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HETEROCYCLIC COMPOUND, AND ORGANIC LIGHT-EMITTING DEVICE AND ELECTRONIC APPARATUS INCLUDING THE SAME

Abstract

A heterocyclic compound represented by Formula 1, and an organic light-emitting device and an electronic apparatus that include the organic light-emitting device are provided.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2024-0019833, filed on Feb. 8, 2024, in the Korean Intellectual Property Office, the entire content of which is incorporated herein by reference.

BACKGROUND

1. Field

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

2. Description of the Related Art

[0003] Organic light-emitting devices are self-emissive devices that, as compared with devices of the related art, have relatively wide viewing angles, relatively high contrast ratios, relatively short response times, and excellent or suitable characteristics in terms of luminance, driving voltage, and response speed, and are configured to produce full-color images.

[0004] In an example, an organic light-emitting device may have a structure in which a first electrode is arranged on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode are sequentially formed on the first electrode. Holes provided from the first electrode move toward the emission layer through the hole transport region, and electrons provided from the second electrode move toward the emission layer through the electron transport region. Carriers, such as holes and electrons, recombine in the emission layer to produce excitons that may transition (e.g., relax) from an excited state to a ground state, thereby generating light (e.g., to display an image).

SUMMARY

[0005] One or more aspects of embodiments of the present disclosure are directed toward a novel heterocyclic compound, and an organic light-emitting device and an electronic apparatus that include the organic light-emitting device.

[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] According to one or more embodiments, there is provided a heterocyclic compound represented by Formula 1:

##STR00001## [0008] wherein, in Formula 1, [0009] X.sub.1 may be O, S, Se, or N(Ar.sub.3), [0010] X.sub.2 may be O, S, Se, or N(Ar.sub.4), [0011] A.sub.1 and A.sub.2 may each independently be a C.sub.5-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, or a group represented by Formula 2, wherein at least one selected from among A.sub.1 and A.sub.2 is the group represented by Formula 2,

##STR00002## [0012] in Formula 2, [0013] X.sub.3 may be O, S, Se, or N(Ar.sub.5), [0014] X.sub.4 may be O, S, Se, or N(Ar.sub.6), [0015] in Formulae 1 and 2, [0016] A.sub.3 to A.sub.5 and A.sub.11 to A.sub.13 may each independently be a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0017] Ar.sub.1 to Ar.sub.6 may each independently be a group represented by Formula 3, 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60

alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2),

##STR00003## [0018] in Formula 3, [0019] A.sub.6 and A.sub.7 may each independently be a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0020] * indicates a binding site to a neighboring atom, [0021] in Formulae 1 to 3, [0022] R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may each independently be 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2), [0023] at least two (e.g., two or more) selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may optionally be bonded together to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0024] b10 and b20 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, or 18, [0025] b30, b40, b50, b60, and b70 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, or 8, [0026] R.sub.10a may be [0027] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group, [0028] 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, or a C.sub.1-C.sub.60 alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), —P(═S)(Q.sub.11)(Q.sub.12), or any combination thereof, [0029] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, or a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, or a C.sub.1-C.sub.60 heteroarylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro 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.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), —P(═S)(Q.sub.21)(Q.sub.22), or any combination thereof, or [0030] —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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), or —P(═S)(Q.sub.31)(Q.sub.32), and [0031] 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 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, or a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C.sub.1-C.sub.60 alkyl group, a C.sub.1-C.sub.6 alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0032] According to one or more embodiments, an organic light-emitting device includes a first electrode, a second electrode, an interlayer arranged between the first electrode and the second electrode and including emission layer, and at least one of the heterocyclic compound.

[0033] According to one or more embodiments, an electronic apparatus includes the organic light-emitting device.

[0034] According to one or more embodiments, a consumer product (e.g. electronic equipment) includes the organic light-emitting device.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The accompanying drawings are included to provide a further understanding of the preceding and other aspects, features, and advantages of certain embodiments of the disclosure are incorporated in and constitute a part of this specification. The drawings illustrate example embodiments and, together with the following description taken in conjunction with the accompanying drawings. In the drawings:

[0036] FIG. **1** is a schematic view of the structure of an organic light-emitting device according to one or more embodiments;

[0037] FIG. **2** is a schematic view of the structure of an electronic apparatus according to one or more embodiments;
[0038] FIG. **3** is a schematic view of the structure of an electronic apparatus according to one or more embodiments;
[0039] FIG. **4** is a schematic perspective view of electronic equipment including an organic light-emitting device according to one or more embodiments;
[0040] FIG. **5** is a schematic view of the exterior of a vehicle as electronic equipment including an organic light-emitting device according to one or more embodiments; and
[0041] FIGS. **6**A-**6**C are each a diagram schematically illustrating the interior of a vehicle according to one or more embodiments.

DETAILED DESCRIPTION

[0042] Reference will now be made in more detail to one or more 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 the specification. 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, one or more embodiments are merely described in more detail, by referring to the drawings, to explain aspects of the present description. An aspect and a characteristic of the disclosure, and a method of accomplishing these will be apparent if referring to one or more embodiments described with reference to the drawings. The same or corresponding components will be denoted by the same reference numerals, and thus redundant description thereof will not be provided.
[0043] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items. Expressions such as “at least one of,” “one of,” “selected from,” and “selected from among,” when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. For example, throughout the disclosure, the expression “at least one of a, b or c” indicates only a, only b, only c, both (e.g., simultaneously) a and b, both (e.g., simultaneously) a and c, both (e.g., simultaneously) b and c, all of a, b, and c, or variations thereof.
[0044] Unless otherwise defined, all chemical names, technical and scientific terms, and terms defined in common dictionaries should be interpreted as having meanings consistent with the context of the related art, and should not be interpreted in an ideal or overly formal sense. It will be understood that although the terms “first,” “second,” and/or the like may be utilized herein to describe one or more suitable components, these components should not be limited by these terms. These terms are only utilized to distinguish one component from another. Thus, a first element could be termed a second element without departing from the teachings of the present disclosure. Similarly, a second element could be termed a first element. An expression utilized in the singular forms such as “a,” “an,” and “the” are intended to encompass the expression of the plural forms as well, unless it has a clearly different meaning in the context.
[0045] It will be further understood that the terms “comprises,” “comprising,” “comprise,” “has,” “have,” “having,” “include,” “includes,” and/or “including,” as utilized herein specify the presence of stated features or elements, but do not preclude the presence or addition of one or more other features or elements.
[0046] As used herein, the terms “use,” “using,” and “used” may be considered synonymous with the terms “utilize,” “utilizing,” and “utilized,” respectively.
[0047] The term “may” will be understood to refer to “one or more embodiments of the present disclosure,” some of which include the described element and some of which exclude that element and/or include an alternate element. Similarly, alternative language such as “or” refers to “one or more embodiments of the present disclosure,” each including a corresponding listed item.
[0048] In the following embodiments, if one or more components such as layers, films, regions, plates, and/or the like are said to be “connected to,” or “on” another component, this may include

not only a case in which other components are “immediately on” the layers, films, regions, or plates, but also a case in which other components may be placed therebetween. Sizes of elements 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.

[0049] Spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper,” “bottom,” “top,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the drawings. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the drawings. For example, if the device in the drawings is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” or “over” the other elements or features. Thus, the term “below” may encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations), and the spatially relative descriptors used herein should be interpreted accordingly.

[0050] In this context, “consisting essentially of” indicates that any additional components will not materially affect the chemical, physical, optical or electrical properties of the target position.

[0051] Further, in this specification, the phrase “on a plane,” or “plan view,” indicates viewing a target portion from the top, and the phrase “on a cross-section” indicates viewing a cross-section formed by vertically cutting a target portion from the side.

[0052] The term “interlayer” as utilized herein refers to a single layer and/or all of a plurality of layers located between the first electrode and the second electrode of the light-emitting device.

[0053] Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

Heterocyclic Compound

[0054] An aspect of the disclosure provides a heterocyclic compound represented by Formula 1:

##STR00004##

[0055] In Formula 1, X.sub.1 may be O, S, Se, or N(Ar.sub.3).

[0056] In Formula 1, X.sub.2 may be O, S, Se. or N(Ar.sub.4).

[0057] In one or more embodiments, X.sub.1 and X.sub.2 may be substantially identical to each other.

[0058] In one or more embodiments, X.sub.1 and X.sub.2 may be different from each other.

[0059] In Formula 1, A.sub.1 and A.sub.2 may each independently be a C.sub.5-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, or a group represented by Formula 2, wherein at least one selected from among A.sub.1 and A.sub.2 is the group represented by Formula 2:

##STR00005##

[0060] In Formula 2, X.sub.3 may be O, S, Se, or N(Ar.sub.5).

[0061] In Formula 2, X.sub.4 may be O, S, Se, or N(Ar.sub.6).

[0062] In one or more embodiments, X.sub.3 and X.sub.4 may be substantially identical to each other.

[0063] In one or more embodiments, X.sub.3 and X.sub.4 may be different from each other.

[0064] In one or more embodiments, A.sub.1 and A.sub.2 may each independently be a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a pyridine group, a pyrimidine group, a furan group, a benzofuran group, a thiophene group, a benzothiophene group, or a group represented by Formula 2A:

##STR00006## [0065] wherein, in Formula 2A, [0066] X.sub.3, X.sub.4, and A.sub.11 to A.sub.13 are each as described herein, [0067] custom-character indicates a single bond or a double bond,

and [0068] * and *′ each indicate a binding site to a neighboring atom.
[0069] In one or more embodiments, a moiety represented by in
##STR00007##
Formula 1 may be a group represented by Formula 2-1, or [0070] a moiety represented by
##STR00008##
in Formula 1 may be a group represented by Formula 2-2:
##STR00009## [0071] wherein, in Formulae 2-1 and 2-2, [0072] X.sub.3 and X.sub.4 are each as described herein, [0073] X.sub.11 may be C(R.sub.11) or N, X.sub.12 may be C(R.sub.12) or N, X.sub.13 may be C(R.sub.13) or N, X.sub.14 may be C(R.sub.14) or N, X.sub.15 may be C(R.sub.15) or N, X.sub.16 may be C(R.sub.16) or N, X.sub.17 may be C(R.sub.17) or N, X.sub.18 may be C(R.sub.18) or N, and X.sub.19 may be C(R.sub.19) or N, [0074] X.sub.21 may be C(R.sub.21) or N, X.sub.22 may be C(R.sub.22) or N, X.sub.23 may be C(R.sub.23) or N, X.sub.24 may be C(R.sub.24) or N, X.sub.25 may be C(R.sub.25) or N, X.sub.26 may be C(R.sub.26) or N, X.sub.27 may be C(R.sub.27) or N, X.sub.28 may be C(R.sub.28) or N, and X.sub.29 may be C(R.sub.29) or N, [0075] R.sub.11 to R.sub.19 may each independently be as described in connection with R.sub.10, [0076] R.sub.21 to R.sub.29 may each independently be as described in connection with R.sub.20, [0077] at least two (e.g., two or more) selected from among neighboring R.sub.11 to R.sub.19 and R.sub.21 to R.sub.29 may optionally be bonded to each other to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0078] R.sub.10a is as described herein, and [0079] * and *′ each indicate a binding site to a neighboring atom.
[0080] In Formulae 1 and 2, A.sub.3 to A.sub.5 and A.sub.11 to A.sub.13 may each independently be a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group.
[0081] In one or more embodiments, A.sub.3 to A.sub.5 and A.sub.11 to A.sub.13 may each independently be a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a pyridine group, a pyrimidine 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, or a dinaphthothiophene group.
[0082] In Formula 1, Ar.sub.1 to Ar.sub.6 may each independently be a group represented by Formula 3, 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed

polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2).

