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HETEROCYCLIC COMPOUND, LIGHT-EMITTING DEVICE INCLUDING HETEROCYCLIC COMPOUND, AND APPARATUS INCLUDING LIGHT-EMITTING DEVICE

Abstract

A light-emitting device includes a heterocyclic compound represented by Formula 1:

##STR00001##

The heterocyclic compound represented by Formula 1 may have a high glass transition temperature (T_{sub.g}) and/or melting point for excellent thermal resistance, and excellent hole injectability and/or transportability. Accordingly, the light-emitting device may have excellent luminance, luminescence efficiency, lifespan, and/or driving voltage.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a divisional of U.S. patent application Ser. No. 17/316,580, filed on May 10, 2021, which claims priority to and the benefit of Korean Patent Application No. 10-2020-0057193, filed on May 13, 2020, in the Korean Intellectual Property Office, the entire contents of both of which are incorporated herein by reference.

BACKGROUND

1. Field

[0002] One or more aspects of embodiments of the present disclosure relate to a heterocyclic compound, a light-emitting device including the heterocyclic compound, and an apparatus including the light-emitting device.

2. Description of Related Art

[0003] Organic light-emitting devices (OLEDs) are self-emissive devices that, compared with devices in the related art, may have wide viewing angles, high contrast ratios, short response times, and/or excellent characteristics in terms of brightness, driving voltage, and/or response speed, and may produce full-color images.

[0004] OLEDs may include a first electrode on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode sequentially stacked 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 the holes and the electrons) may recombine in the emission layer to produce excitons. These excitons transition from an excited state to the ground state to thereby generate light.

SUMMARY

[0005] One or more aspects of embodiments of the present disclosure are directed toward a heterocyclic compound and a light-emitting device including the heterocyclic compound.

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

[0007] One or more example embodiments of the present disclosure provide a heterocyclic compound represented by Formula 1:

##STR00002##

[0008] wherein, in Formula 1, [0009] A.sub.1 to A.sub.3 may each independently be selected from a C.sub.5-C.sub.60 carbocyclic group and a C.sub.1-C.sub.60 heterocyclic group, [0010] L.sub.1 to L.sub.3 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10

cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, [0011] a₁, a₂, and a₃ may each independently be an integer from 0 to 5, [0012] Ar.sub.1 and Ar.sub.2 may each independently be selected from a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, [0013] R.sub.10, R.sub.20, and R.sub.30 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 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.sub.1-C.sub.60 alkyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkenyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkynyl group, a substituted or unsubstituted C.sub.1-C.sub.60 alkoxy group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —C(=O)(Q.sub.1), —S(=O).sub.2(Q.sub.1), and —P(=O)(Q.sub.1)(Q.sub.2), [0014] b₁₀, b₂₀, and b₃₀ may each independently be an integer from 1 to 8, [0015] * and *' each indicate a binding site to an adjacent atom, and [0016] at least one substituent of the substituted C.sub.3-C.sub.10 cycloalkylene group, the substituted C.sub.1-C.sub.10 heterocycloalkylene group, the substituted C.sub.3-C.sub.10 cycloalkenylene group, the substituted C.sub.1-C.sub.10 heterocycloalkenylene group, the substituted C.sub.6-C.sub.60 arylene group, the substituted C.sub.1-C.sub.60 heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C.sub.1-C.sub.60 alkyl group, the substituted C.sub.2-C.sub.60 alkenyl group, the substituted C.sub.2-C.sub.60 alkynyl group, the substituted C.sub.1-C.sub.60 alkoxy group, the substituted C.sub.3-C.sub.10 cycloalkyl group, the substituted C.sub.1-C.sub.10 heterocycloalkyl group, the substituted C.sub.3-C.sub.10 cycloalkenyl group, the substituted C.sub.1-C.sub.10 heterocycloalkenyl group, the substituted C.sub.6-C.sub.60 aryl group, the substituted C.sub.6-C.sub.60 aryloxy group, the substituted C.sub.6-C.sub.60 arylthio group, the substituted C.sub.1-C.sub.60 heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from: [0017] 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.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.60 alkoxy group, [0018] a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.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.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10

heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(=O)(Q.sub.11), —S(=O).sub.2(Q.sub.11), and —P(=O)(Q.sub.11)(Q.sub.12), [0019] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, [0020] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(=O)(Q.sub.21), —S(=O).sub.2(Q.sub.21), and —P(=O)(Q.sub.21)(Q.sub.22), and [0021] —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0022] wherein Q.sub.1 to Q.sub.3, Q.sub.11 to Q.sub.13, Q.sub.21 to Q.sub.23, and Q.sub.31 to Q.sub.33 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0023] One or more example embodiments of the present disclosure provide a light-emitting device including a first electrode, a second electrode facing the first electrode, an interlayer between the first electrode and the second electrode and including an emission layer, and at least one of the heterocyclic compound.

[0024] One or more example embodiments of the present disclosure provide an apparatus including the light-emitting device.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The above and other aspects, features, and advantages of certain embodiments of the disclosure will be more apparent from the following description taken in conjunction with the accompanying drawings, in which:

[0026] FIG. 1 is a schematic cross-sectional view illustrating a light-emitting device according to

an embodiment;

[0027] FIG. 2 is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment;

[0028] FIG. 3 is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment; and

[0029] FIG. 4 is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0030] 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, and duplicative descriptions thereof may not be provided. 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 drawings, to explain aspects 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.

Throughout the disclosure, the expression “at least one of a, b or c” may refer to only a, only b, only c, both a and b, both a and c, both b and c, all of a, b, and c, or variations thereof.

[0031] The present disclosure allows for various changes and numerous embodiments, and selected embodiments will be illustrated in the drawings and described in detail in the written description. Effects, features, and a method of achieving the present disclosure will be obvious by referring to the example embodiments of the present disclosure with reference to the attached drawings. The present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein.

[0032] In the embodiments described in the present specification, an expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context.

[0033] In the present specification, it is to be understood that the terms such as “having,” “includes,” “including,” “comprises,” and “comprising” are intended to indicate the existence of the features or components disclosed in the specification, and are not intended to preclude the possibility that one or more other features or components may exist or may be added.

[0034] As used herein, expressions such as “at least one of,” “one of,” and “selected from,” when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. Further, the use of “may” when describing embodiments of the present disclosure refers to “one or more embodiments of the present disclosure”.

[0035] It will be understood that when a layer, region, or component is referred to as being “on” or “onto” another layer, region, or component, it may be directly or indirectly formed over the other layer, region, or component. That is, for example, intervening layers, regions, or components may be present. When an element is referred to as being “directly on,” “directly connected to,” or “directly coupled to” another element, there are no intervening elements present.

[0036] The sizes of components in the drawings may be exaggerated for convenience of explanation. In other words, because sizes and thicknesses of components in the drawings are arbitrarily illustrated for convenience of explanation, the following embodiments are not limited thereto.

[0037] A heterocyclic compound according to one or more embodiments may be represented by Formula 1:

##STR00003##

[0038] In Formula 1, A.sub.1 to A.sub.3 may each independently be selected from a C.sub.5-C.sub.60 carbocyclic group and a C.sub.1-C.sub.60 heterocyclic group.

[0039] In some embodiments, A.sub.1 to A.sub.3 may each independently be selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene

group, a pyrene group, a chrysene group, a cyclopentadiene group, a 1,2,3,4-tetrahydronaphthalene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an indenopyridine group, an indolopyridine group, a benzofuropyridine group, a benzothienopyridine group, a benzosilolopyridine group, an indenopyrimidine group, an indolopyrimidine group, a benzofuropyrimidine group, a benzothienopyrimidine group, a benzosilolopyrimidine group, a dihydropyridine group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a 2,3-dihydroimidazole group, a triazole group, a 2,3-dihydrotriazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a 2,3-dihydrobenzimidazole group, an imidazopyridine group, a 2,3-dihydroimidazopyridine group, an imidazopyrimidine group, a 2,3-dihydroimidazopyrimidine group, an imidazopyrazine group, a 2,3-dihydroimidazopyrazine group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a 5,6,7,8-tetrahydroisoquinoline group, and a 5,6,7,8-tetrahydroquinoline group.

[0040] In some embodiments, A.sub.1 to A.sub.3 may each independently be selected from a benzene group, a naphthalene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, and a quinazoline group.

[0041] In some embodiments, A.sub.1 to A.sub.3 may each independently be a benzene group or a naphthalene group.

[0042] In Formula 1, L.sub.1 to L.sub.3 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group.

[0043] In some embodiments, L.sub.1 to L.sub.3 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 acenaphthylenylene group, a fluorenylene group, a spiro-bifluorenylene group, a spiro-fluorene-benzofluorenylene 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 pyrrolylene group, a thiophenylene group, a furanylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a pyridinylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, an isoindolylene group, an indolylene group, an indazolylene group, a purinylenylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylene group, a cinnolinylene group, a carbazolylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylene group, a benzofuranylenylene group, a benzothiophenylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an oxadiazolylene group, a triazinylene group, a

dibenzofuranylene group, a dibenzothiophenylylene group, a dibenzosilolylylene group, a benzocarbazolylylene group, a dibenzocarbazolylylene group, a thiadiazolylylene group, an imidazopyridinylylene group, and an imidazopyrimidinylylene group; and [0044] a phenylene group, a pentalenylylene group, an indenylene group, a naphthylylene group, an azulenylylene group, a heptalenylene group, an indacenylene group, an acenaphthylylene group, a fluorenylylene group, a spiro-bifluorenylylene group, a spiro-fluorene-benzofluorenylylene group, a benzofluorenylylene group, a dibenzofluorenylylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylylene group, a fluoranthenylylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylylene group, a perylenylene group, a pentaphenylylene group, a hexacenylene group, a pentacenylene group, a rubicenylylene group, a coronenylylene group, an ovalenylylene group, a pyrrolylylene group, a thiophenylylene group, a furanylylene group, an imidazolylylene group, a pyrazolylylene group, a thiazolylylene group, an isothiazolylylene group, an oxazolylylene group, an isoxazolylylene group, a pyridinylylene group, a pyrazinylylene group, a pyrimidinylylene group, a pyridazinylylene group, an isoindolylylene group, an indolylylene group, an indazolylylene group, a purinylylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylylene group, a naphthyridinylylene group, a quinoxalinylylene group, a quinazolinylene group, a cinnolinylene group, a carbazolylylene group, a phenanthridinylylene group, an acridinylylene group, a phenanthrolinylylene group, a phenazinylylene group, a benzimidazolylylene group, a benzofuranylylene group, a benzothiophenylylene group, an isobenzothiazolylylene group, a benzoxazolylylene group, an isobenzoxazolylylene group, a triazolylylene group, a tetrazolylylene group, an oxadiazolylylene group, a triazinylylene group, a dibenzofuranylylene group, a dibenzothiophenylylene group, a dibenzosilolylylene group, a benzocarbazolylylene group, a dibenzocarbazolylylene group, a thiadiazolylylene group, an imidazopyridinylylene group, and an imidazopyrimidinylylene 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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 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 pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolylylene group, a benzocarbazolyl group, a dibenzocarbazolyl group, a thiadiazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32),

[0045] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a phenyl group substituted with a

C.sub.1-C.sub.10 alkyl group, a biphenyl group, a terphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a triazinyl group, a quinolinyl group, and an isoquinolinyl group.

