene group is divalent.

[0337] 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, except that the C_1-C_{10} heterocycloalkylene group is divalent.

[0338] 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, 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, except that the C_3-C_{10} cycloalkenylene group is divalent.

[0339] 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, except that the C_1-C_{10} heterocycloalkenylene group is divalent.

[0340] 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).

[0341] 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).

[0342] 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 a C_6-C_{60} arylthio group used herein indicates —SA_{103} (wherein A_{103} is the C_6-C_{60} aryl group).

[0343] 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. A detailed example of the monovalent non-aromatic condensed polycyclic group includes a fluorenyl group. The term "divalent non-aromatic condensed polycyclic group," used herein, refers to a divalent group having substantially the same structure as the monovalent non-aromatic condensed polycyclic group, except that the divalent non-aromatic condensed polycyclic group is divalent.

[0344] 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, at least one heteroatom selected from N, O, Si, P, and S, other than carbon atoms, as a ring-forming atom, and no aromaticity in its entire molecular structure. An example of the monovalent non-aromatic condensed heteropolycyclic group includes 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, except that the divalent non-aromatic condensed heteropolycyclic group is divalent.

[0345] 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.

[0346] The term "C_2-C_{60} heterocyclic group" as used herein refers to a group having 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 2 to 60).

[0347] At least one substituent of the substituted C_4-C_{60} carbocyclic group, the substituted C_2-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:

[0348] 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;

[0349] 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 —$P(=O)(Q_{11})(Q_{12})$;

[0350] 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;

[0351] 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

[0352] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

[0353] 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.

[0354] The term "Ph" as used herein represents a phenyl group, the term "Me" as used herein represents a methyl group, the term "Et" as used herein represents an ethyl group, the term "ter-Bu" or "Bu^t," as used herein, represents a tert-butyl group, and the term "OMe" as used herein represents a methoxy group.

[0355] The term "biphenyl group" used herein refers to "a phenyl group" substituted with a phenyl group. The "biphenyl group" may be "a substituted phenyl group" having "a C_6-C_{60} aryl group" as a substituent.

[0356] The term "terphenyl group" used herein refers to a "phenyl group substituted with a biphenyl group. The "terphenyl group" may be "a substituted phenyl group" including "a substituted C_6-C_{60} aryl group" having "a C_6-C_{60} aryl group" as a substituent.

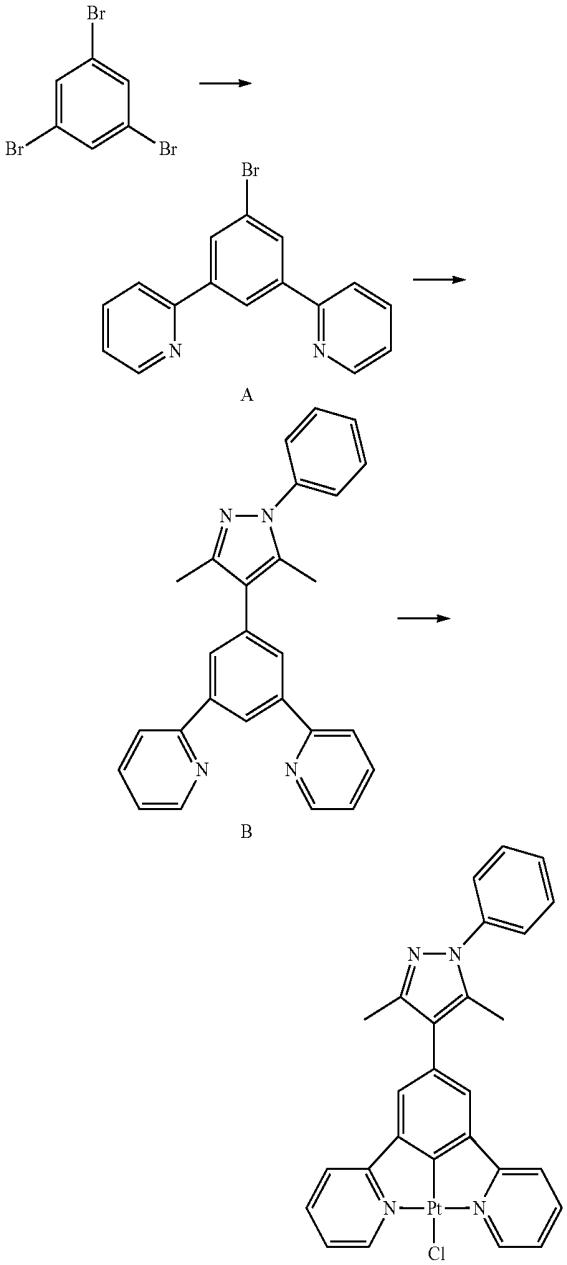
[0357] *and *' used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

[0358] Hereinafter, a compound according to embodiments and an organic light-emitting device according to embodiments will be described in more detail with reference to Synthesis Examples and Examples. The expression "B was used instead of A" used in describing Synthesis Examples means that an identical number of molar equivalents of A was used in place of molar equivalents of B.

EXAMPLES

Synthesis Example 1: Synthesis of Compound 2

[0359]



Compound 2

a) Synthesis of Intermediate A

[0360] 5.26 g (16.7 mmol) of 1,3,5-tribromobenzene, 2.16 g (17.6 mmol) of 2-pyridineboronic acid, 0.68 g (0.59 mmol) of $Pd(PPh_3)_4$, and 4.85 g (35.1 mmol) of K_2CO_3 were dissolved in 60 mL of tetrahydrofuran (THF) and 30 mL of distilled water and then stirred at a temperature of 80° C. for 12 hours. The reaction solution was cooled to room temperature, and an organic layer was extracted therefrom three times by using 50 mL of water and 50 mL of ethyl acetate.