##STR00010## [0083] in Formula 3, [0084] A.sub.6 and A.sub.7 may each independently be a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0085] * indicates a binding site to a neighboring atom.

[0086] In one or more embodiments, Ar.sub.1 and Ar.sub.2 may be substantially identical to each other.

[0087] In one or more embodiments, Ar.sub.1 and Ar.sub.2 may be different from each other.

[0088] In one or more embodiments, Ar.sub.3 and Ar.sub.4 may be substantially identical to each other.

[0089] In one or more embodiments, Ar.sub.3 and Ar.sub.4 may be different from each other.

[0090] In one or more embodiments, Ar.sub.5 and Ar.sub.6 may be substantially identical to each other.

[0091] In one or more embodiments, Ar.sub.5 and Ar.sub.6 may be different from each other.

[0092] In one or more embodiments, the group represented by Formula 3 may be a group represented by any one selected from among Formulae 3A to **3**C:

##STR00011## [0093] wherein, in Formulae 3A to 3C, [0094] A.sub.6, A.sub.7, R.sub.60, R.sub.70, b60, and b70 are each as described herein, [0095] custom-character indicates a single bond or a double bond, and [0096] * indicates a binding site to a neighboring atom.

[0097] In one or more embodiments, the group represented by Formula 3 may be a group represented by any one selected from among Formulae 3-1 to 3-3:

##STR00012## [0098] wherein, in Formulae 3-1 to 3-3, [0099] X.sub.61 may be C(R.sub.61) or N, X.sub.62 may be C(R.sub.62) or N, X.sub.63 may be C(R.sub.63) or N, X.sub.64 may be C(R.sub.64) or N, or X.sub.65 may be C(R.sub.65) or N, [0100] X.sub.71 may be C(R.sub.71) or N, X.sub.72 may be C(R.sub.72) or N, X.sub.73 may be C(R.sub.73) or N, X.sub.74 may be C(R.sub.74) or N, and X.sub.75 may be C(R.sub.75) or N, [0101] R.sub.61 to R.sub.65 may each independently be as described in connection with R.sub.60, [0102] R.sub.71 to R.sub.75 may each independently be as described in connection with R.sub.70, [0103] at least two (e.g., two ro more) selected from among neighboring R.sub.61 to R.sub.65 and R.sub.71 to R.sub.75 may optionally be bonded to each other to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0104] R.sub.10a is as described herein, and [0105] * indicates a binding site to a neighboring atom.

[0106] In one or more embodiments, Ar.sub.1 to Ar.sub.6 may each independently be: a group represented by Formula 3, hydrogen, deuterium, —F, —Cl, —Br, —I, cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; [0107] a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, or a C.sub.3-C.sub.10 cycloalkyl group, each substituted with deuterium, —F, —Cl, —Br, —I, —CDH.sub.2, —CD.sub.2H, —CD.sub.3, a cyano group, a phenyl group, a biphenyl group, or any combination thereof; [0108] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a

pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, or an indolocarbazolyl group; [0109] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a benzoisoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, or an indolocarbazolyl group, each substituted with deuterium, —F, —Cl, —Br, —I, —CDH.sub.2, —CD.sub.2H, —CD.sub.3, a cyano group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an

isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a benzoisoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, an indolocarbazolyl 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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), —P(═S)(Q.sub.31)(Q.sub.32), or any combination thereof; or [0110] —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2).

[0111] In one or more embodiments, Ar.sub.1 to Ar.sub.6 may each independently be: a group represented by Formula 3, hydrogen, deuterium, —F, —Cl, —Br, —I, cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; or a group represented by any one selected from among Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55:

##STR00013## ##STR00014## ##STR00015## ##STR00016## ##STR00017## ##STR00018## ##STR00019## ##STR00020## ##STR00021## ##STR00022## ##STR00023## ##STR00024##

[0112] wherein, in Formulae 5-1 to 5-26 and 6-1 to 6-55, [0113] Y.sub.31 and Y.sub.32 may each independently be O, S, C(Z.sub.33)(Z.sub.34), N(Z33), or Si(Z33)(Z.sub.34), [0114] Z.sub.31 to Z.sub.34 may each independently be selected from among 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, [0115] e2 may be 1 or 2, [0116] e3 may be an integer from 1 to 3, [0117] e4 may be an integer from 1 to 4, [0118] e5 may be an integer from 1 to 5, [0119] e6 may be an integer from 1 to 6, [0120] e7 may be an integer from 1 to 7, [0121] e9 may be an integer from 1 to 9, and [0122] * indicates a binding site to a neighboring atom.

[0123] In one or more embodiments, Ar.sub.1 to Ar.sub.6 may each independently be: a group represented by Formula 3, hydrogen, deuterium, —F, —Cl, —Br, —I, cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; [0124] a C.sub.1-C.sub.20 alkyl group or a C.sub.1-C.sub.20 alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, a cyano group, a phenyl group, a biphenyl group, or any combination thereof; [0125] 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, an acridinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, or a dibenzocarbazolyl

group; or [0126] 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, an acridinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, or a dibenzocarbazolyl group, each substituted with deuterium, —F, —Cl, —Br, —I, a cyano 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, or any combination thereof.

[0127] In Formulae 1 to 3, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may each independently be 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2).

[0128] In one or more embodiments, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may each independently be: hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; [0129] a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, or a C.sub.3-C.sub.10 cycloalkyl group, each substituted with deuterium, —F, —Cl, —Br, —I, —CDH.sub.2, —CD.sub.2H, —CDs, a cyano group, a phenyl group, a biphenyl group, or any combination thereof; [0130] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a benzoisoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a

triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, or an indolocarbazolyl group; [0131] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a benzoisoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, or an indolocarbazolyl group, each substituted with deuterium, —F, —Cl, —Br, —I,-CDH.sub.2,-CD.sub.2H,-CD.sub.3, a cyano group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a C.sub.3-C.sub.10 cycloalkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentacenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, a silolyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolyl group, an isoindolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a benzoisoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzosilolyl group, a

benzothiazolyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, a thiadiazolyl group, an oxadiazolyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a naphthobenzofuranyl group, a naphthobenzothiophenyl group, a naphthobenzosilolyl group, a dibenzocarbazolyl group, a dinaphthofuranyl group, a dinaphthothiophenyl group, a dinaphthosilolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an oxazolopyridinyl group, a thiazolopyridinyl group, a benzonaphthyridinyl group, an azafluorenyl group, an azaspiro-bifluorenyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azadibenzosilolyl group, an indenopyrrolyl group, an indolopyrrolyl group, an indenocarbazolyl group, an indolocarbazolyl 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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), —P(═S)(Q.sub.31)(Q.sub.32), or any combination thereof; or [0132] —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2).

[0133] In one or more embodiments, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may each independently be: hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; or the group represented by any one selected from among Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55.

[0134] In one or more embodiments, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may each independently be: hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, or a C.sub.1-C.sub.20 alkoxy group; [0135] a C.sub.1-C.sub.20 alkyl group or a C.sub.1-C.sub.20 alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, a cyano group, a phenyl group, a biphenyl group, or any combination thereof; [0136] 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, an acridinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, or a dibenzocarbazolyl group; or [0137] 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, an acridinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, or a dibenzocarbazolyl group, each substituted with deuterium, —F, —Cl, —Br, —I, a cyano 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, or any combination thereof.

[0138] In Formulae 1 to 3, at least two (e.g., two or more) selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.10, R.sub.20, Rao, R.sub.40, R.sub.50, Rso, and R.sub.70 may optionally be bonded together to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a.

[0139] In one or more embodiments, at least two (e.g., two or more) selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, Rso, and R.sub.70 may optionally be bonded together to form a cyclopentane group, a cyclohexane group, a cycloheptane group, a fluorene group, or a carbazole group, each unsubstituted or substituted with at least one R.sub.10a.

[0140] In Formula 1, b10 and b20 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, or 18.

[0141] In Formula 2, b10, b20, b30, b40, b50, b60, and b70 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, or 8.

