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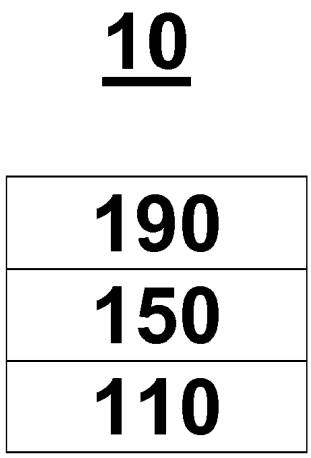
(54) HETEROCYCLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME

(57) A heterocyclic compound is represented by Formula 1. An organic light-emitting device includes: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode and including an emission layer, wherein the organic light-emitting device includes at least one of the heterocyclic compound.

FIG. 1



EP 3 657 563 A2

Description

BACKGROUND

1. Field

[0001] One or more embodiments of the present disclosure relate to a condensed heterocyclic compound and an organic light-emitting device including the same.

2. Description of the Related Art

[0002] 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.

[0003] An example of such organic light-emitting devices may include a first electrode located on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode, which are sequentially located on the first electrode. Holes provided from the first electrode may move toward the emission layer through the hole transport region, and electrons provided from the second electrode may move toward the emission layer through the electron transport region. Carriers, such as holes and electrons, recombine in the emission layer to produce excitons. These excitons transit (e.g., transition or relax) from an excited state to a ground state, thereby generating light.

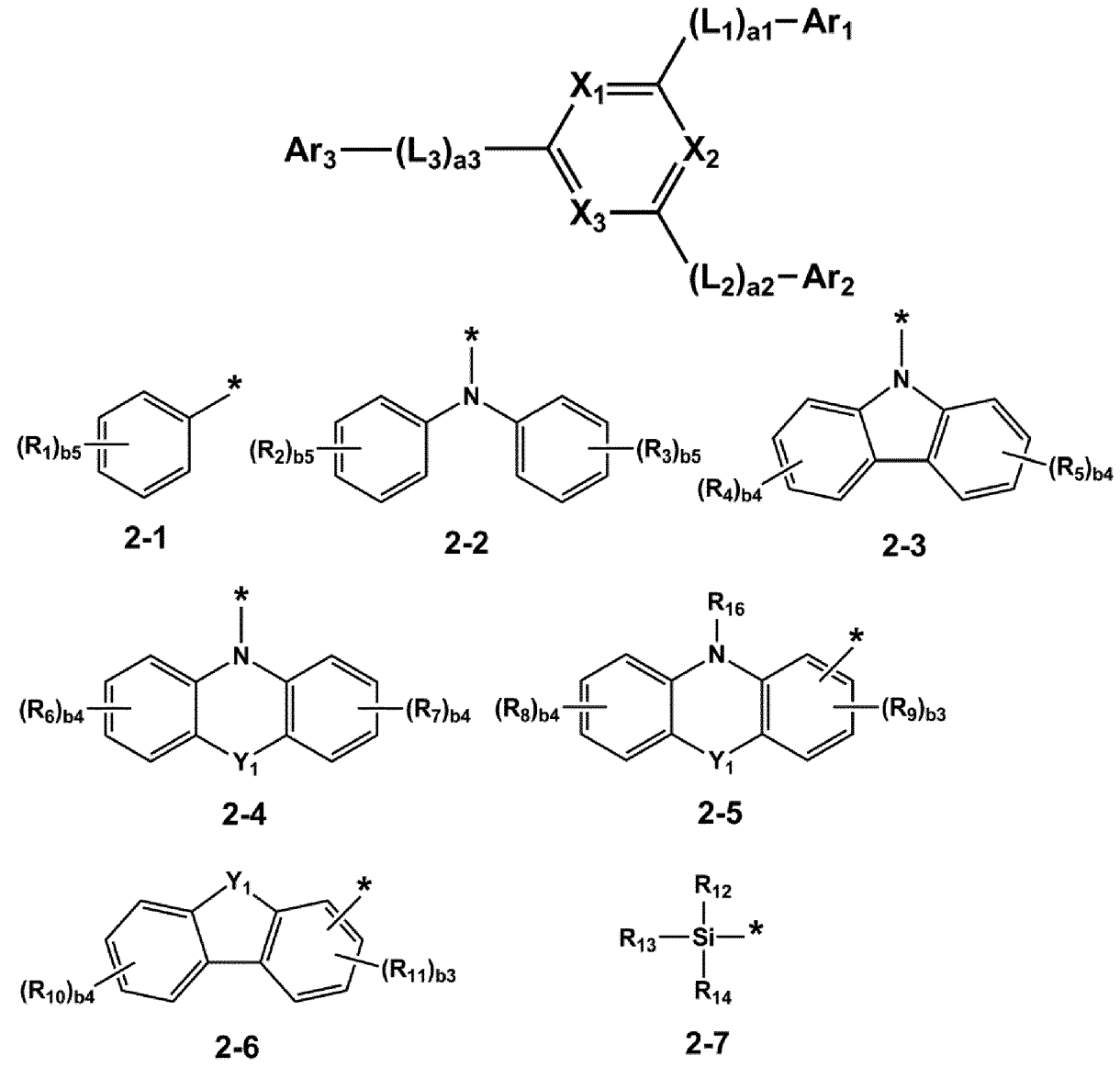
SUMMARY

[0004] One or more embodiments include a novel heterocyclic compound and an organic light-emitting device including the same.

[0005] 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.

[0006] An aspect of an embodiment provides a heterocyclic compound represented by Formula 1 below:

Formula 1



[0007] In Formulae 1 and 2-1 to 2-7,

X_1 to X_3 are each independently N or $C(R_{15})$, wherein at least one selected from X_1 to X_3 is N,
L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,
a1 to a3 are each independently an integer from 0 to 3,
Ar_1 to Ar_3 are each independently a group represented by one selected from Formulae 2-1 to 2-7,
Y_1 is O or S,
R_1 to R_{16} are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heter-

opolycyclic group,-Si(Q_1)(Q_2)(Q_3), -N(Q_1)(Q_2), -B(Q_1)(Q_2), -S(=O)$_2$(Q_1), and -P(=O)(Q_1)(Q_2),
b3 is an integer from 0 to 3, b4 is an integer from 0 to 4, and b5 is an integer from 0 to 5,
in the groups included in the heterocyclic compound represented by Formula 1, at least one selected from the substituents R_1 to R_{11} of Formulae 2-1 to 2-6 is-Si(Q_1)(Q_2)(Q_3),
when Ar_1 is a group represented by Formula 2-7, a1 is 0, when Ar_2 is a group represented by Formula 2-7, a2 is 0, and when Ar_3 is a group represented by Formula 2-7, a3 is 0,
when Ar_1 is a group represented by Formula 2-7, Ar_2 and Ar_3 are not a group represented by Formula 2-1 and L_2 and L_3 are not a benzene group, when Ar_2 is a group represented by Formula 2-7, Ar_1 and Ar_3 are not a group represented by Formula 2-1 and L_1 and L_3 are not a benzene group, and when Ar_3 is a group represented by Formula 2-7, Ar_1 and Ar_2 are not a group represented by Formula 2-1 and L_1 and L_2 are not a benzene group, and
a case in which each of Ar_1 to Ar_3 is a group represented by Formula 2-1 is excluded,
at least one substituent of the substituted C_3-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_2-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_2-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_2-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, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl 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, 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 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, a biphenyl group, a terphenyl 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_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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; and
a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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, 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, and $-Si(R_a)(R_b)(R_c)$,

R_a to R_c are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and

* indicates a binding site to a neighboring atom.

[0008] Another aspect of an embodiment provides an organic light-emitting device including: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode and including an emission layer, wherein the organic light-emitting device further includes at least one of the heterocyclic compound.

[0009] At least some of the above and other features of the invention are set out in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and/or other aspects of embodiments will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

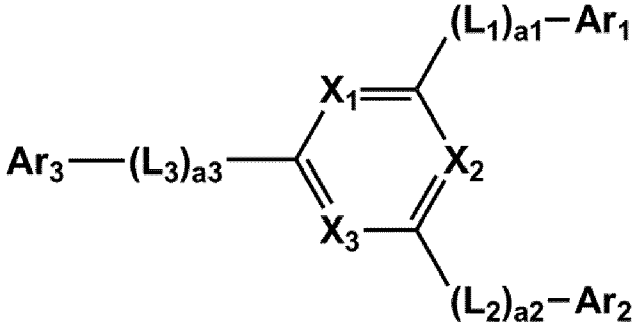
FIG. 1 is a schematic view of an organic light-emitting device according to an embodiment;
FIG. 2 is a schematic view of an organic light-emitting device according to an embodiment;
FIG. 3 is a schematic view of an organic light-emitting device according to an embodiment; and
FIG. 4 is a schematic view of an organic light-emitting device according to an embodiment.

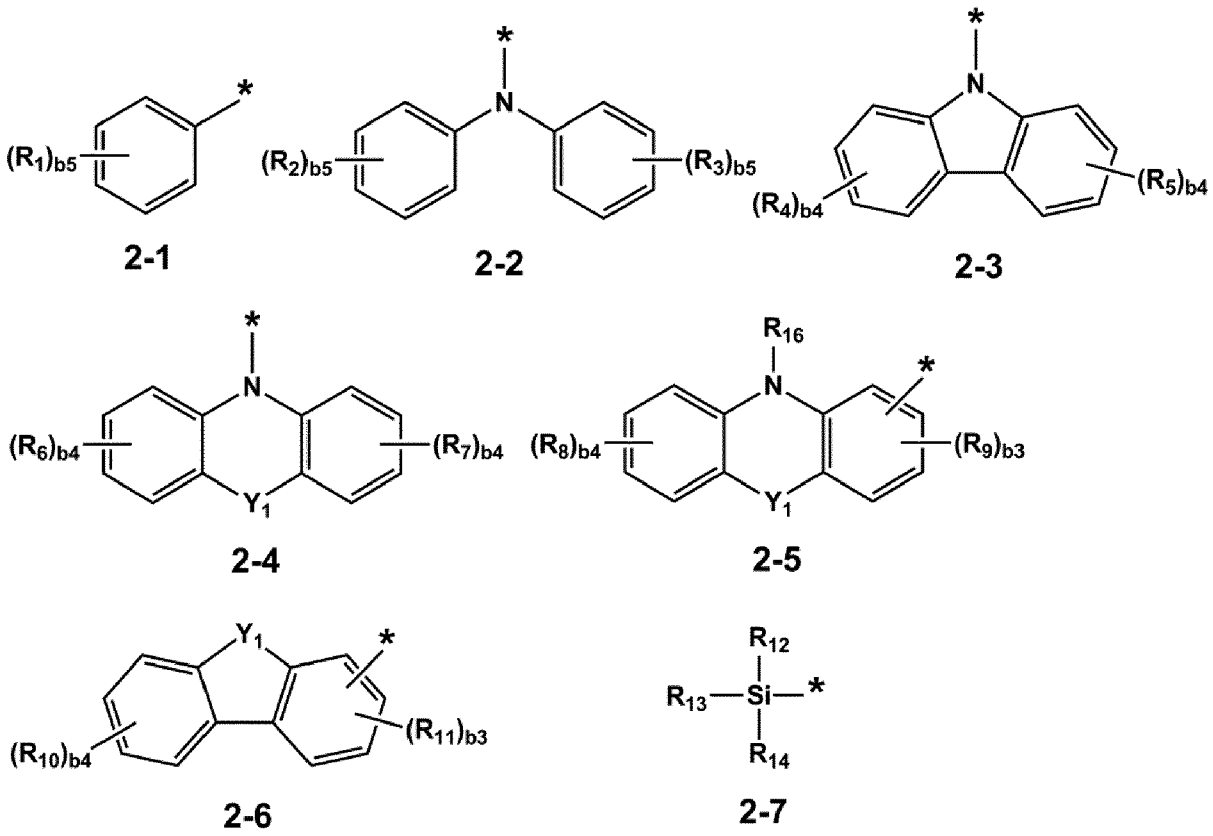
DETAILED DESCRIPTION

[0011] Reference will now be made in more detail to embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects 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.

[0012] According to an aspect of an embodiment of the present disclosure, there is provided a heterocyclic compound represented by Formula 1:

Formula 1





2-1 2-2 2-3

2-4 2-5

2-6 2-7

[0013] In Formulae 1 and 2-1 to 2-7,

X_1 to X_3 are each independently N or C(R_{15}), and at least one selected from X_1 to X_3 is N.

[0014] In Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group.

[0015] For example, in Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{30} heterocyclic group. For example, in Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{20} heterocyclic group. For example, in Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{20} carbocyclic group or a substituted or unsubstituted C_1-C_{20} heterocyclic group. For example, in Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{12} carbocyclic group or a substituted or unsubstituted C_1-C_{20} heterocyclic group. For example, in Formula 1, L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{12} carbocyclic group or a substituted or unsubstituted C_1-C_{12} heterocyclic group.

[0016] In one embodiment, L_1 to L_3 may each independently be selected from:

a benzene group, a pentalene group, an indene group, a naphthalene group, an azulene group, a heptalene group, an indacene group, an acenaphthalene group, a fluorene group, a spiro-bifluorene group, a spiro-benzofluorene-fluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pyrrole group, a thiophene group, a furan group, a silole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a triazine group, a benzofuran group, a benzothiophene group, a benzosilole group, a dibenzosilole group, a quinoline group, an isoquinoline group, a benzimidazole group, an imidazopyridine group, and an imidazopyrimidine group;

a benzene group, a pentalene group, an indene group, a naphthalene group, an azulene group, a heptalene group, an indacene group, an acenaphthalene group, a fluorene group, a spiro-bifluorene group, a spiro-benzofluorene-fluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pyrrole group, a thiophene group, a furan group, a silole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a triazine group, a benzofuran group, a benzothiophene group, a

benzosilole group, a dibenzosilole group, a quinoline group, an isoquinoline group, a benzimidazole group, an imidazopyridine group, and an imidazopyrimidine group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} (e.g. C_1-C_{10}) alkyl group, a C_1-C_{20} (*e.g.* C_1-C_{10}) alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, 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 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 pyrrolyl group, a thiophenyl group, a furanyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a benzofuranyl group, a benzothiophenyl group, -Si(Q_{31})(Q_{32})(Q_{33}), -N(Q_{31})(Q_{32}), and-B(Q_{31})(Q_{32}), and
Q_{31} to Q_{33} may each independently be selected from a C_1-C_{20} (*e.g.* C_1-C_{10}) alkyl group, a C_1-C_{20} (e.g. C_1-C_{10}) alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, and a pyridinyl group.

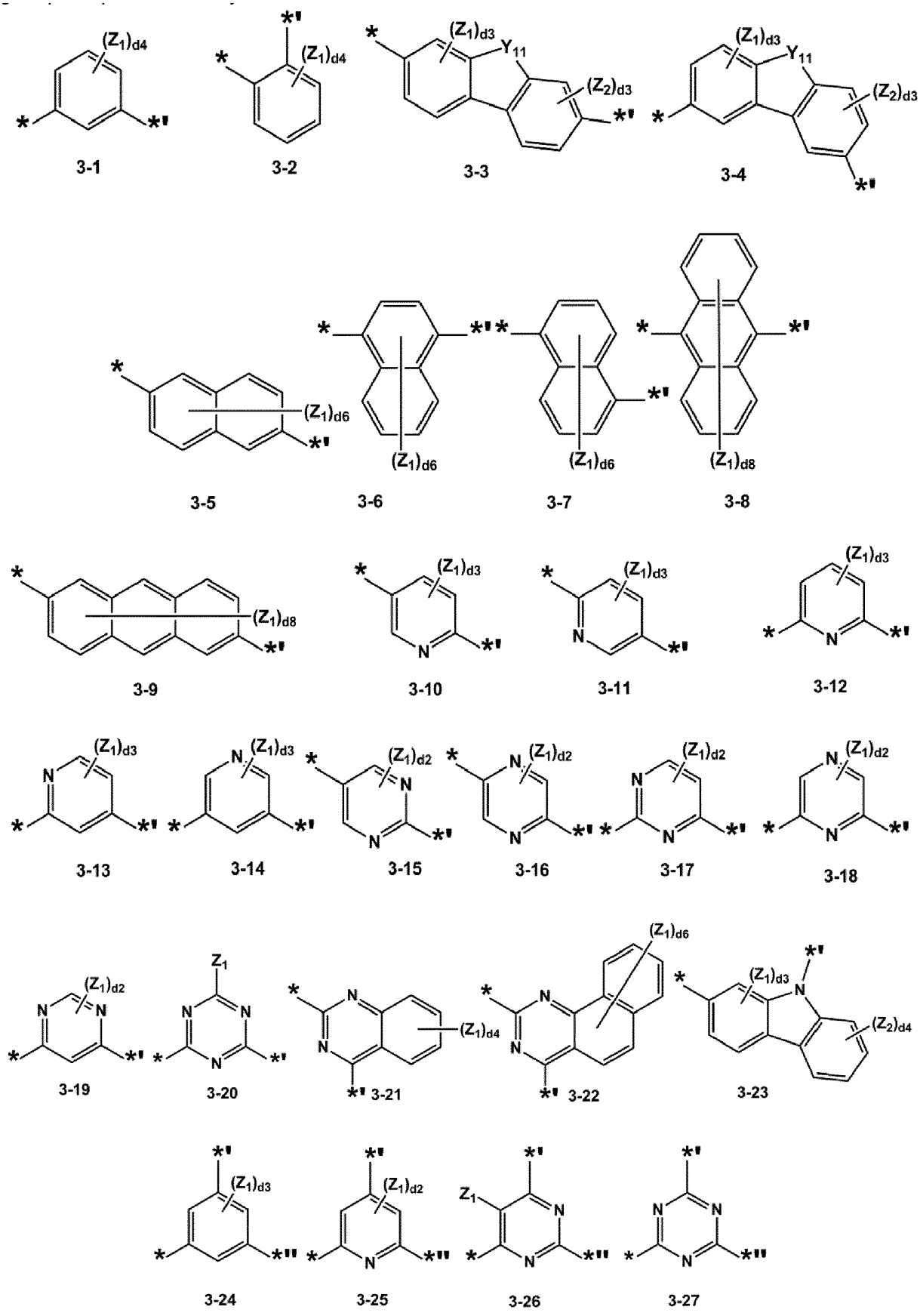
[0017] For example, L_1 to L_3 may each independently be selected from:

a benzene group; and
a benzene 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_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (e.*g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) 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}),
wherein Q_{21} to Q_{23} 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_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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; and
a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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, 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, and -Si(R_a)(R_b)(R_c),

R_a to R_c are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-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.

[0018] In one embodiment, L_1 to L_3 may each independently be selected from groups represented by Formulae 3-1 to 3-27:



[0019] In Formulae 3-1 to 3-27,

Y_{11} is selected from $C(Z_3)(Z_4)$, $N(Z_5)$, $Si(Z_6)(Z_7)$, O, and S,
Z_1 to Z_7 are each independently selected from hydrogen, deuterium, -F, -Cl,-Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} (*e.g.* C_1-C_{10}) alkyl group, a C_1-C_{20} (e.g. C_1-C_{10}) 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 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 pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a dibenzosilolyl group, and $-Si(Q_{31})(Q_{32})(Q_{33})$, and
Q_{31} to Q_{33} are each independently selected from a C_1-C_{20} (*e.g.* C_1-C_{10}) alkyl group, a C_1-C_{20} (*e.g.* C_1-C_{10}) alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, and a pyridinyl group,
d2 is an integer from 0 to 2,
d3 is an integer from 0 to 3,
d4 is an integer from 0 to 4,
d6 is an integer from 0 to 6,
d8 is an integer from 0 to 8, and
* and *' each indicate a binding site to a neighboring atom.

[0020] For example, L_1 to L_3 may each independently be a group represented by one of Formulae 3-1 and 3-2.

[0021] In Formula 1, a1 to a3 are each independently an integer from 0 to 3.

[0022] In one embodiment, a1 to a3 may each independently be 0 or 1.

[0023] In Formula 1, Ar_1 to Ar_3 are each independently a group represented by one of Formulae 2-1 to 2-7.

[0024] In Formulae 2-1 to 2-7, Y_1 is O or S.

[0025] In Formulae 1 and 2-1 to 2-7, R_1 to R_{16} are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C20) alkyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-Si(Q_1)(Q_2)(Q_3)$,$-N(Q_1)(Q_2)$, $-B(Q_1)(Q_2)$, $-S(=O)_2(Q_1)$, and $-P(=O)(Q_1)(Q_2)$.

[0026] In Formulae 2-1 to 2-7, b3 is an integer from 0 to 3, b4 is an integer from 0 to 4, and b5 is an integer from 0 to 5,

wherein, in the groups included in the heterocyclic compound represented by Formula 1, at least one selected from substituents R_1 to R_{11} of Formulae 2-1 to 2-6 is $-Si(Q_1)(Q_2)(Q_3)$,
when Ar_1 is the group represented by Formula 2-7, a1 is 0, when Ar_2 is the group represented by Formula 2-7, a2 is 0, and when Ar_3 is a group represented by Formula 2-7, a3 is 0,
when Ar_1 is the group represented by Formula 2-7, Ar_2 and Ar_3 are not the group represented by Formula 2-1 and L_2 and L_3 are not a benzene group, when Ar_2 is the group represented by Formula 2-7, Ar_1 and Ar_3 are not the group represented by Formula 2-1 and L_1 and L_3 are not a benzene group, and when Ar_3 is the group represented by Formula 2-7, Ar_1 and Ar_2 are not the group represented by Formula 2-1 and L_1 and L_2 are not a benzene group, and a case in which each of Ar_1 to Ar_3 is the group represented by Formula 2-1 is excluded.

[0027] In one embodiment, at least one selected from Ar_1 to Ar_3 may be a group different from the others thereof.

[0028] In one embodiment, at least one selected from Ar_1 to Ar_3 may be a group represented by one selected from Formulae 2-2 to 2-4.

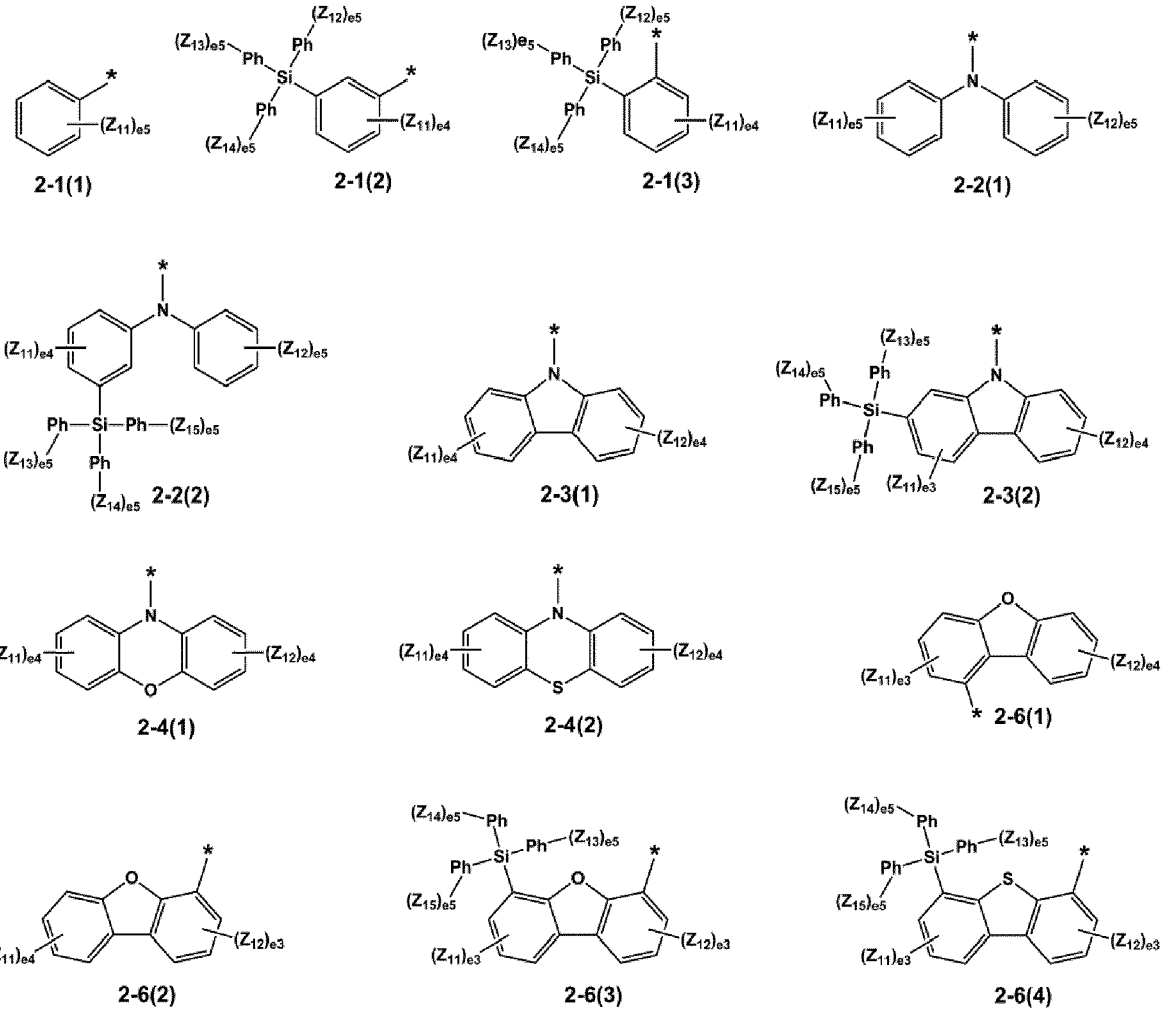
[0029] For example, i) Ar_1 and Ar_2 may each be a group represented by Formula 2-1, and Ar_3 may be a group represented by Formula 2-2;

ii) Ar_1 and Ar_2 may each be a group represented by Formula 2-1, and Ar_3 may be a group represented by Formula 2-3;
iii) Ar_1 and Ar_2 may each be a group represented by Formula 2-1, and Ar_3 may be a group represented by Formula 2-4;
iv) Ar_1 may be a group represented by Formula 2-1, and Ar_2 and Ar_3 may each be a group represented by Formula 2-3;
v) Ar_1 may be a group represented by Formula 2-1, and Ar_2 and Ar_3 may each be a group represented by Formula 2-4;

vi) Ar_1 and Ar_2 may each be a group represented by Formula 2-3, and Ar_3 may be a group represented by Formula 2-6;
vii) Ar_1 may be a group represented by Formula 2-1, Ar_2 may be a group represented by Formula 2-2, and Ar_3 may be a group represented by Formula 2-3; or
viii) Ar_1 may be a group represented by Formula 2-1, Ar_2 may be a group represented by Formula 2-3, and Ar_3 may be a group represented by Formula 2-6, but embodiments of the present disclosure are not limited thereto.

[0030] In one embodiment, i) when Ar_1 is a group represented by Formula 2-1, at least one selected from R_1(s) in the number of b5 may be $-Si(Q_1)(Q_2)(Q_3)$, and
ii) when Ar_1 and Ar_2 are each a group represented by Formula 2-3 and Ar_3 is a group represented by Formula 2-6, at least one selected from Rio(s) in the number of b4 and R_{11}(s) in the number of b3 may be $-Si(Q_1)(Q_2)(Q_3)$.