[0046] In some embodiments, L.sub.1 to L.sub.3 may each independently be represented by any one of Formulae 3-1 to 3-26:

##STR00004## ##STR00005## [0047] wherein, in Formulae 3-1 to 3-26, [0048] Z.sub.11 to Z.sub.14 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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 pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a triazinyl group, a benzimidazolyl group, a phenanthrolinyl group, and —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), [0049] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, [0050] d2 may be an integer from 0 to 2, [0051] d3 may be an integer from 0 to 3, [0052] d4 may be an integer from 0 to 4, [0053] d5 may be an integer from 0 to 5, [0054] d6 may be an integer from 0 to 6, [0055] d8 may be an integer from 0 to 8, and [0056] * and *' each indicate a binding site to an adjacent atom.

[0057] In Formula 1, a1, a2, and a3 may each independently be an integer from 0 to 5.

[0058] In some embodiments, a1, a2, and a3 may each independently be 0, 1, or 2.

[0059] In some embodiments, a1, a2, and a3 may each independently be 0 or 1.

[0060] In some embodiments, a1 and a2 may each be 0, and a3 may be 0 or 1.

[0061] In some embodiments, a3 may be 0.

[0062] In some embodiments, a1, a2, and a3 may each be 0.

[0063] In Formula 1, Ar.sub.1 and Ar.sub.2 may each independently be selected from a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0064] In some embodiments, Ar.sub.1 and Ar.sub.2 may each independently be selected from groups represented by Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55:

##STR00006## ##STR00007## ##STR00008## ##STR00009## ##STR00010## ##STR00011## ##STR00012## ##STR00013## ##STR00014## ##STR00015## ##STR00016## [0065] wherein, in Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55, [0066] Y.sub.31 and Y.sub.32 may each independently be O, S, C(Z.sub.33)(Z.sub.34), N(Z.sub.33), or Si(Z.sub.33)(Z.sub.34), [0067] Z.sub.31 to Z.sub.34 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkenyl group, a C.sub.1-C.sub.20 alkynyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a phenanthrenyl group, an anthracenyl group, a triphenylenyl group, a pyridinyl group, a pyrimidinyl group, a carbazolyl group, and a triazinyl group, [0068] e2 may be 1 or 2, [0069] e3 may be an integer from 1 to 3, [0070] e4 may be an integer from 1 to 4, [0071] e5 may be an integer from 1 to 5, [0072] e6 may be an integer from 1 to 6, [0073] e7 may be an integer from 1 to 7, [0074] e9 may be an integer from 1 to 9, and [0075] * indicates a binding site to an adjacent atom.

[0076] In some embodiments, Ar.sub.1 and Ar.sub.2 may each independently be selected from groups represented by Formulae 5-1 to 5-25.

[0077] In some embodiments, Ar.sub.1 and Ar.sub.2 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, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group.

[0078] In Formula 1, R.sub.10, R.sub.20, and R.sub.30 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 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.sub.1-C.sub.60 alkyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkenyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkynyl group, a substituted or unsubstituted C.sub.1-C.sub.60 alkoxy group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —C(=O)(Q.sub.1), —S(=O).sub.2(Q.sub.1), and —P(=O)(Q.sub.1)(Q.sub.2).

[0079] In some embodiments, R.sub.10, R.sub.20, and R.sub.30 may each independently be selected from: [0080] hydrogen, deuterium, —F —Cl, —Br, —I, a hydroxyl group, and a cyano group; [0081] a C.sub.1-C.sub.20 alkyl group, a C.sub.2-C.sub.20 alkenyl group, a C.sub.2-C.sub.20 alkynyl group, and a C.sub.1-C.sub.20 alkoxy group; [0082] a C.sub.1-C.sub.20 alkyl group, a C.sub.2-C.sub.20 alkenyl group, a C.sub.2-C.sub.20 alkynyl group, and a C.sub.1-C.sub.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 cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32); [0083] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a pentalenyl group, an indenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthrenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a furanyl group, a thiophenyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an

imidazopyridinyl group, and an imidazopyrimidinyl group; and [0084] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a pentalenyl group, an indenyl group, a naphthyl 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 pyrrolyl group, a furanyl group, a thiophenyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.20 alkyl group, a C.sub.2-C.sub.20 alkenyl group, a C.sub.2-C.sub.20 alkynyl group, a C.sub.1-C.sub.20 alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a pentalenyl group, an indenyl group, a naphthyl 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 pyrrolyl group, a furanyl group, a thiophenyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0085] wherein Q.sub.31 to Q.sub.33 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, a C.sub.2-C.sub.20 alkenyl group, a C.sub.2-C.sub.20 alkynyl group, a C.sub.1-C.sub.20 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.20 aryl group, a C.sub.1-C.sub.20 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0086] In some embodiments, R.sub.10, R.sub.20, and R.sub.30 may each independently be selected from: [0087] hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, and a C.sub.1-C.sub.20 alkoxy group; [0088] a C.sub.1-C.sub.20 alkyl group and a C.sub.1-C.sub.20 alkoxy group, each substituted with at least one selected from deuterium,

—F, —Cl, —Br, —I, a cyano group, a phenyl group, and a biphenyl group; [0089] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group; and [0090] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a phenyl group, and a biphenyl group.

[0091] In some embodiments, R.sub.10 may be hydrogen.

[0092] In some embodiments, R.sub.20 and R.sub.30 may each be hydrogen.

[0093] In some embodiments, the heterocyclic compound may include one amine group.

[0094] In Formula 1, b10 and b30 may each independently be an integer from 1 to 7, and b20 and b40 may each independently be an integer from 1 to 8.

[0095] In some embodiments, b10 and b30 may each independently be 1, 2, or 3.

[0096] In some embodiments, b20 and b40 may each independently be 1, 2, 3, or 4.

[0097] * and *' each indicate a binding site to an adjacent atom.

[0098] At least one substituent of the substituted C.sub.5-C.sub.60 carbocyclic group, the substituted C.sub.1-C.sub.60 heterocyclic group, the substituted C.sub.1-C.sub.60 alkyl group, the substituted C.sub.2-C.sub.60 alkenyl group, the substituted C.sub.2-C.sub.60 alkynyl group, the substituted C.sub.1-C.sub.60 alkoxy group, the substituted C.sub.3-C.sub.10 cycloalkyl group, the substituted C.sub.1-C.sub.10 heterocycloalkyl group, the substituted C.sub.3-C.sub.10 cycloalkenyl group, the substituted C.sub.1-C.sub.10 heterocycloalkenyl group, the substituted C.sub.6-C.sub.60 aryl group, the substituted C.sub.6-C.sub.60 aryloxy group, the substituted C.sub.6-C.sub.60 arylthio group, the substituted C.sub.1-C.sub.60 heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from: [0099] 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.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.60 alkoxy group; [0100] a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.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.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(=O)(Q.sub.11), —S(=O).sub.2(Q.sub.11), and —P(=O)(Q.sub.11)(Q.sub.12); [0101] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group; [0102] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed

heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(=O)(Q.sub.21), —S(=O).sub.2(Q.sub.21), and —P(=O)(Q.sub.21)(Q.sub.22); and [0103] —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0104] wherein Q.sub.1 to Q.sub.3, Q.sub.11 to Q.sub.13, Q.sub.21 to Q.sub.23, and Q.sub.31 to Q.sub.33 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0105] The heterocyclic compound according to one or more embodiments may be represented by any one of Formulae 10.sup.-1 to 10.sup.-3:

##STR00017## [0106] wherein, in Formulae 10.sup.-1 to 10.sup.-3, [0107] L.sub.1 to L.sub.3, a₁, a₂, a₃, Ar.sub.1, and Ar.sub.2 may each independently be the same as described above, [0108] R.sub.11 to R.sub.13 may each independently be the same as described in connection with R.sub.10, [0109] R.sub.21 to R.sub.23 may each independently be the same as described in connection with R.sub.20, and [0110] R.sub.31 to R.sub.33 may each independently be the same as described in connection with R.sub.30.

[0111] In some embodiments, the heterocyclic compound may be selected from Compounds 1 to 123:

##STR00018## ##STR00019## ##STR00020## ##STR00021## ##STR00022## ##STR00023##
##STR00024## ##STR00025## ##STR00026## ##STR00027## ##STR00028## ##STR00029##
##STR00030## ##STR00031## ##STR00032## ##STR00033## ##STR00034## ##STR00035##
##STR00036## ##STR00037## ##STR00038## ##STR00039## ##STR00040## ##STR00041##
##STR00042## ##STR00043## ##STR00044## ##STR00045## ##STR00046## ##STR00047##
##STR00048## ##STR00049## ##STR00050## ##STR00051## ##STR00052## ##STR00053##
##STR00054## ##STR00055## ##STR00056## ##STR00057## ##STR00058##

[0112] The heterocyclic compound represented by Formula 1 according to one or more embodiments may have a high glass transition temperature (T.sub.g) and/or a high melting point, and may thus have excellent thermal resistance.

[0113] In addition, the heterocyclic compound represented by Formula 1 may have excellent hole injectability and/or transportability. As a result of its structure, the heterocyclic compound may provide improved hole mobility in the light-emitting device, thereby facilitating improved control of charge balance in the light-emitting device and improving its lifespan and/or efficiency.

[0114] Accordingly, when the heterocyclic compound is used as a material for a light-emitting device, the light-emitting device may have excellent durability during storage and/or may have excellent driving voltage, and thus, the light-emitting device may have high efficiency, low driving voltage, high luminance, and/or long lifespan.

[0115] Methods of synthesizing the heterocyclic compound represented by Formula 1 should be

readily understood by those of ordinary skill in the art by referring to Examples described herein. [0116] At least one heterocyclic compound represented by Formula 1 may be included between a pair of electrodes in a light-emitting device. In some embodiments, the heterocyclic compound may be included in at least one selected from a hole transport region, an electron transport region, and an emission layer.

[0117] In some embodiments, the heterocyclic compound represented by Formula 1 may be used as a material for forming a capping layer on at least one outer side of the pair of electrodes in the light-emitting device (e.g., on a side of the cathode facing away from the anode and/or on a side of the anode facing away from the cathode).

[0118] Accordingly, there is provided a light-emitting device including a first electrode; a second electrode facing the first electrode; an interlayer between the first electrode and the second electrode and including an emission layer; and at least one heterocyclic compound represented by Formula 1.

[0119] In an embodiment, the first electrode may be an anode, and the second electrode may be a cathode, [0120] the interlayer may include the heterocyclic compound, and [0121] the interlayer may further include a hole transport region between the first electrode and the emission layer, and an electron transport region between the emission layer and the second electrode, [0122] wherein the hole transport region may include a hole injection layer, a hole transport layer, an emission auxiliary layer, an electron blocking layer, or any combination thereof, and [0123] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or a combination thereof.

[0124] In some embodiments, the hole transport region of the light-emitting device may include the heterocyclic compound.

[0125] In some embodiments, the hole transport region of the light-emitting device may include a hole injection layer, and the hole injection layer may include the heterocyclic compound. In some embodiments, the hole transport region of the light-emitting device may include a hole transport layer, and the hole transport layer may include the heterocyclic compound.

[0126] In some embodiments, the emission layer of the light-emitting device may include a host and a dopant. In some embodiments, the emission layer may include at least one of a phosphorescent dopant and a fluorescent dopant as a dopant. In some embodiments, the emission layer may include a fluorescent dopant.