The obtained organic layer was dried by using magnesium sulfate, and a solvent was evaporated therefrom. Then, the residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 3.50 g of Intermediate A.

b) Synthesis of Intermediate B

[0361] 3.50 g (11.3 mmol) of Intermediate A, 2.44 g (11.3 mmol) of 3,5-dimethyl-1-phenyl-1H-pyrazole-4-yl)boronic acid, 0.46 g (0.40 mmol) of $Pd(PPh_3)_4$, and 3.28 g (23.8 mmol) of K_2CO_3 were dissolved in 50 mL of THF and 25 mL of distilled water and then stirred at a temperature of 80° C. for 12 hours. The reaction solution was cooled to room temperature, and an organic layer was extracted therefrom three times by using 50 mL of water and 50 mL of ethyl acetate. The obtained organic layer was dried by using magnesium sulfate, and a solvent was evaporated therefrom. Then, the residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 3.38 g of Intermediate B.

c) Synthesis of Compound 2

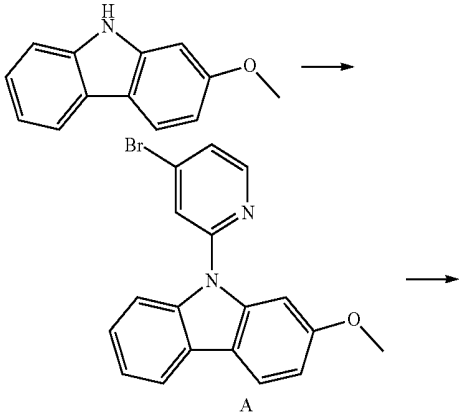
[0362] 1.00 g (2.48 mmol) of Intermediate B and 1.03 g (2.48 mmol) of K_2PtCl_4 were suspended in 120 mL of acetic acid and then stirred at a temperature of 110° C. for 3 days. The reaction solution was cooled to room temperature, and a precipitate was filtered therefrom, sequentially washed by using methanol, distilled water, ethanol, and diethylether, and then dried. A solid obtained therefrom was separated and purified by column chromatography to obtain 0.80 g of Compound 2.

Synthesis Example 2: Synthesis of Compound 3

[0363] 0.65 g of Compound 3 was synthesized in substantially the same manner as in Synthesis Example 1, except that 2,2'-(5-(1,3,5-triphenyl-1H-pyrazol-4-yl)-1,3-phenylene)dipyridine was used instead of Intermediate B.

Synthesis Example 3: Synthesis of Compound 28

[0364]



A

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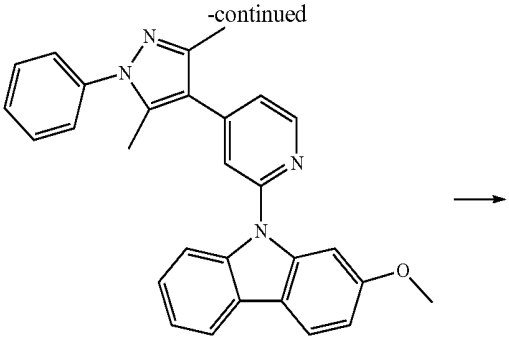

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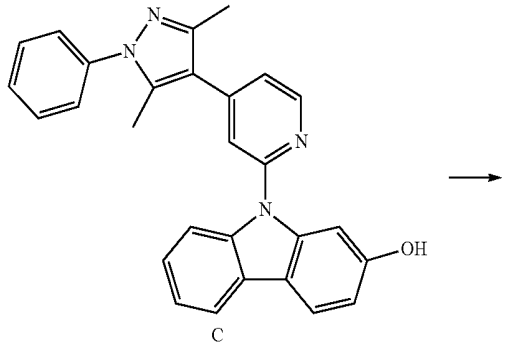
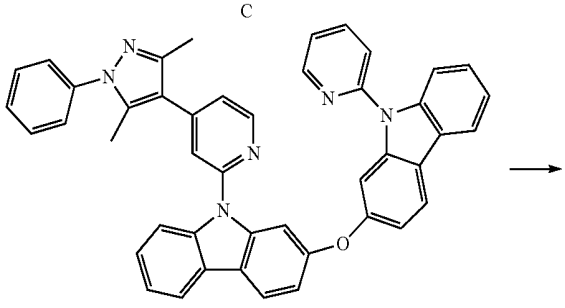
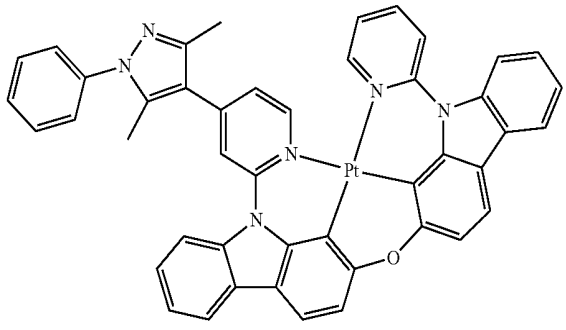


C



D



Compoud 28

a) Synthesis of Intermediate A

[0365] 2.40 g (12.05 mmol) of 2-methoxycarbazole, 4.28 g (18.05 mmol) of 3,5-dibromopyridine, 1.53 g (24.10 mmol) of Cu powder, 6.65 g (48.20 mmol) of potassium carbonate, and 0.315 g (1.200 mmol) of 18-Crown-6 were suspended in 50 mL of dimethylformamide purified by fractional distillation, and then stirred at a temperature of 150° C. for 10 hours. An organic layer was extracted from the reaction mixture by using ethyl acetate and distilled water. The extracted organic layer was dried by using magnesium sulfate and then filtered. Then, the residue obtained therefrom was purified by column chromatography (1/3=dichloromethane/normal hexane) to obtain 1.6 g of Intermediate A.

b) Synthesis of Intermediate B

[0366] 1.6 g (4.50 mmol) of Intermediate A, 1.46 g (6.75 mmol) of (3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl)boronic acid, 1.24 g (9.00 mmol) of potassium carbonate, and 0.30 g (0.27 mmol) of $Pd(PPh_3)_4$ were suspended in 150 mL of a mixed solvent in which a ratio of toluene to distilled water was 4/1, and then stirred at a temperature of 80° C. for 18 hours. An organic layer was extracted from the reaction mixture by using dichloromethane and distilled water. The extracted organic layer was dried by using magnesium sulfate and then filtered. Then, the residue obtained therefrom was purified by column chromatography (1/30=methanol/dichloromethane) to obtain 1.7 g of Intermediate B.

c) Synthesis of Intermediate C

[0367] 1.7 g (3.82 mmol) of Intermediate B was dissolved in 150 mL of dichloromethane and cooled to a temperature of −78° C. 7.83 mL (7.83 mmol) of BBr_3 (1.0 M in n-hexane) was added thereto, stirred for 1 hour, heated to a temperature of 0° C., and then stirred for 2 hours. The reaction was terminated by a sodium bicarbonate aqueous solution, and an organic layer was extracted therefrom by using dichloromethane. The extracted organic layer was dried by magnesium sulfate and then filtered. Then, the residue obtained therefrom was purified by column chromatography (1/2=ethyl acetate/normal hexane) to obtain 1.3 g of Intermediate C.