[0031] In one or more embodiments, Ar_1 to Ar_3 may each independently be a group represented by one selected from Formulae 2-1(1) to 2-1(3), 2-2(1) to 2-2(2), 2-3(1) to 2-3(2), 2-4(1) to 2-4(2), and 2-6(1) to 2-6(4):



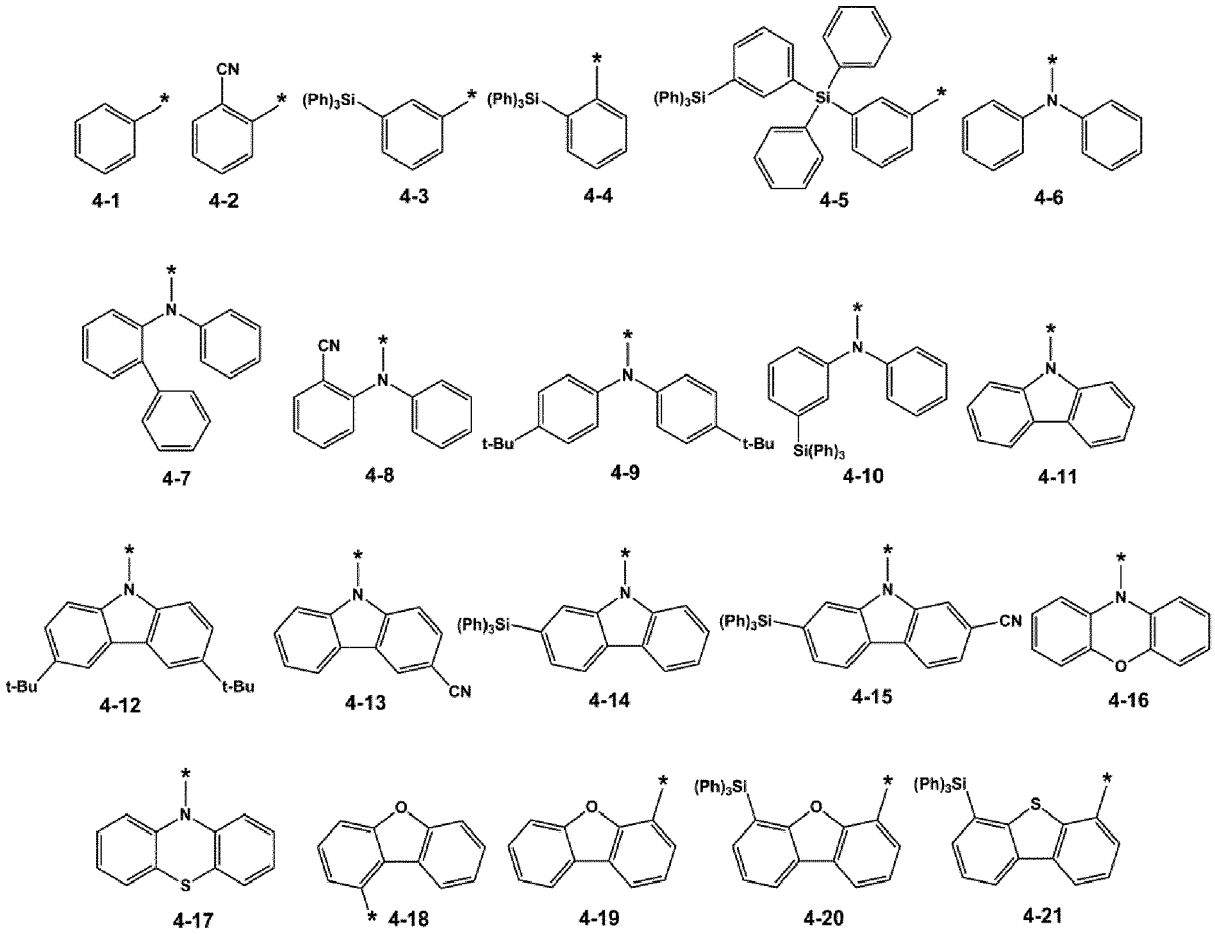
[0032] In Formulae 2-1(1) to 2-1(3), 2-2(1) to 2-2(2), 2-3(1) to 2-3(2), 2-4(1) to 2-4(2), and 2-6(1) to 2-6(4),

Z_{11} to Z_{15} are each independently selected from hydrogen, deuterium, -F,-Cl, -Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} (*e.g.* C_1-C_{10}) alkyl group, a C_1-C_{20} (*e.g.* C_1-C_{10}) 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 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 pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a dibenzosilolyl group, and $-Si(Q_{31})(Q_{32})(Q_{33})$,

Q_{31} to Q_{33} are each independently selected from a C_1-C_{20} (*e.g.* C_1-C_{10}) alkyl group, a C_1-C_{20} (*e.g.* C_1-C_{10}) alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, and a pyridinyl group,
e3 is an integer from 0 to 3,
e4 is an integer from 0 to 4,
e5 is an integer from 0 to 5,
Ph indicates a phenyl group, and
* indicates a binding site to a neighboring atom.

[0033] For example, at least one selected from Ar_1 to Ar_3 may be a group represented by one selected from Formulae 2-1(2), 2-1(3), 2-2(2), 2-3(2), 2-6(3), and 2-6(4), but embodiments of the present disclosure are not limited thereto.

[0034] In one or more embodiments, Ar_1 to Ar_3 may each independently be a group represented by one selected from Formulae 4-1 to 4-21:



[0035] In Formulae 4-1 to 4-21,
Ph indicates a phenyl group, t-Bu indicates a tert-butyl group, and * indicates a binding site to a neighboring atom.

[0036] For example, in Formulae 2-1 to 2-7, b3, b4, and b5 may each independently be 0 or 1.

[0037] In one embodiment, in Formulae 1 and 2-1 to 2-7, R_1 to R_{16} may each independently be selected from hydrogen, a cyano group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, and $-Si(Q_1)(Q_2)(Q_3)$.

[0038] For example, R_1 to R_{16} may each independently be selected from:

hydrogen, a cyano group, a methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an isoamyl group, a hexyl group, and a phenyl group; and
a methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an isoamyl group, a hexyl group, and a phenyl group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, and -I.

[0039] In one embodiment, i) X_1 to X_3 may each be N, and R_{15} may be hydrogen; ii) X_1 and X_2 may each be N, and X_3 may be $C(R_{15})$, and R_{15} may be hydrogen; iii) X_1 and X_3 may each be N, and X_2 may be $C(R_{15})$, and R_{15} may be hydrogen; iv) X_2 and X_3 may each be N, and X_1 may be $C(R_{15})$, and R_{15} may be hydrogen; v) X_1 may be N, and X_2 and X_3 may each be $C(R_{15})$, and R_{15} may be hydrogen; vi) X_2 may be N, and X_1 and X_3 may each be $C(R_{15})$, and R_{15} may be hydrogen; or vii) X_3 may be N, and X_1 and X_2 may each be $C(R_{15})$, and R_{15} may be hydrogen.

[0040] At least one substituent of the substituted C_3-C_{60} carbocyclic group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) heterocyclic group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, the substituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, the substituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_2-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_2-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, the substituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, the substituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, the substituted C_2-C_{60} (*e.g.* C_2-C_{20}) 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} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, and a C_1-C_{60} (e.g. C_1-C_{20}) alkoxy group;

a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C60 (*e.g.* C_2-C_{20}) alkynyl group, and a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a 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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) 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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (e.g. C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl 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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} *(e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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 C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, a terphenyl 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:

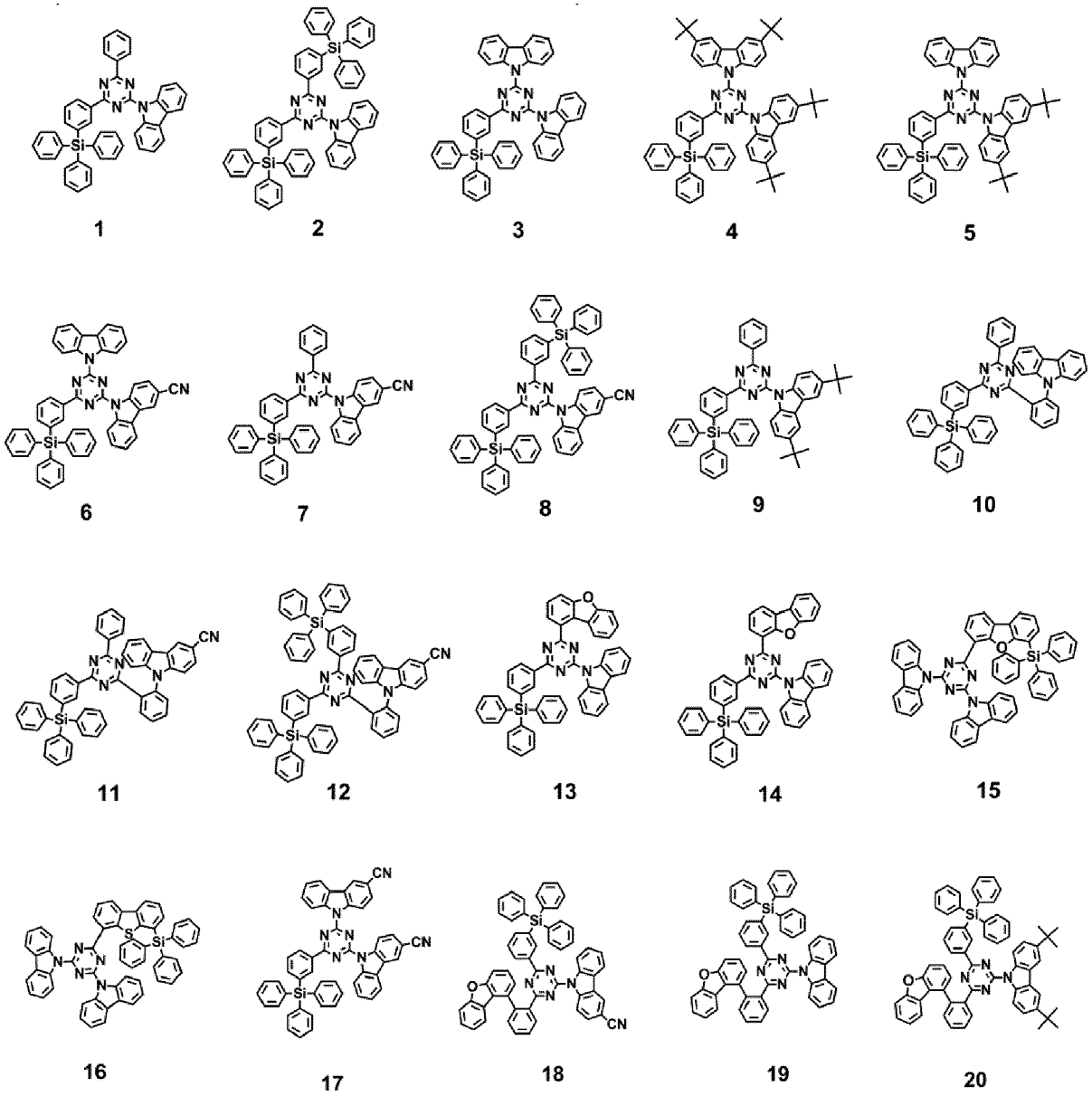
hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group substituted with a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group; and

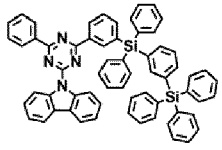
a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group substituted with a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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 C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, and -Si(R_a)(R_b)(R_c),

R_a to R_c are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{20}) heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, wherein the substituents referred herein are the same as defined above.

[0041] In one embodiment, the heterocyclic compound may be selected from Compounds 1 to 59, but embodiments of the present disclosure are not limited thereto:





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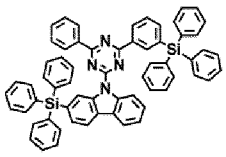

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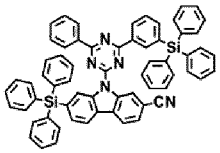

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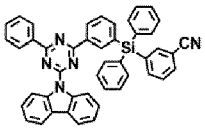

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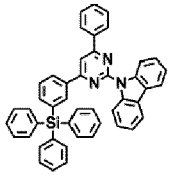

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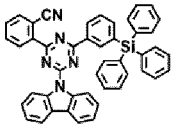

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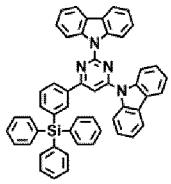

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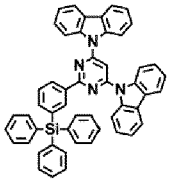

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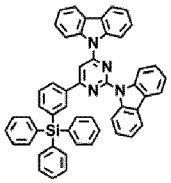

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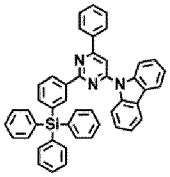

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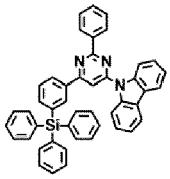

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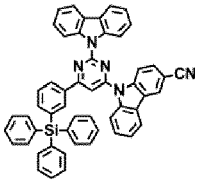

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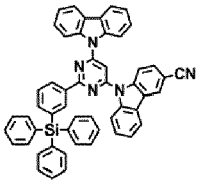

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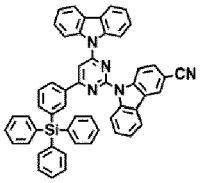

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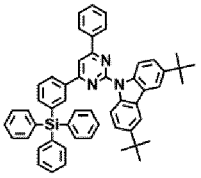

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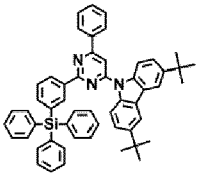

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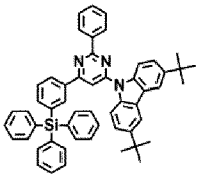

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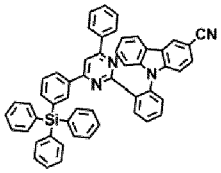

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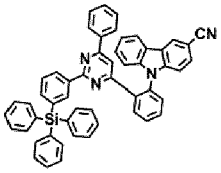

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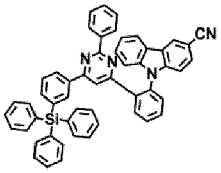

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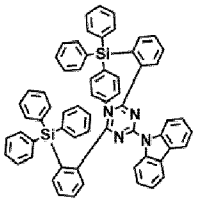

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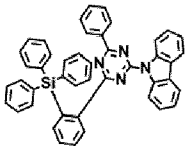

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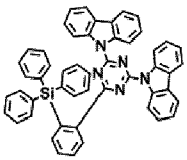

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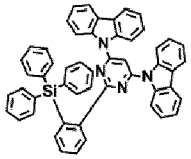

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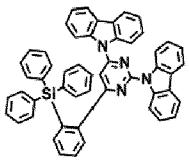

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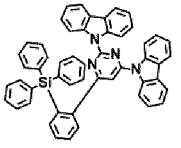

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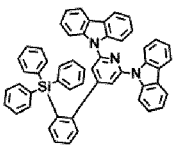

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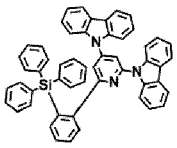

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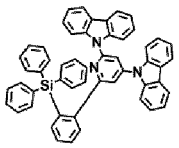

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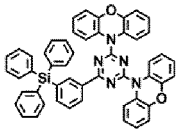

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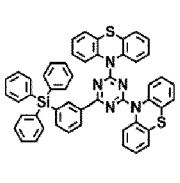

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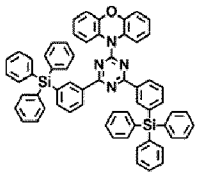

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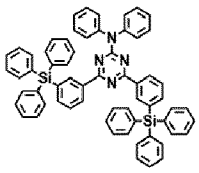

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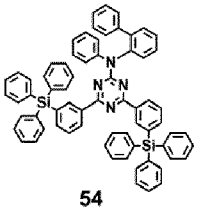

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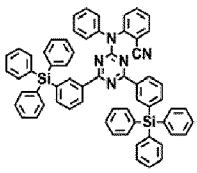

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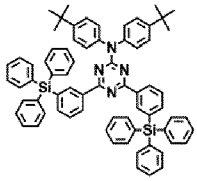

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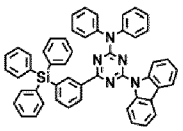

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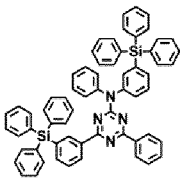

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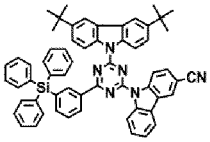

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[0042] The heterocyclic compound of embodiments of the present disclosure has an azine-based core including at least one N atom, and the heterocyclic compound further includes substituents having a large size, such as the groups represented by Formulae 2-1 to 2-7. Therefore, because intermolecular attraction is reduced through steric hindrance caused by the substituents having a large size and because the heterocyclic compound has a relatively high triplet energy level, the heterocyclic compound may be suitable as a phosphorescent host.

[0043] In the heterocyclic compound according to embodiments of the disclosure, when a silyl group substituted benzene group is included in the substituent of the azine-based core, the silyl group is substituted at an ortho or meta position with respect to a linked position between the benzene group and the azine-based core, and a triplet energy level difference may be increased, as compared with a case in which the silyl group is substituted at a para position, thereby providing excellent phosphorescence.

[0044] Therefore, an electronic device such as, for example, an organic light-emitting device, which includes the heterocyclic compound represented by Formula 1, may have a low driving voltage, high efficiency, and a long lifespan.

[0045] A synthesis method for the heterocyclic compound represented by Formula 1 should be readily apparent to those of ordinary skill in the art by referring to the following examples.

[0046] At least one of the heterocyclic compound of Formula 1 may be used between a pair of electrodes of an organic light-emitting device. For example, the heterocyclic compound may be included in an emission layer. In one or more embodiments, the heterocyclic compound represented by Formula 1 may be used as a material for forming a capping layer positioned outside the pair of electrodes of the organic light-emitting device.

[0047] Accordingly, there is provided 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 and at least one heterocyclic compound represented by Formula 1.

[0048] The expression "(an organic layer) includes at least one of the heterocyclic compounds," as used herein, may include a case in which "(an organic layer) includes identical heterocyclic compounds represented by Formula 1" and a case in which "(an organic layer) includes two or more different heterocyclic compounds represented by Formula 1."

[0049] For example, the organic layer may include, as the heterocyclic compound, only Compound 1. In this regard, Compound 1 may be included in an emission layer of the organic light-emitting device. In one or more embodiments, the organic layer may include, as the heterocyclic compound, Compound 1 and Compound 2. In this regard, Compound 1 and Compound 2 may be included in an identical layer (for example, Compound 1 and Compound 2 may both be included in an emission layer), or different layers (for example, Compound 1 may be included in an emission layer and Compound 2 may be included in an electron transport layer).

[0050] According to one embodiment,

the first electrode of the organic light-emitting device may be an anode,
the second electrode of the organic light-emitting device may be a cathode,
the organic layer may include at least one of the heterocyclic compound represented by Formula 1,
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,
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
the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection

layer, or any combination thereof.

[0051] In one or more embodiments, the emission layer may include the heterocyclic compound represented by Formula 1.

[0052] In one or more embodiments, the emission layer may include a dopant and a host, and the host may include at least one of the heterocyclic compound represented by Formula 1.

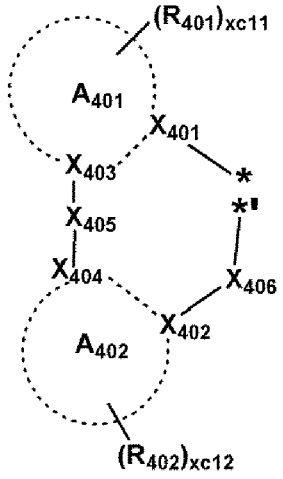
[0053] In one embodiment, an amount of the heterocyclic compound may be in a range of about 50 parts by weight to about 99.9 parts by weight based on 100 parts by weight of the emission layer. For example, an amount of the heterocyclic compound may be in a range of about 90 parts by weight to about 99.9 parts by weight based on 100 parts by weight of the emission layer.

[0054] For example, the dopant may be a phosphorescent dopant.

[0055] In one embodiment, the dopant may include an organometallic complex represented by Formula 401:

Formula 401 $M(L_{401})_{xc1}(L_{402})_{xc2}$

Formula 402



[0056] In Formulae 401 and 402,

M is selected from iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), and thulium (Tm),

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

L_{402} is an organic ligand, and xc2 is an integer from 0 to 4, wherein, when xc2 is two or more, two or more L_{402}(s) are identical to or different from each other,

X_{401} to X_{404} are each independently N or C,

X_{401} and X_{403} are linked via a single bond or a double bond, and X_{402} and X_{404} are linked via a single bond or a double bond,

A401 and A402 are each independently a C_5-C_{60} (*e.g.* C_5-C_{30}) carbocyclic group or a C_1-C_{60} (*e.g.* C_1-C_{20}) heterocyclic group,

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

X_{406} is a single bond, O, or S,

R_{401} and R_{402} 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_{20} alkyl group, a substituted or unsubstituted C_1-C_{20} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a

substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $-Si(Q_{401})(Q_{402})(Q_{403})$, $-N(Q_{401})(Q_{402})$, $-B(Q_{401})(Q_{402})$, $-C(=O)(Q_{401})$, $-S(=O)_2(Q_{401})$, and $-P(=O)(Q_{401})(Q_{402})$, wherein Q_{401} to Q_{403} are each independently selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a C_6-C_{20} aryl group, and a C_1-C_{20} heteroaryl group,
xc11 and xc12 are each independently an integer from 0 to 10, and
* and *' in Formula 402 each indicate a binding site to M in Formula 401.

[0057] In one embodiment, the hole transport region may include a p-dopant having a lowest unoccupied molecular orbital (LUMO) energy level of about -3.5 eV or less.

[0058] In one embodiment, the electron transport region 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, alkaline earth metal complex, a rare earth metal complex, or any combination thereof.

[0059] In one embodiment, the emission layer may be a first emission layer configured to emit a first color light, and the organic light-emitting device may further include i) at least one second emission layer configured to emit a second color light or ii) at least one second emission layer configured to emit a second color light and at least one third emission layer configured to emit a third color light, between the first electrode and the second electrode.

[0060] A maximum emission wavelength of the first color light, a maximum emission wavelength of the second color light, and a maximum emission wavelength of the third color light may be identical to or different from each other, and the first color light and the second color light may be emitted in the form of mixed light, or the first color light, the second color light, and the third color light may be emitted in the form of mixed light.

[0061] The term "organic layer," as used herein, refers to a single layer and/or a plurality of layers between the first electrode and the second electrode of an organic light-emitting device. A material included in the "organic layer" is not limited to an organic material. For example, the organic layer may include an inorganic material.

[0062] For example, the organic light-emitting device may have i) a stacked structure including a first electrode, an organic layer, a second electrode, and a second capping layer which are sequentially stacked in this stated order, ii) a stacked structure including a first capping layer, a first electrode, an organic layer, and a second electrode which are sequentially stacked in this stated order, or iii) a stacked structure including a first capping layer, a first electrode, an organic layer, a second electrode, and a second capping layer which are sequentially stacked in this stated order, and at least one selected from the first capping layer and the second capping layer may include the heterocyclic compound.

Description of FIG. 1

[0063] FIG. 1 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.

[0064] Hereinafter, the structure of the organic light-emitting device 10 according to an embodiment and a method of manufacturing the organic light-emitting device 10 will be described in connection with FIG. 1.

First electrode 110

[0065] In FIG. 1, a substrate may be additionally located 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.

[0066] 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 110 may be selected from materials with a high work function to facilitate hole injection.

[0067] 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 110 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 reflective electrode, a material for forming a first electrode 110 may be selected from magnesium (Mg), silver (Ag), aluminium (Al), aluminium-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.

[0068] 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.

Organic layer 150

[0069] The organic layer 150 is located on the first electrode 110. The organic layer 150 may include an emission layer.

[0070] 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.

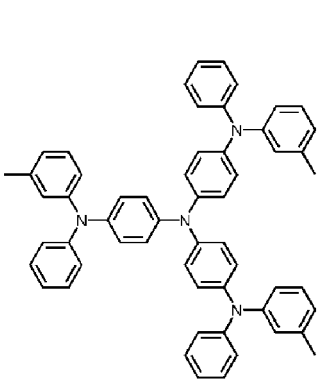
Hole transport region in organic layer 150

[0071] 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.

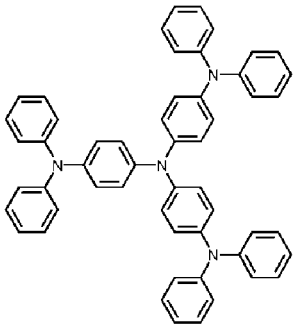
[0072] The hole transport region may include at least one layer selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

[0073] 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.

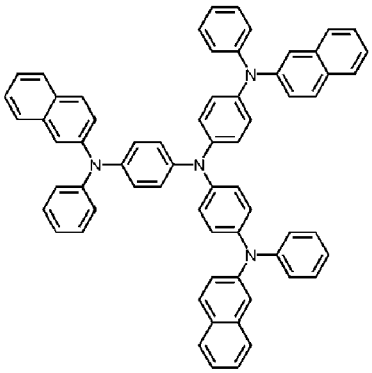
[0074] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB(NPD), β-NPB, TPD, Spiro-TPD, Spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4"-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzenesulfonic acid (PANI/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrenesulfonate) (PANI/PSS), a compound represented by Formula 201, and a compound represented by Formula 202:



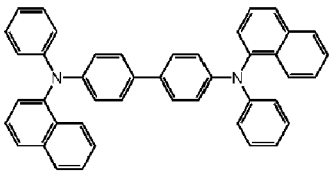
m-MTDATA



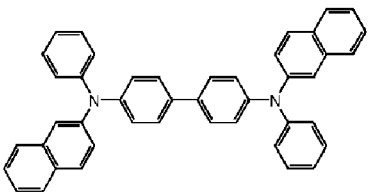
TDATA



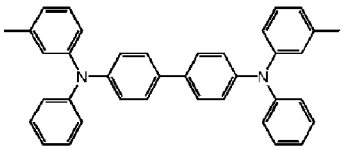
2-TNATA



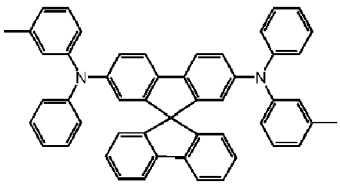
NPB



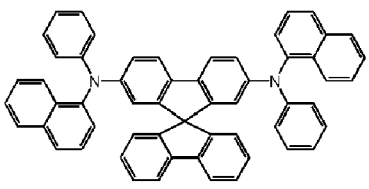
β-NPB



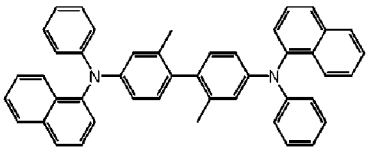
TPD



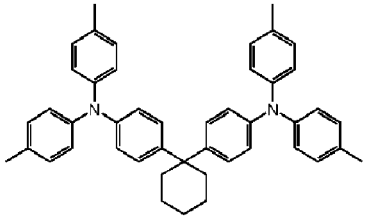
Spiro-TPD



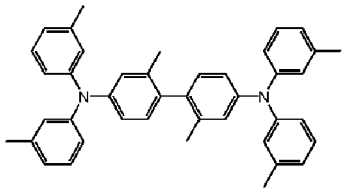
Spiro-NPB



methylated NPB

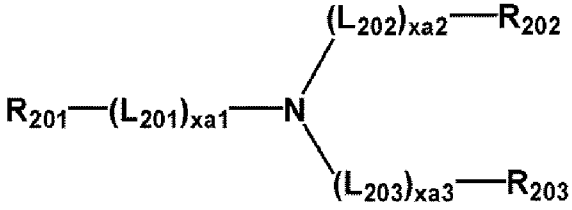


TAPC

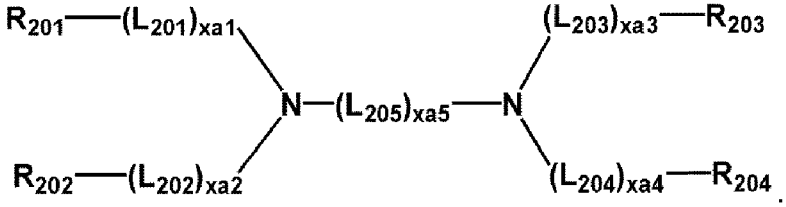


HMTPD

Formula 201



Formula 202



[0075] In Formulae 201 and 202,

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} (*e.g.* C_6-C_{32}) arylene group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

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} (*e.g.* C_6-C_{32}) arylene group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

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

xa5 may be an integer from 1 to 10, and

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} (*e.g.* C_6-C_{32}) aryl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{32}) aryloxy group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{32}) arylthio group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0076] 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.

[0077] In one or more embodiments, in Formulae 201 and 202,

L_{201} to L_{205} may each independently be selected from:
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
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
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.

[0078] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0079] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0080] In one or more embodiments, R_{201} to R_{204} and Q_{201} may each independently be selected from:

a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and
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
Q_{31} to Q_{33} are the same as described above.

[0081] In one or more embodiments, in Formula 201, at least one selected from R_{201} to R_{203} may each independently be selected from:

a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and
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,
but embodiments of the present disclosure are not limited thereto.