[0127] In some embodiments, the emission layer of the light-emitting device may be to emit blue light having a maximum emission wavelength of about 420 nanometers (nm) to about 490 nm.

[0128] An emission layer of the light-emitting device may include quantum dots.

[0129] The term “interlayer” as used herein refers to a single layer and/or a plurality of all layers between a first electrode and a second electrode in a light-emitting device.

[0130] The materials included in the “interlayer” are not limited to being an organic material.

Description of FIG. 1

[0131] FIG. 1 is a schematic view of a light-emitting device **10** according to an embodiment. The light-emitting device **10** may include a first electrode **110**, an interlayer **150**, and a second electrode **190**.

[0132] Hereinafter, the structure of the light-emitting device **10** according to an embodiment and a method of manufacturing the near-infrared light-emitting diode **10** according to an embodiment will be described in connection with FIG. 1.

First Electrode **110**

[0133] In FIG. 1, a substrate may be additionally located under the first electrode **110** and/or above the second electrode **190**. The substrate may be a glass substrate and/or a plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and/or water resistance.

[0134] The first electrode **110** may be formed by depositing or sputtering a material for forming the

first electrode **110** onto the substrate. When the first electrode **110** is an anode, the material for forming the first electrode **110** may be selected from materials with a high work function to facilitate hole injection.

[0135] 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, the material for forming the first electrode **110** may be selected from indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO₂), zinc oxide (ZnO), and any combination thereof, but embodiments are not limited thereto. In some embodiments, when the first electrode **110** is a semi-transmissive electrode or a reflective electrode, at least one of magnesium (Mg), silver (Ag), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or any combination thereof may be used as the material for forming the first electrode **110**, but embodiments are not limited thereto.

[0136] The first electrode **110** may have a single-layered structure, or a multi-layered structure including two or more layers. In some embodiments, the first electrode **110** may have a triple-layered structure of ITO/Ag/ITO, but embodiments are not limited thereto.

Interlayer **150**

[0137] The interlayer **150** may be on the first electrode **110**. The interlayer **150** may include an emission layer.

[0138] The interlayer **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 Interlayer **150**

[0139] The hole transport region may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.

[0140] The hole transport region may include at least one selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

[0141] For example, the hole transport region may have a single-layered structure including a plurality of different materials or a multi-layered structure, e.g., 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 the constituting layers of each structure are sequentially stacked on the first electrode **110** in each stated order, but embodiments are not limited thereto.

[0142] The hole transport region may include the heterocyclic compound.

[0143] In some embodiments, the hole transport region may additionally include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB (NPD), p-NPB, TPD, a spiro-TPD, a spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4''-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzene sulfonic acid (PANI/DBSA), poly(3,4-ethylene dioxythiophene)/poly(4-styrene sulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrene sulfonate) (PANI/PSS), a compound represented by Formula 201, and a compound represented by Formula 202:

##STR00059## ##STR00060## ##STR00061## ##STR00062## [0144] wherein, in Formulae 201 and 202, [0145] L.sub.201 to L.sub.204 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed

heteropolycyclic group, [0146] L.sub.205 may be selected from *—O—*, *—S—*, *—N(Q.sub.201)—*, a substituted or unsubstituted C.sub.1-C.sub.20 alkylene group, a substituted or unsubstituted C.sub.2-C.sub.20 alkenylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, [0147] xa1 to xa4 may each independently be an integer from 0 to 3, [0148] xa5 may be an integer from 1 to 10, and [0149] R.sub.201 to R.sub.204 and Q.sub.201 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0150] In some embodiments, in Formula 202, R.sub.201 and R.sub.202 may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R.sub.203 and R.sub.204 may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0151] In some embodiments, in Formulae 201 and 202, [0152] L.sub.201 to L.sub.205 may each independently be selected from: [0153] 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 [0154] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.1-C.sub.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.sub.31)(Q.sub.32)(Q.sub.33), and —N(Q.sub.31)(Q.sub.32), [0155] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0156] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0157] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0158] In one or more embodiments, R.sub.201 to R.sub.204 and Q.sub.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 [0159] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.1-C.sub.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.

group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), and —N(Q.sub.31)(Q.sub.32), [0160] wherein Q.sub.31 to Q.sub.33 may each independently be the same as described above.

[0161] In one or more embodiments, in Formula 201, at least one of R.sub.201 to R.sub.203 may be selected from: [0162] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and [0163] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.1-C.sub.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, [0164] but embodiments are not limited thereto.

[0165] In one or more embodiments, in Formula 202, i) R.sub.201 and R.sub.202 may be bound via a single bond, and/or ii) R.sub.203 and R.sub.204 may be bound via a single bond.

[0166] In one or more embodiments, in Formula 202, at least one of R.sub.201 to R.sub.204 may be selected from: [0167] a carbazolyl group; and [0168] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.1-C.sub.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, [0169] but embodiments are not limited thereto.

##STR00063##

[0170] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201-2, but embodiments are not limited thereto:

##STR00064##

[0171] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201-2(1), but embodiments are not limited thereto:

##STR00065##

[0172] The compound represented by Formula 201 may be represented by Formula 201A:

##STR00066##

[0173] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A(1), but embodiments are not limited thereto:

##STR00067##

[0174] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A-1, but embodiments are not limited thereto:

##STR00068##

[0175] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202-1:

##STR00069##

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

##STR00070##

[0177] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A:

##STR00071##

[0178] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A-1:

##STR00072##

[0179] In Formulae 201-1, 201-2, 201-2(1), 201A, 201A(1), 201A-1, 202-1, 202-1(1), 202A, and 202A-1, [0180] L.sub.201 to L.sub.203, xa1 to xa3, xa5, and R.sub.202 to R.sub.204 may each independently be the same as described above, [0181] L.sub.205 may be selected from a phenylene group and a fluorenylene group, [0182] X.sub.211 may be selected from O, S, and N(R.sub.211), [0183] X.sub.212 may be selected from O, S, and N(R.sub.212), [0184] R.sub.211 and R.sub.212 may each independently be the same described in connection with R.sub.203, and [0185]

R.sub.213 to R.sub.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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.1-C.sub.1 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.

[0186] The hole transport region may include at least one compound selected from Compounds HT1 to HT48, but embodiments are not limited thereto:

##STR00073## ##STR00074## ##STR00075## ##STR00076## ##STR00077## ##STR00078## ##STR00079## ##STR00080##

[0187] The thickness of the hole transport region may be about 100 (Angstroms) Å to about 10,000 Å, and in some embodiments, 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 about 100 Å to about 9,000 Å, and in some embodiments, about 100 Å to about 1,000 Å, and the thickness of the hole transport layer may be about 50 Å to about 2,000 Å, and in some embodiments, about 100 Å to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within any of these ranges, excellent hole transport characteristics may be obtained without a substantial increase in driving voltage.

[0188] The emission auxiliary layer may increase the light emission efficiency of the device by compensating for an optical resonance distance of the wavelength of light emitted by an emission layer. The electron blocking layer may reduce or eliminate the flow of electrons from an electron transport region. The emission auxiliary layer and the electron blocking layer may each include the materials described above.

p-Dopant

[0189] The hole transport region may include a charge generating material in addition to the above-described materials, to improve the conductive properties of the hole transport region. The charge generating material may be substantially homogeneously or non-homogeneously dispersed in the hole transport region.

[0190] The charge generating material may include, for example, a p-dopant.

[0191] In some embodiments, the lowest unoccupied molecular orbital (LUMO) energy level of the

p-dopant may be -3.5 eV or less.

[0192] The p-dopant may include at least one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments are not limited thereto.

[0193] In some embodiments, the p-dopant may include: [0194] a quinone derivative (such as tetracyanoquinodimethane (TCNQ) and/or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ)); [0195] a metal oxide (such as tungsten oxide and/or molybdenum oxide); [0196] 1,4,5,8,9,12-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and [0197] a compound represented by Formula 221, [0198] but embodiments are not limited thereto:

##STR00081## [0199] wherein, in Formula 221, [0200] R.sub.221 to R.sub.223 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.1 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, wherein at least one selected from R.sub.221 to R.sub.223 may include at least one substituent selected from a cyano group, $-F$, $-Cl$, $-Br$, $-I$, a C.sub.1-C.sub.20 alkyl group substituted with $-F$, a C.sub.1-C.sub.20 alkyl group substituted with $-C$.sub.1, a C.sub.1-C.sub.20 alkyl group substituted with $-Br$, and a C.sub.1-C.sub.20 alkyl group substituted with $-I$.

Emission Layer in Interlayer 150

[0201] When the light-emitting device **10** is a full color light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, and a blue emission layer, according to a sub-pixel. In one or more embodiments, the emission layer may have a stacked structure. The stacked structure may include two or more layers selected from a red emission layer, a green emission layer, and a blue emission layer. In some embodiments, the two or more layers may be in direct contact with each other. In some embodiments, the two or more layers may be separated from each other. In one or more embodiments, the emission layer may include two or more materials. The two or more materials may each independently include a red light-emitting material, a green light-emitting material, or a blue light-emitting material. The two or more materials may be mixed with each other in a single layer. In some embodiments, the two or more materials mixed with each other in the single layer may be to emit white light.

[0202] The emission layer may include a host and a dopant. The dopant may include at least one of a fluorescent dopant and a phosphorescent dopant.

[0203] The amount of the dopant in the emission layer may be about 0.01 parts to about 15 parts by weight based on 100 parts by weight of the host, but embodiments are not limited thereto.

[0204] The thickness of the emission layer may be about 100 Å to about 1,000 Å, and in some embodiments, about 200 Å to about 600 Å. When the thickness of the emission layer is within any of these ranges, improved luminescence characteristics may be obtained without a substantial increase in driving voltage.

Host in Emission Layer

[0205] The host may include a compound represented by Formula 301:

[Ar.sub.301].sub.xb11—[(L.sub.301).sub.xb1—R.sub.301].sub.xb21, Formula 301 [0206] wherein, in Formula 301, [0207] Ar.sub.301 may be selected from a substituted or unsubstituted C.sub.5-C.sub.60 carbocyclic group and a substituted or unsubstituted C.sub.1-C.sub.60 heterocyclic group, [0208] xb11 may be 1, 2, or 3, [0209] L.sub.301 may be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene

group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, [0210] xb1 may be an integer from 0 to 5, [0211] R.sub.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.sub.1-C.sub.60 alkyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkenyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkynyl group, a substituted or unsubstituted C.sub.1-C.sub.60 alkoxy group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.301)(Q.sub.302)(Q.sub.303), —N(Q.sub.301)(Q.sub.302), —B(Q.sub.301)(Q.sub.302), —C(=O)(Q.sub.301), —S(=O).sub.2(Q.sub.301), and —P(=O)(Q.sub.301)(Q.sub.302), and [0212] xb21 may be an integer from 1 to 5, [0213] wherein Q.sub.301 to Q.sub.303 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0214] In some embodiments, in Formula 301, Ar.sub.301 may be selected from: [0215] 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 [0216] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0217] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0218] When xb11 in Formula 301 is 2 or greater, at least two Ar.sub.301(s) may be bound via a single bond.