[0142] In one or more embodiments, at least one (e.g., one or more) selected from among Ar.sub.1 to Ar.sub.6, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 may be: deuterium, a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, a sec-butyl group, an isobutyl group, a tert-butyl group, an n-pentyl group, a tert-pentyl group, a neopentyl group, an isopentyl group, a sec-pentyl group, a 3-pentyl group, a sec-isopentyl group, an n-hexyl group, an isohexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an isoheptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an isooctyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an isononyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an isodecyl group, a sec-decyl group, a tert-decyl group, a cyclohexyl group, a phenyl group, or a naphthyl group; or [0143] a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, a sec-butyl group, an isobutyl group, a tert-butyl group, an n-pentyl group, a tert-pentyl group, a neopentyl group, an isopentyl group, a sec-pentyl group, a 3-pentyl group, a sec-isopentyl group, an n-hexyl group, an isohexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an isoheptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an isooctyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an isononyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an isodecyl group, a sec-decyl group, a tert-decyl group, a cyclohexyl group, a phenyl group, or a naphthyl group, each substituted with at least one deuterium. [0144] R.sub.10a may be: [0145] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group; [0146] 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, or a C.sub.1-C.sub.60 alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), —P(═S)(Q.sub.11)(Q.sub.12), or any combination thereof; [0147] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, or a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, or a C.sub.1-C.sub.60 heteroarylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro 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.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), —P(═S)(Q.sub.21)(Q.sub.22), or any combination thereof; or [0148] —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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), or —P(═S)(Q.sub.31)(Q.sub.32), and [0149] 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 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, or a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C.sub.1-C.sub.60 alkyl group, a C.sub.1-C.sub.60 alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0150] In one or more embodiments, the heterocyclic compound represented by Formula 1 may be a compound represented by one of Formula 11 or 12:
##STR00025## [0151] wherein, in Formulae 11 and 12, [0152] X.sub.1 to X.sub.4, A.sub.1 to A.sub.5, A.sub.11 to A.sub.13, Ar.sub.1, Ar.sub.2, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, b10, b20, b30, [0153] b40 and b50 are each as described herein, [0154] b11 and b21 may each independently be 0, 1, 2, 3, or 4, and [0155] b12, b13, b22, and b23 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, or 8.
[0156] In one or more embodiments, the sum of b11, b12, and b13 may be equal to b10, and the sum of b21, b22, and b23 may be equal to b20.
[0157] In one or more embodiments, the heterocyclic compound represented by Formula 1 may be a compound represented by one of Formula 21 or 22:
##STR00026## [0158] wherein, in Formulae 21 and 22, [0159] X.sub.1 to X.sub.4, Ar.sub.1, and Ar.sub.2 are each as described herein, [0160] R.sub.11 to R.sub.19 may each independently be as described in connection with R.sub.10, [0161] R.sub.21 to R.sub.29 may each independently be as described in connection with R.sub.20, [0162] R.sub.31 is as described in connection with R.sub.30, and [0163] R.sub.41 to R.sub.44 may each independently be as described in connection with R.sub.40, [0164] R.sub.51 to R.sub.53 may each independently be as described in connection with R.sub.50, [0165] at least two (e.g., two or more) selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.11 to R.sub.19, R.sub.21 to R.sub.29, R.sub.31, R.sub.41 to R.sub.44, and R.sub.51 to R.sub.53 may optionally be bonded together to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, and [0166] R.sub.10a is as described herein.
[0167] In one or more embodiments, the heterocyclic compound represented by Formula 1 may be any one selected from among Compounds 1 to 80, but embodiments are not limited thereto:
##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##
[0168] The heterocyclic compound represented by Formula 1 is a heteroring including a boron atom, satisfying a structure in which at least one selected from among A.sub.1 and A.sub.2 is the group represented by Formula 2. Due to this structure, the heterocyclic compound may have a narrow full width at half maximum (FWHM), high color purity, and high luminescence efficiency.
[0169] Also, although not being limited to any specific theory, the heterocyclic compound satisfying the structure of Formula 1 may further strengthen multiple resonance effects as sequential separation of a highest occupied molecular orbital (HOMO) and a lowest unoccupied molecular orbital (LUMO) occurs, to improve the stability of materials, (e.g., by reducing intermolecular interactions due to steric effects), and suppress or reduce Dexter energy transfer. Accordingly, the organic light-emitting devices of the present disclosure that utilize the heterocyclic compound satisfying the structure of Formula 1 may thereby exhibit improved or enhanced high efficiency characteristics.
[0170] For example, if (e.g., when) the heterocyclic compound represented by Formula 1 is applied to an organic light-emitting device, the driving voltage may be lowered and the color purity, luminescence efficiency, and lifespan characteristics may be improved. For example, if (e.g., when) an emission layer of the organic light-emitting device includes the heterocyclic compound represented by Formula 1, a deep blue organic light-emitting device with low driving voltage, high color purity, high luminescence efficiency, and long lifespan may be implemented.
[0171] In one or more embodiments, the heterocyclic compound may be to emit blue light. For

example, the heterocyclic compound may be to emit blue light (bottom emission CIE.sub.x,y color coordinates of 0.15, 0.05 to 0.15) having a maximum emission wavelength of at least 400 nanometer (nm) and at most (e.g., less than) 500 nm, e.g., blue light having a maximum emission wavelength in a range of about 410 nm to about 490 nm. Accordingly, the heterocyclic compound represented by Formula 1 may be useful in manufacturing an organic light-emitting device emitting blue light.

[0172] In one or more embodiments, the heterocyclic compound may be to emit deep blue having a maximum emission wavelength in a range of about 410 nm to about 465 nm.

[0173] Synthesis methods of the heterocyclic compound represented by Formula 1 may be recognizable by one of ordinary skill in the art by referring to Examples provided herein.

[0174] In one or more embodiments, [0175] a first electrode of an organic light-emitting device may be an anode, [0176] a second electrode of an organic light-emitting device may be a cathode, and [0177] an interlayer of an organic light-emitting device may include a hole transport region arranged between the first electrode and the emission layer and an electron transport region arranged between the emission layer and the second electrode, [0178] 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 [0179] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0180] In one or more embodiments, the electron transport region may include a hole blocking layer.

[0181] In one or more embodiments, the hole blocking layer may be in direct contact with the emission layer.

[0182] In one or more embodiments, the hole blocking layer may include a phosphine oxide-containing compound, a silyl-containing compound, and/or a (e.g., any suitable) combination thereof.

[0183] In one or more embodiments, the emission layer may include the heterocyclic compound represented by Formula 1. For example, the emission layer may be to emit blue light having a maximum emission wavelength of about 400 nm to about 500 nm.

[0184] In one or more embodiments, the emission layer of the light-emitting device may further include a dopant and a host, and the dopant may include the heterocyclic compound represented by Formula 1. For example, the heterocyclic compound may act as a dopant. The emission layer may be to emit, for example, blue light. The blue light may have, for example, a maximum emission wavelength in a range of about 400 nm to about 500 nm.

[0185] In one or more embodiments, the emission layer may be to emit deep blue having a maximum emission wavelength in a range of about 410 nm to about 465 nm.

[0186] In one or more embodiments, the emission layer may include a host and a dopant.

[0187] In one or more embodiments, in the emission layer, an amount of the host may be greater than that of the dopant, based on a weight.

[0188] In one or more embodiments, the host may include a silicon-containing compound, a phosphine oxide-containing compound, and/or a (e.g., any suitable) combination thereof.

[0189] In one or more embodiments, for descriptions of the host, reference may be made to the present specification.

[0190] Therefore, a light-emitting device (e.g., the organic light-emitting device) including the heterocyclic compound represented by Formula 1 may have high color purity, high luminescence efficiency, low driving voltage, and long lifespan characteristics.

[0191] In one or more embodiments, the heterocyclic compound represented by Formula 1 may be to emit blue light. For example, the heterocyclic compound represented by Formula 1 may be to emit blue light having a maximum emission wavelength in a range of about 390 nm to about 500 nm, about 410 nm to about 500 nm, about 410 nm to about 490 nm, about 430 nm to about 480 nm,

about 440 nm to about 475 nm, or about 455 nm to about 470 nm.
[0192] In one or more embodiments, the heterocyclic compound represented by Formula 1 may have color purity with a bottom emission CIEx coordinate in a range of about 0.12 to about 0.15 or about 0.13 to about 0.14 and a bottom emission CIEy coordinate in a range of about 0.06 to about 0.25, about 0.10 to about 0.20, or about 0.13 to about 0.20.
[0193] The term “interlayer” as used herein refers to a single layer and/or each (e.g., any or all) of multiple layers arranged between the first electrode and the second electrode of the light-emitting device.
[0194] Another aspect of the disclosure provides an electronic apparatus including the organic light-emitting device. The electronic apparatus may further include a thin-film transistor. For example, the electronic apparatus may further include a thin-film transistor including a source electrode and a drain electrode, wherein the first electrode of the organic light-emitting device may be electrically connected to the source electrode or the drain electrode. In one or more embodiments, the electronic apparatus may further include a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof. For more descriptions of the electronic apparatus, reference may be made to the present specification.
[0195] Another aspect of the disclosure provides an electronic apparatus including the organic light-emitting device.
[0196] For example, the electronic device may be any one selected from among a flat panel display, a curved display, a computer monitor, a medical monitor, a TV, a billboard, indoor or outdoor illuminations and/or signal light, a head-up display, a fully or partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a phone, a cell phone, a tablet, a phablet, a personal digital assistant (PDA), a wearable device, laptop computers, digital cameras, camcorders, viewfinders, micro displays, 3D displays, virtual or augmented reality displays, vehicles, a video wall including multiple displays tiled together, a theater or stadium screen, a phototherapy device, and/or a signage, and/or combinations thereof.
Description of FIG. **1**
[0197] FIG. **1** is a schematic cross-sectional view of an organic light-emitting device **10** according to one or more embodiments. The organic light-emitting device **10** includes a first electrode **110**, an interlayer **130**, and a second electrode **150**. Hereinafter, the structure of the organic light-emitting device **10** according to one or more embodiments and a method of manufacturing the organic light-emitting device **10** will be described with reference to FIG. **1**.
First Electrode **110**
[0198] In FIG. **1**, a substrate may be additionally arranged under the first electrode **110** or on the second electrode **150**. In one or more embodiments, as the substrate, a glass substrate or a plastic substrate may be used. In one or more embodiments, the substrate may be a flexible substrate, and may include plastics with excellent or suitable heat resistance and durability, such as polyimide, polyethylene terephthalate (PET), polycarbonate, polyethylene naphthalate, polyarylate (PAR), polyetherimide, or any combination thereof.
[0199] The first electrode **110** may be formed by, for example, depositing or sputtering, onto the substrate, a material for forming the first electrode **110**. When the first electrode **110** is an anode, a material for forming the first electrode **110** may be a high-work function material that facilitates injection of holes.
[0200] The first electrode **110** may be a reflective electrode, a transflective electrode, or a transmissive electrode. In one or more embodiments, if (e.g., when) the first electrode **110** is a transmissive electrode, a material for forming the first electrode **110** may include indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO.sub.2), zinc oxide (ZnO), or any combination thereof. In one or more embodiments, if (e.g., when) the first electrode **110** is a transflective electrode or a reflective electrode, a material for forming the first electrode **110** may include magnesium (Mg), silver (Ag), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca),

magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or any combination thereof.
[0201] The first electrode **110** may have a single-layer structure including (e.g., consisting of) a single layer, or a multi-layer structure including multiple layers. For example, the first electrode **110** may have a three-layer structure of ITO/Ag/ITO.

Interlayer **130**

[0202] The interlayer **130** may be arranged on the first electrode **110**. The interlayer **130** may include an emission layer.
[0203] The interlayer **130** 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 **150**.
[0204] The interlayer **130** may further include a metal-containing compound such as a heterocyclic compound, an inorganic material such as a quantum dot, and/or the like, in addition to one or more suitable organic materials.
[0205] In one or more embodiments, the interlayer **130** may include i) two or more emitting units sequentially stacked between the first electrode **110** and the second electrode **150**, and ii) a charge generation layer between neighboring two emitting units. When the interlayer **130** includes two or more emitting units and the charge generation layer as described herein, the organic light-emitting device **10** may be a tandem organic light-emitting device.