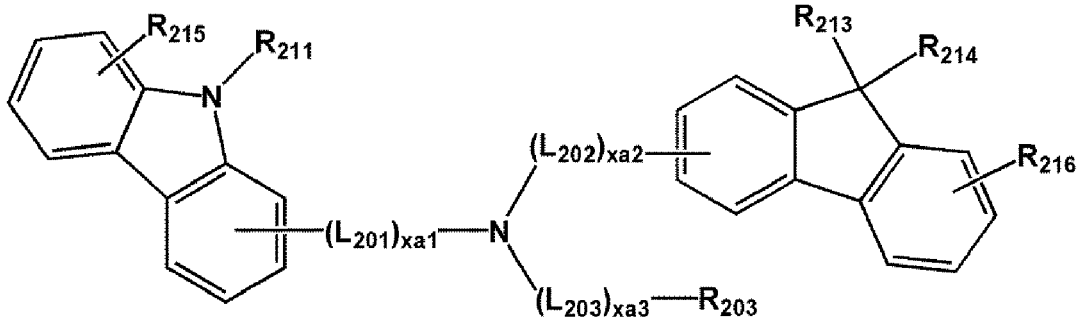
[0082] In one or more embodiments, in Formula 202, i) R_{201} and R_{202} may be linked via a single bond, and/or ii) R_{203} and R_{204} may be linked via a single bond.

[0083] In one or more embodiments, in Formula 202, at least one selected from R_{201} to R_{204} may be selected from:

a carbazolyl group; and
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,
but embodiments of the present disclosure are not limited thereto.

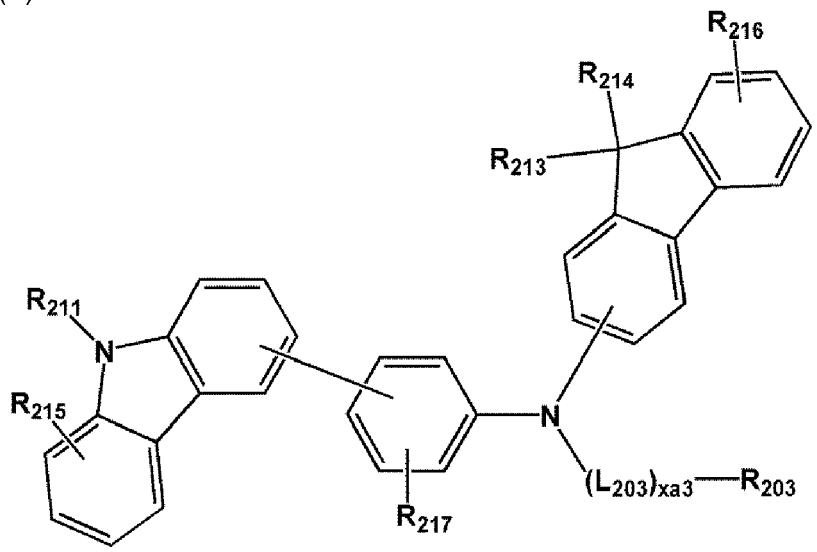
[0084] The compound represented by Formula 201 may be represented by Formula 201A:

Formula 201A



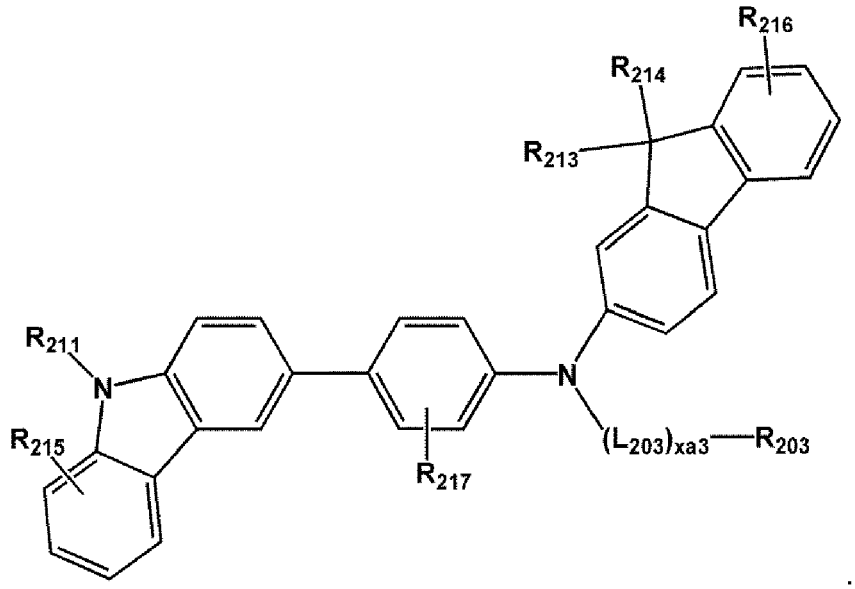
[0085] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A(1) below, but embodiments of the present disclosure are not limited thereto:

Formula 201A(1)



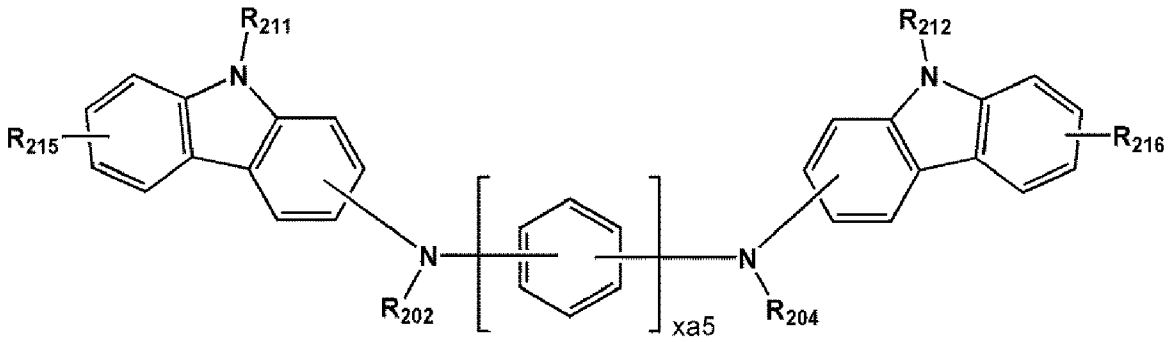
[0086] In one embodiment, the compound represented by Formula 201 may be represented by Formula 201A-1 below, but embodiments of the present disclosure are not limited thereto:

Formula 201A-1



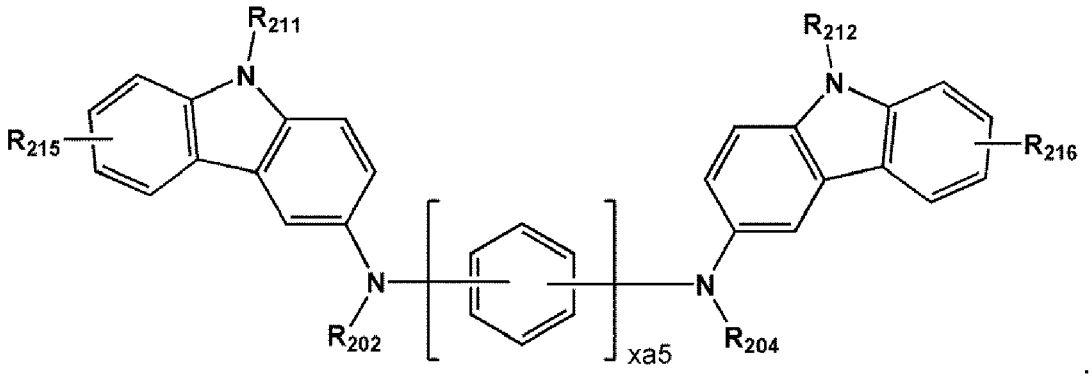
[0087] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A:

Formula 202A



[0088] In one embodiment, the compound represented by Formula 202 may be represented by Formula 202A-1:

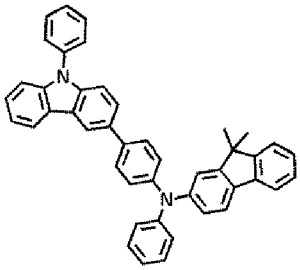
Formula 202A-1



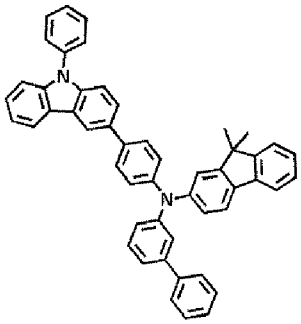
[0089] In Formulae 201A, 201A(1), 201A-1, 202A, and 202A-1,

L_{201} to L_{203}, xa1 to xa3, xa5, and R_{202} to R_{204} are the same as described above,
R_{211} and R_{212} may each independently be defined the same as R_{203}.
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.

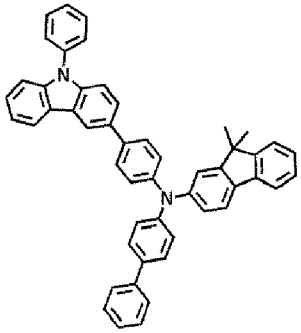
[0090] The hole transport region may include at least one compound selected from Compounds HT1 to HT39, but embodiments of the present disclosure are not limited thereto:



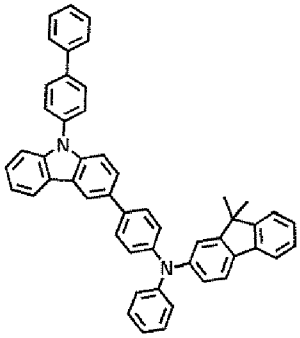
HT1



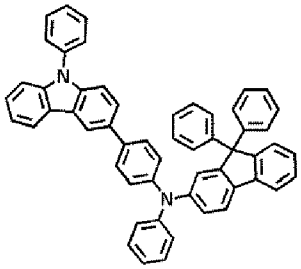
HT2



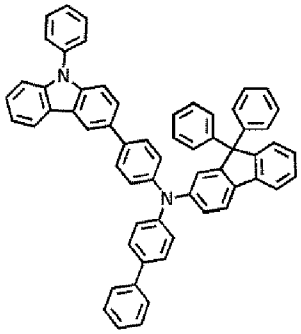
HT3



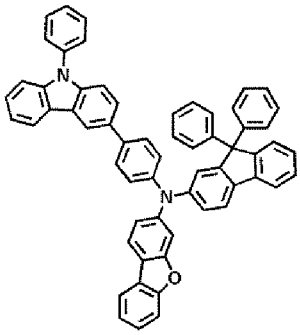
HT4



HT5



HT6



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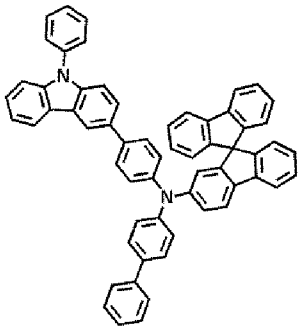

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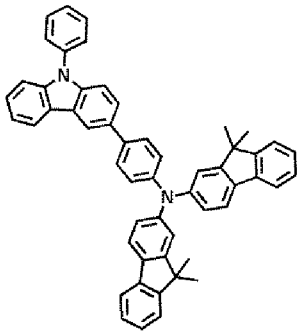

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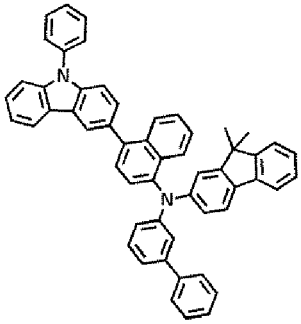

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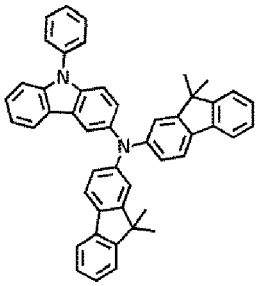

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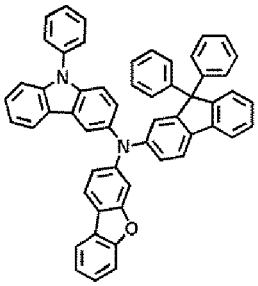

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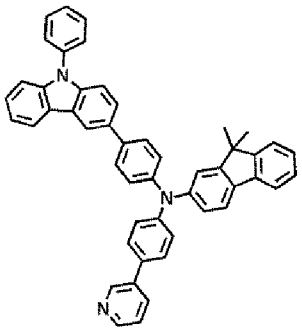

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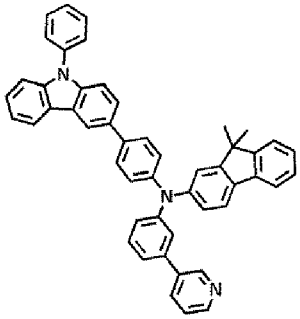

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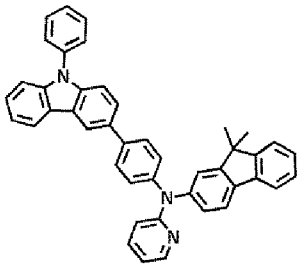

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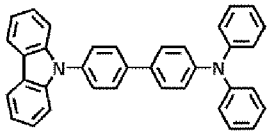

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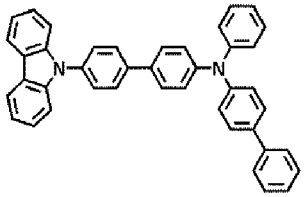

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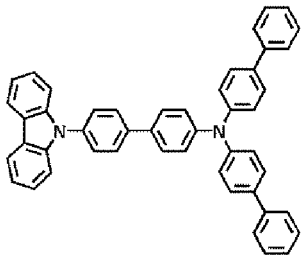

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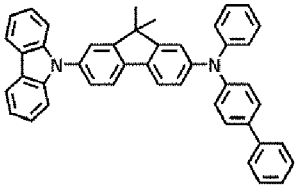

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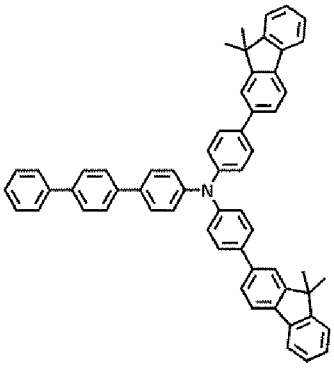

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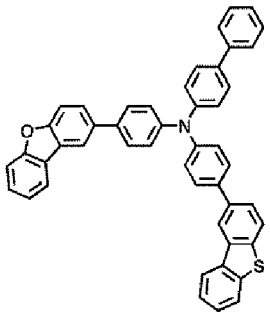

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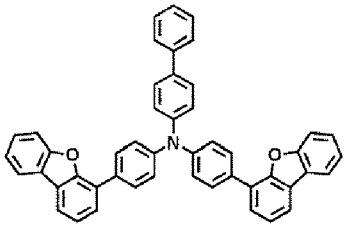

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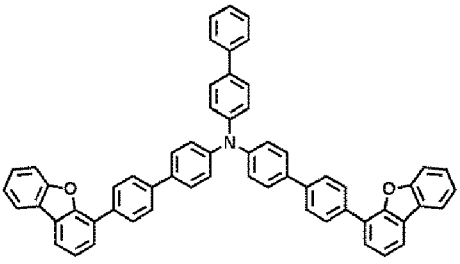

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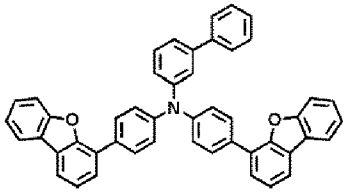

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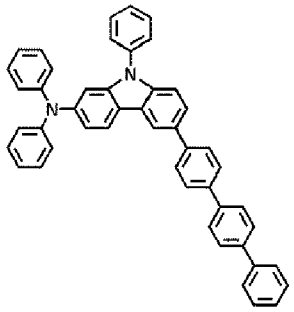

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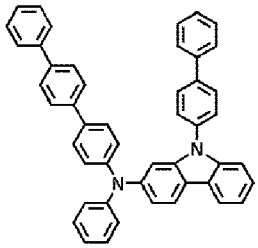

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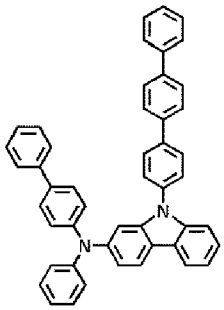

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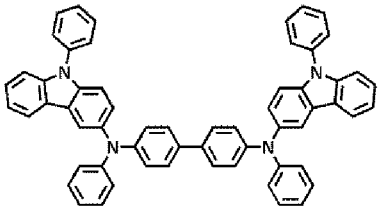

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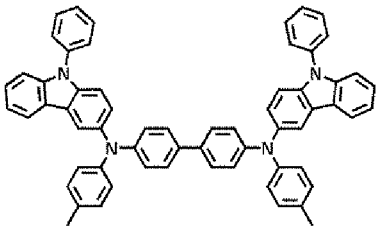

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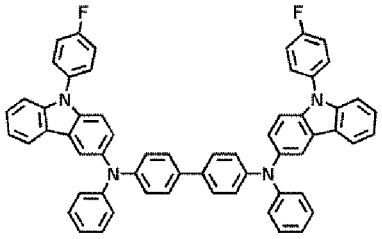

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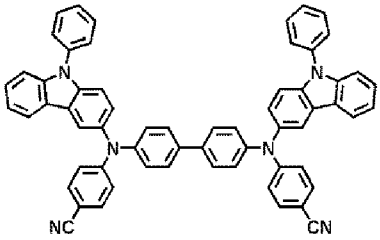

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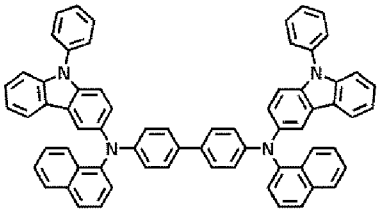

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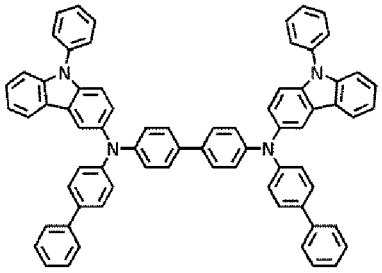

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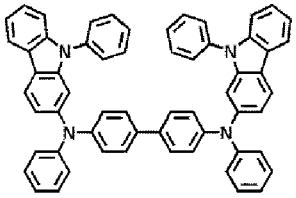

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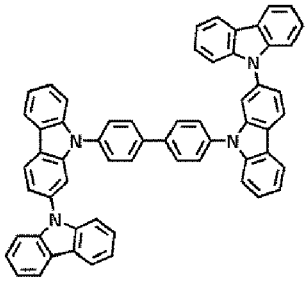

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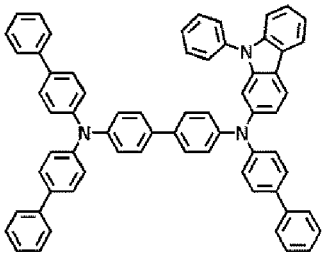

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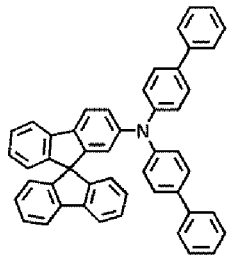

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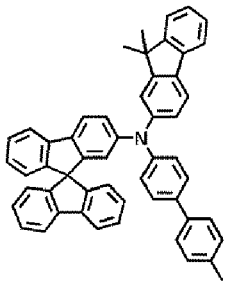

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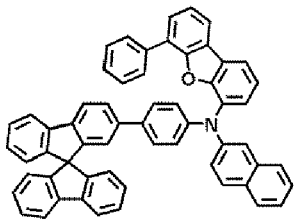


HT39

[0091] A thickness of the hole transport region may be in a range of about 100 Å to about 10,000 Å, and for example, about 100 Å to about 7000 Å, about 100 Å to about 5000 Å, about 100 Å to about 3000 Å, or about 100 Å to about 1,000 Å. When the hole transport region includes at least one selected from a hole injection layer and a hole transport layer, the thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, and for example, about 100 Å to about 7,000 Å, about 100 Å to about 5,000 Å, about 100 Å to about 3,000 Å, about 100 Å to about 2,000 Å, about 100 Å to about 1,000 Å or about 200 Å to about 400 Å, and the thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, and for example, about 100 Å to about 1500 Å about 100 Å to about 1,000 Å, about 100 Å to about 800 Å, about 100 Å to about 500 Å, or about 100 Å to about 300 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.

[0092] 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.

p-dopant

[0093] 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.

[0094] The charge-generation material may be, for example, a p-dopant.

[0095] In one embodiment, the p-dopant may have a LUMO energy level of about - 3.5 eV or less.

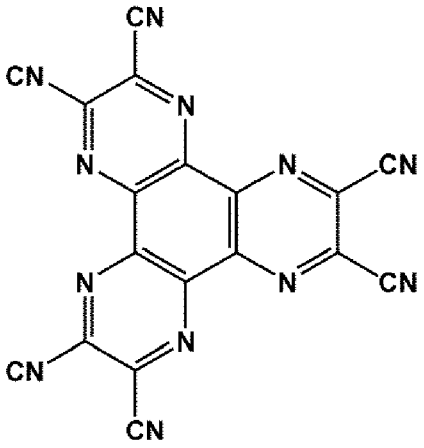
[0096] The p-dopant may include at least one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments of the present disclosure are not limited thereto.

[0097] For example, the p-dopant may include at least one selected from:

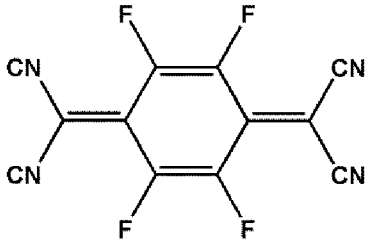
a quinone derivative, such as tetracyanoquinodimethane (TCNQ) or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ);
a metal oxide, such as tungsten oxide or molybdenum oxide;
1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and
a compound represented by Formula 221,

but embodiments of the present disclosure are not limited thereto:

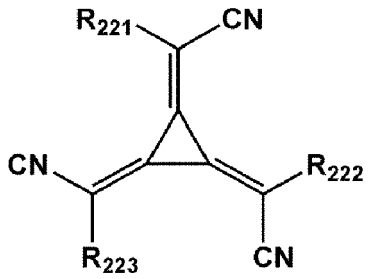
HAT-CN



F4-TCNQ



Formula 221



[0098] In Formula 221,
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} (*e.g.* C_6-C_{32}) aryl group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, provided that at least one selected from R_{221} to R_{223} has at least one substituent selected from a cyano group, -F, -Cl, -Br, -I, a C_1-C_{20} alkyl group substituted with -F, a C_1-C_{20} alkyl group substituted with -Cl, a C_1-C_{20} alkyl group substituted with -Br, and a C_1-C_{20} alkyl group substituted with -I.

Emission layer in organic layer 150

[0099] 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.

[0100] The emission layer may include the heterocyclic compound represented by Formula 1.

[0101] 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.

[0102] An amount of the dopant in the emission layer may be in a range of about 0.01 parts by weight to about 15 parts by weight based on 100 parts by weight of the host, but embodiments of the present disclosure are not limited thereto.

[0103] A thickness of the emission layer may be in a range of about 100 Å to about 1,000 Å, for example, about 100 Å to about 800 Å, about 150 Å to about 800 Å, about 150 Å to about 700 Å, about 150 Å to about 650 Å, about 200 Å to about 600 Å or about 200 Å to about 300 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.

Host in emission layer

[0104] The host may include the heterocyclic compound represented by Formula 1.

[0105] In one or more embodiments, the host may further include a compound represented by Formula 301 below.

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

[0106] In Formula 301,

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,
xb11 may be 1, 2, or 3,
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;
xb1 may be an integer from 0 to 5,
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-$P(=O)(Q_{301})(Q_{302})$,
xb21 may be an integer from 1 to 5, and
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.

[0107] For example, Ar_{301} may be a substituted or unsubstituted C_6-C_{32} carbocyclic group or a substituted or unsubstituted C_1-C_{12} heterocyclic group, but embodiments are not limited thereto.

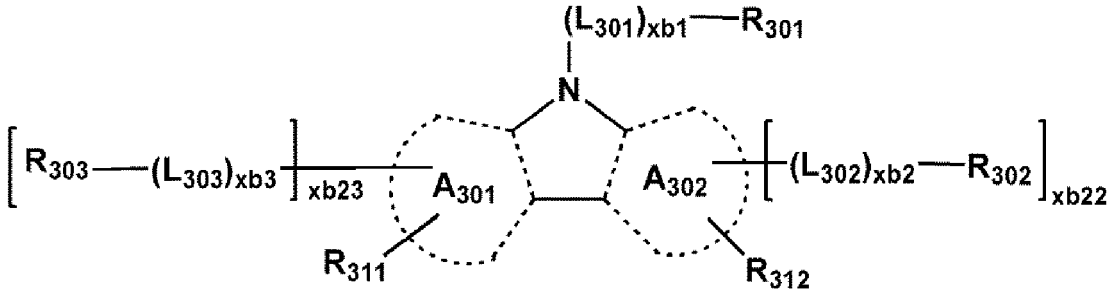
[0108] In one embodiment, Ar_{301} in Formula 301 may be selected from:

a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group; and
a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group, each substituted with at least one selected from deuterium,-F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group,-$Si(Q_{31})(Q_{32})(Q_{33})$, -$N(Q_{31})(Q_{32})$, -$B(Q_{31})(Q_{32})$, -$C(=O)(Q_{31})$, -$S(=O)_2(Q_{31})$, and-$P(=O)(Q_{31})(Q_{32})$, and
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.

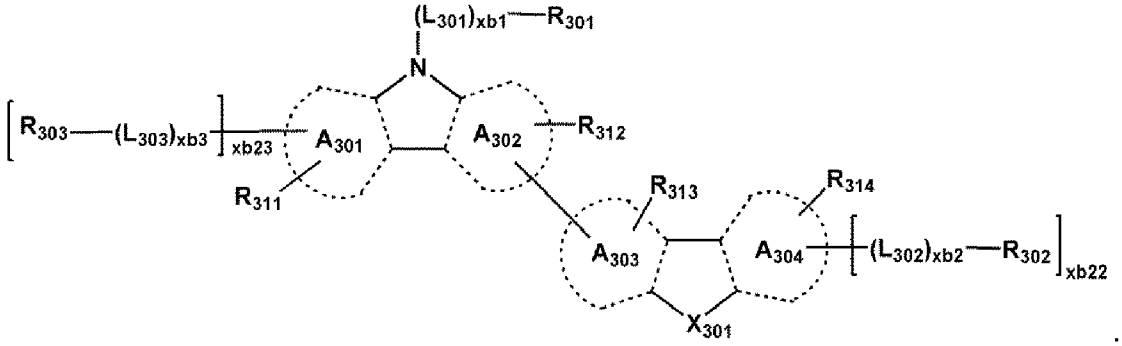
[0109] In Formula 301, when xb11 is two or more, two or more Ar_{301}(s) may be linked via a single bond.

[0110] 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



[0111] In Formulae 301-1 and 301-2,

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

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

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 -$P(=O)(Q_{31})(Q_{32})$,

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

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

L_{302} to L_{304} may each independently be defined the same as L_{301},

xb2 to xb4 may each independently be defined the same as xb1, and

R_{302} to R_{304} may each independently be defined the same as R_{301}.

[0112] For example, L_{301} to L_{304} in Formulae 301, 301-1, and 301-2 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_{30} arylene group, a substituted or unsubstituted C_1-C_{20} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, but embodiments are not limited thereto.

[0113] For example, in Formulae 301, 301-1, and 301-2, L_{301} to L_{304} may each independently be selected from:

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

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

Q_{31} to Q_{33} may each independently be the same as described above.

[0114] As another example, R_{301} to R_{304} in Formulae 301, 301-1, and 301-2 may each independently 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} (*e.g.* C_1-C_{10}) alkyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{10}) alkenyl group, a substituted or unsubstituted C_2-C_{60} (*e.g.* C_2-C_{10}) alkynyl group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{10}) 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_{30} aryl group, a substituted or unsubstituted C_6-C_{30} aryloxy group, a substituted or unsubstituted C_6-C_{30} arylthio group, a substituted or unsubstituted C_1-C_{20} 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 $-P(=O)(Q_{301})(Q_{302})$, but embodiments are not limited thereto.

[0115] In one embodiment, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

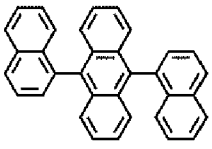
a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl 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 ben-

zocarbazolyl 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

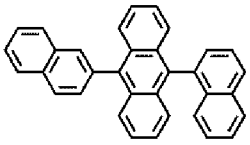
a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl 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 Q_{31} to Q_{33} may each independently be the same as described above.

[0116] In one or more embodiments, the host may include an alkaline earth metal complex. For example, the host may include a complex selected from a Be complex (for example, Compound H55), a Mg complex, and a Zn complex. For example, the host may be selected from a Be complex (for example, Compound H55), a Mg complex, and a Zn complex.