[0219] In one or more embodiments, the compound represented by Formula 301 may be represented by Formula 301-1 or 301-2:

##STR00082## [0220] wherein, in Formulae 301-1 to 301-2, [0221] A.sub.301 to A.sub.304 may each independently be selected from a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a pyridine group, a pyrimidine group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a carbazole group, a benzocarbazole group, a dibenzocarbazole group, a furan group, a benzofuran group, a dibenzofuran group, a naphthofuran group, a benzonaphthofuran group, a dinaphthofuran group, a thiophene group, a benzothiophene

group, a dibenzothiophene group, a naphthothiophene group, a benzonaphthothiophene group, and a dinaphthothiophene group, [0222] X.sub.301 may be O, S, or N—[(L.sub.304).sub.xb4—R.sub.304], [0223] R.sub.311 to R.sub.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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0224] xb22 and xb23 may each independently be 0, 1, or 2, [0225] L.sub.301, xb1, R.sub.301, and Q.sub.31 to Q.sub.33 may each independently be the same as described above, [0226] L.sub.302 to L.sub.304 may each independently be the same as described herein in connection with L.sub.301, [0227] xb2 to xb4 may each independently be the same as described herein in connection with xb1, and [0228] R.sub.302 to R.sub.304 may each independently be the same as described herein in connection with R.sub.301.

[0229] In some embodiments, in Formulae 301, 301-1, and 301-2, L.sub.301 to L.sub.304 may each independently be selected from: [0230] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group; and [0231] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group, each substituted with at least one selected from deuterium, —F, —Cl,

—Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0232] wherein Q.sub.31 to Q.sub.33 may each independently be the same as described above.

[0233] In some embodiments, in Formulae 301, 301-1, and 301-2, R.sub.301 to R.sub.304 may each independently be selected from: [0234] 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 [0235] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0236] wherein Q.sub.31 to Q.sub.33 may each independently be the same as described above.

[0237] In some embodiments, the host may include an alkaline earth metal complex. For example, the host may include a beryllium (Be) complex, e.g., Compound H55, or a magnesium (Mg) complex. In some embodiments, the host may be or include a zinc (Zn) complex.

[0238] 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 are not limited thereto:

##STR00083## ##STR00084## ##STR00085## ##STR00086## ##STR00087## ##STR00088##
##STR00089## ##STR00090## ##STR00091## ##STR00092## ##STR00093## ##STR00094##
##STR00095##

[0239] In some embodiments, the emission layer may include quantum dots.

[0240] A quantum dot is a particle having a crystal structure of several to tens of nanometers in size. The quantum dot may include hundreds to thousands of atoms.

[0241] Because the quantum dot is very small in size, quantum confinement effects may occur. “Quantum confinement” is a phenomenon in which a band gap of an object (e.g., of a crystal or particle) becomes larger when the object becomes smaller in size and approaches the above-described nanometer scale. Accordingly, when light having an energy larger than the band gap of the quantum dot is incident on the quantum dot, the quantum dot absorbs the light so that an electron is excited and then falls to the ground state, such that light (e.g., a photon) having a particular wavelength is emitted.

[0242] In this case, the wavelength of the emitted light may have a value corresponding to the band gap of the quantum dot.

[0243] A core of the quantum dot may include a II-VI compound, a III-VI compound, a III-V compound, a IV-VI compound, a Group IV element or compound, a I-III-VI compound, or a combination thereof.

[0244] The II-VI compound may be selected from: a binary compound selected from the group consisting of CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnO, HgS, HgSe, HgTe, MgSe, MgS, and

mixtures thereof; a ternary compound selected from the group consisting of CdSeS, CdSeTe, CdSTe, ZnSeS, ZnSeTe, ZnSTe, HgSeS, HgSeTe, HgSTe, CdZnS, CdZnSe, CdZnTe, CdHgS, CdHgSe, CdHgTe, HgZnS, HgZnSe, HgZnTe, MgZnSe, MgZnS, and mixtures thereof; and a quaternary compound selected from the group consisting of CdZnSeS, CdZnSeTe, CdZnSTe, CdHgSeS, CdHgSeTe, CdHgSTe, HgZnSeS, HgZnSeTe, HgZnSTe, and mixtures thereof.

[0245] The III-VI compound may include a binary compound such as In.sub.2S.sub.3 or In.sub.2Se.sub.3; a ternary compound such as InGaS.sub.3 or InGaSe.sub.3; or any combination thereof.

[0246] The III-V compound may be selected from: a binary compound selected from the group consisting of GaN, GaP, GaAs, GaSb, AlN, AlP, AlAs, AlSb, InN, InP, InAs, InSb and mixtures thereof; a ternary compound selected from the group consisting of GaNP, GaNAs, GaNSb, GaPAs, GaPSb, AlNP, AlNAs, AlNSb, AlPAs, AlPSb, InGaP, InAlP, InNP, InNAs, InNSb, InPAs, InPSb, GaAlNP, and mixtures thereof; and a quaternary compound selected from the group consisting of GaAlNAs, GaAlNSb, GaAlPAs, GaAlPSb, GaInNP, GaInNAs, GaInNSb, GaInPAs, GaInPSb, InAlNP, InAlNAs, InAlNSb, InAlPAs, InAlPSb, and mixtures thereof. The III-V semiconductor compound may further include a Group II metal (e.g., InZnP).

[0247] The IV-VI compound may be selected from: a binary compound selected from the group consisting of SnS, SnSe, SnTe, PbS, PbSe, PbTe, and mixtures thereof; a ternary compound selected from the group consisting of SnSeS, SnSeTe, SnSTe, PbSeS, PbSeTe, PbSTe, SnPbS, SnPbSe, SnPbTe, and mixtures thereof; and a quaternary compound selected from the group consisting of SnPbSSe, SnPbSeTe, SnPbSTe, and mixtures thereof. The Group IV element may be selected from the group consisting of Si, Ge, and mixtures thereof. The IV compound may be a binary compound selected from the group consisting of SiC, SiGe, and mixtures thereof.

[0248] The I-III-VI semiconductor compound may include a ternary compound such as AgInS, AgInS.sub.2, CuInS, CuInS.sub.2, CuGaO.sub.2, AgGaO.sub.2, AgAlO.sub.2, or any combination thereof.

[0249] In some embodiments, the binary compound, the ternary compound, and/or the quaternary compound may be present in each particle at a substantially uniform concentration. or may be included at varying concentrations within each particle (e.g., to form a gradient within each particle). In some embodiments, for example, a quantum dot may have a core-shell structure. An interface between the core and the shell may have a concentration gradient, in which the concentration of elements present in the shell decreases toward the center (e.g., is decreased or absent in the core).

[0250] In some embodiments, for example, the quantum dot may have a core-shell structure, including a core as the nanocrystal described above and a shell surrounding the core. The shell of the quantum dot may serve as a protective layer to prevent or reduce chemical denaturation of the core to maintain its semiconductor characteristics, and/or as a charging layer for imparting electrophoretic characteristics to the quantum dot. The shell may be a monolayer or a multilayer structure. The interface between the core and the shell may have a concentration gradient where a concentration of elements present in the shell decreases toward the center. Non-limiting examples of materials that may be included in the shell of the quantum dot include metal or nonmetal oxide, a semiconductor compound, or a combination thereof.

[0251] In some embodiments, the metal or nonmetal oxide may be a binary compound (such as SiO.sub.2, Al.sub.2O.sub.3, TiO.sub.2, ZnO, MnO, Mn.sub.2O.sub.3, Mn.sub.3O.sub.4, CuO, FeO, Fe.sub.2O.sub.3, Fe.sub.3O.sub.4, CoO, CO.sub.3O.sub.4, and/or NiO), or a ternary compound (such as MgAl.sub.2O.sub.4, CoFe.sub.2O.sub.4, NiFe.sub.2O.sub.4, and/or CoMn.sub.2O.sub.4), but embodiments are not limited thereto.

[0252] In addition, the semiconductor compound may be CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnSeS, ZnTeS, GaAs, GaP, GaSb, HgS, HgSe, HgTe, InAs, InP, InGaP, InSb, AlAs, AlP, or AlSb, but embodiments are not limited thereto.

[0253] The quantum dot may have a spectral full width at half maximum (FWHM) of an emission wavelength of about 45 nm or less, about 40 nm or less, or about 30 nm or less. When the FWHM of the quantum dot is within this range, color purity and/or color reproducibility may be improved. In addition, because light emitted by the quantum dot is emitted in all directions, an optical viewing angle of a device including the organic light emitting device including the quantum dot may be improved.

[0254] The form (format or shape) of the quantum dot may have any suitable form available in the art, and is not particularly limited. For example, the quantum dot may have a spherical form, a pyramidal form, or a multi-armed form, or may have the shape of a cubic nanoparticle, a nanotube, a nanowire, a nanofiber, a nano-plate particle, and/or the like.

[0255] The quantum dot may control color of emitted light according to the particle size. Accordingly, the quantum dot may have various emission colors such as blue, red, or green.

Phosphorescent Dopant Included in Emission Layer of Interlayer 150

[0256] The phosphorescent dopant may include an organometallic complex represented by Formula 401:

##STR00096## [0257] wherein, in Formulae 401 and 402, [0258] M may be 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), [0259] L.sub.401 may be selected from ligands represented by Formula 402, and xc1 may be 1, 2, or 3; and when xc1 is 2 or greater, at least two L.sub.401(s) may be identical to or different from each other, [0260] L.sub.402 may be an organic ligand, and xc2 may be an integer selected from 0 to 4; and when xc2 is 2 or greater, at least two L.sub.402(s) may be identical to or different from each other, [0261] X.sub.401 to X.sub.404 may each independently be a nitrogen or a carbon, [0262] X.sub.401 and X.sub.403 may be bound to each other via a single bond or a double bond, and X.sub.402 and X.sub.404 may be bound to each other via a single bond or a double bond, [0263] A.sub.401 and A.sub.402 may each independently be a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0264] X.sub.405 may be a single bond, *—O—*, *—S—* *—C(=O)—*, *—N(Q.sub.411)—*, *—C(Q.sub.411)(Q.sub.412)—*, *—C(Q.sub.411)=C(Q.sub.412)—*, *—C(Q.sub.411)=*, or *=C=*, wherein Q.sub.411 and Q.sub.412 may each independently be hydrogen, deuterium, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, [0265] X.sub.406 may be a single bond, O, or S, [0266] R.sub.401 and R.sub.402 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C.sub.1-C.sub.20 alkyl group, a substituted or unsubstituted C.sub.1-C.sub.20 alkoxy group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.1 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.401)(Q.sub.402)(Q.sub.403), —N(Q.sub.401)(Q.sub.402), —B(Q.sub.401)(Q.sub.402), —C(=O)(Q.sub.401), —S(=O).sub.2(Q.sub.401), and —P(=O)(Q.sub.401)(Q.sub.402), wherein Q.sub.401 to Q.sub.403 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a C.sub.6-C.sub.20 aryl group, and a C.sub.1-C.sub.20 heteroaryl group, [0267] xc11 and xc12 may each independently be an integer from 0 to 10, and [0268] * and *' in Formula 402 each indicate a binding site to M in Formula 401.

[0269] In some embodiments, in Formula 402, A.sub.401 and A.sub.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.

[0270] In one or more embodiments, in Formula 402, i) X.sub.401 may be nitrogen, and X.sub.402 may be carbon, or ii) X.sub.401 and X.sub.402 may each be nitrogen.