Hole Transport Region in Interlayer **130**

[0206] The hole transport region may have i) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) a single material, ii) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) multiple materials that are different from each other, or iii) a multi-layer structure including multiple layers including multiple materials that are different from each other.
[0207] 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.
[0208] For example, the hole transport region may have a multi-layer structure including 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 layers in each structure are sequentially stacked from the first electrode **110**.
[0209] The hole transport region may include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof:
##STR00058## [0210] wherein, in Formulae 201 and 202, [0211] L.sub.201 to L.sub.204 may each independently be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0212] L.sub.205 may be *—O—*′, *—S—*′, *—N(Q.sub.201)-*′, a C.sub.1-C.sub.20 alkylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.20 alkenylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a, or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0213] xa1 to xa4 may each independently be an integer from 0 to 5, [0214] xa5 may be an integer from 1 to 10, [0215] R.sub.201 to R.sub.204 and Q.sub.201 may each independently be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0216] R.sub.201 and R.sub.202 may optionally be linked to each other via a single bond, a C.sub.1-C.sub.5 alkylene group unsubstituted or substituted with at least one R.sub.10a, or a C.sub.2-C.sub.5 alkenylene group unsubstituted or substituted with at least one R.sub.10a, to form a C.sub.8-C.sub.60 polycyclic group (e.g., a carbazole group, and/or the like) unsubstituted or

substituted with at least one R.sub.10a (e.g., Compound HT16, and/or the like), [0217] R.sub.203 and R.sub.204 may optionally be linked to each other via a single bond, a C.sub.1-C.sub.5 alkylene group unsubstituted or substituted with at least one R.sub.10a, or a C.sub.2-C.sub.5 alkenylene group unsubstituted or substituted with at least one R.sub.10a, to form a C.sub.8-C.sub.60 polycyclic group unsubstituted or substituted with at least one R.sub.10a, and [0218] na1 may be an integer from 1 to 4.

[0219] For example, each of Formulae 201 and 202 may include at least one of (e.g., selected from among) groups represented by Formulae CY201 to CY217:

##STR00059## ##STR00060## [0220] wherein, in Formulae CY201 to CY217, R.sub.10b and R.sub.10c are each as described in connection with R.sub.10a, ring CY201 to ring CY204 may each independently be a C.sub.3-C.sub.20 carbocyclic group or a C.sub.1-C.sub.20 heterocyclic group, and at least one hydrogen in Formulae CY201 to CY217 may be unsubstituted or substituted with R.sub.10a.

[0221] In one or more embodiments, in Formulae CY201 to CY217, ring CY.sub.201 to ring CY.sub.204 may each independently be a benzene group, a naphthalene group, a phenanthrene group, or an anthracene group.

[0222] In one or more embodiments, each of Formulae 201 and 202 may include at least one of (e.g., selected from among) groups represented by Formulae CY201 to CY203.

[0223] In one or more embodiments, Formula 201 may include at least one of groups represented by Formulae CY201 to CY203 and at least one of groups represented by Formulae CY204 to CY217.

[0224] In one or more embodiments, in Formula 201, xa1 may be 1, R.sub.201 may be one of groups represented by Formulae CY201 to CY203, xa2 may be 0, and R.sub.202 may be one of groups represented by one of Formulae CY204 to CY207.

[0225] In one or more embodiments, each of Formulae 201 and 202 may not include (e.g., may exclude any of) groups represented by Formulae CY201 to CY203.

[0226] In one or more embodiments, each of Formulae 201 and 202 may not include (e.g., may exclude any of the) groups represented by Formulae CY201 to CY203, and may include at least one of groups represented by Formulae CY204 to CY217.

[0227] In one or more embodiments, each of Formulae 201 and 202 may not include (e.g., may exclude any of the) groups represented by Formulae CY201 to CY217.

[0228] For example, the hole transport region **120** may include: at least one of (e.g., one or more selected from among) Compounds HT1 to HT46; m-MTDATA; TDATA; 2-TNATA; NPB(NPD); β-NPB; TPD; spiro-TPD; spiro-NPB; methylated NPB; TAPC; HMTPD; 4,4′,4″-tris(N-carbazolyl)triphenylamine (TCTA); polyaniline/dodecylbenzenesulfonic acid (PANI/DBSA); poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS); polyaniline/camphor sulfonic acid (PANI/CSA); polyaniline/poly(4-styrenesulfonate) (PANI/PSS); or any combination thereof:

##STR00061## ##STR00062## ##STR00063## ##STR00064## ##STR00065## ##STR00066## ##STR00067## ##STR00068## ##STR00069## ##STR00070## ##STR00071## ##STR00072##

[0229] A thickness of the hole transport region may be in a range of about 50 Å to about 10,000 Å, for example, about 100 Å to about 4,000 Å. When the hole transport region includes a hole injection layer, a hole transport layer, or any combination thereof, a thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, for example, about 100 Å to about 1,000 Å, and a thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, for example, about 100 to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within these ranges, satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

[0230] The emission auxiliary layer may increase light emission efficiency by compensating for an optical resonance distance according to the wavelength of light emitted by the emission layer, and

the electron blocking layer may block the leakage of electrons from the emission layer to the hole transport region. Materials that may be included in the hole transport region may be included in the emission auxiliary layer and the electron blocking layer.

p-Dopant

[0231] The hole transport region may further include, in addition to the aforementioned materials, a charge-generation material for the improvement of conductive properties. The charge-generation material may be uniformly (e.g., substantially uniformly) or non-uniformly (e.g., substantially non-uniformly) dispersed in the hole transport region (e.g., in the form of a single layer including (e.g., consisting of) the charge-generation material).

[0232] The charge-generation material may be, for example, a p-dopant.

[0233] For example, the p-dopant may have a lowest unoccupied molecular orbital (LUMO) energy level of −3.5 eV or less.

[0234] In one or more embodiments, the p-dopant may include a quinone derivative, a cyano group-containing compound, a compound including element EL1 and element EL2, or any combination thereof.

[0235] Examples of the quinone derivative may include TCNQ, F4-TCNQ, and/or the like.

[0236] Examples of the cyano group-containing compound may include HAT-CN, a compound represented by Formula 221, and/or the like:

##STR00073## [0237] wherein, in Formula 221, [0238] R.sub.221 to R.sub.223 may each independently be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, and [0239] at least one of (e.g., selected from among) R.sub.221 to R.sub.223 may each independently be a C.sub.3-C.sub.60 carbocyclic group and/or a C.sub.1-C.sub.60 heterocyclic group, each substituted with: a cyano group; —F; —Cl; —Br; —I; a C.sub.1-C.sub.20 alkyl group substituted with a cyano group, —F, —Cl, —Br, —I, or any combination thereof.

[0240] In the compound including element EL1 and element EL2, the element EL1 may be a metal, metalloid, and/or a (e.g., any suitable) combination thereof, and the element EL2 may be a non-metal, metalloid, and/or a (e.g., any suitable) combination thereof.

[0241] Examples of the metal may include: alkali metal (e.g., lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), and/or the like); alkaline earth metal brlim mgeim((e.g., beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and/or the like); transition metal (e.g., titanium (Ti), zirconium (Zr), hafnium (Hf), vanadium (V), niobium (Nb), tantalum (Ta), chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), and/or the like); post-transition metal (e.g., zinc (Zn), indium (In), tin (Sn), and/or the like); lanthanide metal (e.g., lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), and/or the like); and/or the like.

[0242] Examples of the metalloid may include silicon (Si), antimony (Sb), tellurium (Te), and/or the like.

[0243] Examples of the non-metal may include oxygen (O), a halogen (e.g., F, Cl, Br, I, and/or the like), and/or the like.

[0244] For example, the compound including element EL1 and element EL2 may include metal oxide, metal halide (e.g., metal fluoride, metal chloride, metal bromide, metal iodide, and/or the like), metalloid halide (e.g., metalloid fluoride, metalloid chloride, metalloid bromide, metalloid iodide, and/or the like), metal telluride, or any combination thereof.

[0245] Examples of the metal oxide may include tungsten oxide (e.g., WO, W.sub.2O.sub.3, WO.sub.2, WO.sub.3, W.sub.2O.sub.5, and/or the like), vanadium oxide (e.g., VO, V.sub.2O.sub.3, VO.sub.2, V.sub.2O.sub.5, and/or the like), molybdenum oxide (e.g., MoO, Mo.sub.2O.sub.3,

MoO.sub.2, MoO.sub.3, Mo.sub.2O.sub.5, and/or the like), rhenium oxide (e.g., ReO.sub.3, and/or the like), and/or the like.
[0246] Examples of the metal halide may include alkali metal halide, alkaline earth metal halide, transition metal halide, post-transition metal halide, lanthanide metal halide, and/or the like.
[0247] Examples of the alkali metal halide may include LiF, NaF, KF, RbF, CsF, LiCl, NaCl, KCl, RbCl, CsCl, LiBr, NaBr, KBr, RbBr, CsBr, LiI, NaI, KI, RbI, CsI, and/or the like.
[0248] Examples of the alkaline earth metal halide may include BeF.sub.2, MgF.sub.2, CaF.sub.2, SrF.sub.2, BaF.sub.2, BeCl.sub.2, MgCl.sub.2, CaCl.sub.2), SrCl.sub.2, BaCl.sub.2, BeBr.sub.2, MgBr.sub.2, CaBr.sub.2, SrBr.sub.2, BaBr.sub.2, BeI.sub.2, Mg.sub.12, CaI.sub.2, Sr.sub.12, BaI.sub.2, and/or the like.
[0249] Examples of the transition metal halide may include titanium halide (e.g., TiF.sub.4, TiCl.sub.4, TiBr.sub.4, TiI.sub.4, and/or the like), zirconium halide (e.g., ZrF.sub.4, ZrCl.sub.4, ZrBr.sub.4, ZrI.sub.4, and/or the like), hafnium halide (e.g., HfF.sub.4, HfC.sub.14, HfBr.sub.4, HfI.sub.4, and/or the like), vanadium halide (e.g., VF.sub.3, VCI.sub.3, VBrs, VIs, and/or the like), niobium halide (e.g., NbF.sub.3, NbCl.sub.3, NbBr.sub.3, NbI.sub.3, and/or the like), tantalum halide (e.g., TaF.sub.3, TaCl.sub.3, TaBr.sub.3, TaI.sub.3, and/or the like), chromium halide (e.g., CrF.sub.3, CrCl.sub.3, CrBr.sub.3, CrI.sub.3, and/or the like), molybdenum halide (e.g., MoF.sub.3, MoCl.sub.3, MoBr.sub.3, MoI.sub.3, and/or the like), tungsten halide (e.g., WF.sub.3, WCl.sub.3, WBr.sub.3, WI.sub.3, and/or the like), manganese halide (e.g., MnF.sub.2, MnCl.sub.2, MnBr.sub.2, MnI.sub.2, and/or the like), technetium halide (e.g., TcF.sub.2, TcCl.sub.2, TcBr.sub.2, TcI.sub.2, and/or the like), rhenium halide (e.g., ReF.sub.2, ReCl.sub.2, ReBr.sub.2, ReI.sub.2, and/or the like), Iron(II) halide (e.g., FeF.sub.2, FeCl.sub.2, FeBr.sub.2, FeI.sub.2, and/or the like), ruthenium halide (e.g., RuF.sub.2, RuCl.sub.2, RuBr.sub.2, RuI.sub.2, and/or the like), osmium halide (e.g., OsF.sub.2, OsC.sub.12, OsBr.sub.2, OsI.sub.2, and/or the like), cobalt halide (e.g., CoF.sub.2, COCl.sub.2, CoBr.sub.2, C.sub.012, and/or the like), rhodium halide (e.g., RhF.sub.2, RhCl.sub.2, RhBr.sub.2, RhI.sub.2, and/or the like), iridium halide (e.g., IrF.sub.2, IrCl.sub.2, IrBr.sub.2, IrI.sub.2, and/or the like), nickel halide (e.g., NiF.sub.2, NiCl.sub.2, NiBr.sub.2, NiI.sub.2, and/or the like), palladium halide (e.g., PdF.sub.2, PdCl.sub.2, PdBr.sub.2, PdI.sub.2, and/or the like), platinum halide (e.g., PtF.sub.2, PtCl.sub.2, PtBr.sub.2, PtI.sub.2, and/or the like), Copper(I) halide (e.g., CuF, CuCl, CuBr, CuI, and/or the like), silver halide (e.g., AgF, AgCl, AgBr, AgI, and/or the like), gold halide (e.g., AuF, AuCl, AuBr, AuI, and/or the like), and/or the like.
[0250] Examples of the post-transition metal halide may include zinc halide (e.g., ZnF.sub.2, ZnCl.sub.2, ZnBr.sub.2, Zn.sub.12, and/or the like), indium halide (e.g., InI.sub.3, and/or the like), tin halide (e.g., Sn.sub.12, and/or the like), and/or the like.
[0251] Examples of the lanthanide metal halide may include YbF, YbF.sub.2, YbF.sub.3, SmF.sub.3, YbCl, YbCl.sub.2, YbCl.sub.3, SmCl.sub.3, YbBr, YbBr.sub.2, YbBr.sub.3, SmBr.sub.3, YbI, YbI.sub.2, YbI.sub.3, SmI.sub.3, and/or the like.
[0252] Examples of the metalloid halide may include antimony halide (e.g., SbCl.sub.5, and/or the like) and/or the like.
[0253] Examples of the metal telluride may include alkali metal telluride (e.g., Li.sub.2Te, Na.sub.2Te, K.sub.2Te, Rb.sub.2Te, Cs.sub.2Te, and/or the like), alkaline earth metal telluride (e.g., BeTe, MgTe, CaTe, SrTe, BaTe, and/or the like), transition metal telluride (e.g., TiTe.sub.2, ZrTe.sub.2, HfTe.sub.2, V.sub.2Te.sub.3, Nb.sub.2Te.sub.3, Ta.sub.2Te.sub.3, Cr.sub.2Te.sub.3, Mo.sub.2Te.sub.3, W.sub.2Te.sub.3, MnTe, TcTe, ReTe, FeTe, RuTe, OsTe, CoTe, RhTe, IrTe, NiTe, PdTe, PtTe, Cu.sub.2Te, CuTe, Ag.sub.2Te, AgTe, Au.sub.2Te, and/or the like), post-transition metal telluride (e.g., ZnTe, and/or the like), lanthanide metal telluride (e.g., LaTe, CeTe, PrTe, NdTe, PmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, and/or the like), and/or the like.
Emission Layer in Interlayer **130**
[0254] When the organic light-emitting device **10** is a full-color organic light-emitting device, the