d) Synthesis of Intermediate D

[0368] 1.2 g (2.79 mmol) of Intermediate C, 1.0 g (3.20 mmol) of 2-bromo-9-(pyridin-2-yl)-carbazole, 0.14 g (1.06 mmol) of picolinic acid, 0.11 g (0.53 mmol) of copper(I) iodide, and 1.14 g (5.58 mmol) of potassium phosphate were added to a round-bottom flask and suspended in 100 mL of dimethylsulfoxide. The reaction mixture was heated to a temperature of 120° C. and stirred for 20 hours. An organic layer was extracted from the reaction mixture by using ethyl acetate and distilled water. The extracted organic layer was dried by using magnesium sulfate and then filtered. Then, the residue obtained therefrom was purified by column chromatography (1/1=ethyl acetate/normal hexane) to obtain 1.0 g of Intermediate D.

e) Synthesis of Compound 28

[0369] 0.35 g (0.52 mmol) of Intermediate D, 0.23 g (0.54 mmol) of potassium tetrachloroplatinate, and 0.017 g (0.052 mmol) of Bu_4NBr were suspended in 30 mL of acetic acid. The reaction solution was bubbled with nitrogen for 30 minutes and stirred at room temperature for 8 hours. The reaction mixture was heated to a temperature of 120° C. and additionally stirred for 36 hours. Then, the reaction mixture was cooled to room temperature, and 100 mL of distilled water was added thereto. A precipitate was filtered therefrom, washed three times by using distilled water, and then dried with warm air. Then, a solid obtained therefrom was purified by column chromatography (1/1=dichloromethane/normal hexane) to obtain 0.24 g of Compound 28.

Synthesis Example 4: Synthesis of Compound 17

[0370] 0.85 g of Compound 17 was synthesized in substantially the same manner as in Synthesis Example 3, except that 2-(3-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl)-5-(1-methyl-1H-imidazol-2-yl)phenoxy)-9-(pyridin-2-yl)-9H-carbazole was used instead of Intermediate D.

Synthesis Example 5: Synthesis of Compound 22

[0371] 1.00 g of Compound 22 was synthesized in substantially the same manner as in Synthesis Example 3, except that 2-(3-(3-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl)-5-(1-methyl-1H-314-imidazol-3-yl)phenoxy)phenoxy) pyridine was used instead of Intermediate D.

Synthesis Example 6: Synthesis of Compound 24

[0372] 1.28 g of Compound 24 was synthesized in substantially the same manner as in Synthesis Example 3, except that N-(3-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl)-5-((9-(pyridin-2-yl)-9H-carbazol-2-yl)oxy)phenyl)-N-phenylpyridin-2-amine was used instead of Intermediate D.

Synthesis Example 7: Synthesis of Compound 26

[0373] 0.55 g of Compound 26 was synthesized in substantially the same manner as in Synthesis Example 3, except that 2-(3-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl)-5-(1-methyl-1H-imidazol-2-yl)phenoxy)-9-(1-methyl-1H-imidazol-2-yl)-9H-carbazole was used instead of Intermediate D.

Synthesis Example 8: Synthesis of Compound 2

[0374] 1.05 g of Compound 40 was synthesized in substantially the same manner as in Synthesis Example 3, except that 9-(4-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl) pyridin-2-yl)-2-((9-(4-methylpyridin-2-yl)-9H-carbazol-2-yl)oxy)-9H-carbazole was used instead of Intermediate D.

Synthesis Example 9: Synthesis of Compound 41

[0375] 0.88 g of Compound 41 was synthesized in substantially the same manner as in Synthesis Example 3, except that ((9-(4-phenylpyridin-2-yl)-9H-carbazol-2-yl) oxy)-9H-carbazole was used instead of Intermediate D.

Synthesis Example 10: Synthesis of Compound 42

[0376] 0.85 g of Compound 42 was synthesized in substantially the same manner as in Synthesis Example 3, except that 9-(4-(3,5-dimethyl-1-phenyl-1H-pyrazol-4-yl) pyridin-2-yl)-2-((9-(4-isopropylpyridin-2-yl)-9H-carbazol-2-yl)oxy)-9H-carbazole was used instead of Intermediate D.

[0377] High resolution electron impact mass spectrometry (HR-EIMS) values and ^1H nuclear magnetic resonance (NMR) measurement results measured for the Synthesis Examples are shown in Table 1 below.