[0271] In an embodiment, in Formula 402, R.sub.401 and R.sub.402 may each independently be selected from: [0272] 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.sub.1-C.sub.20 alkyl group, and a C.sub.1-C.sub.20 alkoxy group; [0273] a C.sub.1-C.sub.20 alkyl group and a C.sub.1-C.sub.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 adamantyl group, a norbornanyl group, and a norbornenyl group; [0274] a cyclopentyl group, a cyclohexyl group, an adamantyl 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; [0275] a cyclopentyl group, a cyclohexyl group, an adamantyl 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a cyclopentyl group, a cyclohexyl group, an adamantyl 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 [0276] —Si(Q.sub.401)(Q.sub.402)(Q.sub.403), —N(Q.sub.401)(Q.sub.402), —B(Q.sub.401)(Q.sub.402), —C(=O)(Q.sub.401), —S(=O).sub.2(Q.sub.401), and —P(=O)(Q.sub.401)(Q.sub.402), [0277] wherein Q.sub.401 to Q.sub.403 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0278] In one or more embodiments, when xc1 in Formula 401 is 2 or greater, two A.sub.401 (s) of the at least two L.sub.401 (s) may optionally be linked via X.sub.407 as a linking group; and/or two A.sub.402(s) may optionally be linked via X.sub.408 as a linking group (see Compounds PD1 to PD4 and PD7). X.sub.407 and X.sub.408 may each independently be selected from a single bond, *—O—*, *—S—*, *—C(=O)—*, *—N(Q.sub.413)—*, *—C(Q.sub.413)(Q.sub.414)—*, and *—C(Q.sub.413)=C(Q.sub.414)—*, wherein Q.sub.413 and Q.sub.414 may each independently be hydrogen, deuterium, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, but embodiments are not limited thereto.

[0279] L.sub.402 in Formula 401 may be any suitable monovalent, divalent, or trivalent organic ligand. For example, L.sub.402 may be selected from a halogen, a diketone (e.g., acetylacetonate),

a carboxylic acid (e.g., picolinate), —C(=O) , an isonitrile, —CN , and a phosphorus-based group (e.g., phosphine or phosphite), but embodiments are not limited thereto.

[0280] In some embodiments, the phosphorescent dopant may include, for example, at least one selected from Compounds PD1 to PD25, but embodiments are not limited thereto:

##STR00097## ##STR00098## ##STR00099## ##STR00100## ##STR00101## ##STR00102##
Fluorescent Dopant in Emission Layer

[0281] The fluorescent dopant may include an arylamine compound or a styrylamine compound.

[0282] In some embodiments, the fluorescent dopant may include a compound represented by Formula 501:

##STR00103## [0283] wherein, in Formula 501, [0284] Ar.sub.501 may be selected from a substituted or unsubstituted C.sub.5-C.sub.60 carbocyclic group and a substituted or unsubstituted C.sub.1-C.sub.60 heterocyclic group, [0285] L.sub.501 to L.sub.503 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, [0286] xd1 to xd3 may each independently be an integer from 0 to 3, [0287] R.sub.501 and R.sub.502 may each independently be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.1 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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 [0288] xd4 may be an integer from 1 to 6.

[0289] In some embodiments, in Formula 501, Ar.sub.501 may be selected from: [0290] 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 [0291] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0292] In an embodiment, in Formula 501, L.sub.501 and L.sub.503 may each independently be selected from: [0293] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a

dibenzofuranylene group, a dibenzothiophenylylene group, a benzocarbazolylylene group, a dibenzocarbazolylylene group, a dibenzosilolylylene group, and a pyridinylylene group; and [0294] a phenylene group, a naphthylylene group, a fluorenylylene group, a spiro-bifluorenylylene group, a benzofluorenylylene group, a dibenzofluorenylylene group, a phenanthrenylylene group, an anthracenylylene group, a fluoranthenylylene group, a triphenylenylylene group, a pyrenylylene group, a chrysenylylene group, a perylenylylene group, a pentaphenylylene group, a hexacenylylene group, a pentacenylylene group, a thiophenylylene group, a furanylylene group, a carbazolylylene group, an indolylylene group, an isoindolylylene group, a benzofuranylylene group, a benzothiophenylylene group, a dibenzofuranylylene group, a dibenzothiophenylylene group, a benzocarbazolylylene group, a dibenzocarbazolylylene group, a dibenzosilolylylene group, and a pyridinylylene 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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.

[0295] In an embodiment, in Formula 501, R.sub.501 and R.sub.502 may each independently be selected from: [0296] 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 [0297] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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 —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), [0298] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group. [0299] In one or more embodiments, xd4 in Formula 501 may be 2, but embodiments are not limited thereto.

[0300] In some embodiments, the fluorescent dopant may be selected from Compounds FD1 to FD22:

##STR00104## ##STR00105## ##STR00106## ##STR00107## ##STR00108## ##STR00109##
[0301] In some embodiments, the fluorescent dopant may be selected from the following compounds, but embodiments are not limited thereto:
##STR00110##

Electron Transport Region in Interlayer 150

[0302] The electron transport region may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure each having a plurality of layers, each having a plurality of different materials.

[0303] 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 are not limited thereto.

[0304] In some embodiments, 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 the constituting layers of each structure are sequentially stacked on the emission layer in each stated order, but embodiments are not limited thereto.

[0305] The electron transport region (for example, the buffer layer, the hole blocking layer, the electron control layer, or the electron transport layer in the electron transport region) may include a metal-free compound including at least one π electron-depleted nitrogen-containing ring.

[0306] The term “ π electron-depleted nitrogen-containing ring” as used herein refers to a C.sub.1-C.sub.60 heterocyclic group having at least one *—N=* moiety as a ring-forming moiety.

[0307] 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 at least two 5-membered to 7-membered heteromonocyclic groups, each having at least one *—N=* moiety, are condensed, or iii) a heteropolycyclic group in which at least one of a 5-membered to 7-membered heteromonocyclic group, each having at least one *—N=* moiety, is condensed with at least one C.sub.5-C.sub.60 carbocyclic group.

[0308] Examples of the π electron-depleted nitrogen-containing ring include imidazole, pyrazole, thiazole, isothiazole, oxazole, isoxazole, pyridine, pyrazine, pyrimidine, pyridazine, indazole, purine, quinoline, isoquinoline, benzoquinoline, phthalazine, naphthyridine, quinoxaline, quinazoline, cinnoline, phenanthridine, acridine, phenanthroline, phenazine, benzimidazole, isobenzothiazole, benzoxazole, isobenzoxazole, triazole, tetrazole, oxadiazole, triazine, thiadiazole, imidazopyridine, imidazopyrimidine, and azacarbazole, but embodiments are not limited thereto.

[0309] In some embodiments, the electron transport region may include a compound represented by Formula 601:

[Ar.sub.601].sub.xe11—[(L.sub.601).sub.xe1—R.sub.601].sub.xe21, Formula 601 [0310]
wherein, in Formula 601, [0311] Ar.sub.601 may be selected from a substituted or unsubstituted C.sub.5-C.sub.60 carbocyclic group and a substituted or unsubstituted C.sub.1-C.sub.60 heterocyclic group, [0312] xe11 may be 1, 2, or 3, [0313] L.sub.601 may be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed

heteropolycyclic group, [0314] xe1 may be an integer from 0 to 5, [0315] R.sub.601 may be selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.601)(Q.sub.602)(Q.sub.603), —C(=O)(Q.sub.601), —S(=O).sub.2(Q.sub.601), and —P(=O)(Q.sub.601)(Q.sub.602), [0316] wherein Q.sub.601 to Q.sub.603 may each independently be a C.sub.1-C.sub.1 alkyl group, a C.sub.1-C.sub.1 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, and [0317] xe21 may be an integer from 1 to 5.

[0318] In some embodiments, at least one selected from the xe11 Ar.sub.601(s) and the xe21 R.sub.601(s) (i.e., Ar.sub.601(s) in the number of xe11 and R.sub.601(s) in the number of xe21) may include the π electron-depleted nitrogen-containing ring.

[0319] In some embodiments, in Formula 601, ring Ar.sub.601 may be selected from: [0320] 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 [0321] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), [0322] wherein Q.sub.31 to Q.sub.33 may each independently be selected from a C.sub.1-C.sub.10 alkyl group, a C.sub.1-C.sub.10 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0323] When xe11 in Formula 601 is 2 or greater, at least two Ar.sub.601(s) may be bound via a single bond.

[0324] In one or more embodiments, Ar.sub.601 in Formula 601 may be an anthracene group.

[0325] In some embodiments, the compound represented by Formula 601 may be represented by Formula 601-1:

##STR00111## [0326] wherein, in Formula 601-1, [0327] X.sub.614 may be N or C(R.sub.614), X.sub.615 may be N or C(R.sub.615), X.sub.616 may be N or C(R.sub.616), at least one selected from X.sub.614 to X.sub.616 may be N, [0328] L.sub.611 to L.sub.613 may each independently be the same as described in connection with L.sub.601, [0329] xe611 to xe613 may each independently be the same as described in connection with xe1, [0330] R.sub.611 to R.sub.613 may each independently be the same as described in connection with R.sub.601, and [0331] R.sub.614 to R.sub.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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0332] In some embodiments, in Formulae 601 and 601-1, L.sub.601 and L.sub.611 to L.sub.613 may each independently be selected from: [0333] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and an azacarbazolylenylene group; and [0334] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylenylene group, a fluoranthenylenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylenylene group, a hexacenylenylene group, a pentacenylenylene group, a thiophenylenylene group, a furanylenylene group, a carbazolylenylene group, an indolylenylene group, an isoindolylenylene group, a benzofuranylenylene group, a benzothiophenylenylene group, a dibenzofuranylenylene group, a dibenzothiophenylenylene group, a benzocarbazolylenylene group, a dibenzocarbazolylenylene group, a dibenzosilolylenylene group, a pyridinylenylene group, an imidazolylenylene group, a pyrazolylenylene group, a thiazolylenylene group, an isothiazolylenylene group, an oxazolylenylene group, an isoxazolylenylene group, a thiadiazolylenylene group, an oxadiazolylenylene group, a pyrazinylenylene group, a pyrimidinylenylene group, a pyridazinylenylene group, a triazinylenylene group, a quinolinylenylene group, an isoquinolinylenylene group, a benzoquinolinylenylene group, a phthalazinylenylene group, a naphthyridinylenylene group, a quinoxalinylenylene group, a quinazolinylenylene group, a cinnolinylenylene group, a phenanthridinylenylene group, an acridinylenylene group, a phenanthrolinylenylene group, a phenazinylenylene group, a benzimidazolylenylene group, an isobenzothiazolylenylene group, a benzoxazolylenylene group, an isobenzoxazolylenylene group, a triazolylenylene group, a tetrazolylenylene group, an imidazopyridinylenylene group, an imidazopyrimidinylenylene group, and

an azacarbazolylenyl 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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, [0335] but embodiments are not limited thereto.

[0336] In one or more embodiments, in Formulae 601 and 601-1, xe1 and xe611 to xe613 may each independently be 0, 1, or 2.

[0337] In one or more embodiments, in Formulae 601 and 601-1, R.sub.601 and R.sub.611 to R.sub.613 may each independently be selected from: [0338] 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; [0339] 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.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.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 [0340] —S(=O).sub.2(Q.sub.601) and —P(=O)(Q.sub.601)(Q.sub.602), [0341] wherein Q.sub.601 and Q.sub.602 may each independently be the same as described above.