emission layer may be patterned into a red emission layer, a green emission layer, and/or a blue emission layer, according to a subpixel. In one or more embodiments, the emission layer may have a stacked structure in which two or more layers among a red emission layer, a green emission layer, and a blue emission layer contact each other or are separated from each other to emit white light. In one or more embodiments, the emission layer may have a structure in which two or more materials among a red light-emitting material, a green light-emitting material, and a blue light-emitting material are mixed with each other in a single layer to emit white light.

[0255] In one or more embodiments, the emission layer may include a host and a dopant. The dopant may include a phosphorescent dopant, a fluorescent dopant, or any combination thereof.

[0256] An amount of the dopant in the emission layer may be in a range of about 0.01 parts by weight to about 15 parts by weight, based on 100 parts by weight of the host.

[0257] In one or more embodiments, the emission layer may include quantum dots.

[0258] In one or more embodiments, the emission layer may include a delayed fluorescence material. The delayed fluorescence material may act as a host or a dopant in the emission layer.

[0259] The emission layer may further include a host, an auxiliary dopant, a sensitizer, a delayed fluorescence material, or any combination thereof, in addition to the aforementioned heterocyclic compound. Each of the host, the auxiliary dopant, the sensitizer, the delayed fluorescence material, or any combination thereof may include at least one deuterium.

[0260] For example, the emission layer may include the heterocyclic compound and the host. The host may be different from the heterocyclic compound, and the host may include an electron-transporting compound, a hole-transporting compound, a bipolar compound, or any combination thereof. The host may not include (e.g., may exclude) a metal. The electron-transporting compound, the hole-transporting compound, and the bipolar compound may be different from each other.

[0261] In one or more embodiments, the emission layer may include the heterocyclic compound and the host, and the host may include an electron-transporting compound and a hole-transporting compound.

[0262] In one or more embodiments, the electron-transporting compound and the hole-transporting compound may form an exciplex.

[0263] A thickness of the emission layer may be in a range of about 100 Å to about 1,000 Å, for example, about 200 Å to about 600 Å. When the thickness of the emission layer is within the ranges described herein, excellent or suitable luminescence characteristics may be obtained without a substantial increase in driving voltage.

Host

[0264] In one or more embodiments, 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 [0265] wherein, in Formula 301, [0266] Ar.sub.301 and L.sub.301 may each independently be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0267] xb11 may be 1, 2, or 3, [0268] xb1 may be an integer from 0 to 5, [0269] R.sub.301 may be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.1-C.sub.60 alkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, —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), or —P(═O)(Q.sub.301)(Q.sub.302), [0270] xb21 may be an integer from 1 to 5, and [0271] Q.sub.301 to Q.sub.303 may each independently be as described in connection with Q.sub.1.
[0272] For example, if (e.g., when) xb11 in Formula 301 is 2 or more, two or more of Ar.sub.301 may be linked to each other via a single bond.
[0273] In one or more embodiments, the host may include a compound represented by Formula 301-1, a compound represented by Formula 301-2, or any combination thereof:
##STR00074## [0274] wherein, in Formulae 301-1 and 301-2, [0275] ring A.sub.301 to ring A.sub.304 may each independently be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0276] X.sub.301 may be O, S, N-[(L.sub.304).sub.xb4-R.sub.304], C(R.sub.304)(R.sub.305), or Si(R.sub.304)(R.sub.305), [0277] xb22 and xb23 may each independently be 0, 1, or 2, [0278] L.sub.301, xb1, and R.sub.301 may each independently be as described herein, [0279] L.sub.302 to L.sub.304 are each as described in connection with L.sub.301, [0280] xb2 to xb4 are each as described in connection with xb1, and [0281] R.sub.302 to R.sub.305 and R.sub.311 to R.sub.314 are each as described in connection with R.sub.301.
[0282] In one or more embodiments, the host may include an alkaline earth metal complex, a post-transition metal complex, or any combination thereof. In one or more embodiments, the host may include a Be complex (e.g., Compound H55), an Mg complex, a Zn complex, or any combination thereof.
[0283] In one or more embodiments, the host may include at least one of (e.g., one or more selected from among) Compounds H1 to H124; 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(carbazol-9-yl)benzene (mCP); 1,3,5-tri(carbazol-9-yl)benzene (TCP); or any combination thereof.
##STR00075## ##STR00076## ##STR00077## ##STR00078## ##STR00079## ##STR00080## ##STR00081## ##STR00082## ##STR00083## ##STR00084## ##STR00085## ##STR00086## ##STR00087## ##STR00088## ##STR00089## ##STR00090## ##STR00091## ##STR00092## ##STR00093## ##STR00094## ##STR00095## ##STR00096## ##STR00097## ##STR00098## ##STR00099## ##STR00100## ##STR00101## ##STR00102## ##STR00103## ##STR00104## ##STR00105## ##STR00106##
[0284] In one or more embodiments, the host may include a first host compound and a second host compound.
[0285] In one or more embodiments, the first host compound may be a hole transporting host.
[0286] In one or more embodiments, the second host compound may be an electron-transporting host.
[0287] In one or more embodiments, the term “hole-transporting host” as used herein may be a compound including a hole-transporting moiety.
[0288] In one or more embodiments, the term “electron-transporting host” as used herein may be a compound not only including an electron-transporting moiety but also having bipolar properties.
[0289] The terms “hole-transporting host” and “electron-transporting host” as used herein may be understood according to the relative difference in hole mobility and electron mobility therebetween. For example, even if (e.g., when) the electron transporting host does not include an electron transporting moiety, a bipolar compound exhibiting relatively higher electron mobility than the hole transporting host may be also understood as the electron transporting host.
[0290] In one or more embodiments, the hole transporting host may be represented by any one selected from among Formulae 311-1 to 311-6, and the electron transporting host may be represented by any one selected from among Formulae 312-1 to 312-4, 313 and 313A:
##STR00107## [0291] wherein, in Formulae 311-1 to 311-6, 312-1 to 312-4, 313, and 313A,
[0292] Ar.sub.301 may be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with

at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0293] A.sub.301 to A.sub.304 may each independently be a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0294] X.sub.301 may be O, S, N-[(L.sub.304).sub.xb4-R.sub.304], C[(L.sub.304).sub.xb4-R.sub.304][(L.sub.305).sub.xb5-R.sub.305], or Si[(L.sub.304).sub.xb4-R.sub.304][(L.sub.305).sub.xb5-R.sub.305], [0295] X.sub.302, Y.sub.301, and Y.sub.302 may each independently be a single bond, O, S, N-[(L.sub.305).sub.xb5-R.sub.305], C[(L.sub.304).sub.xb4-R.sub.304][(L.sub.305).sub.xb5-R.sub.305], Si[(L.sub.304).sub.xb4-R.sub.304][(L.sub.305).sub.xb5-R.sub.305], or S(═O).sub.2, [0296] xb1 to xb5 may each be 0,1, 2, 3, 4, or 5, [0297] xb6 may be 1, 2, 3, 4, or 5, [0298] X.sub.321 to X.sub.328 may each independently be N or C[(L.sub.324).sub.xb24-R.sub.324], [0299] Y.sub.321 may be *—O—*′, *—S—*′, *—N[(L.sub.325).sub.xb25-R.sub.325]—*′, *—C[(L.sub.325).sub.xb25-R.sub.325][(L.sub.326).sub.xb26-R.sub.326]—*′, *—C[(L.sub.325).sub.xb25-R.sub.325]=C[(L.sub.326).sub.xb26-R.sub.326]—*′, *—C[(L.sub.325).sub.xb25-R.sub.325]=N—*′, or *—N=C[(L.sub.326).sub.xb26-R.sub.326]—*′, [0300] k21 may be 0, 1, or 2, wherein Y.sub.321 is not present if (e.g., when) k21 is 0, [0301] xb21 to xb26 may each independently be 0, 1, 2, 3, 4, or 5, [0302] A.sub.31, A.sub.32, and A.sub.34 may each independently be a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.30 heterocyclic group, [0303] A.sub.33 may be a group represented by Formula 313A, [0304] X.sub.31 may be N[(L.sub.335).sub.xb35-(R.sub.335)], O, S, Se, C[(L.sub.335).sub.xb35-(R.sub.335)][(L.sub.336).sub.xb36-(R.sub.336)], or Si[(L.sub.335).sub.xb35-(R.sub.335)][(L.sub.336).sub.xb36-(R.sub.336)], [0305] xb31 to xb36 may each independently be 0, 1, 2, 3, 4, or 5, [0306] xb42 to xb44 may each independently be 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, [0307] L.sub.301 to L.sub.306, L.sub.321 to L.sub.326, and L.sub.331 to L.sub.336 may each independently be a single bond, a C.sub.1-C.sub.20 alkylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.20 alkenylene group unsubstituted or substituted with at least one R.sub.11a, a C.sub.1-C.sub.20 alkynylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.1a heterocycloalkylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylene group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylene group unsubstituted or substituted with at least one R.sub.10a, a divalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, or a divalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, [0308] R.sub.301 to R.sub.305, R.sub.311 to R.sub.314, R.sub.321 to R.sub.324, and R.sub.331 to R.sub.336 may each independently be 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group

unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2), [0309] at least two (e.g., two or more) selected from among neighboring R.sub.321 to R.sub.324 may optionally be bonded to each other to form a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a,