TABLE 1

Compound	^{1}H NMR ($CDCl_3$, 500 MHz)	HR-EIMS found	HR-EIMS calc.
2	δ8.42~8.44 (m, 2H), 8.13~8.16(m, 2H), 7.99~8.12(m, 2H), 7.62~7.65(m, 2H), 7.37~7.47(m, 3H), 7.10~7.13(m, 4H), 2.20(s, 3H), 2.14(s, 3H)	632.0329	632.0355
3	δ8.45~8.47(m, 2H), 7.99~8.13(m, 4H), 7.66~7.69(m, 2H), 7.45~7.51 (m, 6H), 7.35~7.38(m, 4H), 7.28~7.33(m, 3H), 7.17 (d, 2H), 7.12(d, 2H)	756.1723	756.1754
17	δ7.98~8.10(m, 2H), 7.85(d, 1H), 7.80(d, 1H), 7.61~7.64 (m, 3H), 7.47~7.49(m, 2H), 7.37(d, 2H), 7.25~7.29 (m, 3H), 7.24(m, 1H), 7.09(d, 2H), 6.84(d, 1H), 6.77(d, 1H), 6.44(m, 1H), 6.22(m, 1H), 3.57(s, 3H), 2.20(s, 3H), 2.14(s, 3H)	779.7715	779.7756
22	δ8.08~8.12(d, 2H), 7.63(d, 2H), 7.37~7.40(m, 3H), 7.06(d, 2H), 6.93(d, 2H), 6.45~6.55(m, 4H), 6.11~6.20(m, 4H), 5.70(m, 1H), 3.10(s, 3H), 2.23(s, 3H), 2.15(s, 3H)	829.8341	829.8382
24	δ8.31 (d, 1H), 8.06~8.09(m, 2H), 7.85~7.88(m, 2H), 7.59~7.63(m, 3H), 7.37~7.42(m, 5H), 7.30~7.33(m, 2H), 7.10~7.18(m, 3H), 6.78~6.84(m, 3H), 6.55~6.57(m, 2H), 6.47(d, 2H), 6.06(d, 1H), 2.20(s, 3H), 2.13(s, 3H)	867.8818	867.8847
26	δ8.25~8.27(d, 1H), 8.05~8.10(m, 2H), 7.93(m, 2H), 7.88(m, 2H), 7.62~7.66(m, 3H), 7.32~7.39(m, 7H), 7.08~7.13(m, 2H), 6.74~6.80(m, 3H), 6.55~6.57(m, 2H), 6.47(d, 2H), 6.06(d, 1H), 2.21(s, 3H), 2.15(s, 3H)	782.7754	782.7720
28	δ7.94~8.10(m, 7H), 7.83~7.85(m, 2H), 7.68(d, 1H), 7.59~7.64(m, 4H), 7.48(m, 1H), 7.37(d, 2H), 7.29(m, 2H), 7.02~7.08(m, 3H), 6.58~7.03(m, 2H), 2.33(s, 3H), 2.30(s, 3H)	865.8634	865.8683
40	δ7.99~8.08(m, 5H), 7.79~7.84(m, 3H), 7.64~7.68(m, 3H), 7.60(d, 2H), 7.35~7.38(m, 3H), 7.29(m, 2H), 7.12(d, 1H), 7.00~7.03(m, 2H), 6.59(m, 2H), 2.29(s, 3H), 2.25(s, 3H), 2.20(s, 3H)	879.8921	879.8944
41	δ8.02~8.10(m, 5H), 7.73~7.82(m, 6H), 7.60~7.63(m, 4H), 7.57(m, 2H), 7.39~7.45(m, 6H), 7.29(m, 2H), 6.58~7.03(m, 3H), 2.28(s, 3H), 2.24(s, 3H)	941.9682	941.9637
42	δ7.99~8.09(m, 6H), 7.77~7.81(m, 3H), 7.61~7.65(m, 4H), 7.46~7.48(m, 2H), 7.37(d, 2H), 7.29(m, 2H), 6.94(m, 1H), 6.66~7.68(m, 1H), 6.59(d, 2H), 2.97(m, 1H), 2.29(s, 3H), 2.26(s, 3H), 1.45(s, 6H)	907.9453	907.9415

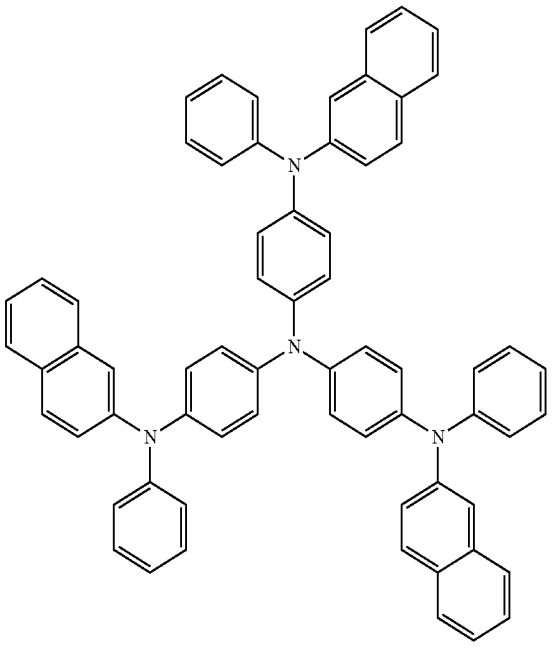
Example 1

[0378] As a substrate and an ITO anode, a Corning 15 Ω/cm^2 (1,200 Å) 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 resultant ITO glass substrate was provided to a vacuum deposition apparatus.

[0379] 2-TNATA was vacuum-deposited on the ITO anode formed on the ITO glass substrate to form a hole injection layer having a thickness of 600 Å, and NPB was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 300 Å.

[0380] BCPDS (bis(4-(9H-carbazol-9-yl)phenyl)diphenylsilane) and POPCPA ((4-{1-[4-(diphenylphosphoryl)phenyl]cyclohexyl}phenyl)diphenylamine) (co-host) (weight ratio of BCPDS to POPCPA was 1:1), and Compound 1 (dopant), were co-deposited on the hole transport layer at a weight ratio of the co-host to the dopant of 90:10, thereby forming an emission layer having a thickness of 300 Å.

[0381] TSPO1 (diphenyl-4-triphenylsilyl-phenylphosphine oxide) was deposited on the emission layer to form a hole blocking layer having a thickness of 50 Å, Alq_3 was deposited on the hole blocking layer to form an electron transport layer having a thickness of 300 Å, LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å, and Al was vacuum-deposited on the electron injection layer to form a cathode having a thickness of 3,000 Å, thereby completing the manufacture of an organic light-emitting device.



2-TNATA

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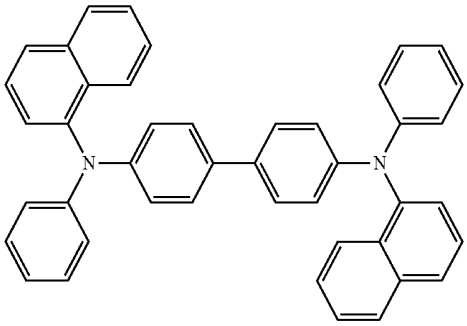
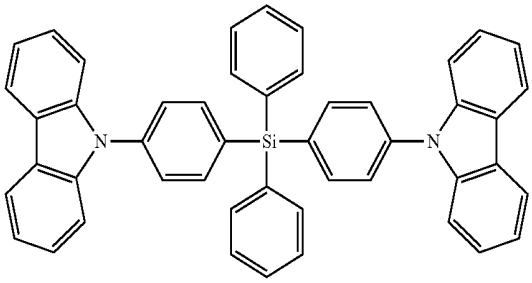
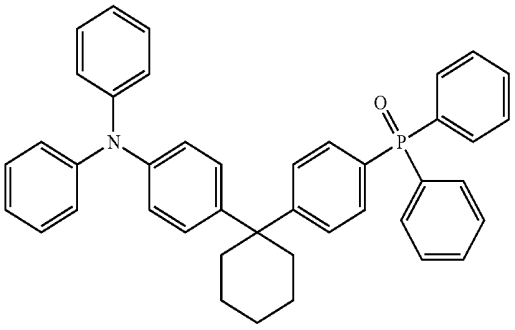