[0342] The electron transport region may include at least one compound selected from Compounds ET1 to ET36, but embodiments are not limited thereto:

##STR00112## ##STR00113## ##STR00114## ##STR00115## ##STR00116## ##STR00117##
##STR00118## ##STR00119## ##STR00120## ##STR00121## ##STR00122## ##STR00123##

[0343] In some embodiments, the electron transport region may include at least one compound selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq.sub.3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ:

##STR00124##

[0344] The thicknesses of the buffer layer, the hole blocking layer, and/or the electron control layer may each independently be about 20 Å to about 1,000 Å, and in some embodiments, about 30 Å to about 300 Å. When the thicknesses of the buffer layer, the hole blocking layer, and/or the electron control layer are within any of these ranges, excellent hole blocking characteristics or excellent electron controlling characteristics may be obtained without a substantial increase in driving voltage.

[0345] The thickness of the electron transport layer may be about 100 Å to about 1,000 Å, and in some embodiments, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within any of these ranges, excellent electron transport characteristics may be obtained without a substantial increase in driving voltage.

[0346] 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.

[0347] The metal-containing material may include at least one selected from an alkali metal complex and an alkaline earth metal complex. The alkali metal complex may include a metal ion selected from a lithium (Li) ion, a sodium (Na) ion, a potassium (K) ion, a rubidium (Rb) ion, and a cesium (Cs) ion. The alkaline earth metal complex may include a metal ion selected from a beryllium (Be) ion, a magnesium (Mg) ion, a calcium (Ca) ion, a strontium (Sr) ion, and a barium (Ba) ion. Each ligand coordinated with the metal ion of the alkali metal complex and the alkaline

earth metal complex may independently be selected from hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments are not limited thereto.

[0348] For example, the metal-containing material may include a Li complex. The Li complex may include, e.g., Compound ET-D1 (LiQ) or Compound ET-D2:

##STR00125##

[0349] 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 be in direct contact with the second electrode **190**.

[0350] The electron injection layer may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers, each including a plurality of different materials.

[0351] 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 a combination thereof.

[0352] The alkali metal may be selected from lithium (Li), sodium (Na), potassium (K), rubidium (Rb), and cesium (Cs). In some embodiments, the alkali metal may be Li, Na, or Cs. In one or more embodiments, the alkali metal may be Li or Cs, but embodiments are not limited thereto.

[0353] The alkaline earth metal may be selected from magnesium (Mg), calcium (Ca), strontium (Sr), and barium (Ba).

[0354] The rare earth metal may be selected from scandium (Sc), yttrium (Y), cerium (Ce), terbium (Tb), ytterbium (Yb), and gadolinium (Gd).

[0355] The alkali metal compound, the alkaline earth metal compound, and the rare earth metal compound may each independently be selected from oxides and halides (e.g., fluorides, chlorides, bromides, and/or iodines) of the alkali metal, the alkaline earth metal, and the rare earth metal, respectively.

[0356] The alkali metal compound may be selected from alkali metal oxides (such as Li.sub.2O, Cs.sub.2O, and/or K.sub.2O), and alkali metal halides (such as LiF, NaF, CsF, KF, LiI, NaI, CsI, and/or KI). In some embodiments, the alkali metal compound may be selected from LiF, Li.sub.2O, NaF, LiI, NaI, CsI, and KI, but embodiments are not limited thereto.

[0357] The alkaline earth-metal compound may be selected from alkaline earth-metal compounds (such as BaO, SrO, CaO, Ba_xSr_{1-x}O (wherein 0<x<1), and/or Ba_xCa_{1-x}O (wherein 0<x<1)). In some embodiments, the alkaline earth metal compound may be selected from BaO, SrO, and CaO, but embodiments are not limited thereto.

[0358] The rare earth metal compound may be selected from YbF₃, ScF₃, ScO₃, Y₂O₃, Ce₂O₃, GdF₃, and TbF₃. In some embodiments, the rare earth metal compound may be selected from YbF₃, ScF₃, TbF₃, YbI₃, ScI₃, and TbI₃, but embodiments are not limited thereto.

[0359] The alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may respectively include an ion of the above-described alkali metal, alkaline earth metal, and rare earth metal. Each ligand coordinated with the metal ion of the alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may independently be selected from hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments

are not limited thereto.

[0360] The electron injection layer may include (e.g., 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 combination thereof, as described above. In some embodiments, the electron injection layer may further include an organic material. When the electron injection layer further includes an organic material, the alkali metal, the alkaline earth metal, the rare earth metal, the alkali metal compound, the alkaline earth metal compound, the rare earth metal compound, the alkali metal complex, the alkaline earth metal complex, the rare earth metal complex, or a combination thereof may be substantially homogeneously or non-homogeneously dispersed in a matrix including the organic material.

[0361] The thickness of the electron injection layer may be about 1 Å to about 100 Å, and in some embodiments, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within any of these ranges, excellent electron injection characteristics may be obtained without a substantial increase in driving voltage.

Second Electrode **190**

[0362] The second electrode **190** may be on the interlayer **150**. In an embodiment, the second electrode **190** may be a cathode, which is an electron injection electrode. In this embodiment, a material for forming the second electrode **190** may be a material having a low work function, for example, a metal, an alloy, an electrically conductive compound, or a combination thereof.

[0363] The second electrode **190** may include at least one selected from lithium (Li), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ITO, and IZO, but embodiments are not limited thereto. The second electrode **190** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0364] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

Description of FIGS. **2** to **4**

[0365] As shown in FIG. **2**, a light-emitting device **20** has structure including a first capping layer **210**, the first electrode **110**, the interlayer **150**, and the second electrode **190**, wherein the layers are sequentially stacked in this stated order. As shown in FIG. **3**, a light-emitting device **30** has the first electrode **110**, the interlayer **150**, the second electrode **190**, and a second capping layer **220** structure, wherein the layers are sequentially stacked in this stated order. As shown in FIG. **4**, a light-emitting device **40** has the first capping layer **210**, the first electrode **110**, the interlayer **150**, the second electrode **190**, and the second capping layer **220** structure, wherein the layers are sequentially stacked in this stated order.

[0366] The first electrode **110**, the interlayer **150**, and the second electrode **190** illustrated in FIGS. **2** to **4** may respectively be understood by referring to the descriptions of the first electrode **110**, the interlayer **150**, and the second electrode **190** illustrated in FIG. **1**.

[0367] In the light-emitting devices **20** and **40**, light emitted from the emission layer in the interlayer **150** may pass through the first electrode **110** (which may be a semi-transmissive electrode or a transmissive electrode) and through the first capping layer **210** to the outside. In the light-emitting devices **30** and **40**, light emitted from the emission layer in the interlayer **150** may pass through the second electrode **190** (which may be a semi-transmissive electrode or a transmissive electrode) and through the second capping layer **220** to the outside.

[0368] The first capping layer **210** and the second capping layer **220** may improve the external luminescence efficiency based on the principle of constructive interference.

[0369] The first capping layer **210** and the second capping layer **220** may each independently be a 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.

[0370] At least one of 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, porphyrin derivatives, phthalocyanine derivatives, naphthalocyanine derivatives, alkali metal complexes, and alkaline earth metal complexes. The carbocyclic compound, the heterocyclic compound, and the amine group-containing compound may optionally be substituted with a substituent containing at least one element selected from O, N, S, Se, Si, F, Cl, Br, and I.

[0371] In some embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include an amine-based compound.

[0372] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound represented by Formula 201 or a compound represented by **202**.

[0373] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound selected from Compounds HT28 to HT33 and Compound CP1 to CP5, but embodiments are not limited thereto:

##STR00126## ##STR00127##

[0374] Hereinbefore, the light-emitting devices have been described with reference to FIGS. **1** to **4**, but embodiments are not limited thereto.

[0375] The layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region may each be formed in a set or predetermined region using one or more suitable methods (such as vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, ink-jet printing, laser printing, and/or laser-induced thermal imaging).

[0376] When the layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region are each formed by vacuum deposition, the vacuum deposition may be performed at a deposition temperature of about 100° C. to about 500° C., at a vacuum degree of about 10.sup.-8 torr to about 10.sup.-3 torr, and at a deposition rate of about 0.01 Angstroms per second (Å/sec) to about 100 Å/sec, depending on the material to be included and the structure of each layer to be formed.

[0377] When the layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region are each formed by spin coating, the spin coating may be performed at a coating rate of about 2,000 revolutions per minute (rpm) to about 5,000 rpm and at a heat treatment temperature of about 80° C. to about 200° C., depending on the material to be included and the structure of each layer to be formed.

Apparatus

[0378] The light-emitting device described above may be applied to or integrated within various devices.

[0379] Accordingly, according to one or more embodiments, a device (apparatus) may include the above-described light-emitting device.

[0380] For example, the apparatus may be a light-emitting apparatus, an authentication apparatus, or an electronic apparatus, but embodiments are not limited thereto.

[0381] The emission apparatus may be used in any suitable display, light source, and/or the like.

[0382] The authentication apparatus may be, for example, a biometric authentication apparatus that identifies an individual according to their biometric information (e.g., a fingertip, a pupil, or the like).

[0383] The authentication apparatus may further include a biometric information collecting unit, in addition to the light-emitting device described above.

[0384] The electronic apparatus may be applied to or integrated within a personal computer (e.g., a mobile personal computer), a cellphone, a digital camera, an electronic note, an electronic dictionary, an electronic game console, a medical device (e.g., an electronic thermometer, a blood pressure meter, a glucometer, a pulse measuring device, a pulse wave measuring device, an electrocardiograph recorder, an ultrasonic diagnosis device, an endoscope display device), a fish

finder, various measurement devices, gauges (e.g., gauges of an automobile, an airplane, a ship), a projector, but embodiments are not limited thereto.

[0385] The apparatus may further include a thin-film transistor, in addition to the light-emitting device. In this embodiment, the thin-film transistor may include a source electrode, an activation layer, and a drain electrode, and the first electrode of the light-emitting device may be electrically connected to one of the source electrode and the drain electrode of the thin-film transistor.

General Definitions of Substituents

[0386] The term “C.sub.1-C.sub.60 alkyl group” as used herein refers to a linear or branched aliphatic hydrocarbon monovalent group having 1 to 60 carbon atoms. Non-limiting examples thereof include a methyl group, an ethyl group, a propyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an iso-amyl group, and a hexyl group. The term “C.sub.1-C.sub.60 alkylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.1-C.sub.60 alkyl group.

[0387] The term “C.sub.2-C.sub.60 alkenyl group” as used herein refers to a hydrocarbon group having at least one carbon-carbon double bond in the middle or at the terminus of the C.sub.2-C.sub.60 alkyl group. Non-limiting examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term “C.sub.2-C.sub.60 alkenylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.2-C.sub.60 alkenyl group.

[0388] The term “C.sub.2-C.sub.60 alkynyl group” as used herein refers to a hydrocarbon group having at least one carbon-carbon triple bond in the middle or at the terminus of the C.sub.2-C.sub.60 alkyl group. Non-limiting examples thereof include an ethynyl group and a propynyl group. The term “C.sub.2-C.sub.60 alkynylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.2-C.sub.60 alkynyl group.