[0310] R.sub.10a is: [0311] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group; [0312] 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, or a C.sub.1-C.sub.60 alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), —P(═S)(Q.sub.11)(Q.sub.12), or any combination thereof; [0313] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, or a C.sub.1-C.sub.60 heteroarylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro 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.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(**021**), —S(═O)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), —P(═S)(Q.sub.21)(Q.sub.22), or any combination thereof; or [0314] —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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), or —P(═S)(Q.sub.31)(Q.sub.32), and [0315] Q.sub.11 to Q.sub.13, Q.sub.21 to Q.sub.23, Q.sub.31 to Q.sub.33, Q.sub.41 to Q.sub.43, Q.sub.301 to Q.sub.303, Q.sub.321 to Q.sub.323, and Q.sub.331 to Q.sub.333 may each independently be: 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; or a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C.sub.1-C.sub.60 alkyl group, a C.sub.1-C.sub.60 alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0316] In one or more embodiments, the first host compound and the second host compound may form an exciplex.

[0317] In one or more embodiments, the first host compound may include (e.g., may be) any one of (e.g., selected from among) Compounds HTH1 to HTH56 and/or a (e.g., any suitable) combination thereof:

##STR00108## ##STR00109## ##STR00110## ##STR00111## ##STR00112## ##STR00113## ##STR00114## ##STR00115## ##STR00116## ##STR00117## ##STR00118## ##STR00119##

##STR00120## ##STR00121##
[0318] In one or more embodiments, the second host compound may include (e.g., may be) any one of (e.g., selected from among) Compounds ETH1 to ETH86 and/or a (eg.,any suitable)combination thereof:
##STR00122## ##STR00123## ##STR00124## ##STR00125## ##STR00126## ##STR00127## ##STR00128## ##STR00129## ##STR00130## ##STR00131## ##STR00132## ##STR00133## ##STR00134## ##STR00135## ##STR00136## ##STR00137## ##STR00138## ##STR00139## ##STR00140## ##STR00141## ##STR00142## ##STR00143##
Phosphorescent Dopant
[0319] In one or more embodiments, the emission layer may further include a phosphorescent dopant.
[0320] For example, the emission layer may further include a phosphorescent dopant, and the phosphorescent dopant may serve as a sensitizer.
[0321] The phosphorescent dopant may include at least one transition metal as a central metal.
[0322] The phosphorescent dopant may include a monodentate ligand, a bidentate ligand, a tridentate ligand, a tetradentate ligand, a pentadentate ligand, a hexadentate ligand, or any combination thereof.
[0323] The phosphorescent dopant may be electrically neutral.
[0324] In one or more embodiments, the phosphorescent dopant may be the heterocyclic compound.
[0325] In one or more embodiments, the phosphorescent dopant may include an organometallic compound represented by Formula 401:

M(L.sub.401)xc1(L.sub.402).sub.xc2 Formula 401
##STR00144## [0326] wherein, in Formulae 401 and 402, [0327] M may be a transition metal (e.g., Ir, Pt, Pd, Os, Ti, Au, Hf, Eu, Tb, Rh, Re, or Tm), [0328] L.sub.401 may be a ligand represented by Formula 402, and xc1 may be 1, 2, or 3, wherein, if (e.g., when) xc1 is 2 or more, two or more of L.sub.401 may be substantially identical to or different from each other, [0329] L.sub.402 may be an organic ligand, and xc2 may be 0, 1, 2, 3, or 4, wherein, if (e.g., when) xc2 is 2 or more, two or more of L.sub.402 may be substantially identical to or different from each other, [0330] X.sub.401 and X.sub.402 may each independently be nitrogen or carbon, [0331] ring A.sub.401 and ring A.sub.402 may each independently be a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0332] T.sub.401 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=*′, [0333] X.sub.403 and X.sub.404 may each independently be a chemical bond (e.g., a covalent bond or a coordination bond), O, S, N(Q.sub.413), B(Q.sub.413), P(Q.sub.413), C(Q.sub.413)(Q.sub.414), or Si(Q.sub.413)(Q.sub.414), [0334] Q.sub.411 to Q.sub.414 are each as described in connection with Q.sub.1, [0335] R.sub.401 and R.sub.402 may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.1-C.sub.20 alkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.20 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, —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), or —P(═O)(Q.sub.401)(Q.sub.402), [0336] Q.sub.401 to Q.sub.403 are each as described in connection with Q.sub.1, [0337] xc11 and xc12 may each independently be an integer from 0 to 10, and [0338] * and *′ in Formula 402 each indicate a binding site to M in Formula 401.
[0339] For example, in Formula 402, i) X.sub.401 may be nitrogen and X.sub.402 may be carbon, or ii) each of X.sub.401 and X.sub.402 may be nitrogen.

[0340] In one or more embodiments, if (e.g., when) xc1 in Formula 401 is 2 or more, two ring A.sub.401(s) among two or more L.sub.401(s) may optionally be linked to each other via T.sub.402, which is a linking group, and two ring A.sub.402(s) among two or more L.sub.401(s) may optionally be linked to each other via T.sub.403, which is a linking group (see Compounds PD1 to PD4 and PD7). T.sub.402 and T.sub.403 may each be defined as for T.sub.401.
[0341] In Formula 401, L.sub.402 may be an organic ligand. For example, L.sub.402 may include a halogen group, a diketone group (e.g., an acetylacetonate group), a carboxylic acid group (e.g., a picolinate group), —C(═O), an isonitrile group, a —CN group, a phosphorus group (e.g., a phosphine group, a phosphite group, and/or the like), or any combination thereof.
[0342] The phosphorescent dopant may include, for example, at least one of (e.g., one or more selected from among) Compounds PD1 to PD41, or any combination thereof:
##STR00145## ##STR00146## ##STR00147## ##STR00148## ##STR00149## ##STR00150## ##STR00151## ##STR00152## ##STR00153## ##STR00154##
Fluorescent Dopant
[0343] In one or more embodiments, the emission layer may further include a fluorescent dopant.
[0344] The fluorescent dopant may include an amine group-containing compound, a styryl group-containing compound, or any combination thereof.
[0345] For example, the fluorescent dopant may include a compound represented by Formula 501:
##STR00155## [0346] wherein, in Formula 501, [0347] Ar.sub.501, L.sub.501 to L.sub.503, R.sub.501, and R.sub.502 may each independently include a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, [0348] xd1 to xd3 may each independently be 0, 1, 2, or 3, and [0349] xd4 may be 1, 2, 3, 4, 5, or 6.
[0350] For example, Ar.sub.501 in Formula 501 may be a condensed cyclic group (e.g., an anthracene group, a chrysene group, a pyrene group, and/or the like) in which three or more monocyclic groups are condensed together.
[0351] For example, xd4 in Formula 501 may be 2.
[0352] In one or more embodiments, the fluorescent dopant may include: at least one of (e.g., one or more selected from among) Compounds FD1 to FD36; DPVBi; DPAVBi; or any combination thereof:
##STR00156## ##STR00157## ##STR00158## ##STR00159## ##STR00160## ##STR00161## ##STR00162## ##STR00163## ##STR00164##
Delayed Fluorescence Material
[0353] In one or more embodiments, the emission layer may further include a delayed fluorescence material.
[0354] In the present specification, the delayed fluorescence material may be selected from among compounds capable of emitting delayed fluorescence based on a delayed fluorescence emission mechanism.
[0355] The delayed fluorescence material included in the emission layer may act as a host or a dopant depending on the type or kind of other materials included in the emission layer.
[0356] In one or more embodiments, a difference between a triplet energy level (eV) of the delayed fluorescence material and the singlet energy level (eV) of the delayed fluorescence material may be in a range of about 0 eV to about 0.5 eV. When the difference between the triplet energy level (eV) of the delayed fluorescence material and the singlet energy level (eV) of the delayed fluorescence material is within the range described herein, up-conversion from the triplet state to the singlet state of the delayed fluorescence material may effectively occur, and thus, the organic light-emitting device **10** may have improved luminescence efficiency.
[0357] For example, the delayed fluorescence material may include i) a material including at least one electron donor (e.g., a π electron-rich C.sub.3-C.sub.60 cyclic group, such as a carbazole group, and/or the like) and at least one electron acceptor (e.g., a sulfoxide group, a cyano group, a π

electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group, and/or the like), and ii) a material including a C.sub.8-C.sub.60 polycyclic group in which two or more cyclic groups are condensed while sharing boron (B).

[0358] Examples of the delayed fluorescence material may include at least one of (e.g., one or more selected from among) Compounds DF1 to DF9:

##STR00165## ##STR00166## ##STR00167##

Quantum Dots

[0359] The emission layer may include quantum dots.

[0360] The term “quantum dots” as used herein refers to crystals of a semiconductor compound, and may include any material capable of emitting light of one or more suitable emission wavelengths according to the size of the crystals.

[0361] A diameter of the quantum dots may be, for example, in a range of about 1 nanometer (nm) to about 10 nm. In the present disclosure, when quantum dot, quantum dots, or quantum dot particles are spherical, “diameter” indicates a particle diameter or an average particle diameter, and when the particles are non-spherical, the “diameter” indicates a major axis length or an average major axis length. The diameter of the particles may be measured utilizing a scanning electron microscope or a particle size analyzer. As the particle size analyzer, for example, HORIBA, LA-950 laser particle size analyzer, may be utilized. When the size of the particles is measured utilizing a particle size analyzer, the average particle diameter is referred to as D50. D50 refers to the average diameter of particles whose cumulative volume corresponds to 50 vol % in the particle size distribution (e.g., cumulative distribution), and refers to the value of the particle size corresponding to 50% from the smallest particle when the total number of particles is 100% in the distribution curve accumulated in the order of the smallest particle size to the largest particle size.