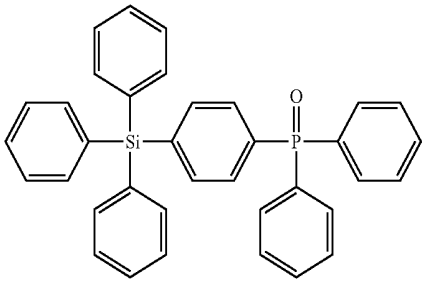
NPB



BCPDS



POPCPA

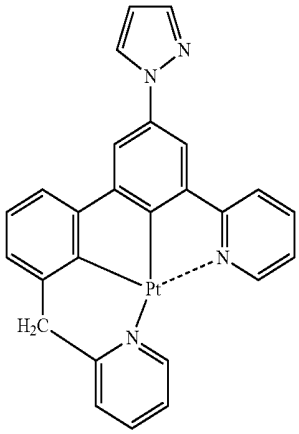


TSPO1

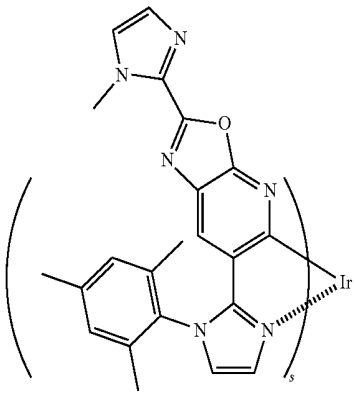
Examples 2 to 10 and Comparative Examples 1 to 4

[0382] Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that Compounds shown in Table 2 were each used instead of Compound 1 as a dopant in forming an emission layer.

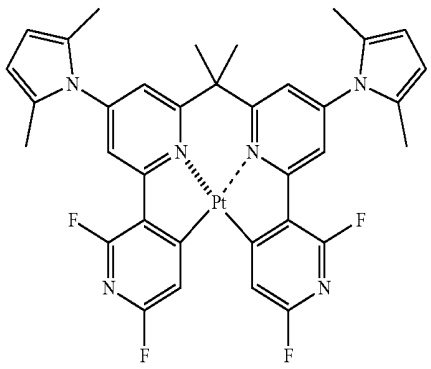
Comparative Compund A



Comparative Compound B



Comparative Compound C



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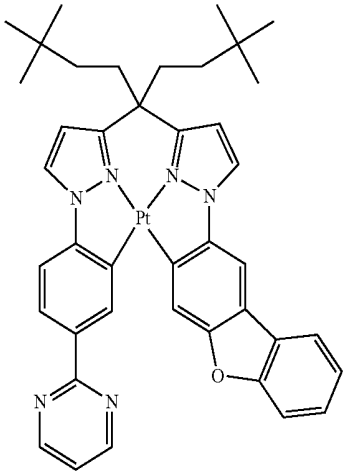
Comparative Compound D



Evaluation Example 1

[0383] The driving voltage, current density, luminance, luminescent efficiency, and maximum emission wavelength of the organic light-emitting devices manufactured according to Examples 1 to 10 and Comparative Examples 1 to 4 were measured by using Keithley SMU 236 and a luminance meter PR650, and evaluation results thereof are shown in Table 2.

TABLE 2

	Dopant	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Luminescent efficiency (cd/A)	Emission color	Maximum emission wavelength (nm)
Example 1	Compound 2	3.4	0.09	15	17.8	Blue	450
Example 2	Compound 3	3.4	0.08	15	18.2	Blue	449
Example 3	Compound 17	3.3	0.08	15	18.1	Blue	452
Example 4	Compound 18	3.3	0.08	15	18.2	Blue	446
Example 5	Compound 24	3.3	0.09	15	17.6	Blue	450
Example 6	Compound 26	3.3	0.08	15	18.1	Blue	451
Example 7	Compound 28	3.4	0.08	15	18.2	Blue	455
Example 8	Compound 40	3.4	0.06	15	18.6	Blue	456
Example 9	Compound 41	3.3	0.10	15	16.4	Blue	448
Example 10	Compound 42	3.4	0.10	15	16.9	Blue	448
Comparative Example 1	Comparative Compound A	3.9	0.09	15	10.2	Green	514
Comparative Example 2	Comparative Compound B	4.5	0.11	15	13.8	Blue	455
Comparative Example 3	Comparative Compound C	3.7	0.15	15	15.5	Light blue	490
Comparative Example 4	Comparative Compound D	5.2	0.09	15	17.0	Blue	473

[0384] Referring to Table 2, it is confirmed that the organic light-emitting devices of Examples 1 to 10 have a low driving voltage, high luminance, and high luminescent efficiency, and are suitable for deep blue light emission, as compared with those of the organic light-emitting devices of Comparative Examples 1 to 4.

[0385] According to one or more embodiments, an organic light-emitting device including the organometallic compound may have a low driving voltage, high luminescent efficiency, high luminance, and a long lifespan.

[0386] 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.

[0387] As used herein, the terms "combination thereof" and "combinations thereof" may refer to a chemical combination (e.g., an alloy or chemical compound), a mixture, or a laminated structure of components.

[0388] 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.

[0389] 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 figures. 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 figures. For example, if the device in the figures 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.

[0390] 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.

[0391] 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.

[0392] 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.

[0393] Also, any numerical range recited herein is intended to include all sub-ranges 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.

[0394] 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 as defined by the following claims, and equivalents thereof.