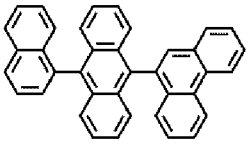
[0117] The host may include at least one selected from 9,10-di(2-naphthyl)anthracene) (ADN), 2-methyl-9,10-bis(naphthalen-2-yl)anthracene (MADN), 9,10-di-(2-naphthyl)-2-t-butyl-anthracene (TBADN), 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP), 1,3-di-9-carbazolylbenzene (mCP), 1,3,5-tri(carbazol-9-yl)benzene (TCP), and Compounds H1 to H55, but embodiments of the present disclosure are not limited thereto:



H1



H2



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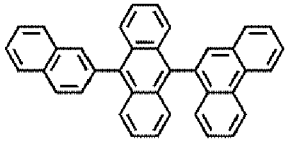

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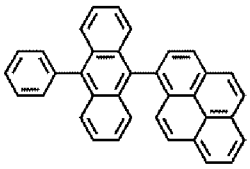

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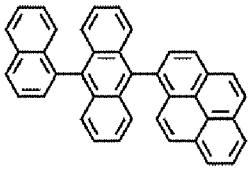
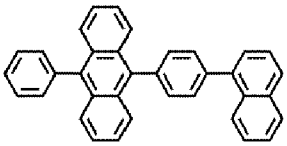
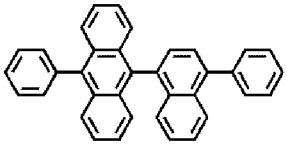


H6



H7



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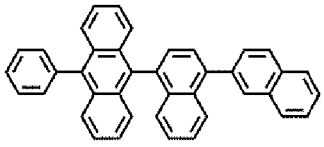
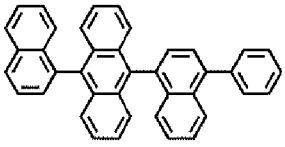


H9



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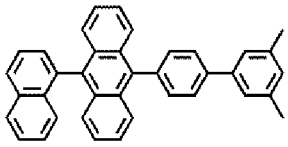

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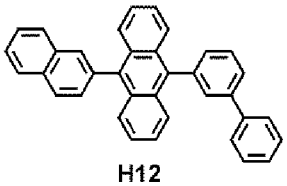

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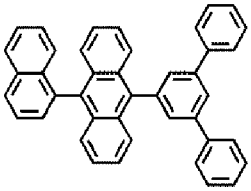

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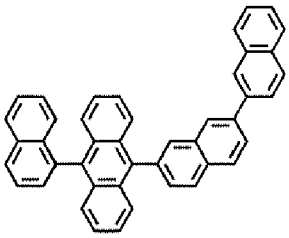
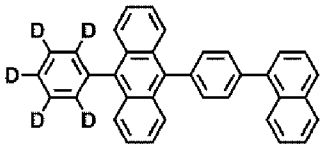


H14



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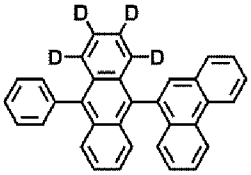

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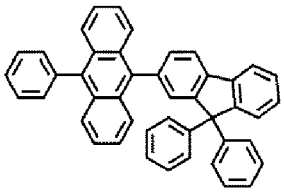

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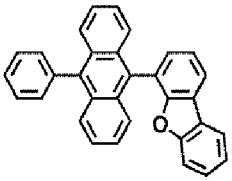

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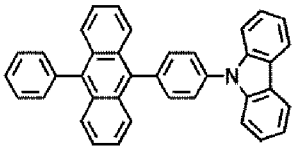

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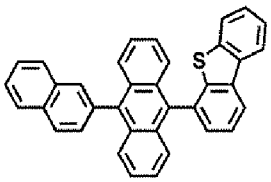

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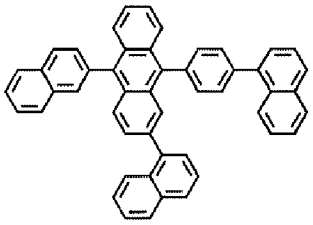

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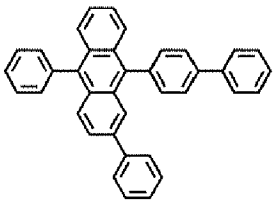

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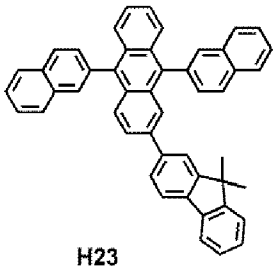

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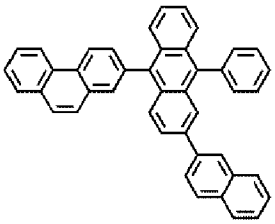

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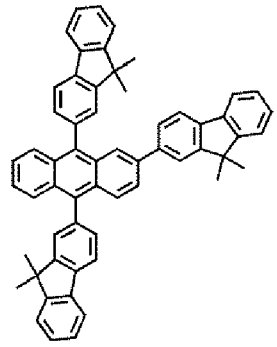
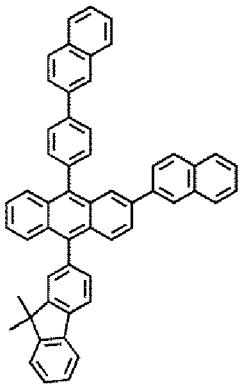


H25



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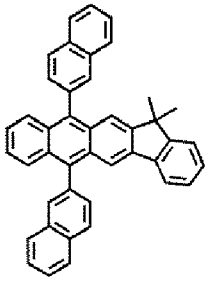

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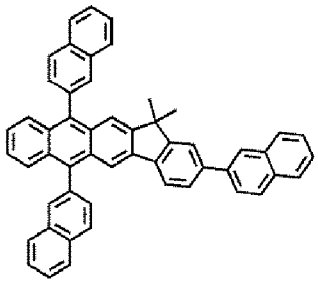

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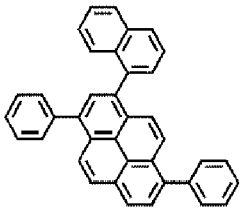

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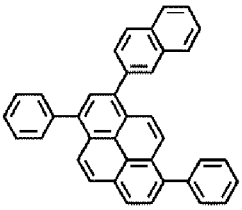

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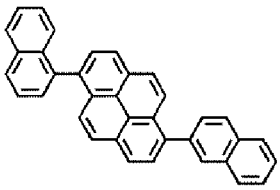

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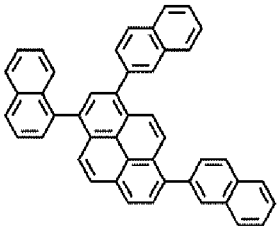

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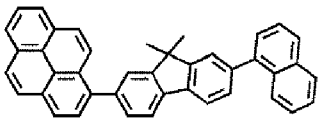

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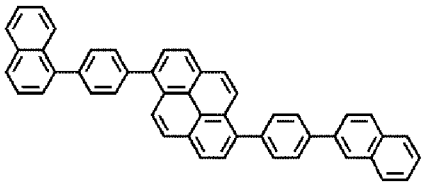

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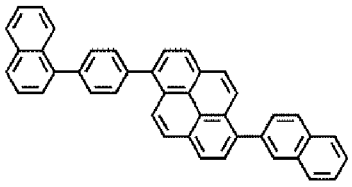

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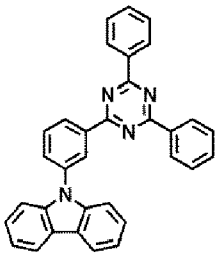

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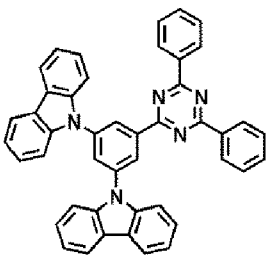

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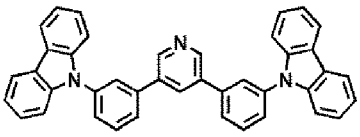

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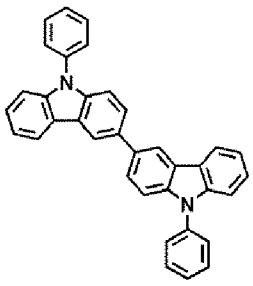

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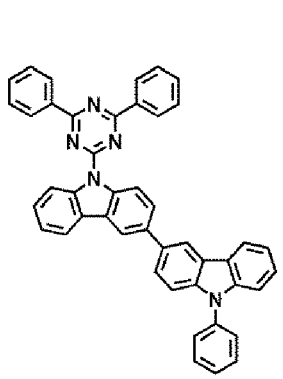

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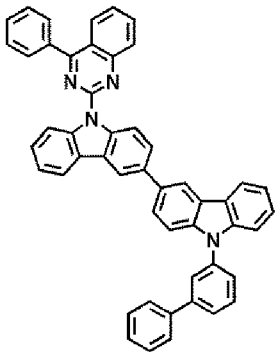

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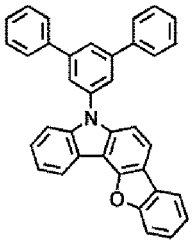

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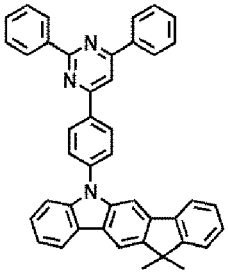

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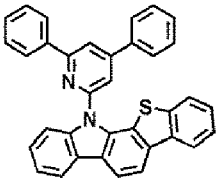

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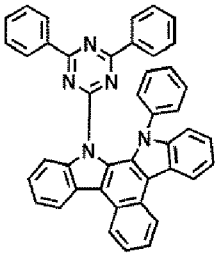

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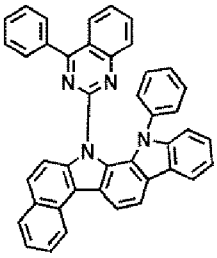

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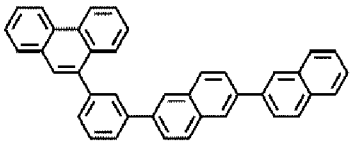

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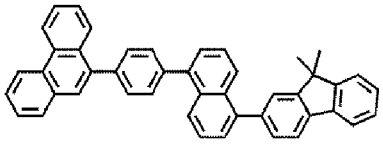

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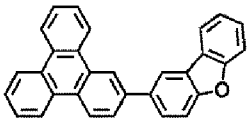

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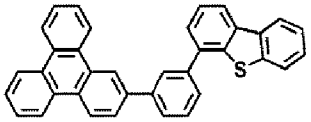

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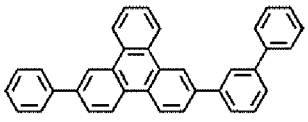

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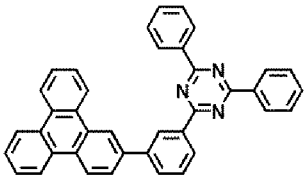

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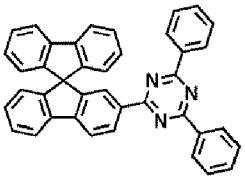

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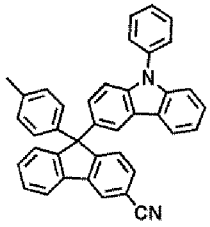

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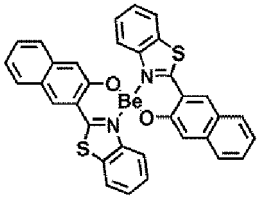


H55

Phosphorescent dopant included in emission layer in organic layer 150

[0118] The phosphorescent dopant may include the organometallic complex represented by Formula 401.

[0119] In one embodiment, in Formula 402, A_{401} and A_{402} may each independently be selected from a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, an indene group, a pyrrole group, a thiophene group, a furan group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an

isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a quinoxaline group, a quinazoline group, a carbazole group, a benzimidazole group, a benzofuran group, a benzothiophene group, an isobenzothiophene group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a dibenzofuran group, and a dibenzothiophene group.

[0120] In one or more embodiments, in Formula 402, i) X_{401} may be nitrogen, and X402 may be carbon, or ii) X_{401} and X_{402} may each be nitrogen concurrently (e.g., at the same time).

[0121] In one or more embodiments, R_{401} and R_{402} in Formula 402 may each independently be selected from:

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

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

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

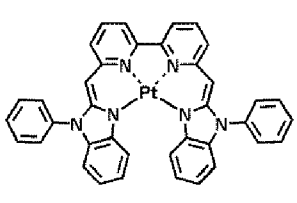
a cyclopentyl group, a cyclohexyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl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

$-Si(Q_{401})(Q_{402})(Q_{403})$, $-N(Q_{401})(Q_{402})$, $-B(Q_{401})(Q_{402})$, $-C(=O)(Q_{401})$, $-S(=O)_2(Q_{401})$, and $-P(=O)(Q_{401})(Q_{402})$, and Q_{401} to Q_{403} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, and a naphthyl group, but are not limited thereto.

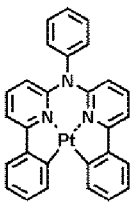
[0122] In one or more embodiments, when xc1 in Formula 401 is two or more, two A_{401}(s) in two or more L_{401}(s) may optionally be linked via X_{407}, which is a linking group, or two A_{402}(s) in two or more L_{401}(s) may optionally be linked via X_{408}, which is a linking group (see Compounds PD1 to PD4 and PD7). X_{407} and X_{408} may each independently be a single bond, *-O-*', *-S-*', *-C(=O)-*', *-N(Q_{413})-*', *-C(Q_{413})(Q_{414})-*', or *-C(Q_{413})=C(Q_{414})-*' (wherein Q_{413} and Q_{414} may each independently be hydrogen, deuterium, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group), but embodiments of the present disclosure are not limited thereto.

[0123] L_{402} in Formula 401 may be a monovalent, divalent, or trivalent organic ligand. For example, L_{402} may be halogen, diketone (for example, acetylacetonate), carboxylic acid (for example, picolinate), -C(=O), isonitrile, -CN, and a phosphorus-containing material (for example, phosphine or phosphite), but embodiments of the present disclosure are not limited thereto.

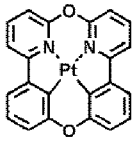
[0124] In one or more embodiments, the phosphorescent dopant may be selected from, for example, Compounds PD1 to PD26, but embodiments of the present disclosure are not limited thereto:



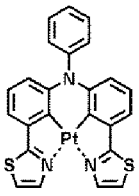
PD1



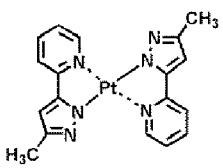
PD2



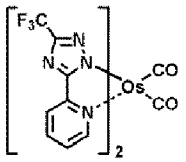
PD3



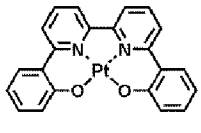
PD4



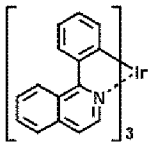
PD5



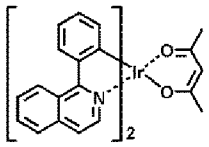
PD6



PD7



PD8



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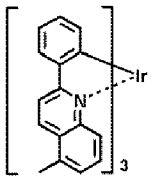

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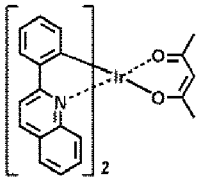
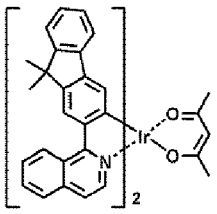
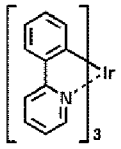


PD11



PD12



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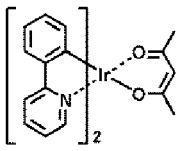

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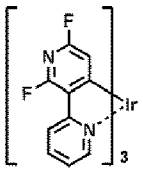

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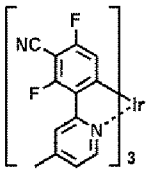

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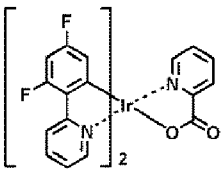
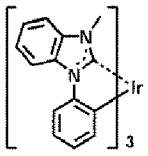


PD17



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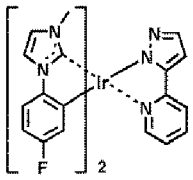

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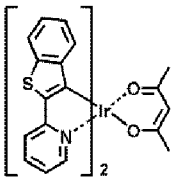

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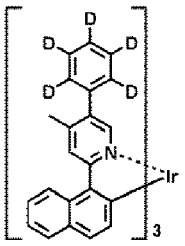
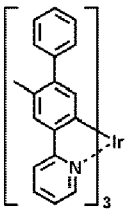
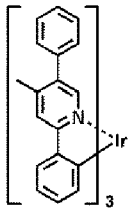


PD21



PD22



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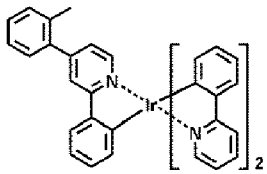
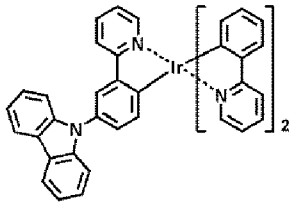
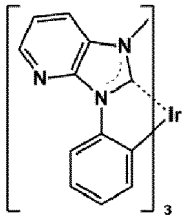


PD24



PD25



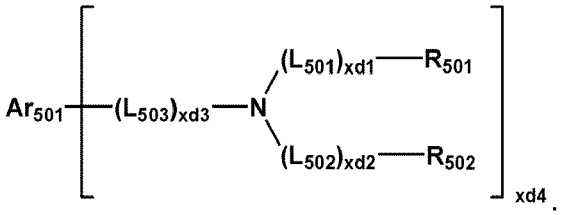
PD26

Fluorescent dopant in emission layer

[0125] The fluorescent dopant may include an arylamine compound or a styrylamine compound.

[0126] The fluorescent dopant may include a compound represented by Formula 501:

Formula 501



[0127] In Formula 501,

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

L_{501} to L_{503} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} (e.g. C_6-C_{30}) arylene group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

xd1 to xd3 may each independently be an integer from 0 to 3;

R_{501} and R_{502} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a substituted or unsubstituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a substituted or unsubstituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,

xd4 may be an integer from 1 to 6.

[0128] For example, Ar_{501} may be a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{20} heterocyclic group, but embodiments are not limited thereto.

[0129] In one embodiment, Ar_{501} in Formula 501 may be selected from:

a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group; and

a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group, each substituted with at least one 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, and a naphthyl group.

[0130] In one or more embodiments, L_{501} to L_{503} in Formula 501 may each independently be selected from:

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, and a pyridinylene group; and

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,

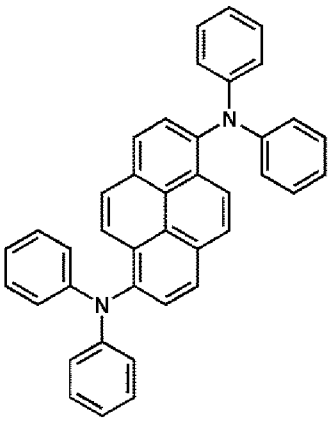
a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, 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 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, and a pyridinyl group.

[0131] In one or more embodiments, R_{501} and R_{502} in Formula 501 may each independently be selected from:

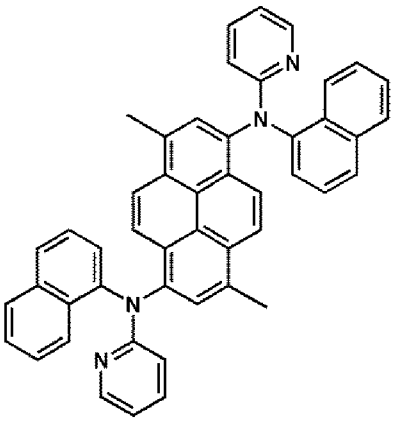
a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl 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, and a pyridinyl group; and
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, 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 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, and - $Si(Q_{31})(Q_{32})(Q_{33})$, and
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.

[0132] In one or more embodiments, xd4 in Formula 501 may be 2 or more (*e.g.* 2), but embodiments of the present disclosure are not limited thereto.

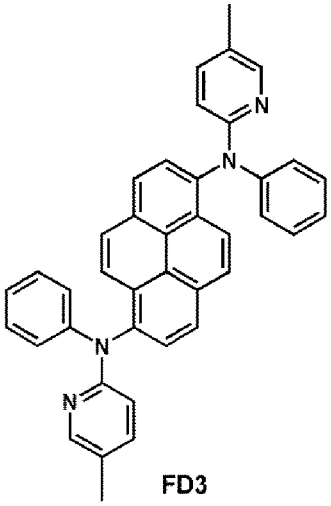
[0133] For example, the fluorescent dopant may be selected from Compounds FD1 to FD22:



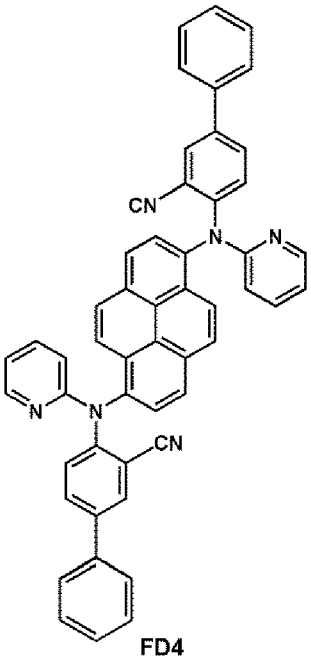
FD1



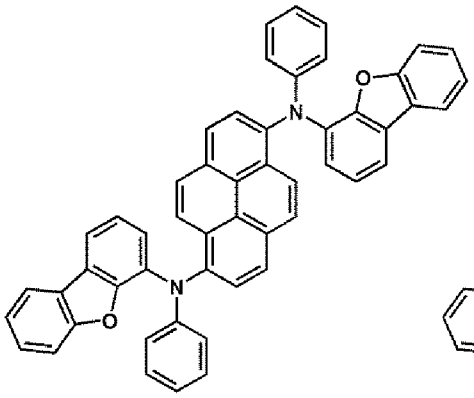
FD2



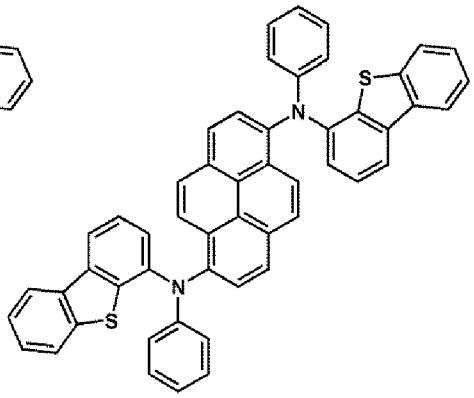
FD3



FD4



FD5



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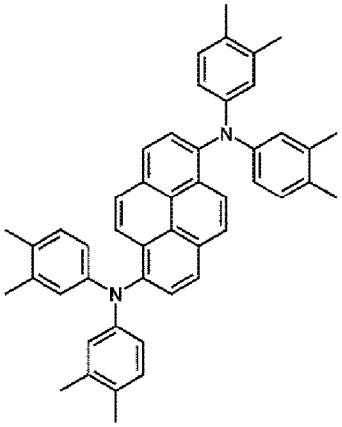
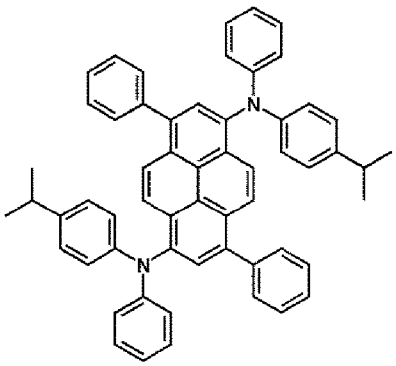
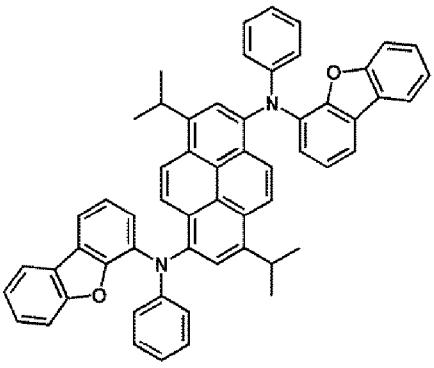


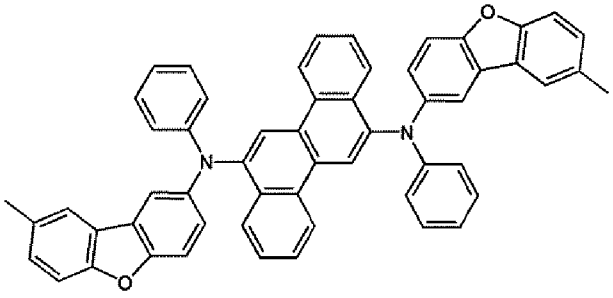
FD7



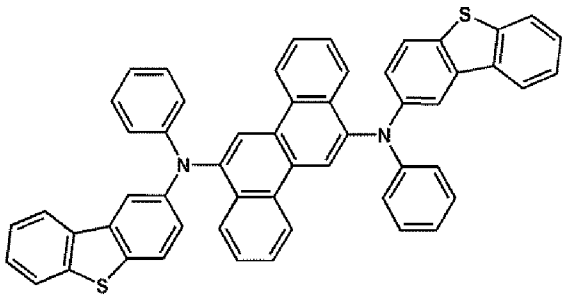
FD8



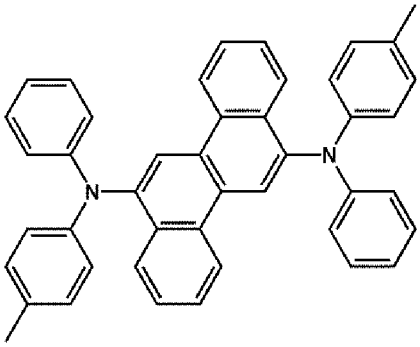
FD9



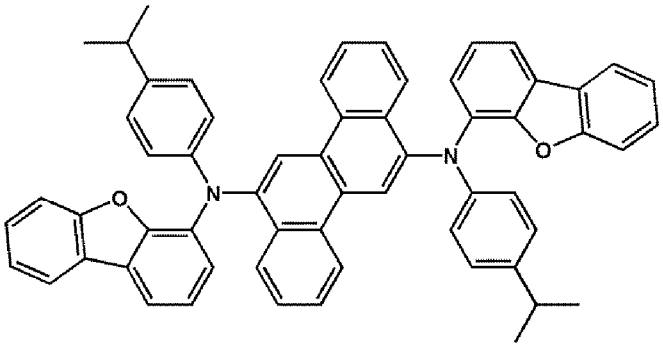
FD10



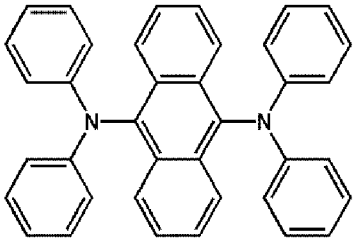
FD11



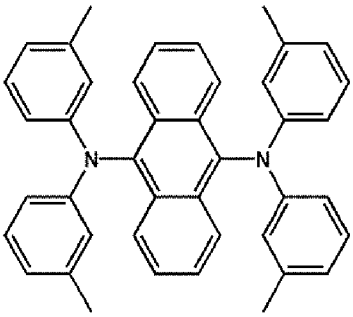
FD12



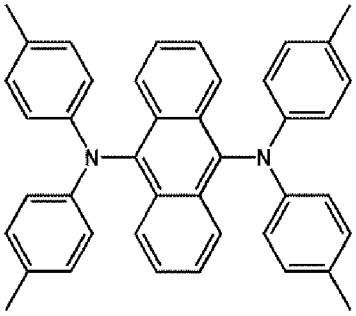
FD13



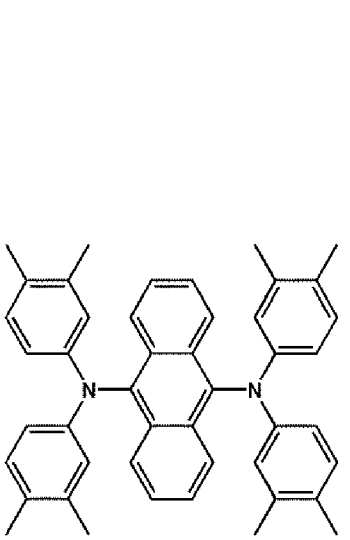
FD14



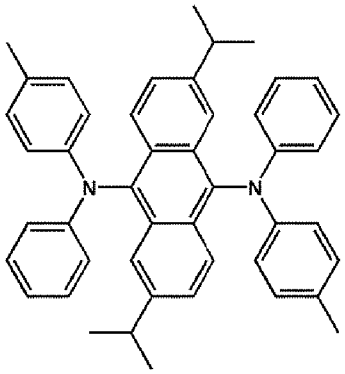
FD15



FD16



FD17



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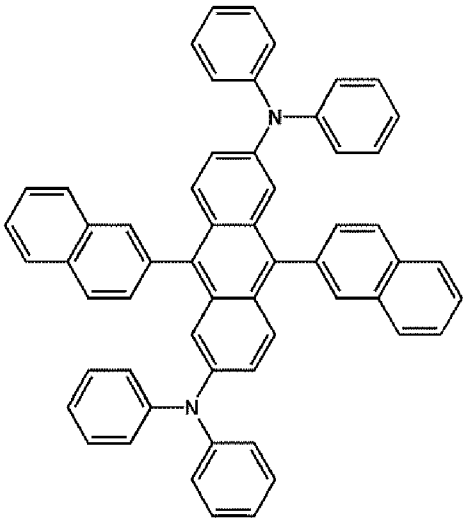

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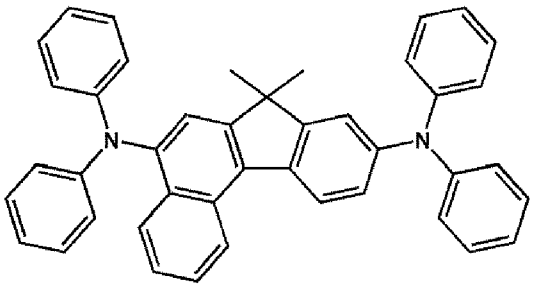
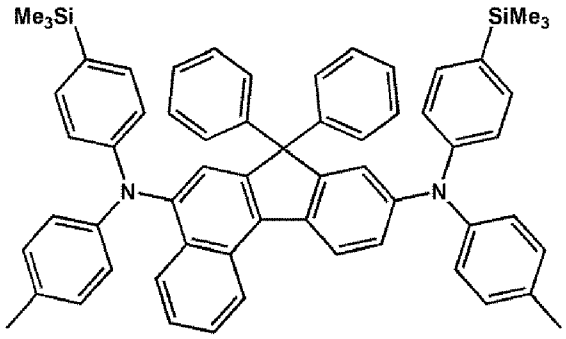
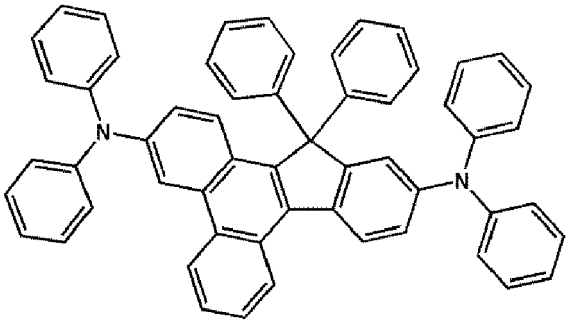


FD20

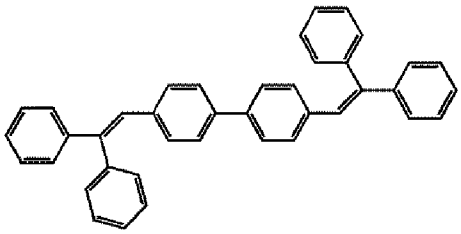


FD21

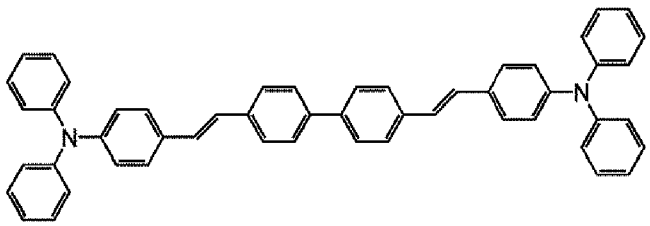


FD22

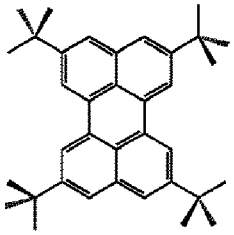
[0134] In one or more embodiments, the fluorescent dopant may be selected from the following compounds, but embodiments of the present disclosure are not limited thereto.