[0362] The quantum dots may be synthesized by a wet chemical process, a metal organic chemical vapor deposition process, a molecular beam epitaxy process, or any process similar thereto.

[0363] The wet chemical process is a method including mixing a precursor material with an organic solvent and then growing quantum dot particle crystals. When the crystals grow, the organic solvent naturally acts as a dispersant coordinated on the surface of the quantum dot crystals and controls the growth of the crystals so that the growth of quantum dot particles may be controlled or selected through a process which costs lower and is easier than vapor deposition methods, such as metal organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE).

[0364] The quantum dot may include: a Group II-VI semiconductor compound; a Group III-V semiconductor compound; a Group III-VI semiconductor compound; a Group I—III-VI semiconductor compound; a Group IV-VI semiconductor compound; a Group IV element or compound; or any combination thereof.

[0365] Examples of the Group II-VI semiconductor compound may include: a binary compound, such as CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnO, HgS, HgSe, HgTe, MgSe, MgS, and/or the like; a ternary compound, such as CdSeS, CdSeTe, CdSTe, ZnSeS, ZnSeTe, ZnSTe, HgSeS, HgSeTe, HgSTe, CdZnS, CdZnSe, CdZnTe, CdHgS, CdHgSe, CdHgTe, HgZnS, HgZnSe, HgZnTe, MgZnSe, MgZnS, and/or the like; a quaternary compound, such as CdZnSeS, CdZnSeTe, CdZnSTe, CdHgSeS, CdHgSeTe, CdHgSTe, HgZnSeS, HgZnSeTe, HgZnSTe, and/or the like; or any combination thereof.

[0366] Examples of the Group III-V semiconductor compound may include: a binary compound, such as GaN, GaP, GaAs, GaSb, AlN, AIP, AIAs, AISb, InN, InP, InAs, InSb, and/or the like a ternary compound, such as GaNP, GaNAs, GaNSb, GaPAs, GaPSb, AlNP, AlNAs, AlNSb, AIPAs, AIPSb, InGaP, InNP, InAIP, InNAs, InNSb, InPAs, InPSb, and/or the like; a quaternary compound, such as GaAINP, GaAINAs, GaAINSb, GaAIPAs, GaAIPSb, GaInNP, GaInNAs, GalnNSb, GaInPAs, GalnPSb, InAINP, InAINAs, InAINSb, InAIPAs, InAIPSb, and/or the like; or any combination thereof. In one or more embodiments, the Group III-V semiconductor compound may further include a Group II element. Examples of the Group III-V semiconductor compound further

including a Group II element may include InZnP, InGaZnP, InAIZnP, and/or the like.
[0367] Examples of the Group III-VI semiconductor compound may include: a binary compound, such as GaS, GaSe, Ga.sub.2Se.sub.3, GaTe, InS, InSe, In.sub.2S.sub.3, In.sub.2Se.sub.3, InTe, and/or the like; a ternary compound, such as InGaS.sub.3, InGaSes, and/or the like; or any combination thereof.
[0368] Examples of the Group I-III-VI semiconductor compound may include: a ternary compound, such as AgInS, AgInS.sub.2, CuInS, CulnS.sub.2, CuGaO.sub.2, AgGaO.sub.2, AgAIO.sub.2, and/or the like; or any combination thereof.
[0369] Examples of the Group IV-VI semiconductor compound may include: a binary compound, such as SnS, SnSe, SnTe, PbS, PbSe, or PbTe; a ternary compound, such as SnSeS, SnSeTe, SnSTe, PbSeS, PbSeTe, PbSTe, SnPbS, SnPbSe, SnPbTe, and/or the like; a quaternary compound, such as SnPbSSe, SnPbSeTe, SnPbSTe, and/or the like; or any combination thereof.
[0370] The Group IV element or compound may include: a single element compound, such as Si, Ge, and/or the like; a binary compound, such as SiC, SiGe, and/or the like; or any combination thereof.
[0371] Each element included in a multi-element compound, such as the binary compound, the ternary compound, and the quaternary compound, may be present at a substantially uniform concentration or substantially non-uniform concentration in a particle.
[0372] In one or more embodiments, the quantum dots may have a single structure in which the concentration of each element in the quantum dots is substantially uniform, or a core-shell dual structure. For example, materials included in the core and materials included in the shell may be different from each other.
[0373] The shell of the quantum dots may act as a protective layer that prevents chemical degeneration of the core to maintain semiconductor characteristics, and/or as a charging layer that imparts electrophoretic characteristics to the quantum dots. The shell may be single-layered or multi-layered. The interface between the core and the first shell may have a concentration gradient in which the concentration of an element existing in the first shell decreases toward the center of the core **10**.
[0374] Examples of the shell of the quantum dots may include: an oxide of metal, metalloid, or non-metal; a semiconductor compound: or any combination thereof. Examples of the oxide of metal, metalloid, or non-metal may include: 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, NiO, and/or the like; a ternary compound, such as MgAl.sub.2O.sub.4, CoFe.sub.2O.sub.4, NiFe.sub.2O.sub.4, CoMn.sub.2O.sub.4, and/or the like; or any combination thereof. Examples of the semiconductor compound may include: as described herein, a Group II-VI semiconductor compound; a Group III-V semiconductor compound; a Group III-VI semiconductor compound; a Group I-III-VI semiconductor compound; a Group IV-VI semiconductor compound; or any combination thereof. Examples of the semiconductor compound may include CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnSeS, ZnTeS, GaAs, GaP, GaSb, HgS, HgSe, HgTe, InAs, InP, InGaP, InSb, AlAs, AlP, AlSb, or any combination thereof.
[0375] A full width at half maximum (FWHM) of an emission wavelength spectrum of the quantum dots may be about 45 nm or less, for example, about 40 nm or less, and for example, about 30 nm or less, and within these ranges, the color purity or color reproducibility of the quantum dots may be improved. In some embodiments, because light emitted through the quantum dots is emitted in all directions, the wide viewing angle may be improved.
[0376] In some embodiments, the quantum dots may be nanoparticles, nanotubes, nanowires, nanofibers, nanoplates, and/or the like, for example, in the form of spherical particles, pyramidal particles, multi-arm particles, or cubic particles.
[0377] By controlling the size of the quantum dots, the energy band gap may be adjustable so that

light having one or more suitable wavelength bands may be obtained from the emission layer including the quantum dots. Accordingly, by using quantum dots of different sizes, the organic light-emitting device that emits light of one or more suitable wavelengths may be implemented. In one or more embodiments, the size of quantum dots **100** may be selected to emit red light, green light, and/or blue light. In some embodiments, the size of quantum dots **100** may be configured to emit white light by combining light of one or more suitable colors.

Electron Transport Region in Interlayer **130**

[0378] The electron transport region may have: i) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) a single material, ii) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) multiple materials that are different from each other, or iii) a multi-layer structure including multiple layers including multiple materials that are different from each other.

[0379] The electron transport region may include a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0380] For example, the electron transport region may have an electron transport layer/electron injection layer structure, a hole blocking layer/electron transport layer/electron injection layer structure, an electron control layer/electron transport layer/electron injection layer structure, or a buffer layer/electron transport layer/electron injection layer structure, wherein layers in each structure are sequentially stacked from the emission layer.

[0381] In one or more embodiments, the electron transport region (e.g., 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-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group.

[0382] For example, 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

[0383] wherein, in Formula 601, [0384] Ar.sub.601 and L.sub.601 may each independently be a C.sub.3-C.sub.60 carbocyclic group that is unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group that is unsubstituted or substituted with at least one R.sub.10a, [0385] xe11 may be 1, 2, or 3, [0386] xe1 may be 0, 1, 2, 3, 4, or 5, [0387] R.sub.601 may be a C.sub.3-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.601)(Q.sub.602)(Q.sub.603), —C(═O)(Q.sub.601), —S(═O).sub.2(Q.sub.601), or —P(═O)(Q.sub.601)(Q.sub.602), [0388] Q.sub.601 to Q.sub.603 are each as described in connection with Q.sub.1, [0389] xe21 may be 1, 2, 3, 4, or 5, and [0390] at least one selected from among Ar.sub.601, L.sub.601, and R.sub.601 may each independently be a π electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group unsubstituted or substituted with at least one R.sub.10a.

[0391] For example, if (e.g., when) xe11 in Formula 601 is 2 or more, two or more of Ar.sub.601 may be linked to each other via a single bond.

[0392] In one or more embodiments, Ar.sub.601 in Formula 601 may be an anthracene group unsubstituted or substituted with at least one R.sub.10a.

[0393] In one or more embodiments, the electron transport region may include a compound represented by Formula 601-1:

##STR00168## [0394] wherein, in Formula 601-1, [0395] X.sub.614 may be N or C(R.sub.614), X.sub.615 may be N or C(R.sub.615), and X.sub.616 may be N or C(R.sub.616), wherein at least one selected from among X.sub.614 to X.sub.616 may be N, [0396] L.sub.611 to L.sub.613 are each as described in connection with L.sub.601, [0397] xe611 to xe613 are each as described in connection with xe1, [0398] R.sub.611 to R.sub.613 are each as described in connection with

R.sub.601, and [0399] R.sub.614 to R.sub.616 may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, a C.sub.3-C.sub.60 carbocyclic group that is unsubstituted or substituted with at least one R.sub.10a, or a C.sub.1-C.sub.60 heterocyclic group that is unsubstituted or substituted with at least one R.sub.10a.

[0400] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0401] In one or more embodiments, the electron transport region may include: at least one of (e.g., one or more selected from among) Compounds ET1 to ET45; 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP); 4,7-diphenyl-1,10-phenanthroline (Bphen); Alq.sub.3; BAIq; TAZ; NTAZ; or any combination thereof:

##STR00169## ##STR00170## ##STR00171## ##STR00172## ##STR00173## ##STR00174## ##STR00175## ##STR00176## ##STR00177## ##STR00178## ##STR00179## ##STR00180## ##STR00181## ##STR00182## ##STR00183##

[0402] A thickness of the electron transport region may be in a range of about 100 angstrom (Å) to about 5,000 Å, for example, about 160 Å to about 4,000 Å. When the electron transport region includes a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, or any combination thereof, a thickness of the buffer layer, the hole blocking layer, or the electron control layer may be in a range of about 20 Å to about 1,000 Å, for example, about 30 Å to about 300 Å, and a thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, for example, about 150 Å to about 500 Å. When the thicknesses of the buffer layer, the hole blocking layer, the electron control layer, the electron transport layer, and/or the electron transport region are within these ranges, satisfactory electron transporting characteristics may be obtained without a substantial increase in driving voltage.

[0403] The electron transport region (e.g., an electron transport layer in the electron transport region) may further include, in addition to the aforementioned materials, a metal-containing material.