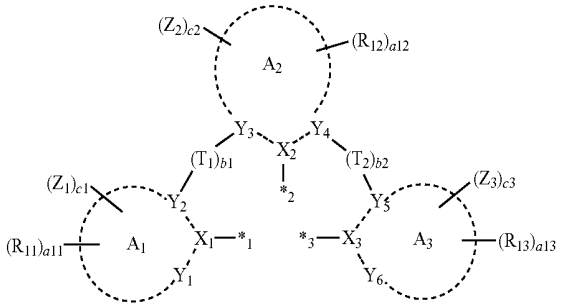
What is claimed is:

1. An organometallic compound represented by Formula 1:

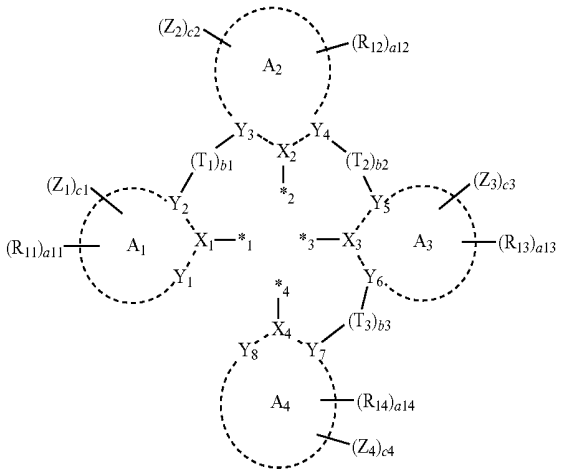
Formula 1

$$M(L_1)_{n1}(L_2)_{n2}$$

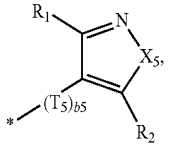
Formula 2A



Formula 2B



Formula 3



wherein M in Formula 1 is Pt, Pd, Ir, or Os,

in Formula 1, L_1 is a ligand represented by Formula 2A or 2B, and n1 is 1 or 2, wherein, when n1 is two, two L_1(s) are identical to or different from each other,

in Formula 1, L_2 is a monovalent organic ligand or a divalent organic ligand, and n2 is 0, 1, or 2,

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

$*^1$, $*^2$ and $*^3$ in Formula 2A and $*^1$, $*^2$, $*^3$, and $*^4$ in Formula 2B each indicate a binding site to M in Formula 1,

X_1 is N or C, X_2 is N or C, X_3 is N or C, and X_4 is N or C,

Y_1 to Y_8 are each independently N or C,

a bond between X_1 and Y_1 is a single bond or a double bond,

a bond between X_1 and Y_2 is a single bond or a double bond,

a bond between X_2 and Y_3 is a single bond or a double bond,

a bond between X_2 and Y_4 is a single bond or a double bond,

a bond between X_3 and Y_5 is a single bond or a double bond,

a bond between X_3 and Y_6 is a single bond or a double bond,

rings A_1 to A_4 are each independently a C_5-C_{30} carbocyclic group or a C_2-C_{60} heterocyclic group,

T_1 to T_3 are each independently selected from *—N[$(L_5)_{a5}$-(R_{15})]—*', *—B(R_{15})—*', *—P(R_{15})—*', *—C(R_{15})(R_{15})—*', *—Si(R_{15})(R_{15})—*', *—Ge(R_{15})(R_{16})—*', *—S—*', *—Se—*', *—O—*', *—C(=O)—*', *—S(=O)—*', *—S(=O)$_2$—*', *—C(R_{15})=*', *=C(R_{15})—*', *—C(R_{15})=C(R_{16})—*', *—C(=S)—*', and *—C≡C—*',

a5 is selected from 1 to 3, wherein, when a5 is two or more, two or more L_5(s) are identical to or different from each other,

R_{15} and R_{16} are optionally linked to a neighboring substituent selected from R_{11} to R_{14} to form a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group,

b1 to b4 are each independently 0, 1, 2, or 3, wherein, when b1 is zero, *-$(T_1)_{b1}$-*' is a single bond, when b2 is zero, *-$(T_2)_{b2}$-*' is a single bond, when b3 is zero, *$(T_3)_{b3}$-*' is a single bond, and when b4 is zero, *-$(T_4)_{b4}$-*' is a single bond,

and' each indicate a binding site to a neighboring atom,

Z_1 to Z_4 are each represented by Formula 3,

c1 to c4 are each independently 0, 1, 2, or 3,

the sum of c1, c2, and c3 in Formula 2A is one or more,

the sum of c1, c2, c3, and c4 in Formula 2B is one or more,

T_5 in Formula 3 is a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_2-C_{60} heterocyclic group,

b5 is an integer from 0 to 5,

X_5 is O, S, or N(R_3),

R_1 to R_3 and R_{11} to R_{16} 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), and —P(=O)(Q_1)(Q_2),

at least one substituent of 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, the substituted monovalent non-aromatic condensed heteropolycyclic group, the substituted C_4-C_{60} carbocyclic group, and the substituted C_2-C_{60} heterocyclic group is selected from:

deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a 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_1 to Q_3, 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 biphenyl group, and a terphenyl group.

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

M in Formula 1 is platinum, and n2 is 0.

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

rings A_1 to A_4 are each independently selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a fluorene group, a phenalene group, a pyrene group, a fluoranthene group, a tetracene group, a chrysene group, a triphenylene group, a benzofluorene group, a perylene group, an indene group, an acenaphthene group, a biphenyl group, a terphenyl 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 pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazol group, a benzopyrazole group, a benzimidazole group, an imidazopyrazinyl group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, and a benzothiadiazol group.

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

rings A_1 to A_4 are each independently selected from a benzene group, a pyridine group, a pyrimidine group, a triazine group, a pyrazole group, an imidazole group, a triazole group, a benzopyrazole group, a benzimidazole group, and an imidazopyrazinyl group.

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

R_1 and R_2 are each independently 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_6-C_{60} aryl group, and a substituted or unsubstituted C_1-C_{60} heteroaryl group.

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

b5 is 0.

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

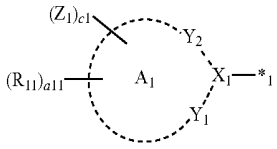
R_3 and R_{11} to R_{16} are each independently selected from:

hydrogen, deuterium, —F, —Cl, —Br, —I, a phenyl group, a naphthyl group, a biphenyl group, and a terphenyl group; and

a phenyl group, a naphthyl group, a biphenyl group, and a terphenyl 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 methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, a pentyl group, an iso-amyl group, a hexyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a pyridyl group, a pyrimidyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, a benzonaphthofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group.