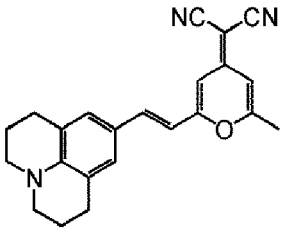
DPVBi



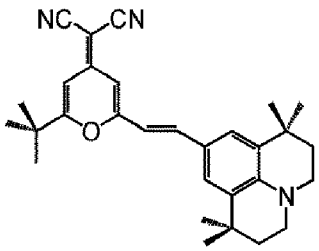
DPAVBi



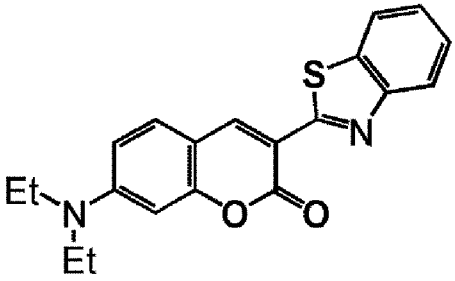
TBPe



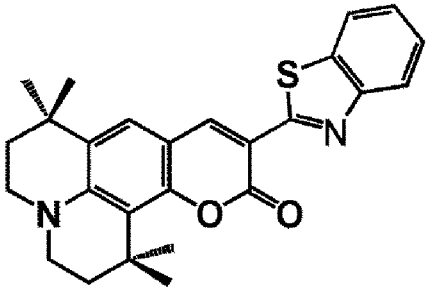
DCM



DCJTB



Coumarin 6



C545T

Electron transport region in organic layer 150

[0135] 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.

[0136] 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.

[0137] 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 in this stated order. However, embodiments of the structure of the electron transport region are not limited thereto.

[0138] 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.

[0139] The term "π electron-depleted nitrogen-containing ring," as used herein, refers to a C_1-C_{60} (*e.g.* a C_1-C_{30}) heterocyclic group having at least one *-N=*' moiety as a ring-forming moiety.

[0140] For example, the "π electron-depleted nitrogen-containing ring" may be i) a 5-membered to 7-membered heteromonocyclic group having at least one *-N=*' moiety, ii) a heteropolycyclic group in which two or more 5-membered to 7-membered heteromonocyclic groups each having at least one *-N=*' moiety are condensed with each other (e.g., combined together), or iii) a heteropolycyclic group in which at least one of 5-membered to 7-membered heteromonocyclic groups, each having at least one *-N=*' moiety, is condensed with (e.g., combined with) at least one C_5-C_{60} (*e.g.* a C_5-C30) carbocyclic group.

[0141] 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, a thiadiazole, an imidazopyridine, an imidazopyrimidine, and an azacarbazole, but are not limited thereto.

[0142] For example, the electron transport region may include a compound represented by Formula 601:

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

[0143] In Formula 601,

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,
xe11 may be 1, 2, or 3,
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,
xe1 may be an integer from 0 to 5,
R_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, - $Si(Q_{601})(Q_{602})(Q_{603})$, $-C(=O)(Q_{601})$, $-S(=O)_2(Q_{601})$, and $-P(=O)(Q_{601})(Q_{602})$,
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
xe21 may be an integer from 1 to 5.

[0144] 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.

[0145] For example, Ar_{601} may be a substituted or unsubstituted C_5-C_{30} carbocyclic group or a substituted or unsubstituted C_1-C_{20} heterocyclic group, but embodiments are not limited thereto.

[0146] In one embodiment, Ar_{601} in Formula 601 may be selected from:

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

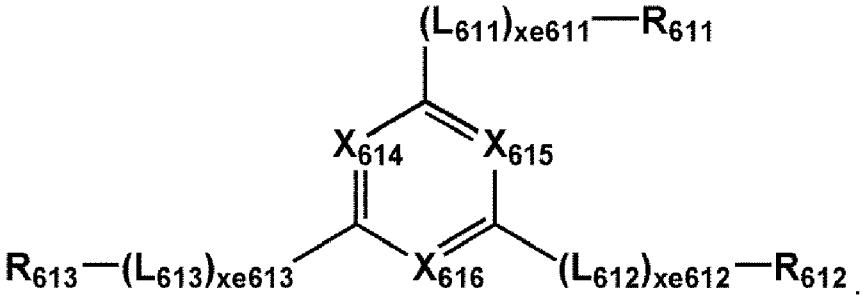
isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, $-Si(Q_{31})(Q_{32})(Q_{33})$, $-S(=O)_2(Q_{31})$, and $-P(=O)(Q_{31})(Q_{32})$, and
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.

[0147] When xe11 in Formula 601 is two or more, two or more Ar_{601}(s) may be linked via a single bond.

[0148] In one or more embodiments, Ar_{601} in Formula 601 may be an anthracene group.

[0149] In one or more embodiments, a compound represented by Formula 601 may be represented by Formula 601-1 :

Formula 601-1



[0150] In Formula 601-1,

X_{614} may be N or C(R_{614}), X_{615} may be N or C(R_{615}), X_{616} may be N or C(R_{616}), and at least one selected from X_{614} to X_{616} may be N,
L_{611} to L_{613} may each independently be the same as described in connection with L_{601},
xe611 to xe613 may each independently be defined the same as xe1,
R_{611} to R_{613} may each independently be defined the same as R_{601}, and
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.

[0151] For example, L_{601} and L_{611} to L_{613} in Formulae 601 and 601-1 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_{30} arylene group, a substituted or unsubstituted C_1-C_{20} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, but embodiments are not limited thereto.

[0152] In one embodiment, L_{601} and L_{611} to L_{613} in Formulae 601 and 601-1 may each independently be selected from:

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
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,
but embodiments of the present disclosure are not limited thereto.

[0153] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0154] For example, R_{601} and R_{611} to R_{613} in Formulae 601 and 601-1 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_{30} aryl group, a substituted or unsubstituted C_6-C_{30} aryloxy group, a substituted or unsubstituted C_6-C_{30} arylthio group, a substituted or unsubstituted C_1-C_{20} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, - $Si(Q_{601})(Q_{602})(Q_{603})$, $-C(=O)(Q_{601})$, $-S(=O)_2(Q_{601})$, and $-P(=O)(Q_{601})(Q_{602})$.

[0155] 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:

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;

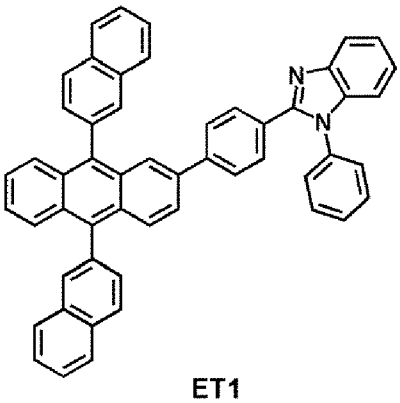
a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl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

group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

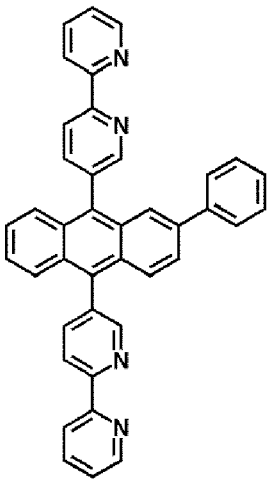
$-S(=O)_2(Q_{601})$ and $-P(=O)(Q_{601})(Q_{602})$, and

Q_{601} and Q_{602} may each independently be the same as described above.

[0156] 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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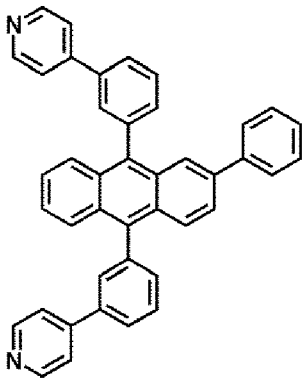
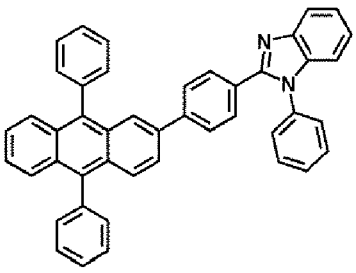
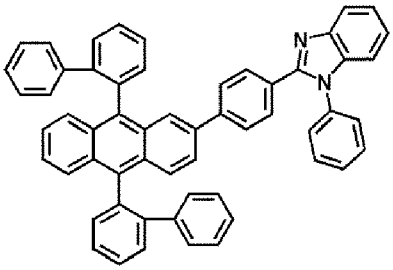


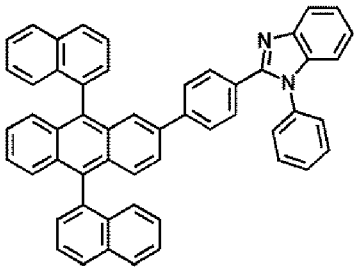
ET3



ET4



ET5



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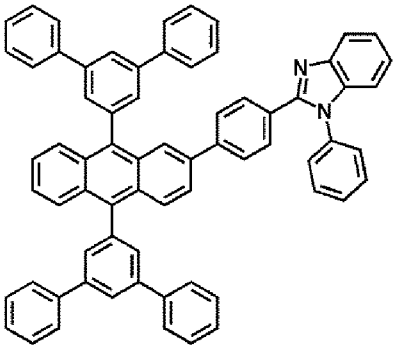
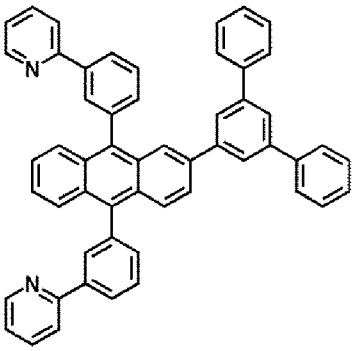
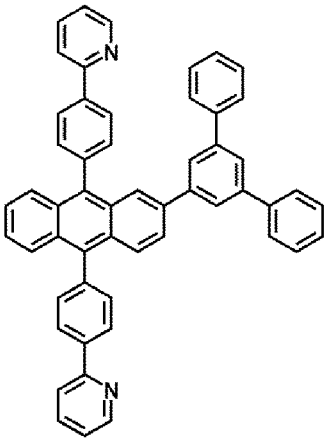


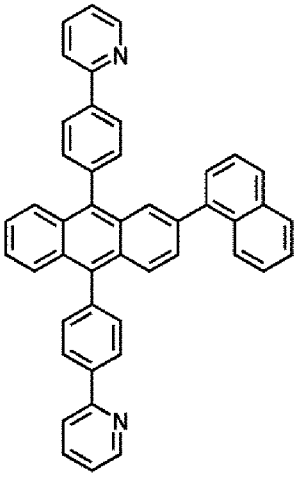
ET7



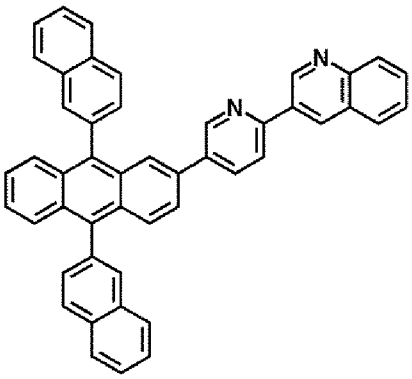
ET8



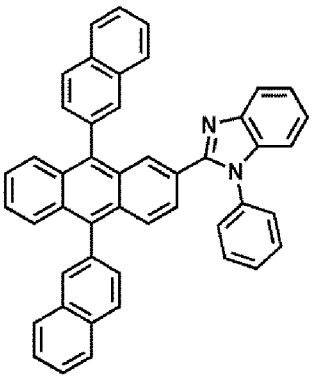
ET9



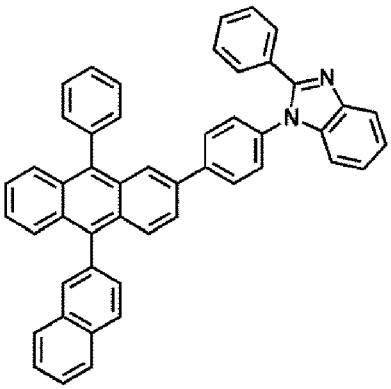
ET10



ET11



ET12



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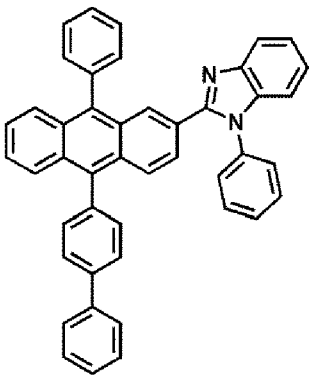

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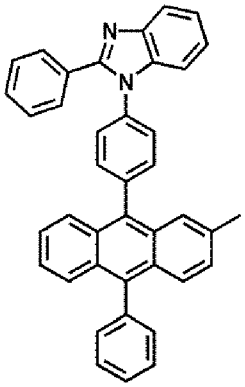

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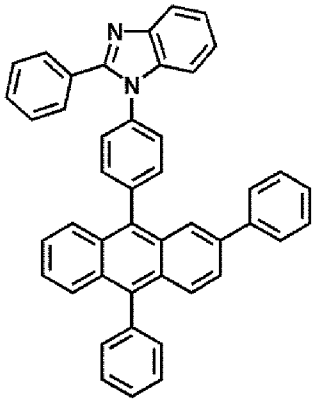

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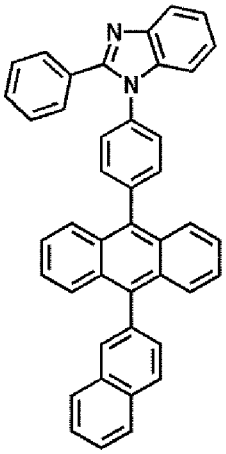

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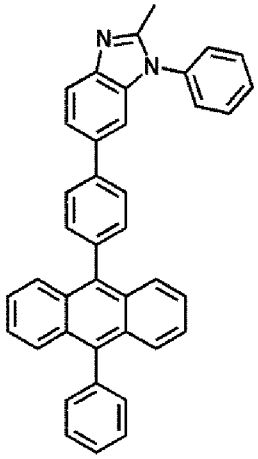

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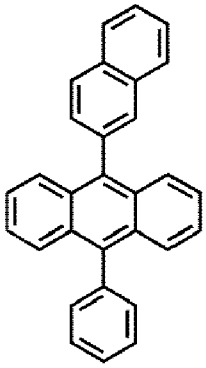

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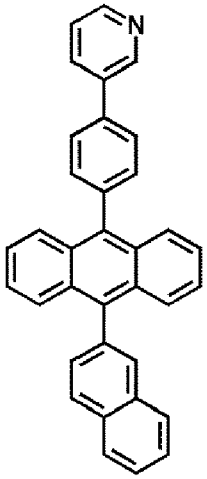

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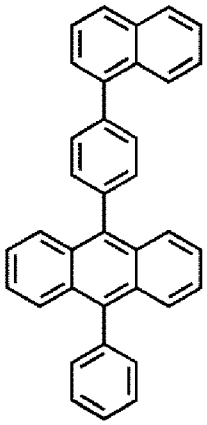

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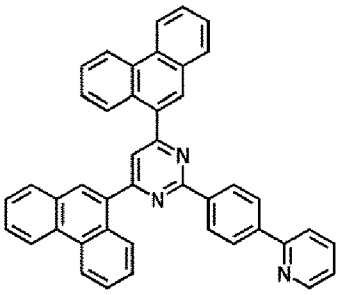

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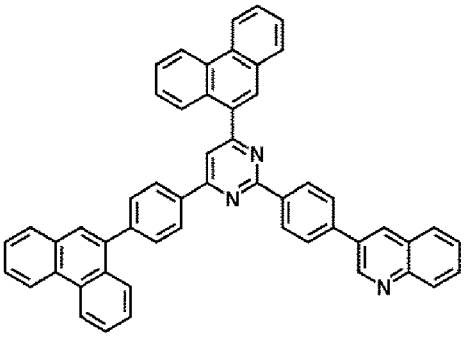

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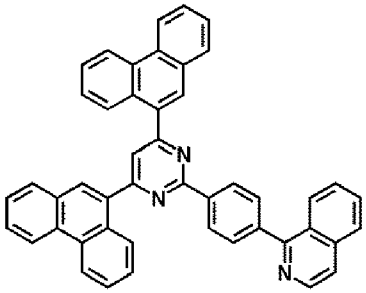

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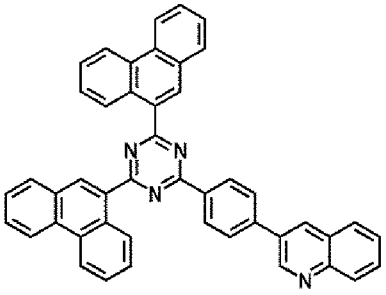

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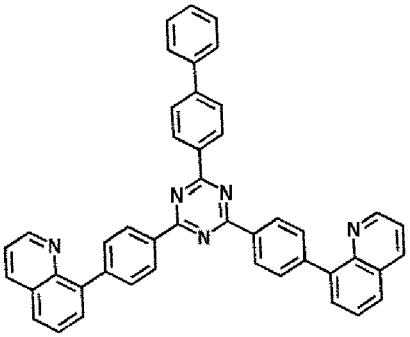

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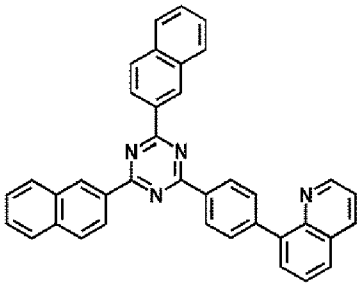

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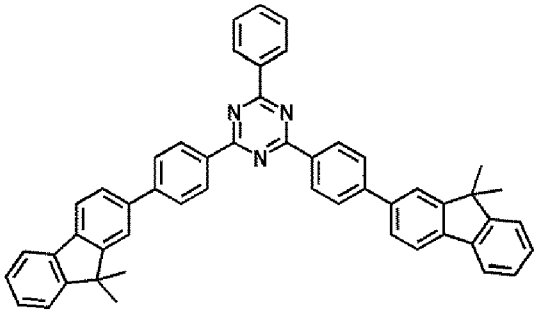

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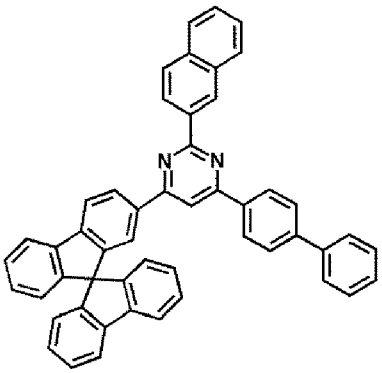

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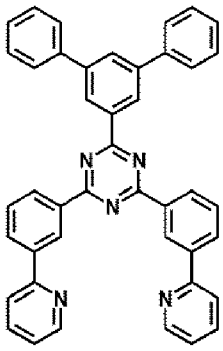

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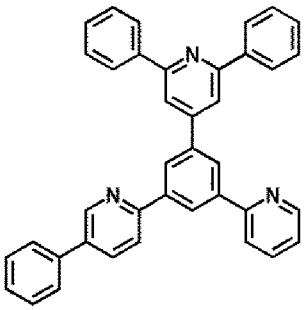

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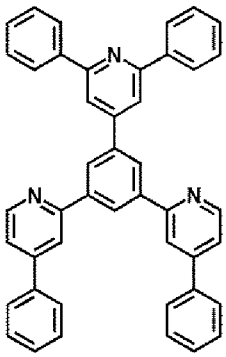

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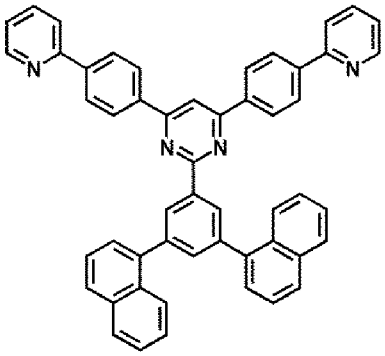

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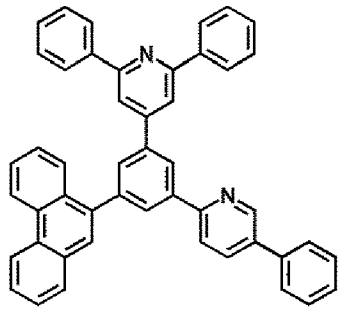

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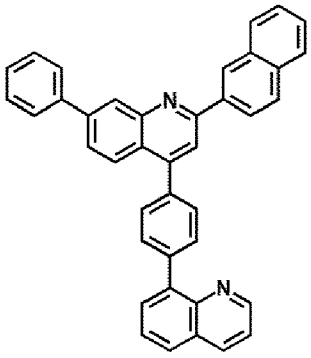

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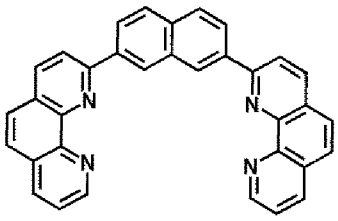
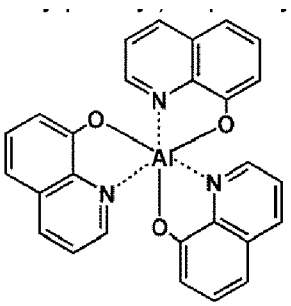
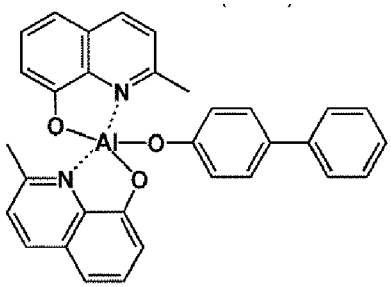


ET36

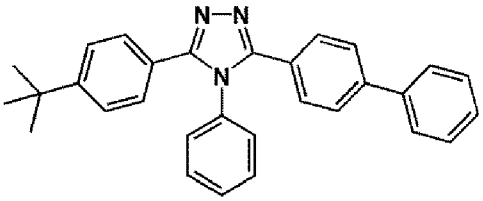
[0157] In one or more embodiments, the electron transport region may include at least one selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq_3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ.



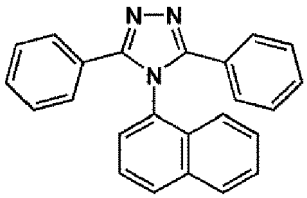
Alq_3



BAlq



TAZ



NTAZ

[0158] Thicknesses of the buffer layer, the hole blocking layer, and the electron control layer may each be in a range of about 20 Å to about 1,000 Å, for example, about 20 Å to about 700 Å, about 20 Å to about 500 Å, about 20 Å to about 400 Å, about 30 Å to about 400 Å or about 30 Å to about 300 Å. When the thicknesses of the buffer layer, the hole blocking layer, and the electron control layer are within these ranges, the electron transport region may have excellent hole blocking characteristics or electron control characteristics without a substantial increase in driving voltage.

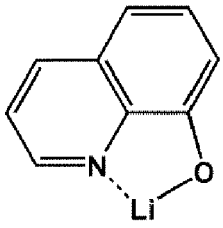
[0159] A thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 100 Å to about 700 Å, about 100 Å to about 600 Å, about 150 Å to about 600 Å, about 150 Å to about 500 Å or about 150 Å to about 250 Å. When the thickness of the electron transport 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.

[0160] 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.

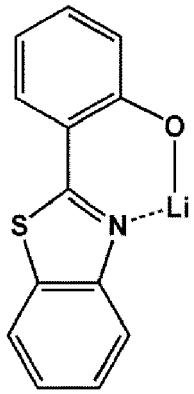
[0161] The metal-containing material may include at least one selected from alkali metal complex and alkaline earth-metal complex. The alkali metal complex may include a metal ion selected from a Li ion, a Na ion, a K ion, a Rb ion, and a Cs ion, and the alkaline earth-metal complex may include a metal 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 hydroxy quinoline, hydroxy isoquinoline, hydroxy benzoquinoline, hydroxy acridine, hydroxy phenanthridine, hydroxy phenyloxazole, hydroxy phenylthiazole, hydroxy diphenyloxadiazole, hydroxy diphe-

nylthiadiazole, hydroxy phenylpyridine, hydroxy phenylbenzimidazole, hydroxy phenylbenzothiazole, a bipyridine, a phenanthroline, and a cyclopentadiene, but embodiments of the present disclosure are not limited thereto.

[0162] For example, the metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (lithium quinolate, LiQ) or ET-D2.