[0389] The term “C.sub.1-C.sub.60 alkoxy group” as used herein refers to a monovalent group represented by —OA.sub.101 (wherein A.sub.101 is a C.sub.1-C.sub.60 alkyl group). Non-limiting examples thereof include a methoxy group, an ethoxy group, and an isopropoxy group.

[0390] The term “C.sub.3-C.sub.10 cycloalkyl group” as used herein refers to a monovalent monocyclic saturated hydrocarbon group including 3 to 10 carbon atoms. Non-limiting examples thereof include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group. The term “C.sub.3-C.sub.10 cycloalkylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.3-C.sub.10 cycloalkyl group.

[0391] The term “C.sub.1-C.sub.10 heterocycloalkyl group” as used herein refers to a monovalent monocyclic group including at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, and 1 to 10 carbon atoms. Non-limiting examples thereof include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuranyl group, and a tetrahydrothiophenyl group. The term “C.sub.1-C.sub.10 heterocycloalkylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.1-C.sub.10 heterocycloalkyl group.

[0392] The term “C.sub.3-C.sub.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 its ring, and is not aromatic. Non-limiting examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term “C.sub.3-C.sub.10 cycloalkenylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.3-C.sub.10 cycloalkenyl group.

[0393] The term “C.sub.1-C.sub.10 heterocycloalkenyl group” as used herein refers to a monovalent monocyclic group including 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.sub.1-C.sub.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.sub.1-C.sub.10 heterocycloalkylene group” as used herein refers to a divalent group having substantially the same structure as the C.sub.1-C.sub.10 heterocycloalkyl group.

[0394] The term “C.sub.6-C.sub.60 aryl group” as used herein refers to a monovalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. The term “C.sub.6-C.sub.60 arylene group” as used herein refers to a divalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. Non-limiting examples of the C.sub.6-C.sub.60 aryl group include a phenyl group, a naphthyl group, an anthracenyl group, a phenanthrenyl group, a pyrenyl group, a fluorenyl group, and a chrysenyl group. When the C.sub.6-C.sub.60 aryl group and the C.sub.6-C.sub.60 arylene group each independently include two or more rings, the respective rings may be fused.

[0395] The term “C.sub.1-C.sub.60 heteroaryl group” as used herein refers to a monovalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, and 1 to 60 carbon atoms. The term “C.sub.1-C.sub.60 heteroarylene group” as used herein refers to a divalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 60 carbon atoms. Non-limiting examples of the C.sub.1-C.sub.60 heteroaryl group include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a quinolinyl group, and an isoquinolinyl group.

[0396] When the C.sub.1-C.sub.60 heteroaryl group and the C.sub.1-C.sub.60 heteroarylene group each independently include two or more rings, the respective rings may be fused.

[0397] The term “C.sub.6-C.sub.60 aryloxy group” as used herein is represented by —OA.sub.102 (wherein A.sub.102 is a C.sub.6-C.sub.60 aryl group). The term “C.sub.6-C.sub.60 arylthio group” as used herein is represented by —SA.sub.103 (wherein A.sub.103 is a C.sub.6-C.sub.60 aryl group).

[0398] The term “monovalent non-aromatic condensed polycyclic group” as used herein refers to a monovalent group that has two or more rings condensed and only carbon atoms as ring forming atoms (e.g., 8 to 60 carbon atoms), wherein the entire molecular structure is non-aromatic. Non-limiting examples of the monovalent non-aromatic condensed polycyclic group may include an adamantyl 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.

[0399] The term “monovalent non-aromatic condensed heteropolycyclic group” as used herein refers to a monovalent group that has two or more condensed rings and at least one heteroatom selected from N, O, Si, P, and S, in addition to carbon atoms (e.g., 1 to 60 carbon atoms), as a ring-forming atom, wherein the entire molecular structure is non-aromatic. Non-limiting examples of the monovalent non-aromatic condensed heteropolycyclic group may include an azaadamantyl 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.

[0400] The term “C.sub.5-C.sub.60 carbocyclic group” as used herein refers to a monocyclic or polycyclic group having 5 to 60 carbon atoms only as ring-forming atoms. The C.sub.5-C.sub.60 carbocyclic group may be an aromatic carbocyclic group or a non-aromatic carbocyclic group. The term “C.sub.5-C.sub.60 carbocyclic group” as used herein refers to a ring (e.g., a benzene group), a monovalent group (e.g., a phenyl group), or a divalent group (e.g., a phenylene group). Also, depending on the number of substituents connected to the C.sub.5-C.sub.60 carbocyclic group, the C.sub.5-C.sub.60 carbocyclic group may be a trivalent group or a quadrivalent group.

[0401] The term “C.sub.1-C.sub.60 heterocyclic group” as used herein refers to a group having substantially the same structure as the C.sub.5-C.sub.60 carbocyclic group, except that at least one heteroatom selected from N, O, Si, P, and S is used as a ring-forming atom, in addition to carbon atoms (e.g., 1 to 60 carbon atoms).

[0402] In the present specification, at least one substituent of the substituted C.sub.5-C.sub.60 carbocyclic group, the substituted C.sub.1-C.sub.60 heterocyclic group, the substituted C.sub.3-C.sub.10 cycloalkylene group, the substituted C.sub.1-C.sub.10 heterocycloalkylene group, the

substituted C.sub.3-C.sub.10 cycloalkenylene group, the substituted C.sub.1-C.sub.10 heterocycloalkenylene group, the substituted C.sub.6-C.sub.60 arylene group, the substituted C.sub.1-C.sub.60 heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C.sub.1-C.sub.60 alkyl group, the substituted C.sub.2-C.sub.60 alkenyl group, the substituted C.sub.2-C.sub.60 alkynyl group, the substituted C.sub.1-C.sub.60 alkoxy group, the substituted C.sub.3-C.sub.10 cycloalkyl group, the substituted C.sub.1-C.sub.10 heterocycloalkyl group, the substituted C.sub.3-C.sub.10 cycloalkenyl group, the substituted C.sub.1-C.sub.10 heterocycloalkenyl group, the substituted C.sub.6-C.sub.60 aryl group, the substituted C.sub.6-C.sub.60 aryloxy group, the substituted C.sub.6-C.sub.60 arylthio group, the substituted C.sub.1-C.sub.60 heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from: [0403] 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.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.60 alkoxy group; [0404] a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.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.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(=O)(Q.sub.11), —S(=O).sub.2(Q.sub.11), and —P(=O)(Q.sub.11)(Q.sub.12); [0405] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group; [0406] a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(=O)(Q.sub.21), —S(=O).sub.2(Q.sub.21), and —P(=O)(Q.sub.21)(Q.sub.22); and [0407] —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and [0408] P(=O)(Q.sub.31)(Q.sub.32), [0409] wherein Q.sub.11 to Q.sub.13, Q.sub.21 to Q.sub.23, and Q.sub.31 to Q.sub.33 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy

group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0410] 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 “But” as used herein refers to a tert-butyl group. The term “OMe” as used herein refers to a methoxy group.

[0411] The term “biphenyl group” as used herein refers to a phenyl group substituted with a phenyl group. The “biphenyl group” may be a substituted phenyl group having a C.sub.6-C.sub.60 aryl group as a substituent.

[0412] The term “terphenyl group” as used herein refers to a phenyl group substituted with a biphenyl group. The “terphenyl group” may be a substituted phenyl group having a C.sub.6-C.sub.60 aryl group substituted with a C.sub.6-C.sub.60 aryl group as a substituent.

[0413] The symbols * and *' as used herein, unless defined otherwise, refer to a binding site to an adjacent atom in a corresponding formula.

[0414] Hereinafter, compounds and a light-emitting device according to one or more 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 number of molar equivalents of B was used in place of A.

EXAMPLES

Synthesis Example

Synthesis of Intermediates T1 and T2

[0415] Intermediates T1 and T2 were respectively synthesized according to the following synthesis scheme:

##STR00128##

Synthesis Example 1: Synthesis of Compound 1

##STR00129##

[0416] 2.2 grams (g) of aniline (reactant), 5.4 g of 3-bromo-9,9-dimethyl-9H-fluorene, 0.2 g of Pd.sub.2(dba).sub.3, 0.30 g of P(t-Bu).sub.3, and 5.7 g of NaOt-Bu were dissolved in 200 milliliters (mL) of toluene and stirred at a temperature of 90° C. for 2 hours. The reaction solution was cooled to room temperature, and the reaction was terminated by using water. Then an extraction process was performed three times using ethyl ether.

[0417] The separated organic layer was dried using anhydrous magnesium sulfate and distilled under reduced pressure. The residue obtained therefrom was separated and purified through column chromatography to thereby obtain 3.9 g of Intermediate 1-1 (yield: 69%).

[0418] 2.1 g of Compound 1 was obtained in substantially the same manner as in the Synthesis of Intermediate 1-1, except that Intermediate T1 was used instead of 3-bromo-9,9-dimethyl-9H-fluorene, and 3.38 g of Intermediate 1-1 was reacted with 5.7 g of Intermediate T1 (yield: 26%). The molecular weight of Compound 1 measured by fast-atom bombardment mass spectrometry (FAB-MS) was 557.67. Accordingly, the resulting compound was identified as Compound 1.

Synthesis Example 2: Synthesis of Compound 5

##STR00130##

[0419] 2.5 g of Compound 5 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 2-bromo-1,1-biphenyl and 2-amino-9,9-dimethyl-9H-fluorene were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively (yield: 20%).

Synthesis Example 3: Synthesis of Compound 20

##STR00131##

[0420] 2.3 g of Compound 20 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 3-bromodibenzofuran were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively (yield: 19%).

Synthesis Example 4: Synthesis of Compound 57

##STR00132##

[0421] 2.0 g of Compound 57 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 4-aminobiphenyl and 1-bromo-9,9-dimethyl-9H-fluorene were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively, and Intermediate T2 was used instead of Intermediate T1 (yield: 16%).

Synthesis Example 5: Synthesis of Compound 62

##STR00133##

[0422] 2.1 g of Compound 62 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as a reactant, 2-bromodibenzofuran was used instead of 3-bromo-9,9-dimethyl-9H-fluorene (yield: 20%).

Synthesis Example 6: Synthesis of Compound 69

##STR00134##

[0423] 2.3 g of Compound 69 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 1-bromodibenzofuran were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively, and Intermediate T2 was used instead of Intermediate T1 (yield: 19%).

Synthesis Example 7: Synthesis of Compound 74

##STR00135##

[0424] 2.1 g of Compound 74 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 2-bromodibenzothiophene were used instead of aniline and 3-bromo-9,9-dimethyl-9H-10 fluorene, respectively, and Intermediate T2 was used instead of Intermediate Ti (yield: 17%).

[0425] The compounds synthesized in the Synthesis Examples were identified by ¹H nuclear magnetic resonance (NMR) and mass spectroscopy/fast atom bombardment (MS/FAB). The results are shown in Table 1.