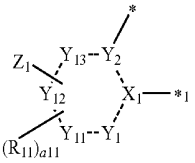
8. The organometallic compound of claim **1**, wherein:

(i) c1 is 1, and a moiety represented by

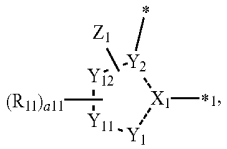


in Formula 2A or 2B is represented by Formula 4A-1 or 4A-2:

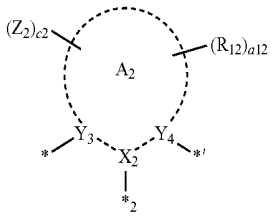
Formula 4A-1



Formula 4A-2

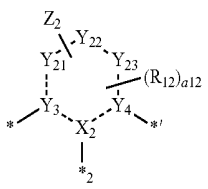


(ii) c2 is 1, and a moiety represented by

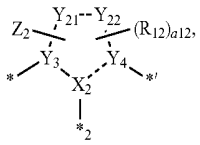


in Formula 2A or 2B is represented by Formula 4B-1 or 4B-2:

Formula 4B-1



Formula 4B-2



wherein, in Formulae 4A-1, 4A-2, 4B-1, and 4B-2,

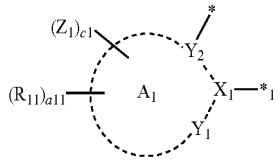
Y_{11}, Y_{12}, Y_{13}, Y_{21}, Y_{22}, and Y_{23} are each independently N or C,

*and *' each indicate a binding site to a neighboring atom, and

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

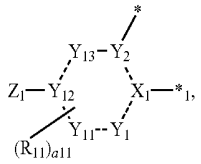
9. The organometallic compound of claim **1**, wherein:

(i) c1 is 1, and a moiety represented by

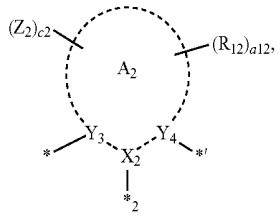


in Formula 2A or 2B is represented by Formula 4A-1-1:

Formula 4A-1-1

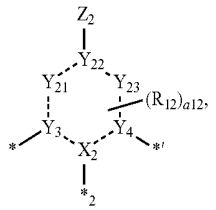


(ii) c2 is 1, and a moiety represented by



in Formula 2A or 2B is represented by Formula 4B-1-1:

Formula 4B-1-1



wherein, in Formulae 4A-1-1 and 4B-1-1,

Y_{11}, Y_{12}, Y_{13}, Y_{21}, Y_{22}, and Y_{23} are each independently N or C,

* and *' each indicate a binding site to a neighboring atom, and

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

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

in Formulae 4A-1-1 and 4B-1-1,

Y_{12} and Y_{22} are each C.

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

when at least one of T_1 to T_3 is *—N[$(L_5)_{a5}$-(R_{15})]—*',

R_{15} is a substituted or unsubstituted C_1-C_{60} aryl group, or is linked to a neighboring substituent selected from R_{11} to R_{14} to form a substituted or unsubstituted C_1-C_{60} heterocyclic group.

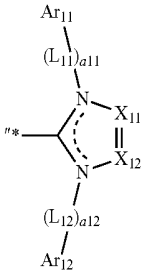
12. The organometallic compound of claim **11**, wherein:

R_{15} is a substituted or unsubstituted phenyl group, or is linked to one of L_1 to L_4 to form a substituted or unsubstituted carbazole ring or a substituted or unsubstituted azacarbazole ring.

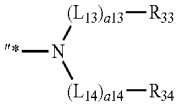
13. The organometallic compound of claim **1**, wherein:

L_2 is selected from ligands represented by Formulae 3A to 3F:

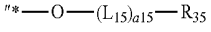
3A



3B

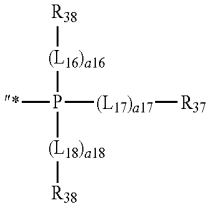


3C

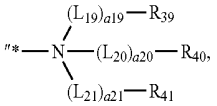


3D

3E



3F



wherein, in Formulae 3A to 3F,

X_{11} is N or C(R_{31}), and X_{12} is N or C(R_{32}),

L_{11} to L_{21} are each independently 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,

a11 to a21 are each independently an integer from 0 to 3,

Ar_{11} and Ar_{12} are each independently 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,

R_{31} to R_{32} 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, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$,

R_{31} and R_{32} are optionally linked to form a saturated or unsaturated ring, and R_{33} and R_{34} are optionally linked to form a saturated or unsaturated ring,

X_{21} is selected from —F, —Cl, —Br, and —I,

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

at least one substituent of 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 is selected from:

deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a 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

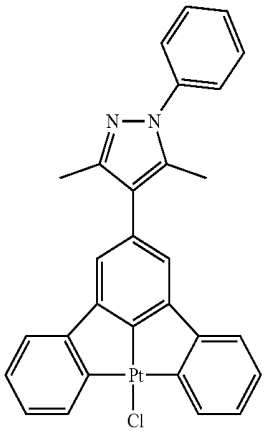
$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$, and

Q_1 to Q_3, 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 biphenyl group, and a terphenyl group.

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

the organometallic compound is selected from Compounds 1 to 42:

1



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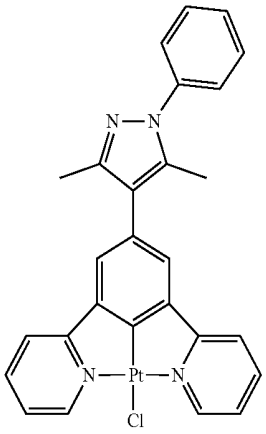

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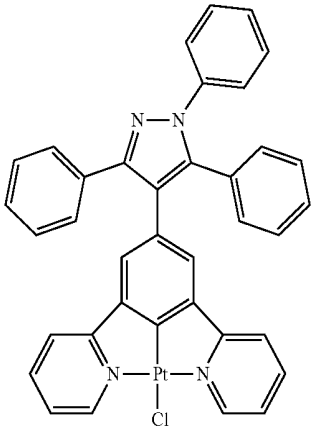

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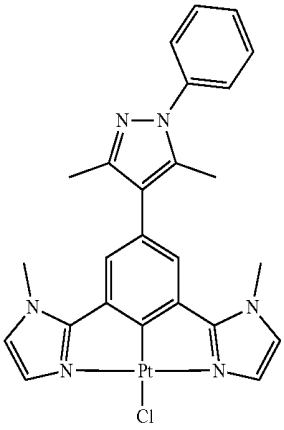

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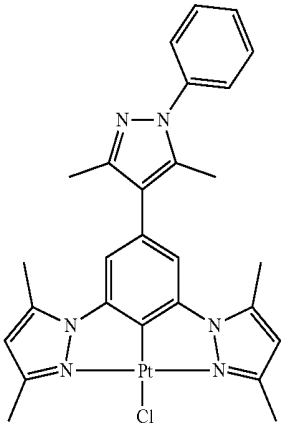