ET-D1



ET-D2

[0163] 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.

[0164] 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.

[0165] 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.

[0166] The alkali metal may be selected from Li, Na, K, Rb, and Cs. In one embodiment, the alkali metal may be Li, Na, or Cs. In one or more embodiments, the alkali metal may be Li or Cs, but embodiments of the present disclosure are not limited thereto.

[0167] The alkaline earth metal may be selected from Mg, Ca, Sr, and Ba.

[0168] The rare earth metal may be selected from Sc, Y, Ce, Tb, Yb, and Gd.

[0169] 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.

[0170] 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.

[0171] 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.

[0172] The rare earth metal compound may be selected from YbF_3, ScF_3, Sc_2O_3, Y_2O_3, Ce_2O_3, GdF_3, and TbF_3. In one embodiment, the rare earth metal compound may be selected from YbF_3, ScF_3, TbF_3, YbI_3, ScI_3, and TbI_3, but embodiments of the present disclosure are not limited thereto.

[0173] 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.

[0174] The electron injection layer may consist of an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth-metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth-metal complex, a rare earth metal complex, or any combinations thereof, as described above. In one or more embodiments, the electron injection layer may further include an organic material. When the electron injection layer further includes an organic material, an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound,

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

[0175] 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 or about 3 Å to about 20 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.

Second electrode 190

[0176] The second electrode 190 may be located 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.

[0177] The second electrode 190 may include at least one selected from lithium (Li), silver (Ag), magnesium (Mg), aluminium (Al), aluminium-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.

[0178] The second electrode 190 may have a single-layered structure, or a multi-layered structure including two or more layers.

Description of FIGS. 2-4

[0179] An organic light-emitting device 20 of FIG. 2 includes a first capping layer 210, a first electrode 110, an organic layer 150, and a second electrode 190 which are sequentially stacked in this stated order. An organic light-emitting device 30 of FIG. 3 includes a first electrode 110, an organic layer 150, a second electrode 190, and a second capping layer 220 which are sequentially stacked in this stated order. An organic light-emitting device 40 of FIG. 4 includes a first capping layer 210, a first electrode 110, an organic layer 150, a second electrode 190, and a second capping layer 220.

[0180] Regarding FIGS. 2-4, the first electrode 110, the organic layer 150, and the second electrode 190 may be understood by referring to the description presented in connection with FIG. 1.

[0181] In the organic layer 150 of each of the organic light-emitting devices 20 and 40, light generated in an emission layer may pass through the first electrode 110, which is a semi-transmissive electrode or a transmissive electrode, and the first capping layer 210 toward the outside, and in the organic layer 150 of each of the organic light-emitting devices 30 and 40, light generated in an emission layer may pass through the second electrode 190, which is a semi-transmissive electrode or a transmissive electrode, and the second capping layer 220 toward the outside.

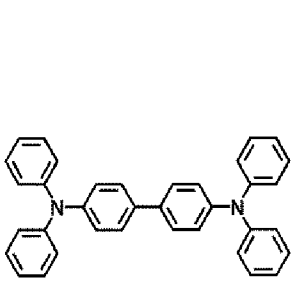
[0182] The first capping layer 210 and the second capping layer 220 may increase external luminescent efficiency according to the principle of constructive interference.

[0183] The first capping layer 210 and the second capping layer 220 may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or a composite capping layer including an organic material and an inorganic material.

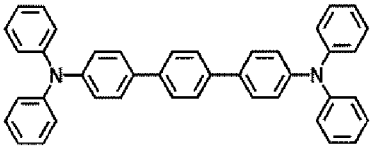
[0184] At least one selected from the first capping layer 210 and the second capping layer 220 may each independently include at least one material selected from carbocyclic compounds, heterocyclic compounds, amine-based compounds, porphyrine derivatives, phthalocyanine derivatives, a naphthalocyanine derivatives, alkali metal complexes, and alkaline earth-based complexes. The carbocyclic compound, the heterocyclic compound, and the amine-based compound may be optionally substituted with a substituent containing at least one element selected from O, N, S, Se, Si, F, Cl, Br, and I. In one embodiment, at least one selected from the first capping layer 210 and the second capping layer 220 may each independently include an amine-based compound.

[0185] In one embodiment, at least one selected from the first capping layer 210 and the second capping layer 220 may each independently include the compound represented by Formula 201 or the compound represented by Formula 202.

[0186] In one or more embodiments, at least one selected from the first capping layer 210 and the second capping layer 220 may each independently include a compound selected from Compounds HT28 to HT33 and Compounds CP1 to CP5, but embodiments of the present disclosure are not limited thereto.



CP1



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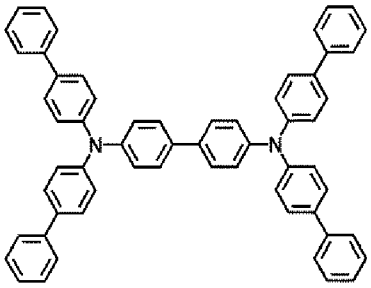

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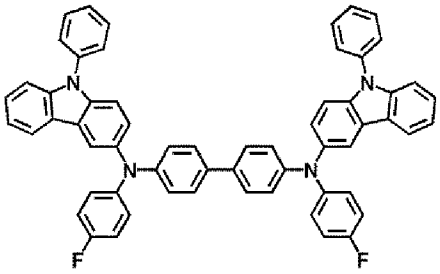

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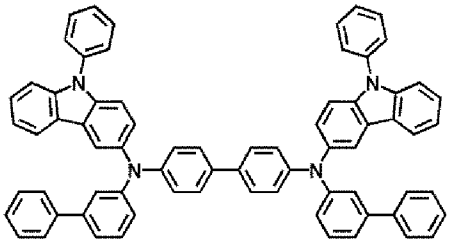


CP5

[0187] Hereinbefore, the organic light-emitting device according to an embodiment has been described in connection with FIGS. 1-4. However, embodiments of the present disclosure are not limited thereto.

[0188] 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.

[0189] When layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region are formed by vacuum deposition, the vacuum deposition may be performed at a deposition temperature of about 100 °C to about 500 °C, a vacuum degree of about 10^{-8} torr to about 10^{-3} torr, and a deposition speed of about 0.01 Å/sec to about 100 Å/sec by taking into account a material to be included in a layer to be formed, and the structure of a layer to be formed.

[0190] 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.

General definition of at least some of the substituents

[0191] The term "C_1-C_{60} alkyl group," as used herein, refers to a linear or branched aliphatic saturated hydrocarbon monovalent group having 1 to 60 carbon atoms, and examples thereof include a methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an isoamyl group, and a hexyl group. The term "C_1-C_{60} alkylene group," as used herein, refers to a divalent group having substantially the same structure as the C_1-C_{60} alkyl group. Corresponding definitions apply to other ranges given for the number of carbon atoms in an alkyl/alkylene group.

[0192] The term "C_2-C_{60} alkenyl group," as used herein, refers to a hydrocarbon group having at least one double bond at a main chain (e.g., in the middle) or at the terminus (e.g., a terminal end) 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. Corresponding definitions apply to other ranges given for the number of carbon atoms in an alkenyl/alkenylene group.

[0193] The term "C_2-C_{60} alkynyl group," as used herein, refers to a hydrocarbon group having at least one triple bond at a main chain (e.g., in the middle) or at the terminus (e.g., at a terminal end) 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. Corresponding definitions apply to other ranges given for the number of carbon atoms in an alkynyl/alkynylene group.

[0194] 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. Corresponding definitions apply to other ranges given for the number of carbon atoms in an alkoxy group.

[0195] 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.

[0196] 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.

[0197] 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 double bond in a ring thereof and no aromaticity (e.g., the entire ring and/or group is not aromatic), and examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group," as used herein, refers to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkenyl group.

[0198] 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 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.

[0199] 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). Corresponding definitions apply to other ranges given for the number of carbon atoms in an aryl/arylene group.

[0200] 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). Corresponding definitions apply to other ranges given for the number of carbon atoms in an heteroaryl/heteroarylene group.

[0201] The term "C_6-C_{60} aryloxy group," as used herein, refers to -OA_{102} (wherein A_{102} is the C_6-C_{60} aryl group), and the term "C_6-C_{60} arylthio group," as used herein, refers to -SA103 (wherein A_{103} is the C_6-C_{60} aryl group). Corresponding definitions apply to other ranges given for the number of carbon atoms in an aryloxy group and an arylthio group.

[0202] The term "monovalent non-aromatic condensed polycyclic group," as used herein, refers to a monovalent group having two or more rings condensed with each other (e.g., combined together), only carbon atoms (for example, having 8 to 60 carbon atoms) as ring-forming atoms, and no aromaticity in its entire molecular structure (e.g., the entire group and/or molecule is not aromatic). An example of the monovalent non-aromatic condensed polycyclic group is a fluorenyl group. The term "divalent non-aromatic condensed polycyclic group," as used herein, refers to a divalent group having substantially the same structure as the monovalent non-aromatic condensed polycyclic group.

[0203] The term "monovalent non-aromatic condensed heteropolycyclic group," as used herein, refers to a monovalent group having two or more rings condensed to each other (e.g., combined together), at least one heteroatom selected from N, O, Si, P, and S, other than carbon atoms (for example, having 1 to 60 carbon atoms), as a ring-forming atom, and no aromaticity in its entire molecular structure (e.g., the entire group and/or molecule is not aromatic). An example of the monovalent non-aromatic condensed heteropolycyclic group is a carbazolyl group. The term "divalent non-aromatic condensed heteropolycyclic group," as used herein, refers to a divalent group having substantially the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0204] The term "C_3-C_{60} carbocyclic group," as used herein, refers to a monocyclic or polycyclic group having 3 to 60 carbon atoms in which a ring-forming atom is a carbon atom only. The C_3-C_{60} carbocyclic group may be an aromatic carbocyclic group or a non-aromatic carbocyclic group. The C_3-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_3-C_{60} carbocyclic group, the C_3-C_{60} carbocyclic group may

be a trivalent group or a quadrivalent group. Corresponding definitions apply to other ranges given for the number of carbon atoms in a carbocyclic group.

[0205] The term "C_1-C_{60} heterocyclic group," as used herein, refers to a monovalent monocyclic group that has substantially the same structure as the C_3-C_{60} carbocyclic group and has at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 60 carbon atoms. Corresponding definitions apply to other ranges given for the number of carbon atoms in a heterocyclic group.

[0206] In the present specification, at least one substituent of the substituted C_3-C_{60} (*e.g.* C_3-C_{30}) carbocyclic group, the substituted C_5-C_{60} (*e.g.* C_5-C_{30}) carbocyclic group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) heterocyclic group, the substituted C_1-C_{20} alkylene group, the substituted C_2-C_{20} alkenylene 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} (*e.g.* C_6-C_{30}) arylene group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, the substituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, the substituted C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) 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} (*e.g.* C_6-C_{30}) aryl group, the substituted C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, the substituted C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, the substituted C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group 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 C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, and a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group;

a C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, and a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a 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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $-Si(Q_{41})(Q_{42})(Q_{43})$, $-N(Q_{41})(Q_{42})$, $-B(Q_{41})(Q_{42})$, $-C(=O)(Q_{41})$, $-S(=O)_2(Q_{41})$, and $-P(=O)(Q_{41})(Q_{42})$;

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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl 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} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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 C_1-C_{60} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryloxy group, a C_6-C_{60} (*e.g.* C_6-C_{30}) arylthio group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, a terphenyl group, $-Si(Q_{51})(Q_{52})(Q_{53})$, $-N(Q_{51})(Q_{52})$, $-B(Q_{51})(Q_{52})$, $-C(=O)(Q_{51})$, $-S(=O)_2(Q_{51})$, and $-P(=O)(Q_{51})(Q_{52})$; and

$-Si(Q_{61})(Q_{62})(Q_{63})$, $-N(Q_{61})(Q_{62})$, $-B(Q_{61})(Q_{62})$, $-C(=O)(O_{61})$, $-S(=O)_2(Q_{61})$, and $-P(=O)(Q_{61})(Q_{62})$, and

Q_{41} to Q_{43}, Q_{51} to Q_{53}, and Q_{61} to Q_{63} 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} (*e.g.* C_1-C_{20}) alkyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkenyl group, a C_2-C_{60} (*e.g.* C_2-C_{20}) alkynyl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} (*e.g.* C_6-C_{30}) aryl group, a C_1-C_{60} (*e.g.* C_1-C_{20}) heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0207] The term "Ph," as used herein, refers to a phenyl group, the term "Me," as used herein, refers to a methyl group, the term "Et," as used herein, refers to an ethyl group, the term "ter-Bu" or "Bu^t," as used herein, refers to a tert-butyl

group, and the term "OMe," as used herein, refers to a methoxy group.

[0208] The term "biphenyl group," as used herein, refers to "a phenyl group substituted with a phenyl group." In other words, the "biphenyl group" is a substituted phenyl group having a C_6-C_{60} aryl group as a substituent.

[0209] The term "terphenyl group," as used herein, refers to "a phenyl group substituted with a biphenyl group." In other words, the "terphenyl group" is a phenyl group having, as a substituent, a C_6-C_{60} aryl group substituted with a C_6-C_{60} aryl group.

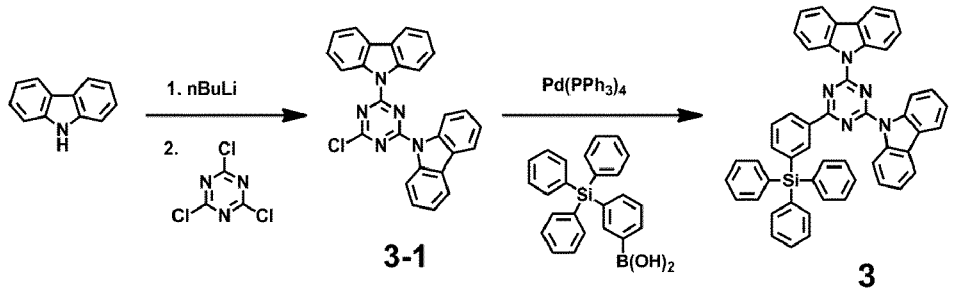
[0210] * and *' as used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

[0211] 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 wording "B was used instead of A" used in describing Synthesis Examples refers to that an identical molar equivalent of B was used in place of an identical molar equivalent of A.

Examples

Synthesis Example 1: Synthesis of Compound 3

[0212]



Synthesis of Intermediate 3-1

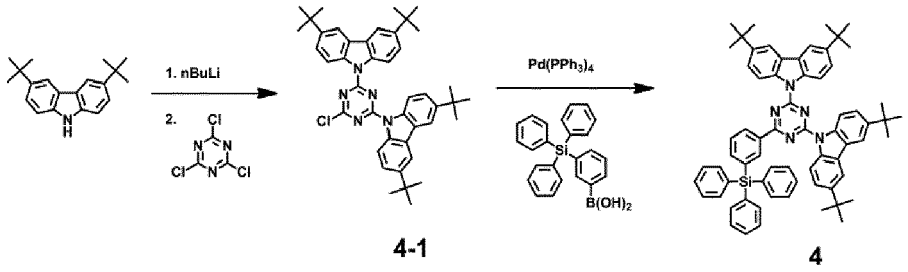
[0213] Carbazole (2eq.) was reacted with nBuLi (2eq.) at 0°C and then reacted with cyanuric chloride (1eq.) to obtain Intermediate 3-1. Intermediate 3-1 was identified by liquid chromatography-mass spectrometry (LC-MS). $C_{27}H_{16}N_5Cl$: M+1 445.1.

Synthesis of Compound 3

[0214] 2.3 g of Intermediate 3-1, 2.4 g of (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1), 0.24 g of tetrakis(triphenylphosphine)palladium, and 1.8 g of potassium carbonate were added to a reaction container, dissolved in 40 mL of toluene, 10 mL of ethanol, and 10 mL of distilled water, and then refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 1.6 g of Compound 3 (yield: 42 %). Compound 3 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 2: Synthesis of Compound 4

[0215]



Synthesis of Intermediate 4-1

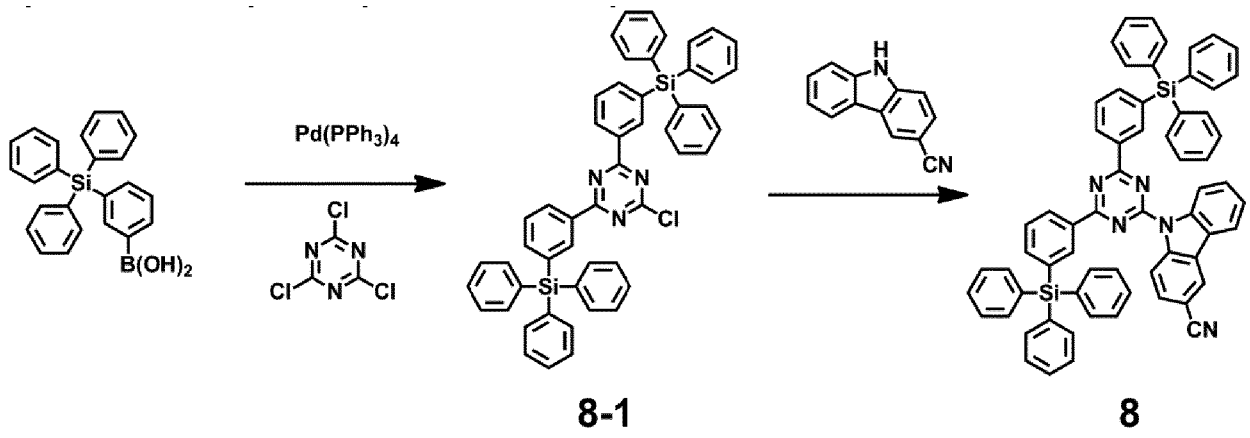
[0216] 3,4-di-tert-butyl-9H-carbazole (2eq.) was reacted with nBuLi (2eq.) at 0°C and then reacted with cyanuric chloride (1eq.) to obtain Intermediate 4-1. Intermediate 4-1 was identified by LC-MS.
$C_{43}H_{48Cl}N_5$: M+1 670.34.

Synthesis of Compound 4

[0217] 1.9 g of Intermediate 4-1, 1.95 g of (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1), 0.20 g of tetrakis(triphenylphosphine)palladium, and 1.47 g of potassium carbonate were added to a reaction container, dissolved in 40 mL of toluene, 10 mL of ethanol, and 10 mL of distilled water, and then refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 2.28 g of Compound 4 (yield: 55 %). Compound 4 was identified by LC-MS and ^{1}H -NMR.

Synthesis Example 3: Synthesis of Compound 8

[0218]



Synthesis of Intermediate 8-1

[0219] (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1) (2eq.) was reacted with cyanuric chloride (1eq.) at 120°C in the presence of a Pd catalyst ($Pd(PPh_3)_4$) (0.05eq.) to obtain Intermediate 8-1. Intermediate 8-1 was identified by LC-MS.
$C_{51}H_{38}ClN_3Si_2$: M+1 784.43.

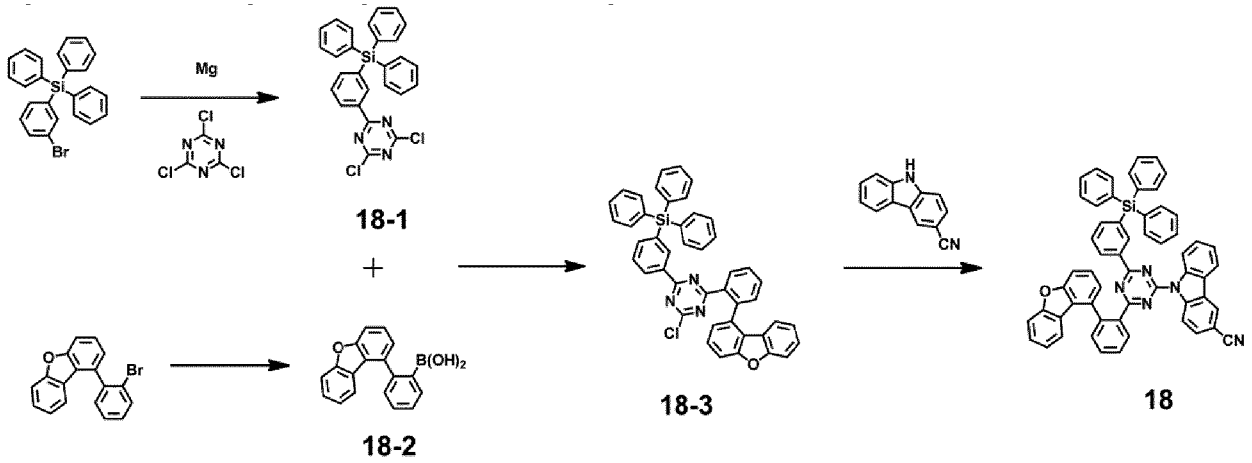
Synthesis of Compound 8

[0220] 3.3 g of Intermediate 8-1, 0.81 g of 9H-carbazole-3-carbonitrile (57102-93-9), 1.8 g of potassium phosphate, and 30 mL of dimethylformamide (DMF) were added to a reaction vessel and then refluxed at a temperature of 160 °C for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained

therefrom was separated and purified by silica gel column chromatography to obtain 2.5 g of Compound 8 (yield: 62 %). Compound 8 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 4: Synthesis of Compound 18

[0221]



Synthesis of Intermediate 18-1

[0222] (3-bromophenyl)triphenylsilane (CAS#=185626-73-7) (1eq.) was reacted with magnesium (1eq.) at 0°C and then reacted with cyanuric chloride (1eq.) to obtain Intermediate 18-1. Intermediate 18-1 was identified by LC-MS. $C_{27}H_{19}Cl_2N_3Si$: M+1 484.08.

Synthesis of Intermediate 18-2

[0223] 1-(2-bromophenyl)dibenzo[b,d]furan (CAS#=1659313-53-7) (1eq.)was reacted with nBuLi (1.2eq.) and then reacted with trimethylborate (1.4eq.) at -78°C to obtain Intermediate 18-2. Intermediate 18-2 was identified by LC-MS. $C_{18}H_{13}BO_3$: M+1 289.12.

Synthesis of Intermediate 18-3

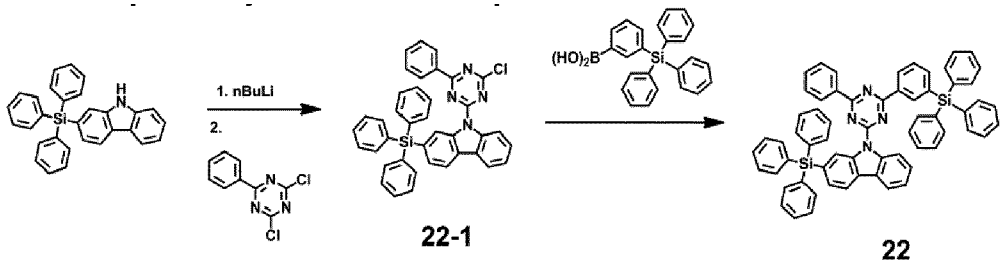
[0224] Intermediate 18-1 (1eq.) and Intermediate 18-2 (1.2eq.) were Suzuki-coupled at 120°C in the presence a $Pd(PPh_3)_4$ catalyst (0.05eq.) to obtain Intermediate 18-3. Intermediate 18-3 was identified by LC-MS. $C_{45}H_{30}ClN_3OSi$: M+1 692.19.

Synthesis of Compound 18

[0225] 1.9 g of Intermediate 18-3, 0.53 g of 9H-carbazole-3-carbonitrile (CAS#=57102-93-9), 1.2 g of potassium phosphate, and 20 mL of DMF were added to a reaction vessel and then refluxed at a temperature of 160 °C for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 1.4 g of Compound 18 (yield: 59 %). Compound 18 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 5: Synthesis of Compound 22

[0226]



Synthesis of Intermediate 22-1

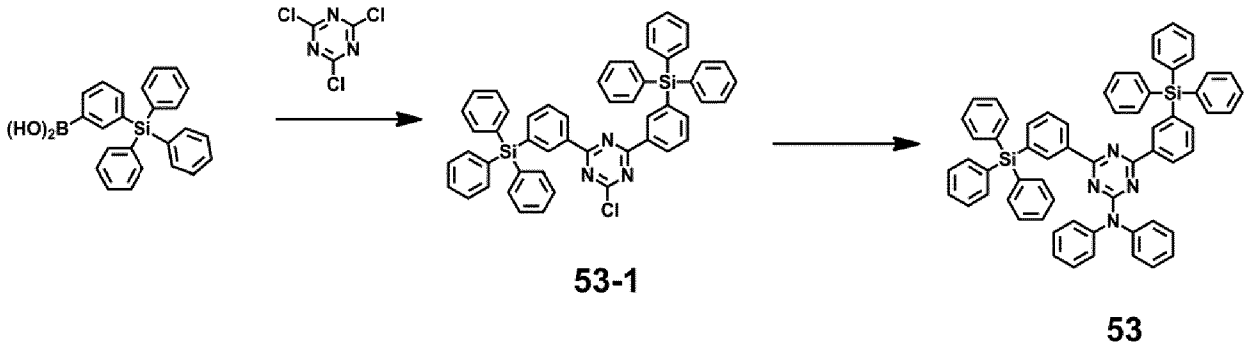
[0227] 2-(triphenylsilyl)-9H-carbazole (CAS#=1262866-95-4) (1eq.) was reacted with nBuLi (1eq.) and then reacted with 2,4-dichloro-6-phenyltriazine (CAS# = 1700-02-3) (1eq.) at -78°C to obtain Intermediate 22-1. Intermediate 22-1 was identified by LC-MS.
$C_{39}H_{27}ClN_4Si$: M+1 615.18.

Synthesis of Compound 22

[0228] 2.3 g of Intermediate 22-1, 1.71 g of (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1), 0.17 g of tetrakis(triphenylphosphine)palladium, and 1.30 g of potassium carbonate were added to a reaction vessel, dissolved in 40 mL of toluene, 10 mL of ethanol, and 10 mL of distilled water, and then refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 1.95 g of Compound 22 (yield: 57 %). Compound 22 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 6: Synthesis of Compound 53

[0229]



Synthesis of Intermediate 53-1

[0230] (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1) (2eq.) was reacted with cyanuric chloride (1eq.) at 120°C in the presence of a $Pd(PPh_3)_4$ catalyst (0.05eq.) to obtain Intermediate 53-1. Intermediate 53-1 was identified by LC-MS.
$C_{51}H_{38}ClN_3Si_2$: M+1 784.33.

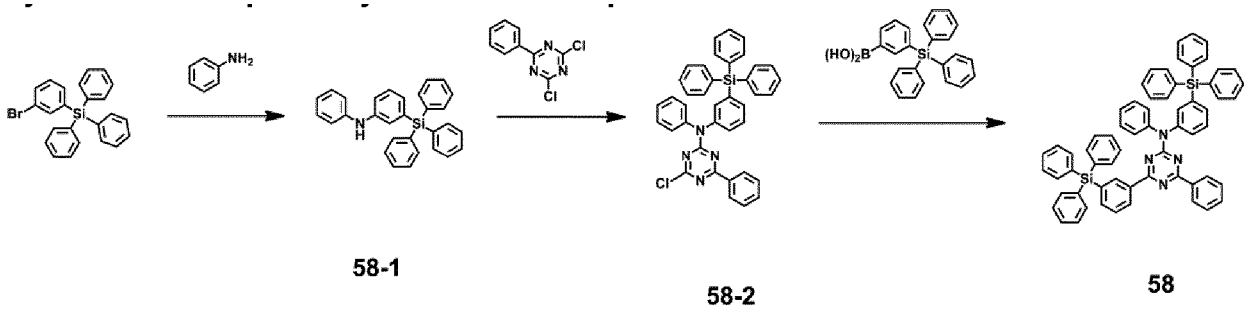
Synthesis of Compound 53

[0231] 2.9 g of Intermediate 53-1, 0.8 g of diphenylamine, 0.17 g of Pd_2dba_3, 0.1 mL of $P(tBu)_3$, and 1.1 g of sodium tert-butoxide were added to a reaction vessel, dissolved in 30 mL of toluene, and then refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and a solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 2.1 g of Compound 53 (yield: 49 %). Compound 53

was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 7: Synthesis of Compound 58

[0232]



58-1 58-2 58

Synthesis of Intermediate 58-1

[0233] (3-bromophenyl)triphenylsilane (CAS#=185626-73-7) (1eq.) was reacted with aniline (1.2eq.) at 120°C in the presence of a Pd_2dba_3 catalyst (0.05eq.) to obtain Intermediate 58-1. Intermediate 58-1 was identified by LC-MS. $C_{30}H_{25}NSi$: M+1 428.22.