TABLE-US-00001 TABLE 1 Compound MS/FAB No. ¹H NMR (CDCl₃, 400 MHz)
found calc. 1 7.91(d, 1H), 7.73(s, 1H), 7.29-6.98(m, 557.67 556.67 19H), 6.86(d, 2H), 6.79(s, 1H), 5.80(m, 2H), 3.62(t, 1H), 2.55(t, 1H) 5 8.10(d, 1H), 7.91(d, 1H), 7.08(s, 1H), 633.76 632.76 7.73-7.08(m, 12H), 6.98(d, 1H), 6.86(d, 2H), 6.79(s, 1H), 6.64(t, 1H), 3.62(t, 1H), 2.55(t, 1H) 20 8.03(s, 1H), 7.91-7.98(m, 2H), 7.73- 605.67 604.67 7.80(m, 4H), 7.17-7.55(m, 12H), 6.86-6.91(m, 2H), 6.52(s, 1H) 57 7.91-7.90(m, 2H), 7.75(d, 2H), 7.14- 631.75 630.75 7.56(m, 15H), 7.06(d, 1H), 6.86(d, 2H), 6.73(d, 1H), 6.36(d, 1H), 1.67(s, 6H) 62 7.91(d, 1H), 7.73(s, 1H), 7.40(s, 1H), 531.58 530.58 7.29-7.00(m, 11H), 6.86(d, 2H), 6.76- 6.64(m, 2H), 6.52(s, 1H), 5.80(m, 2H), 4.73(t, 1H), 3.93(t, 1H) 69 7.98-7.91(m, 1H), 7.75(m, 2H), 7.17- 605.67 604.67 7.54(m, 16H), 6.86-6.91(m, 3H), 6.73(d, 1H), 6.36(d, 1H) 74 8.45(d, 1H), 7.95-7.85(m, 4H), 7.75(d, 621.73 620.73 2H), 7.17-7.56(m, 13H) 6.86(d, 2H), 6.73(d, 1H), 6.36(d, 1H)

[0426] Methods of synthesizing compounds other than those shown in Table 1 may be easily understood by those skilled in the art by referring to the synthesis schemes and raw materials described above.

Comparative Example 1

[0427] A 15 Ohms per square centimeter (Ω/cm) (1,200 Å) ITO glass substrate from Corning was cut to a size of 50 millimeters (mm)×50 mm×0.7 mm, sonicated in isopropyl alcohol and pure water for 5 minutes in each solvent, and cleaned by exposure to ultraviolet rays with ozone to prepare the glass substrate as an anode. Then, the glass substrate was mounted to a vacuum-deposition apparatus.

[0428] 2-TNATA was vacuum-deposited on the glass substrate to form a hole injection layer having

a thickness of 600 Å. Thereafter, 4,4'-bis[N—(1-naphthyl)-N-phenylamino]biphenyl (hereinafter referred to as “NPB”) as a hole transporting compound was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 300 Å.

[0429] 9,10-di(naphthalen-2-yl)anthracene (hereinafter referred to as “DNA”) as a blue fluorescent host, and 4,4'-bis[2-(4-(N,N-diphenylamino)phenyl)vinyl]biphenyl (hereinafter referred to as “DPAVBi”) as a blue fluorescent dopant, were co-deposited on the hole transport layer in a weight ratio of about 98:2 to form an emission layer having a thickness of 300 Å.











##STR00136##

Examples 1 to 7 and Comparative Examples 2 to 4

[0430] Light-emitting devices were manufactured in substantially the same manner as in Comparative Example 1, except that the Compounds shown in Table 2 were used instead of NPB when forming a hole transport layer.

Evaluation Example 1

[0431] The external quantum efficiency, driving voltage, half lifespan, emission color, and emission wavelength of each of the light-emitting devices manufactured in Examples 1 to 7 and Comparative Examples 1 to 4 were measured using a Keithley source-measure unit (SMU) 236 and a luminance meter PR650. The results thereof are shown in Table 2:

TABLE-US-00002 TABLE 2 Hole Half transport Driving Current lifespan layer voltage density
Luminance Efficiency Emission (hr @ Material (V) (mA/cm.sup.2) (cd/m.sup.2) (cd/A) color 100
mA/cm.sup.2) Example 1 Compound 4.46 50 3700 7.40 Blue 361 1 Example 2 Compound 4.43 50
3715 7.43 Blue 367 5 Example 3 Compound 4.45 50 3710 7.42 Blue 371 20 Example 4 Compound
4.47 50 3675 7.35 Blue 368 57 Example 5 Compound 4.42 50 3685 7.37 Blue 365 62 Example 6
Compound 4.41 50 3720 7.44 Blue 373 69 Example 7 Compound 4.52 50 3725 7.45 Blue 370 74
Comparative NPB 7.01 50 2645 5.29 Blue 258 Example 1 Comparative Compound 5.65 50 3010
6.02 Blue 315 Example 2 A Comparative Compound 5.14 50 3045 6.09 Blue 322 Example 3 B
Comparative Compound 5.33 50 3055 6.11 Blue 309 Example 4 C [00137]
[00138][00139][00140][00141]
[00142][00143][00144]
[00145][00146]

[0432] Referring to the results shown in Table 2, the light-emitting devices of Examples 1 to 7 were found to have excellent luminance, luminescence efficiency, and lifespan characteristics, and low driving voltage. In addition, the light-emitting devices of Examples 1 to 7 were found to have excellent luminance, luminescence efficiency, and lifespan characteristics, and low driving voltage, compared with the light-emitting devices of Comparative Examples 1 to 4.

[0433] In other words, when the compounds according to one or more embodiments are used in a light-emitting device, the light-emitting device may have excellent luminance, luminescence efficiency, lifespan, and/or driving voltage.

[0434] As apparent from the foregoing description, a light-emitting device including the heterocyclic compound may have low driving voltage, excellent luminance, excellent efficiency, and/or long lifespan.

[0435] 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.

[0436] Any numerical range recited herein is intended to include all sub-ranges of the same numerical precision subsumed within the recited range. For example, a range of “1.0 to 10.0” is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein and any minimum numerical limitation recited in this specification is intended to include all

higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein.

[0437] 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. While one or more embodiments have been described with reference to the drawings, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope as defined by the following claims and equivalents thereof.

Claims

1. A light-emitting device comprising: a first electrode; a second electrode facing the first electrode; an interlayer between the first electrode and the second electrode and comprising an emission layer; and at least one of a heterocyclic compound represented by Formula 1: ##STR00147## wherein, in Formula 1, A.sub.1 to A.sub.3 are each independently selected from a C.sub.5-C.sub.60 carbocyclic group and a C.sub.1-C.sub.60 heterocyclic group, L.sub.1 to L.sub.3 are each independently selected from a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkylene group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenylene group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenylene group, a substituted or unsubstituted C.sub.6-C.sub.60 arylene group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group, a₁, a₂, and a₃ are each independently an integer from 0 to 5, Ar.sub.1 and Ar.sub.2 are each independently selected from a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.60 heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, R.sub.10, R.sub.20, and R.sub.30 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 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.sub.1-C.sub.60 alkyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkenyl group, a substituted or unsubstituted C.sub.2-C.sub.60 alkynyl group, a substituted or unsubstituted C.sub.1-C.sub.60 alkoxy group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkyl group, a substituted or unsubstituted C.sub.3-C.sub.10 cycloalkenyl group, a substituted or unsubstituted C.sub.1-C.sub.10 heterocycloalkenyl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryl group, a substituted or unsubstituted C.sub.6-C.sub.60 aryloxy group, a substituted or unsubstituted C.sub.6-C.sub.60 arylthio group, a substituted or unsubstituted C.sub.1-C.sub.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.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —C(=O)(Q.sub.1), —S(=O).sub.2(Q.sub.1), and —P(=O)(Q.sub.1)(Q.sub.2), b₁₀, b₂₀, and b₃₀ are each independently an integer from 1 to 8, * and *' each indicate a binding site to an adjacent atom, and at least one substituent of the substituted C.sub.3-C.sub.1 cycloalkylene group, the substituted C.sub.1-C.sub.10 heterocycloalkylene group, the substituted C.sub.3-C.sub.1 cycloalkenylene group, the substituted C.sub.1-C.sub.10 heterocycloalkenylene group, the substituted C.sub.6-C.sub.60 arylene group, the substituted

C.sub.1-C.sub.60 heteroaryl group, the substituted non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C.sub.1-C.sub.60 alkyl group, the substituted C.sub.2-C.sub.60 alkenyl group, the substituted C.sub.2-C.sub.60 alkynyl group, the substituted C.sub.1-C.sub.60 alkoxy group, the substituted C.sub.3-C.sub.10 cycloalkyl group, the substituted C.sub.1-C.sub.10 heterocycloalkyl group, the substituted C.sub.3-C.sub.10 cycloalkenyl group, the substituted C.sub.1-C.sub.10 heterocycloalkenyl group, the substituted C.sub.6-C.sub.60 aryl group, the substituted C.sub.6-C.sub.60 aryloxy group, the substituted C.sub.6-C.sub.60 arylthio group, the substituted C.sub.1-C.sub.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.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.60 alkoxy group; a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, and a C.sub.1-C.sub.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.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(=O)(Q.sub.11), —S(=O).sub.2(Q.sub.11), and —P(=O)(Q.sub.11)(Q.sub.12); a C.sub.3-C.sub.1 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.1 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group; a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.10 heterocycloalkyl group, a C.sub.3-C.sub.10 cycloalkenyl group, a C.sub.1-C.sub.10 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.1 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(=O)(Q.sub.21), —S(=O).sub.2(Q.sub.21), and —P(=O)(Q.sub.21)(Q.sub.22); and —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(=O)(Q.sub.31), —S(=O).sub.2(Q.sub.31), and —P(=O)(Q.sub.31)(Q.sub.32), and wherein Q.sub.1 to Q.sub.3, Q.sub.11 to Q.sub.13, Q.sub.21 to Q.sub.23, and Q.sub.31 to Q.sub.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.sub.1-C.sub.60 alkyl group, a C.sub.2-C.sub.60 alkenyl group, a C.sub.2-C.sub.60 alkynyl group, a C.sub.1-C.sub.60 alkoxy group, a C.sub.3-C.sub.1 cycloalkyl group, a C.sub.1-C.sub.1 heterocycloalkyl group, a C.sub.3-C.sub.1 cycloalkenyl group, a C.sub.1-C.sub.1 heterocycloalkenyl group, a C.sub.6-C.sub.60 aryl group, a C.sub.1-C.sub.60 heteroaryl group, a monovalent non-aromatic

condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

2. The light-emitting device of claim 1, wherein the first electrode is an anode, the second electrode is a cathode, the interlayer comprises the at least one of the heterocyclic compound, and the interlayer 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, and wherein 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. The light-emitting device of claim 2, wherein the hole transport region comprises the at least one of the heterocyclic compound.

4. The light-emitting device of claim 2, wherein the hole transport region comprises the hole transport layer, and the hole transport layer comprises the at least one heterocyclic compound.

5. The light-emitting device of claim 1, wherein the emission layer comprises a host and a dopant.

6. The light-emitting device of claim 5, wherein the emission layer is to emit blue light having a maximum emission wavelength of about 420 nanometers (nm) to about 490 nm.

7. The light-emitting device of claim 1, wherein the emission layer comprises quantum dots.

8. The light-emitting device of claim 2, wherein the at least one of the heterocyclic compound is used as a material for a capping layer on a side of the cathode facing away from the anode and/or on a side of the anode facing away from the cathode.

9. An apparatus comprising the light-emitting device of claim 1.

10. The apparatus of claim 9, further comprising a thin-film transistor, wherein the thin-film transistor comprises a source electrode and a drain electrode, and the first electrode of the light-emitting device is electrically connected to the source electrode or the drain electrode of the thin-film transistor.