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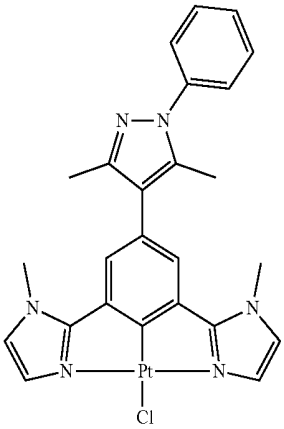

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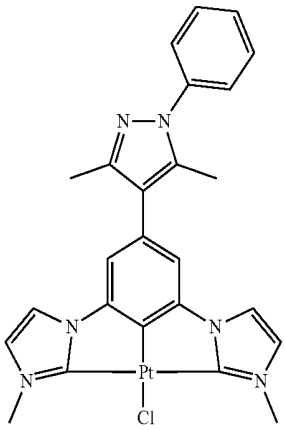

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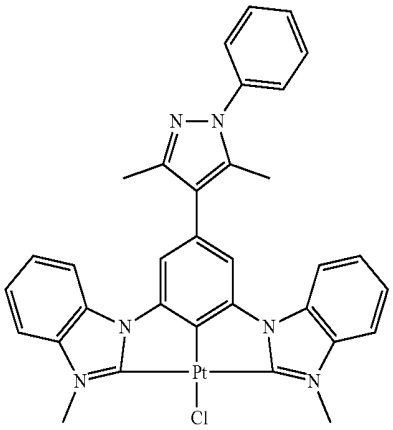

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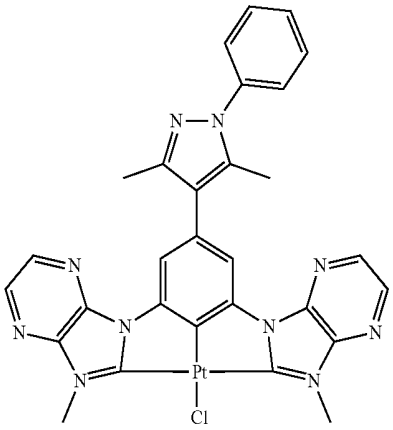

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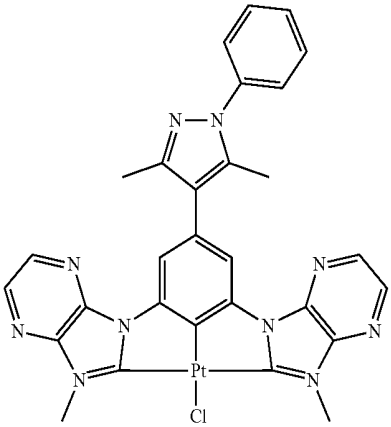

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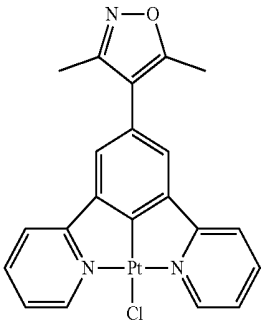

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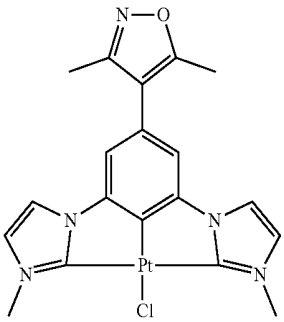

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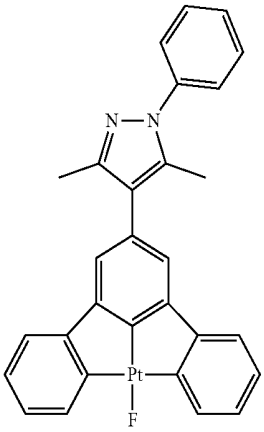

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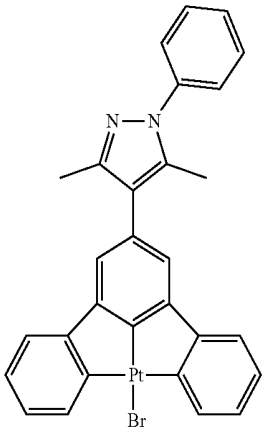

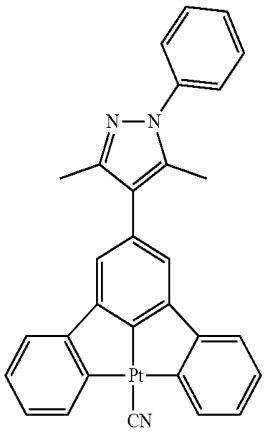

15. An organic light-emitting device comprising:

a first electrode

a second electrode facing the first electrode; and

an organic layer between the first electrode and the second electrode and 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 emission auxiliary 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 **16**, wherein:

the organometallic compound is comprised in the emission layer,

the emission layer further comprises a host, and

an amount of the host in the emission layer is larger than an amount of the organometallic compound in the emission layer.

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

the electron blocking layer or the hole blocking layer comprises the organometallic compound.

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

the host comprises at least one of a silicon-containing compound and a phosphine oxide-containing compound.

20. The organic light-emitting device of claim **16**, further comprising a capping layer on the first electrode or the second electrode,

wherein the capping layer comprises the organometallic compound.

* * * * *

专利名称(译)	有机金属化合物和包括其的有机发光器件		
公开(公告)号	US20180331305A1	公开(公告)日	2018-11-15
申请号	US15/867649	申请日	2018-01-10
[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 SUNGBUM KO SOOBYUNG KIM YOUNGKOOK JEON MINA JUN MIEUN HWANG SEOKHWAN		
发明人	KIM, SUNGBUM KO, SOOBYUNG KIM, YOUNGKOOK JEON, MINA JUN, MIEUN HWANG, SEOKHWAN		
IPC分类号	H01L51/00 C07F15/00 C09K11/06		
CPC分类号	H01L51/5072 H01L51/5092 C09K2211/185 C09K2211/1029 C09K2211/1044 H01L51/0087 C07F15/0086 C09K11/06 H01L51/5024 H01L51/5088 H01L51/5056 H01L51/5096		
优先权	1020170058095 2017-05-10 KR		
外部链接	Espacenet USPTO		

摘要(译)

本发明提供有机金属化合物和包含该有机金属化合物的有机发光器件。有机金属化合物可以由式1表示。在式1中，L 1 可以是由式2A或2B表示的配体，并且L 2 可以是单价有机配体。或二价有机配体。