Synthesis of Intermediate 58-2

[0234] Intermediate 58-1 (1eq.) was reacted with 2,4-dichloro-6-phenyltriazine (CAS#=1700-02-3) (1eq.) at 120°C in the presence of a Pd_2dba_3 catalyst (0.05eq.) to obtain Intermediate 58-2. Intermediate 58-2 was identified by LC-MS. $C_{39}H_{29}ClN_4Si$: M+1 617.32.

Synthesis of Compound 58

[0235] 3.4 g of Intermediate 58-2, 2.52 g of (3-(triphenylsilyl)phenyl)boronic acid (CAS#=1253912-58-1), 0.25 g of tetrakis(triphenylphosphine)palladium, 1.9 g of potassium carbonate were added to a reaction vessel, dissolved in 40 mL of toluene, 10 mL of ethanol, and 10 mL of distilled water, and then refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl acetate. A collected organic layer was dried by using anhydrous magnesium sulfate, and the solvent was evaporated therefrom. A residue obtained therefrom was separated and purified by silica gel column chromatography to obtain 3.08 g of Compound 58 (yield: 61 %). Compound 58 was identified by LC-MS and ^{1}H-NMR.

[0236] ^{1}H nuclear magnetic resonance spectroscopy (NMR) and fast atom bombardment-mass spectrometry)MS/FAB) of Compounds synthesized according to Synthesis Examples 1 to 7 are shown in Table 1.

[0237] Synthesis methods of compounds other than Compounds shown in Table 1 may also be readily recognized by those of ordinary skill in the art by referring to the synthesis mechanisms and source materials described herein above.

Table 1

Compound	^{1}H NMR ($CDCl_3$, 400 MHz)	MS/FAB	
		Found	calc.
3	8.54 (d, 2H), 8.37 (d, 1H), 8.19 (d, 2H), 7.92 (d, 2H), 7.87 (s, 1H), 7.63 (t, 1H), 7.57-7.54 (m, 3H), 7.5 (t, 2H), 7.45-7.32 (m, 17H), 7.2 (t, 2H), 7.12 (t, 2H)	746.33	745.27
4	8.95(s, 2H), 8.37-8.32 (m, 3H), 7.87-7.82 (m, 3H), 7.65-7.60 (m, 2H), 7.55 (d, 1H), 7.49 (d, 2H), 7.45-7.32 (m, 15H), 7.11 (d, 2H), 1.43 (s, 12H)	970.69	969.52
8	8.54 (d, 1H), 8.36 (d, 2H), 7.93 (s, 2H), 7.88-7.74 (m, 2H), 7.76 (t, 2H), 7.56 (d, 2H), 7.45-7.32 (m, 30H), 7.29-7.22 (m, 2H), 7.12 (t, 1H)	940.28	939.32
18	8.55 (d, 1H), 8.3 (d, 1H), 7.98-7.90 (m, 4H), 7.82 (d, 1H), 7.8 (s, 1H), 7.72 (d, 1H), 7.67-7.50 (m, 7H), 7.44-7.40 (m, 7H), 7.32-7.22 (m, 20H), 7.11 (t, 1H)	848.33	847.28

(continued)

Compound	^{1}H NMR ($CDCl_3$, 400 MHz)	MS/FAB	
		Found	calc.
22	8.55(d, 1H), 8.37-8.32 (m, 3H), 8.22 (d, 1H), 7.94 (d, 1H), 7.87 (s, 1H), 7.69-7.62 (m, 2H), 7.56 (d, 1H), 7.51-7.45 (m, 15H), 7.39-7.32 (m, 19H), 7.26 (t, 1H), 7.16 (t, 1H)	915.23	914.33
53	8.38(d, 1H), 7.87 (s, 1H), 7.62 (t, 1H), 7.56 (d, 1H), 7.46 (m, 12H), 7.38 (d, 18H), 7.22 (t, 4H), 7.09 (d, 4H), 6.99 (t, 2H)	917.33	916.34
58	8.38-8.32 (m, 3H), 7.88 (s, 1H), 7.62 (t, 1H), 7.52 (d, 1H), 7.50-7.35 (m, 34H), 7.30 (s, 1H), 7.24 (t, 2H), 7.17 (t, 1H), 7.12 (d, 1H), 7.05 (t, 1H)	917.29	916.34

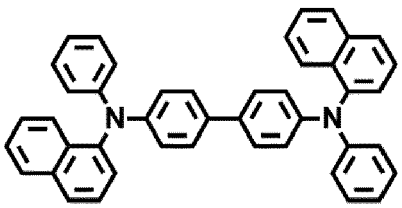
Example 1

[0238] As an anode, a Corning 15 Ω/cm^2 (1,200 Å) indium tin oxide (ITO) glass substrate was cut to a size of 50 mm x 50 mm x 0.5 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. The ITO glass substrate was provided to a vacuum deposition apparatus.

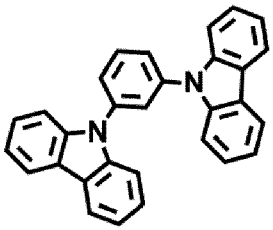
[0239] An available material, N,N'-di(1-naphthyl)-N,N'-diphenylbenzidine (NPB), was vacuum-deposited on the ITO glass substrate to form a hole injection layer having a thickness of 300 Å, and a hole transport compound mCP was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 200 Å.

[0240] As a host, Compound 3 and a phosphorescent dopant PD26 were codeposited on the hole transport layer at a weight ratio of 92:8 to form an emission layer having a thickness of 250 Å.

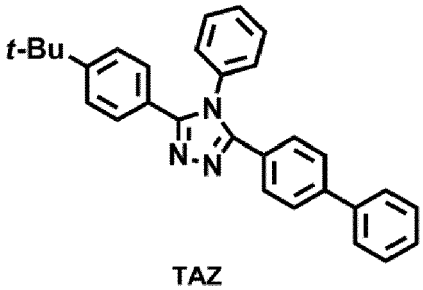
[0241] Then, 3-(4-biphenylyl)-4-phenyl-5-tert-butylphenyl-1,2,4-triazole (TAZ) was deposited on the emission layer to form an electron transport layer having a thickness of 200 Å, an alkali metal halide LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å, and Al was vacuum-deposited on the electron injection layer to form an LiF/Al electrode having a thickness of 100 Å, thereby completing the manufacture of an organic light-emitting device.



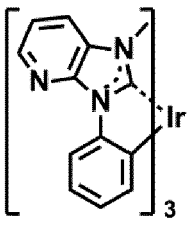
NPB



mCP



TAZ



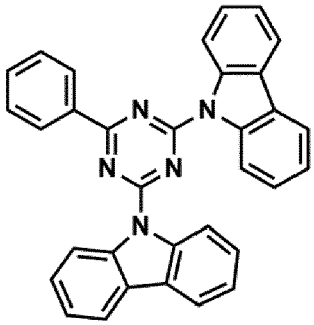
PD26

Examples 2 to 7

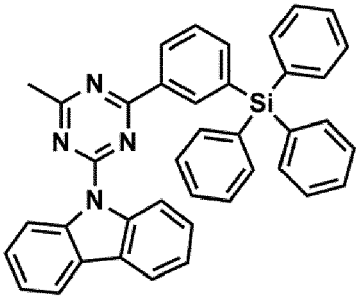
[0242] Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that Compounds shown in Table 2 were each used instead of Compound 3 in forming an emission layer.

Comparative Examples 1 to 5

[0243] Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that Compounds A to E were used in Comparative Examples 1 to 5, respectively, instead of Compound 3 in forming an emission layer.



A



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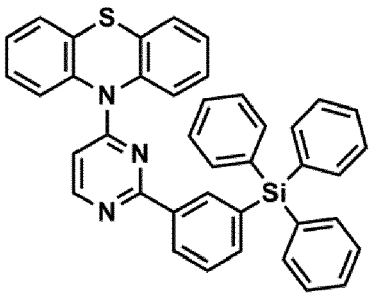
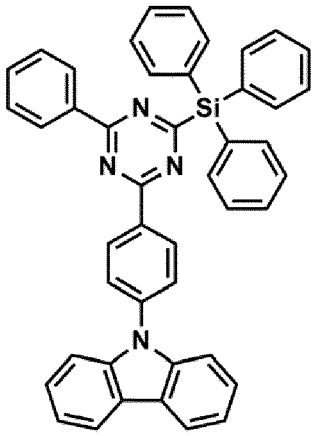
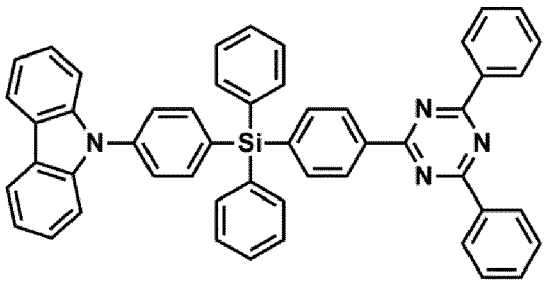


C



D



E

Evaluation Example 1

[0244] The driving voltage, current density, and maximum quantum efficiency of the organic light-emitting devices manufactured according to Examples 1 to 7 and Comparative Examples 1 to 5 were measured at a current density of 10 mA/cm^2 so as to evaluate characteristics of the organic light-emitting devices. The driving voltage and the current density of the organic light-emitting device were measured by using a source meter (manufactured by Keithley Instrument, 2400 series), and the maximum quantum efficiency of the organic light-emitting device was measured by an external quantum efficiency measurement device C9920-2-12 (manufactured by Hamamatsu Photonics). In the evaluation of the maximum quantum efficiency, the luminance and current densities were measured by using a luminance meter, of which a wavelength sensitivity was calibrated, and the maximum quantum efficiency was converted based on an angular luminance distribution (Lambertian) assuming a full diffusive reflective surface. Results of evaluating the characteristics of the organic light-emitting devices are shown in Table 2.

Table 2

Classification	Host in emission layer	Driving voltage (V)	Current Density (mA/cm^2)	Maximum quantum efficiency (%)	Emission color
Example 1	Compound 3	3.6	2.3	18.9	Blue
Example 2	Compound 4	3.8	2.3	18.2	Blue

(continued)

Classification	Host in emission layer	Driving voltage (V)	Current Density (mA/cm^2)	Maximum quantum efficiency (%)	Emission color
Example 3	Compound 8	4.1	2.3	17.3	Blue
Example 4	Compound 18	4.5	2.3	20.2	Blue
Example 5	Compound 22	3.9	2.3	21.3	Blue
Example 6	Compound 53	4.1	2.3	19.1	Blue
Example 7	Compound 58	4.3	2.3	21.5	Blue
Comparative Example 1	A	4.6	2.3	13.3	Blue
Comparative Example 2	B	4.7	2.3	12.9	Blue
Comparative Example 3	C	4.9	2.3	13.1	Blue
Comparative Example 4	D	4.3	2.3	8.9	Blue
Comparative Example 5	E	5.1	2.3	14.3	Blue

[0245] Referring to Table 2, it can be seen that when Compounds according to one or more embodiments are used as the host material of the emission layer, the driving voltage is lowered and the luminescent efficiency and the maximum quantum efficiency are increased, as compared when the compounds of the Comparative Examples are used as the host.

[0246] An organic light-emitting device including the heterocyclic compound according to an embodiment may have a low driving voltage, high luminance, high efficiency, and a long lifespan.

[0247] 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.

[0248] 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.

[0249] 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.

[0250] 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.

[0251] 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.

[0252] 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.

[0253] Also, any numerical range recited herein is intended to include all subranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein, and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein.

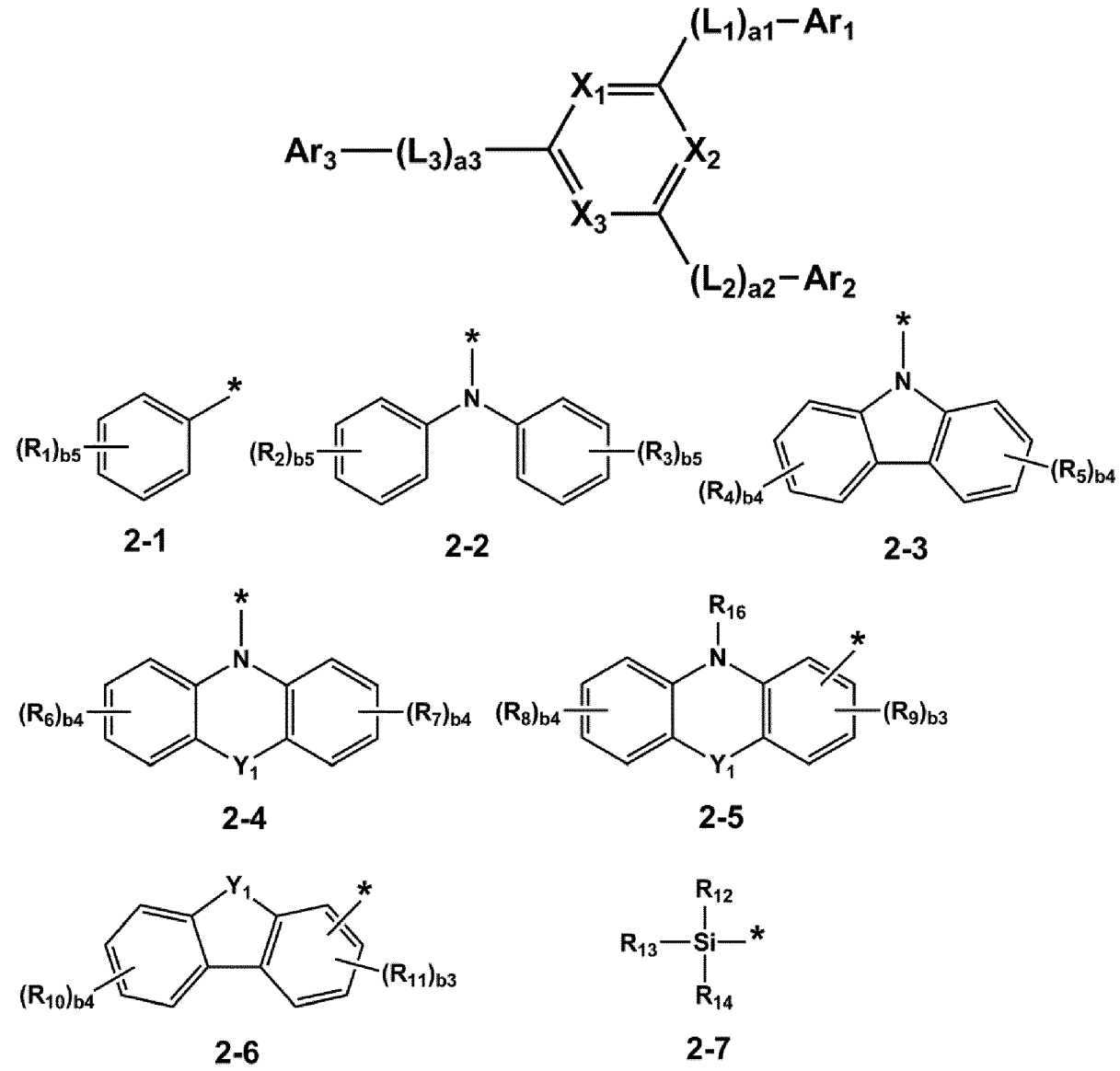
[0254] While one or more embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the scope as defined by the following claims.

Claims

1. An organic light-emitting device comprising:

a first electrode;
a second electrode facing the first electrode;
an organic layer between the first electrode and the second electrode and comprising an emission layer; and
at least one heterocyclic compound represented by Formula 1:

Formula 1



,

wherein, in Formulae 1 and 2-1 to 2-7,

X_1 to X_3 are each independently N or C(R_{15}), wherein at least one selected from X_1 to X_3 is N,
L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,
a1 to a3 are each independently an integer from 0 to 3,
Ar_1 to Ar_3 are each independently a group represented by one selected from Formulae 2-1 to 2-7,
Y_1 is O or S,
R_1 to R_{16} are each independently selected from hydrogen, deuterium, -F, -Cl,-Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic con-

densed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,-$Si(Q_1)(Q_2)(Q_3)$, -$N(Q_1)(Q_2)$, -$B(Q_1)(Q_2)$, -$S(=O)_2(Q_1)$, and -$P(=O)(Q_1)(Q_2)$,
b3 is an integer from 0 to 3, b4 is an integer from 0 to 4, and b5 is an integer from 0 to 5,
in the groups included in the heterocyclic compound represented by Formula 1, at least one selected from the substituents R_1 to R_{11} of the Formulae 2-1 to 2-6 is - $Si(Q_1)(Q_2)(Q_3)$,
when Ar_1 is a group represented by Formula 2-7, a1 is 0, when Ar_2 is a group represented by Formula 2-7, a2 is 0, and when Ar_3 is a group represented by Formula 2-7, a3 is 0,
when Ar_1 is a group represented by Formula 2-7, Ar_2 and Ar_3 are not a group represented by Formula 2-1 and L_2 and L_3 are not a benzene group, when Ar_2 is a group represented by Formula 2-7, Ar_1 and Ar_3 are not a group represented by Formula 2-1 and L_1 and L_3 are not a benzene group, and when Ar_3 is a group represented by Formula 2-7, Ar_1 and Ar_2 are not a group represented by Formula 2-1 and L_1 and L_2 are not a benzene group, and
a case in which each of Ar_1 to Ar_3 is a group represented by Formula 2-1 is excluded,

at least one substituent of the substituted C_3-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_2-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_2-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_2-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, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl 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, 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 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, a biphenyl group, a terphenyl 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-$P(=O)(Q_{31})(Q_{32})$,
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_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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; and
a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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, 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, and -Si(R_a)(R_b)(R_c),

R_a to R_c are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and
* indicates a binding site to a neighboring atom.

2. An organic light-emitting device according to claim 1, wherein:

the first electrode is an anode,
the second electrode is a cathode,
the organic layer comprises at least one of the heterocyclic compound represented by Formula 1,
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.

3. An organic light-emitting device according to claim 1 or claim 2, wherein:

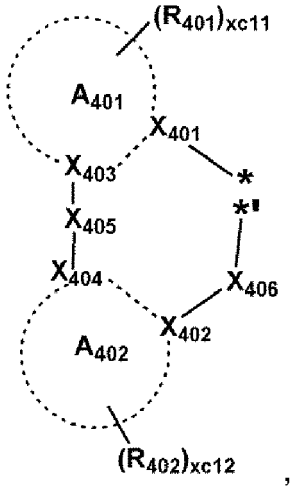
the emission layer comprises a dopant and a host, and
the host comprises at least one of the heterocyclic compound represented by Formula 1.

4. An organic light-emitting device according to claim 3, wherein:
the dopant is a phosphorescent dopant.

5. An organic light-emitting device according to claim 3 or claim 4, wherein:
the dopant comprises an organometallic complex represented by Formula 401:

Formula 401 $M(L_{401})_{xc1}(L_{402})_{xc2}$

Formula 402



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wherein, in Formulae 401 and 402,

M is selected from iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), and thulium (Tm),
L_{401} is selected from ligands represented by Formula 402, and xc1 is 1, 2, or 3, wherein, when xc1 is two or more, two or more L_{401}(s) are identical to or different from each other,
L_{402} is an organic ligand, and xc2 is an integer from 0 to 4, wherein, when xc2 is two or more, two or more L_{402}(s) are identical to or different from each other,
X_{401} to X_{404} are each independently nitrogen or carbon,
X_{401} and X_{403} are linked via a single bond or a double bond, and X_{402} and X_{404} are linked via a single bond or a double bond,
A_{401} and A_{402} are each independently a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,
X_{405} is a single bond, *-O-*', *-S-*', *-C(=O)-*', *-N(Q_{411})-*', *-C(Q_{411})(Q_{412})-*', *-C(Q_{411})=C(Q_{412})-*', *-C(Q_{411})=*', or *=C=*', wherein Q_{411} and Q_{412} are each independently hydrogen, deuterium, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group,
X_{406} is a single bond, O, or S,
R_{401} and R_{402} 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_{20} alkyl group, a substituted or unsubstituted C_1-C_{20} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,-Si(Q_{401})(Q_{402})(Q_{403}), -N(Q_{401})(Q_{402}), -B(Q_{401})(Q_{402}), -C(=O)(Q_{401}), -S(=O)$_2$(Q_{401}), and-P(=O)(Q_{401})(Q_{402}), wherein Q_{401} to Q_{403} are each independently selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a C_6-C_{20} aryl group, and a C_1-C_{20} heteroaryl group,
xc11 and xc12 are each independently an integer from 0 to 10, and
* and *' in Formula 402 each indicate a binding site to M in Formula 401.

6. An organic light-emitting device according to any one of claims 2 to 5, wherein:
the hole transport region further comprises a p-dopant having a lowest unoccupied molecular orbital (LUMO) level of about -3.5 eV or less.

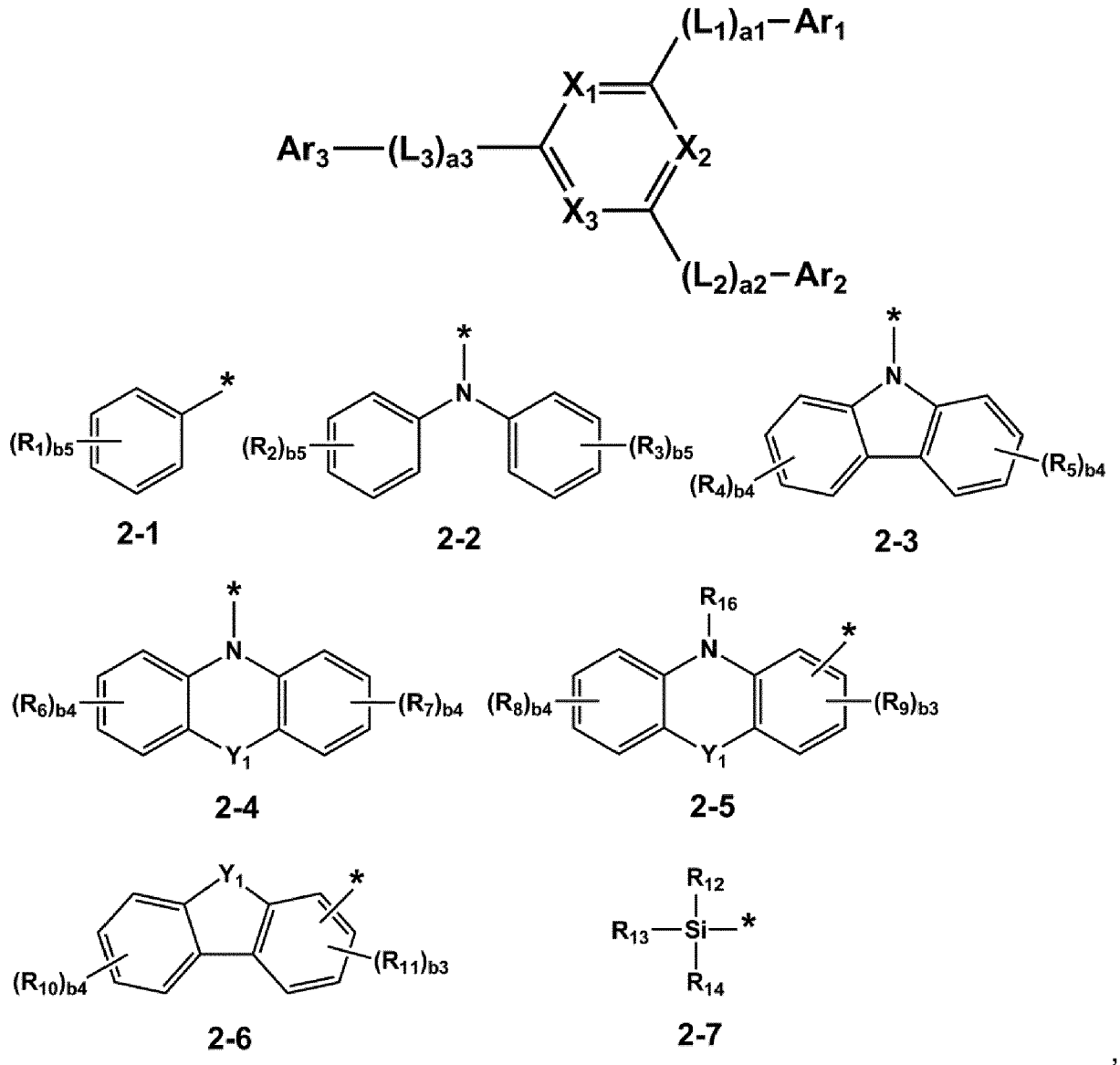
7. An organic light-emitting device according to any one of claims 2 to 6, wherein:
the electron transport region comprises an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof.

8. An organic light-emitting device according to any one of claims 1 to 7, wherein:

the emission layer comprises a first emission layer configured to emit a first color light,
the organic light-emitting device further comprises, between the first electrode and the second electrode, i) at least one second emission layer configured to emit a second color light or ii) at least one second emission layer configured to emit a second color light and at least one third emission layer configured to emit a third color light,
a maximum emission wavelength of the first color light, a maximum emission wavelength of the second color light, and a maximum emission wavelength of the third color light are identical to or different from each other, and the first color light and the second color light are emitted in a form of mixed light, or the first color light, the second color light, and the third color light are emitted in a form of mixed light.

9. A heterocyclic compound represented by Formula 1:

Formula 1



,

wherein, in Formulae 1 and 2-1 to 2-7,

X_1 to X_3 are each independently N or C(R_{15}), wherein at least one selected from X_1 to X_3 is N,
L_1 to L_3 are each independently a substituted or unsubstituted C_3-C_{60} carbocyclic group or a substituted or

unsubstituted C_1-C_{60} heterocyclic group,
a1 to a3 are each independently an integer from 0 to 3,
Ar_1 to Ar_3 are each independently a group represented by one selected from Formulae 2-1 to 2-7,
Y_1 is O or S,
R_1 to R_{16} are each independently selected from hydrogen, deuterium, -F, -Cl,-Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,-$Si(Q_1)(Q_2)(Q_3)$, -$N(Q_1)(Q_2)$, -$B(Q_1)(Q_2)$, -$S(=O)_2(Q_1)$, and -$P(=O)(Q_1)(Q_2)$,
b3 is an integer from 0 to 3, b4 is an integer from 0 to 4, and b5 is an integer from 0 to 5,
in the groups included in the heterocyclic compound represented by Formula 1, at least one selected from the substituents R_1 to R_{11} of the Formulae 2-1 to 2-6 is-$Si(Q_1)(Q_2)(Q_3)$,
when Ar_1 is a group represented by Formula 2-7, a1 is 0, when Ar_2 is a group represented by Formula 2-7, a2 is 0, and when Ar_3 is a group represented by Formula 2-7, a3 is 0,
when Ar_1 is a group represented by Formula 2-7, Ar_2 and Ar_3 are not a group represented by Formula 2-1 and L_2 and L_3 are not a benzene group, when Ar_2 is a group represented by Formula 2-7, Ar_1 and Ar_3 are not a group represented by Formula 2-1 and L_1 and L_3 are not a benzene group, and when Ar_3 is a group represented by Formula 2-7, Ar_1 and Ar_2 are not a group represented by Formula 2-1 and L_1 and L_2 are not a benzene group, and
a case in which each of Ar_1 to Ar_3 is a group represented by Formula 2-1 is excluded,
at least one substituent of the substituted C_3-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_2-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_2-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_2-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, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl 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, 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 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, a biphenyl group, a terphenyl 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-$P(=O)(Q_{31})(Q_{32})$,

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_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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; and a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryl group substituted with a C_1-C_{60} alkyl 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, 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, and $-Si(R_a)(R_b)(R_c)$,

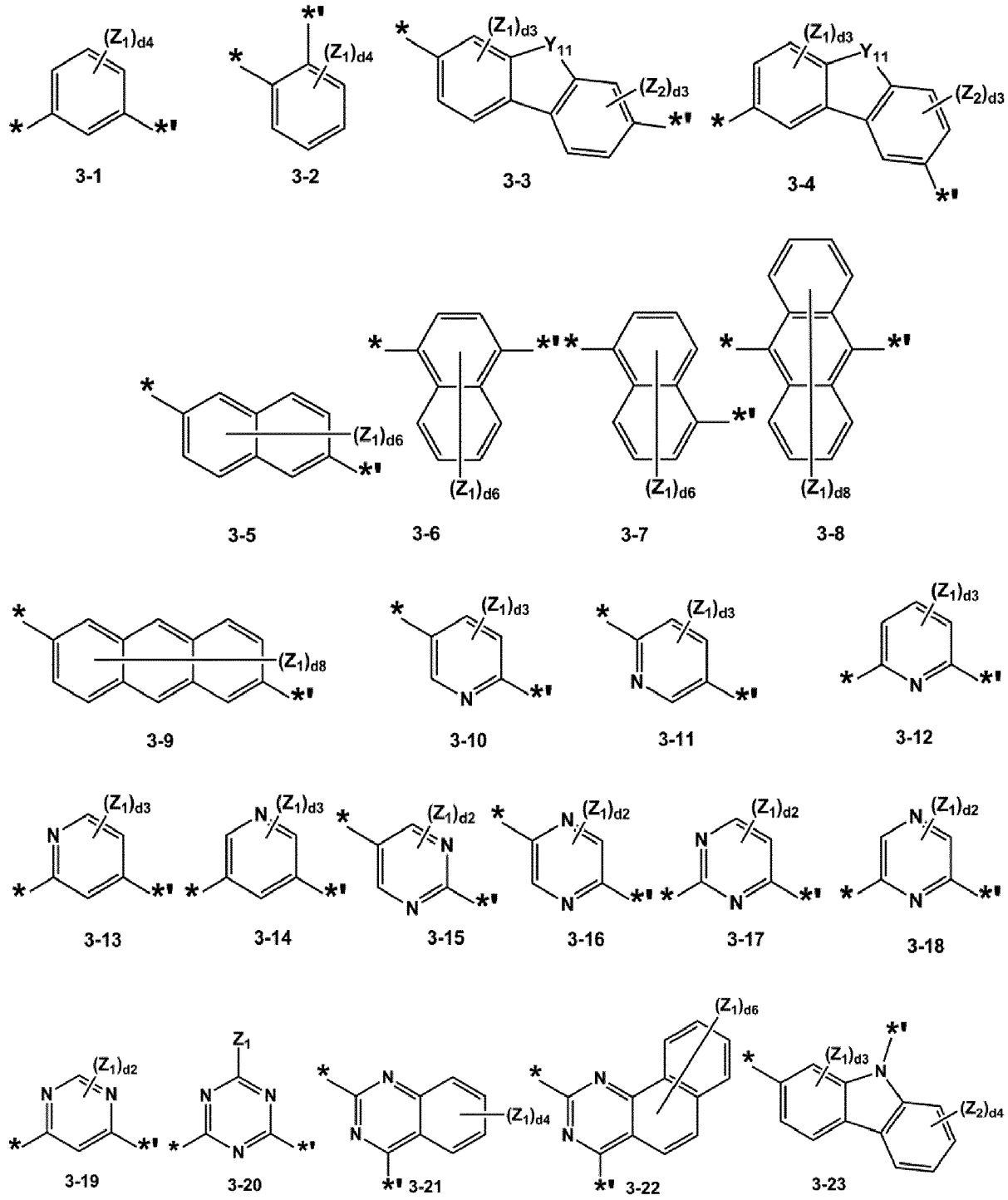
R_a to R_c are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-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_2-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and
* indicates a binding site to a neighboring atom.

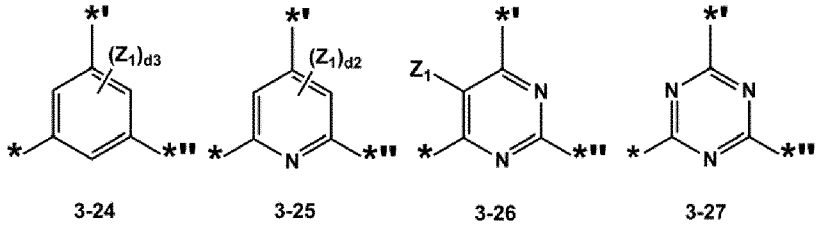
10. A heterocyclic compound according to claim 9, wherein:
L_1 to L_3 are each independently selected from:

a benzene group, a pentalene group, an indene group, a naphthalene group, an azulene group, a heptalene group, an indacene group, an acenaphthalene group, a fluorene group, a spiro-bifluorene group, a spiro-benzofluorene-fluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pyrrole group, a thiophene group, a furan group, a silole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a triazine group, a benzofuran group, a benzothiophene group, a benzosilole group, a dibenzosilole group, a quinoline group, an isoquinoline group, a benzimidazole group, an imidazopyridine group, and an imidazopyrimidine group;
a benzene group, a pentalene group, an indene group, a naphthalene group, an azulene group, a heptalene group, an indacene group, an acenaphthalene group, a fluorene group, a spiro-bifluorene group, a spiro-benzofluorene-fluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pyrrole group, a thiophene group, a furan group, a silole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a triazine group, a benzofuran group, a benzothiophene group, a benzosilole group, a dibenzosilole group, a quinoline group, an isoquinoline group, a benzimidazole group, an imidazopyridine group, and an imidazopyrimidine group, each substituted with at least one selected from deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, 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 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 pyrrolyl group, a thiophenyl group, a furanyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a benzofuranyl group, a benzothiophenyl group, $-Si(Q_{31})(Q_{32})(Q_{33})$, $-N(Q_{31})(Q_{32})$, and $-B(Q_{31})(Q_{32})$, and Q_{31} to Q_{33} are each independently selected from 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, and a pyridinyl group.

11. A heterocyclic compound according to claim 9 or claim 10, wherein:
L_1 to L_3 are each independently selected from groups represented by Formulae 3-1 to 3-27:





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wherein, in Formulae 3-1 to 3-27,

Y_{11} is selected from $C(Z_3)(Z_4)$, $N(Z_5)$, $Si(Z_6)(Z_7)$, O, and S,
Z_1 to Z_7 are each independently selected from hydrogen, deuterium, -F, -Cl, -Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a 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 pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a dibenzosilolyl group, and-$Si(Q_{31})(Q_{32})(Q_{33})$,
Q_{31} to Q_{33} are each independently selected from 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, and a pyridinyl group,
d2 is an integer from 0 to 2,
d3 is an integer from 0 to 3,
d4 is an integer from 0 to 4,
d6 is an integer from 0 to 6,
d8 is an integer from 0 to 8, and
* and *' each indicate a binding site to a neighboring atom.

12. A heterocyclic compound according to any one of claims 9 to 11, wherein:
at least one selected from Ar_1 to Ar_3 is a group that is different from the others thereof.

13. A heterocyclic compound according to any one of claims 9 to 12, wherein:
at least one selected from Ar_1 to Ar_3 is a group represented by one selected from Formulae 2-2 to 2-4.

14. A heterocyclic compound according to any one of claims 9 to 13, wherein:

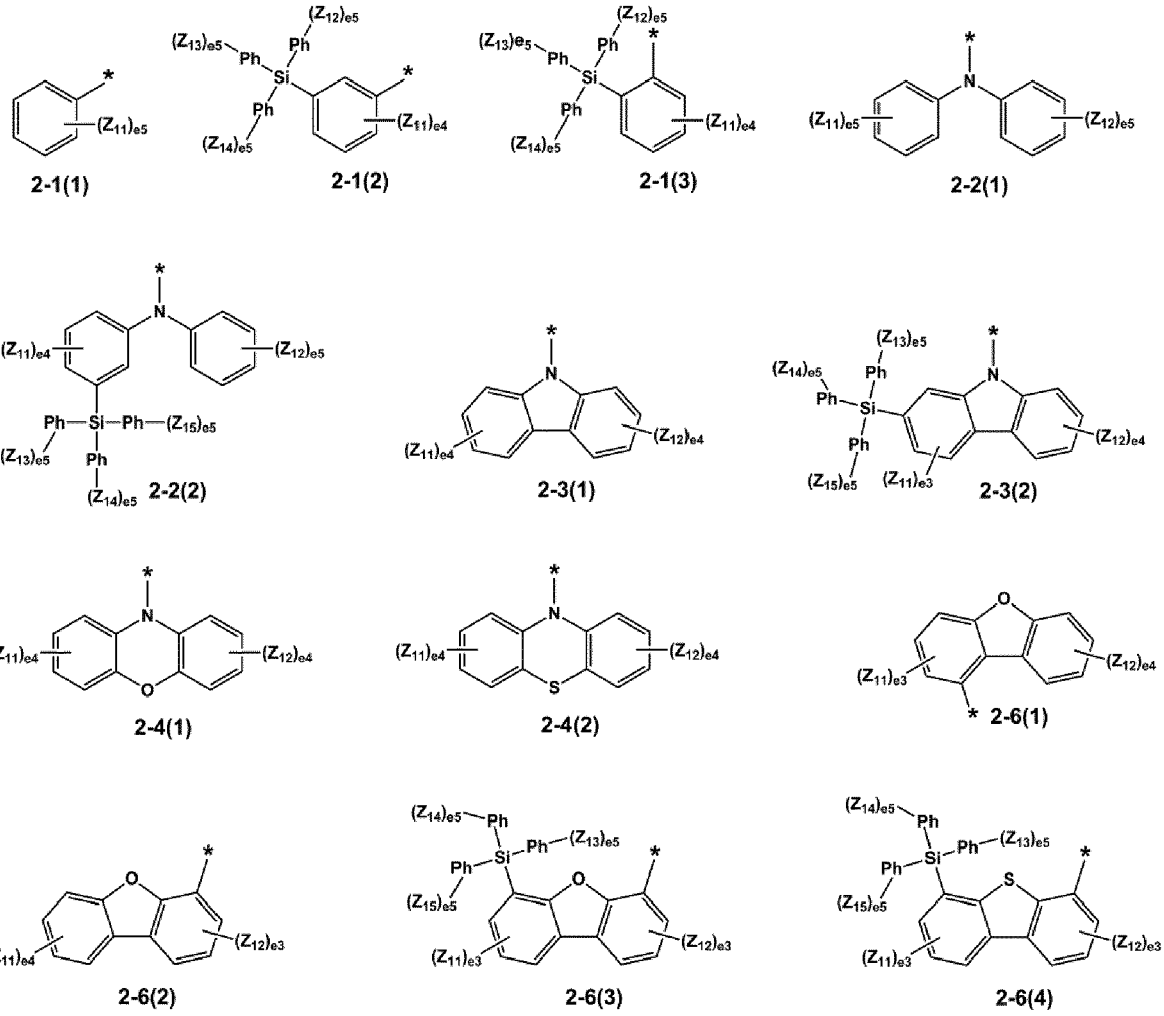
i) Ar_1 and Ar_2 are each a group represented by Formula 2-1, and Ar_3 is a group represented by Formula 2-2;
ii) Ar_1 and Ar_2 are each a group represented by Formula 2-1, and Ar_3 is a group represented by Formula 2-3;
iii) Ar_1 and Ar_2 are each a group represented by Formula 2-1, and Ar_3 is a group represented by Formula 2-4;
iv) Ar_1 is a group represented by Formula 2-1, and Ar_2 and Ar_3 are each a group represented by Formula 2-3;
v) Ar_1 is a group represented by Formula 2-1, and Ar_2 and Ar_3 are each a group represented by Formula 2-4;
vi) Ar_1 and Ar_2 are each a group represented by Formula 2-3, and Ar_3 is a group represented by Formula 2-6;
vii) Ar_1 is a group represented by Formula 2-1, Ar_2 is a group represented by Formula 2-2, and Ar_3 is a group represented by Formula 2-3; or
viii) Ar_1 is a group represented by Formula 2-1, Ar_2 is a group represented by Formula 2-3, and Ar_3 is a group represented by Formula 2-6.

15. A heterocyclic compound according to any one of claims 9 to 14, wherein:

i) when Ar_1 is a group represented by Formula 2-1, at least one selected from R_1(s) in the number of b5 is -$Si(Q_1)(Q_2)(Q_3)$, and
ii) when Ar_1 and Ar_2 are each a group represented by Formula 2-3 and Ar_3 is a group represented by Formula 2-6, at least one selected from R_{10}(s) in the number of b4 and R_{11}(s) in the number of b3 is -$Si(Q_1)(Q_2)(Q_3)$.

16. A heterocyclic compound according to any one of claims 9 to 15, wherein:
Ar_1 to Ar_3 are each independently a group represented by one selected from Formulae 2-1(1) to 2-1(3), 2-2(1) to

2-2(2), 2-3(1) to 2-3(2), 2-4(1) to 2-4(2), and 2-6(1) to 2-6(4):

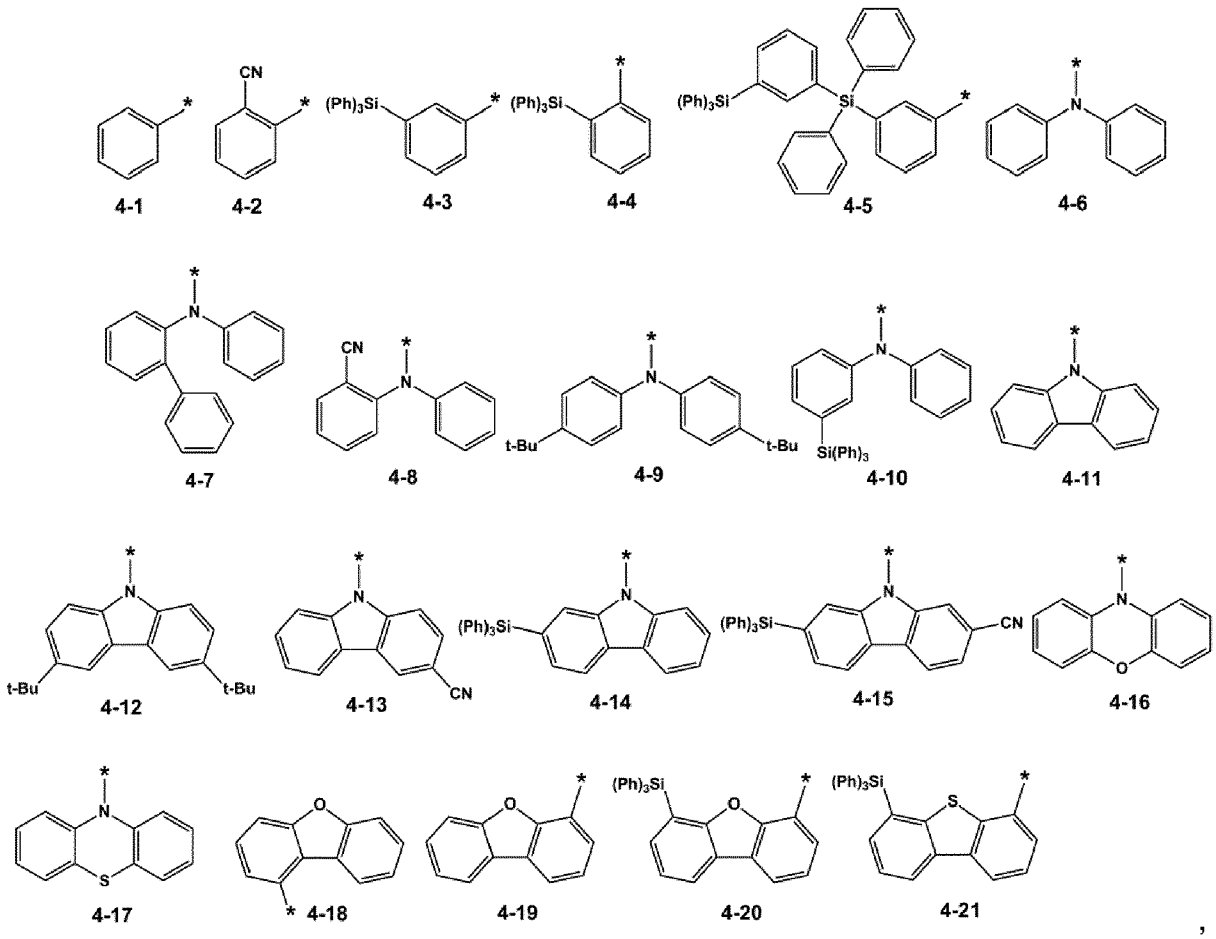


wherein, in Formulae 2-1(1) to 2-1(3), 2-2(1) to 2-2(2), 2-3(1) to 2-3(2), 2-4(1) to 2-4(2), and 2-6(1) to 2-6(4),

Z_{11} to Z_{15} are each independently selected from hydrogen, deuterium, -F, -Cl, - Br, -I, a hydroxyl group, a cyano group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a 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 pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a dibenzosilolyl group, and - $Si(Q_{31})(Q_{32})(Q_{33})$,
Q_{31} to Q_{33} are each independently selected from 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, and a pyridinyl group,
e3 is an integer from 0 to 3,
e4 is an integer from 0 to 4,
e5 is an integer from 0 to 5,
Ph indicates a phenyl group, and
* and *' each indicate a binding site to a neighboring atom.

17. A heterocyclic compound according to claim 16, wherein:
at least one selected from Ar_1 to Ar_3 is a group represented by one selected from Formulae 2-1(2), 2-1(3), 2-2(2), 2-3(2), 2-6(3), and 2-6(4).

18. A heterocyclic compound according to any one of claims 9 to 17, wherein:
Ar_1 to Ar_3 are each independently a group represented by one selected from Formulae 4-1 to 4-21:



,

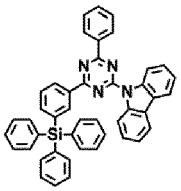
wherein, in Formulae 4-1 to 4-21,
Ph indicates a phenyl group, and t-Bu indicates a tert-butyl group.

19. A heterocyclic compound according to any one of claims 9 to 18, wherein:

i) X_1 to X_3 are each N;
ii) X_1 and X_2 are each N, and X_3 is $C(R_{15})$;
iii) X_1 and X_3 are each N, and X_2 is $C(R_{15})$;
iv) X_2 and X_3 are each N, and X_1 is $C(R_{15})$;
v) X_1 is N, and X_2 and X_3 are each $C(R_{15})$;
vi) X_2 is N, and X_1 and X_3 are each $C(R_{15})$; or
vii) X_3 is N, and X_1 and X_2 are each $C(R_{15})$,

and R_{15} is hydrogen.

20. A heterocyclic compound according to claim 9, wherein:
the heterocyclic compound is selected from Compounds 1 to 59:



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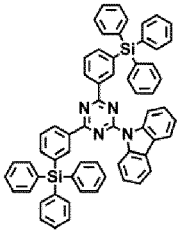

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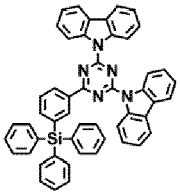

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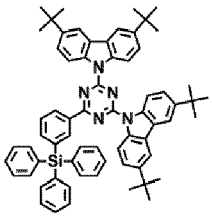

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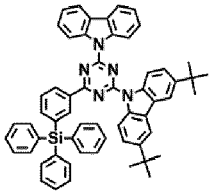

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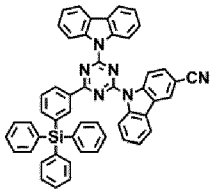

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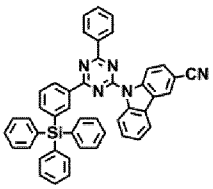

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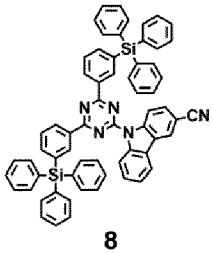

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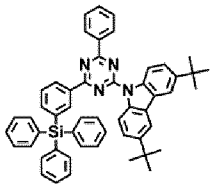

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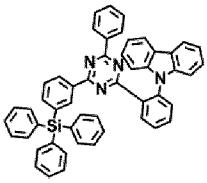

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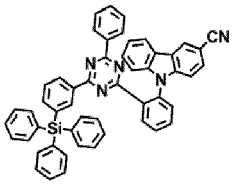

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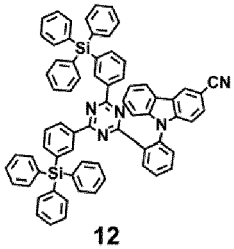

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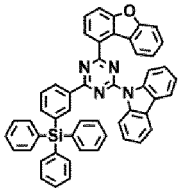

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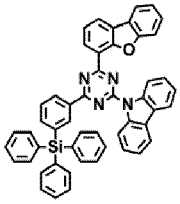

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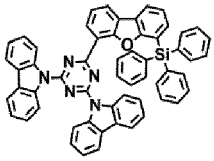

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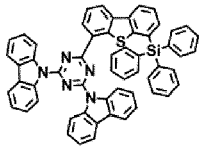

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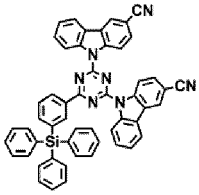

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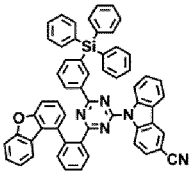

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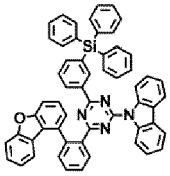

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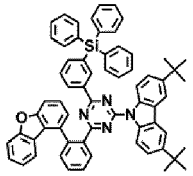

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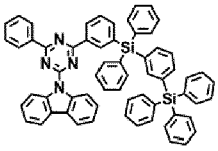

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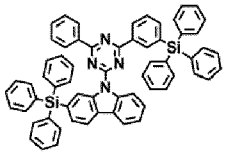

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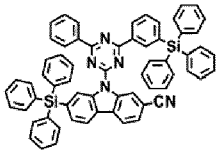

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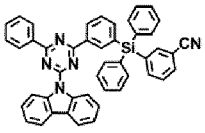

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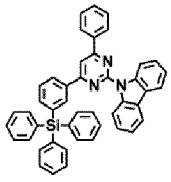

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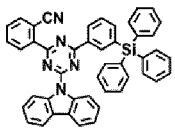

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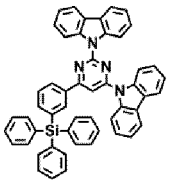

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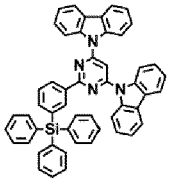

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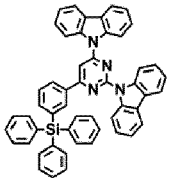

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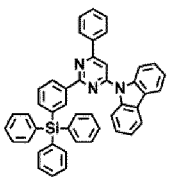

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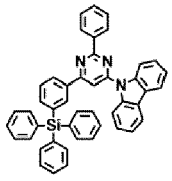

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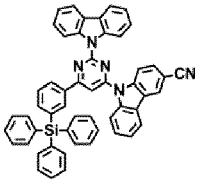

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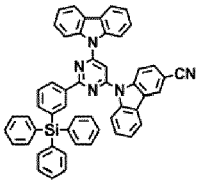

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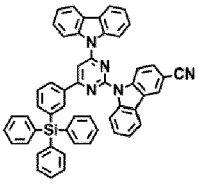

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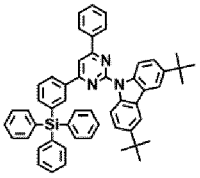

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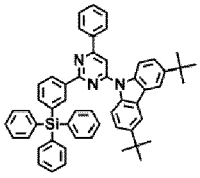

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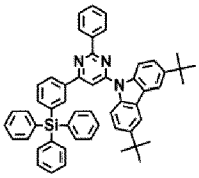

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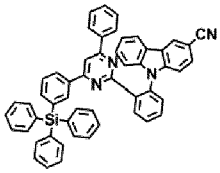

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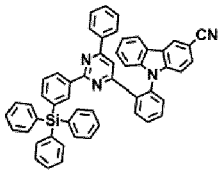

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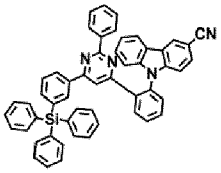

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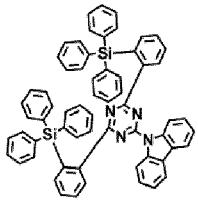

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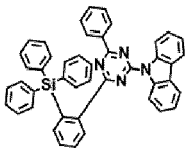

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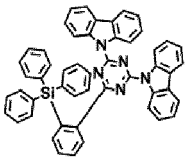

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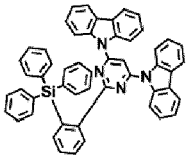

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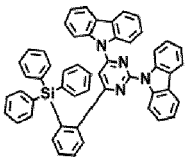

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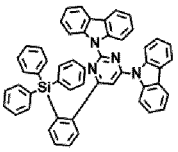

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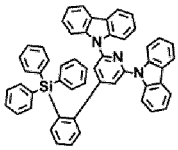

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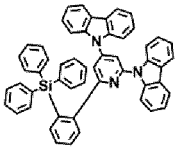

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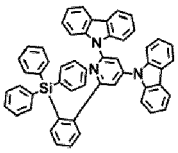

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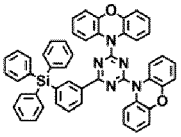

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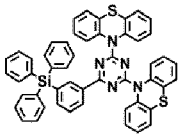

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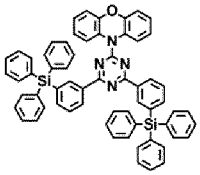

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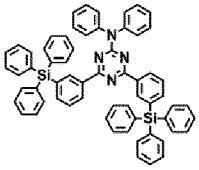

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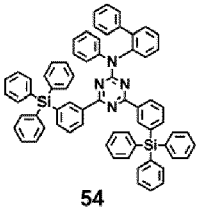

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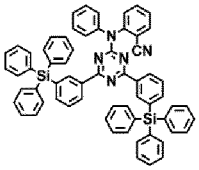

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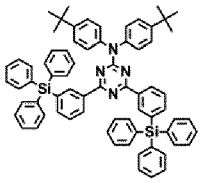

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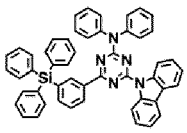

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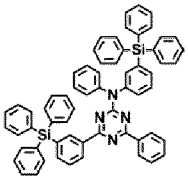

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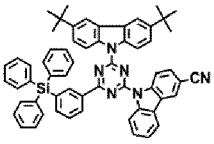


59

FIG. 1

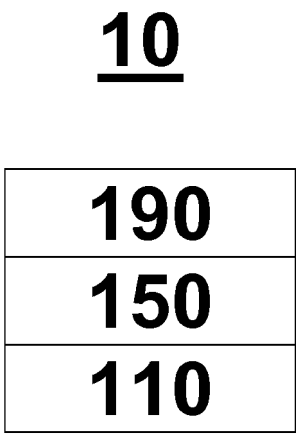


FIG. 2

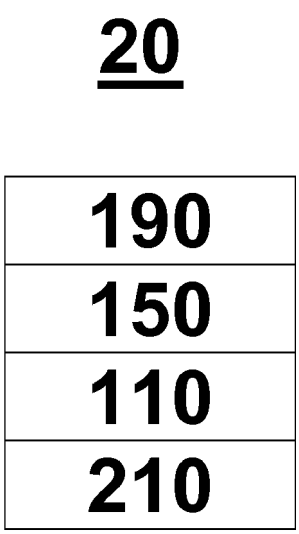


FIG. 3

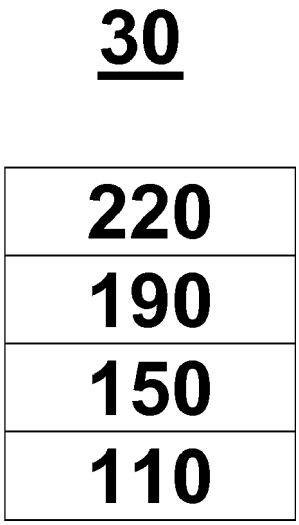
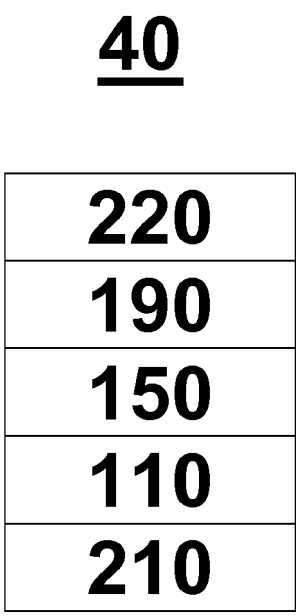


FIG. 4



REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

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专利名称(译)	杂环化合物和有机发光装置		
公开(公告)号	EP3657563A2	公开(公告)日	2020-05-27
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发明人	AHN, HEECHOON KIM, HYEONGMIN UM, HYUNAH LEE, YESEUL IM, YIRANG KO, SOOBYUNG KIM, YOUNGKOOK		
IPC分类号	H01L51/54 C07F7/08		
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优先权	1020180147692 2018-11-26 KR		
外部链接	Espacenet		

摘要(译)

杂环化合物由式1表示。有机发光器件包括：第一电极；和第二电极。面对第一电极的第二电极；在第一电极和第二电极之间的有机层包括发光层，其中有机发光器件包括杂环化合物中的至少一个。

FIG. 1