[0404] The metal-containing material may include an alkali metal complex, an alkaline earth metal complex, or any combination thereof. A metal ion of the alkali metal complex may be a Li ion, a Na ion, a K ion, a Rb ion, or a Cs ion, and a metal ion of the alkaline earth metal complex may be a Be ion, a Mg ion, a Ca ion, a Sr ion, or a Ba ion. A ligand coordinated with the metal ion of the alkali metal complex or the metal ion of the alkaline earth-metal complex may include a hydroxyquinoline, a hydroxyisoquinoline, a hydroxybenzoquinoline, a hydroxyacridine, a hydroxyphenanthridine, a hydroxyphenyloxazole, a hydroxyphenylthiazole, a hydroxyphenyloxadiazole, a hydroxyphenylthiadiazole, a hydroxyphenylpyridine, a hydroxyphenylbenzimidazole, a hydroxyphenylbenzothiazole, a bipyridine, a phenanthroline, a cyclopentadiene, or any combination thereof.

[0405] In one or more embodiments, the metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (LiQ) or ET-D2:

##STR00184##

[0406] The electron transport region may include an electron injection layer that facilitates the injection of electrons from the second electrode **150**. The electron injection layer may directly contact the second electrode **150**.

[0407] The electron injection layer may have: i) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) a single material, ii) a single-layer structure including (e.g., consisting of) a single layer including (e.g., consisting of) multiple layers that are different from each other, or iii) a multi-layer structure including multiple layers including multiple materials that are different from each other.

[0408] In one or more embodiments, the electron injection layer may include an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal-containing compound, an alkaline earth

metal-containing compound, a rare earth metal-containing compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof.
[0409] The alkali metal may include Li, Na, K, Rb, Cs, or any combination thereof. The alkaline earth metal may include Mg, Ca, Sr, Ba, or any combination thereof. The rare earth metal may include Sc, Y, Ce, Tb, Yb, Gd, or any combination thereof.
[0410] The alkali metal-containing compound, the alkaline earth metal-containing compound, and the rare earth metal-containing compound may be oxides, halides (e.g., fluorides, chlorides, bromides, or iodides), or tellurides of the alkali metal, the alkaline earth metal, and the rare earth metal, or any combination thereof.
[0411] The alkali metal-containing compound may include: alkali metal oxides, such as Li.sub.2O, Cs.sub.2O, or K.sub.2O; alkali metal halides, such as LiF, NaF, CsF, KF, LiI, NaI, CsI, or KI; or any combination thereof. The alkaline earth metal-containing compound may include an alkaline earth metal oxide, such as BaO, SrO, CaO, Ba.sub.xSr.sub.1-xO (wherein x is a real number satisfying 0<x<1), Ba.sub.xCa.sub.1-xO (wherein x is a real number satisfying 0<x<1), and/or the like. The rare earth metal-containing compound may include YbF.sub.3, ScF.sub.3, Sc.sub.2O.sub.3, Y.sub.2O.sub.3, Ce.sub.2O.sub.3, GdF.sub.3, TbF.sub.3, YbI.sub.3, ScI.sub.3, TbI.sub.3, or any combination thereof. In one or more embodiments, the rare earth metal-containing compound may include lanthanide metal telluride. Examples of the lanthanide metal telluride may include LaTe, CeTe, PrTe, NdTe, PmTe, SmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, La.sub.2Te.sub.3, Ce.sub.2Te.sub.3, Pr.sub.2Te.sub.3, Nd.sub.2Te.sub.3, Pm.sub.2Te.sub.3, Sm.sub.2Te.sub.3, Eu.sub.2Te.sub.3, Gd.sub.2Te.sub.3, Tb.sub.2Te.sub.3, Dy.sub.2Te.sub.3, Ho.sub.2Te.sub.3, Er.sub.2Te.sub.3, Tm.sub.2Te.sub.3, Yb.sub.2Te.sub.3, Lu.sub.2Te.sub.3, and/or the like.
[0412] The alkali metal complex, the alkaline earth-metal complex, and the rare earth metal complex may include i) one of (e.g., selected from among) ions of the alkali metal, the alkaline earth metal, and the rare earth metal and ii) a ligand bonded to the metal ion(s) (e.g., the selected metal ions(s)), for example, hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenyl benzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, cyclopentadiene, or any combination thereof.
[0413] In one or more embodiments, the electron injection layer may include (e.g., consist of) an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal-containing compound, an alkaline earth metal-containing compound, a rare earth metal-containing compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof, as described herein. In one or more embodiments, the electron injection layer may further include an organic material (e.g., the compound represented by Formula 601).
[0414] In one or more embodiments, the electron injection layer may include (e.g., consist of) i) an alkali metal-containing compound (e.g., an alkali metal halide), or ii) a) an alkali metal-containing compound (e.g., an alkali metal halide), and b) an alkali metal, an alkaline earth metal, a rare earth metal, or any combination thereof. In one or more embodiments, the electron injection layer may be a KI:Yb co-deposited layer, an RbI:Yb co-deposited layer, a LiF:Yb co-deposited layer, and/or the like.
[0415] When the electron injection layer further includes an organic material, the alkali metal, the alkaline earth metal, the rare earth metal, the alkali metal-containing compound, the alkaline earth metal-containing compound, the rare earth metal-containing compound, the alkali metal complex, the alkaline earth-metal complex, the rare earth metal complex, or any combination thereof may be uniformly (e.g., substantially uniformly) or non-uniformly (e.g., substantially non-uniformly) dispersed in a matrix including the organic material.
[0416] A thickness of the electron injection layer may be in a range of about 1 A to about 100 Å, or,

for example, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within these ranges, satisfactory electron injection characteristics may be obtained without a substantial increase in driving voltage.

Second Electrode **150**

[0417] The second electrode **150** may be arranged on the interlayer **130** having the aforementioned structure. The second electrode **150** may be a cathode, which is an electron injection electrode, and as a material for forming the second electrode **150**, a metal, an alloy, an electrically conductive compound, or any combination thereof, each having a low-work function, may be used.

[0418] The second electrode **150** may include Li, Ag, Mg, Al, Al—Li, Ca, Mg—In, Mg—Ag, Yb, Ag—Yb, ITO, IZO, or any combination thereof. The second electrode **150** may be a transmissive electrode, a transflective electrode, or a reflective electrode.

[0419] The second electrode **150** may have a single-layer structure or a multi-layer structure including multiple layers.

Capping Layer

[0420] A first capping layer may be arranged outside (and e.g., on) the first electrode **110**, and/or a second capping layer may be arranged outside (and e.g., on) the second electrode **150**. In particular, the organic light-emitting device **10** may have a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, and the second electrode **150** are sequentially stacked in the stated order, a structure in which the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are sequentially stacked in the stated order, or a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are sequentially stacked in the stated order.

[0421] Light generated in the emission layer of the interlayer **130** of the organic light-emitting device **10** may be extracted toward the outside through the first electrode **110**, which is a transflective electrode or a transmissive electrode, and the first capping layer. Light generated in the emission layer of the interlayer **130** of the organic light-emitting device **10** may be extracted toward the outside through the second electrode **150**, which is a transflective electrode or a transmissive electrode, and the second capping layer.

[0422] The first capping layer and the second capping layer may increase external emission efficiency according to the aspect of constructive interference. Accordingly, the light extraction efficiency of the organic light-emitting device **10** is increased, so that the luminescence efficiency of the organic light-emitting device **10** may be improved.

[0423] Each of the first capping layer and the second capping layer may include a material having a refractive index of 1.6 or more (at 589 nm).

[0424] The first capping layer and the second capping layer may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or an organic-inorganic composite capping layer including an organic material and an inorganic material.

[0425] At least one of (e.g., selected from among) the first capping layer and/or the second capping layer may each independently include a carbocyclic compound, a heterocyclic compound, an amine group-containing compound, a porphine derivative, a phthalocyanine derivative, a naphthalocyanine derivative, an alkali metal complex, an alkaline earth metal complex, or any combination thereof. The carbocyclic compound, the heterocyclic compound, and the amine group-containing compound may optionally be substituted with a substituent including O, N, S, Se, Si, F, Cl, Br, I, or any combination thereof.

[0426] In one or more embodiments, at least one selected from among the first capping layer and the second capping layer may each independently include an amine group-containing compound.

[0427] In one or more embodiments, at least one selected from among the first capping layer and the second capping layer may each independently include the compound represented by Formula 201, the compound represented by Formula 202, or any combination thereof.

[0428] In one or more embodiments, at least one of (e.g., selected from among) the first capping layer and/or the second capping layer may each independently include: at least one of (e.g., selected from among) Compounds HT28 to HT33; at least one of (e.g., selected from among) Compounds CP1 to CP6; β-NPB; or any combination thereof:

##STR00185##

Film

[0429] The heterocyclic compound represented by Formula 1 may be included in one or more suitable films. Thus, another aspect of the disclosure provides a film including the heterocyclic compound represented by Formula 1 and/or a heterocyclic compound represented by Formula 2. The film may be, for example, an optical member (or a light control component) (e.g., a color filter, a color conversion member, a capping layer, a light extraction efficiency enhancement layer, a selective light absorbing layer, a polarizing layer, a quantum dot-containing layer, or like), a light blocking member (e.g., a light reflective layer, a light absorbing layer, and/or the like), a protective member (e.g., an insulating layer, a dielectric layer, and/or the like).

Electronic Apparatus

[0430] The organic light-emitting device may be included in one or more suitable electronic apparatuses. For example, the electronic apparatus including the organic light-emitting device may be a light-emitting apparatus, an authentication apparatus, and/or the like.

[0431] The electronic apparatus (e.g., a light-emitting apparatus) may further include, in addition to the organic light-emitting device, i) a color filter, ii) a color conversion layer, or iii) a color filter and a color conversion layer. The color filter and/or the color conversion layer may be arranged in at least one traveling direction of light emitted from the organic light-emitting device. For example, the light emitted from the organic light-emitting device may be blue light or white light. Details on the organic light-emitting device are as described herein. In one or more embodiments, the color conversion layer may include quantum dots. The quantum dots may be, for example, the aforementioned quantum dots.

[0432] The electronic apparatus may include a first substrate. The first substrate may include a plurality of subpixel areas, the color filter may include a plurality of color filter areas respectively corresponding to the plurality of subpixel areas, and the color conversion layer may include a plurality of color conversion areas respectively corresponding to the plurality of subpixel areas.

[0433] A pixel-defining film may be arranged among the plurality of subpixel areas to define each of the subpixel areas.

[0434] The color filter may further include a plurality of color filter areas and light-shielding patterns thereon, and the color conversion layer may further include a plurality of color conversion areas and light-shielding patterns thereon.

[0435] The plurality of color filter areas (or the plurality of color conversion areas) may include: a first area emitting first color light; a second area emitting second color light; and/or a third area emitting third color light, wherein the first color light, the second color light, and/or the third color light may have different maximum emission wavelengths from one another. In one or more embodiments, the first color light may be red light, the second color light may be green light, and the third color light may be blue light. In one or more embodiments, the plurality of color filter areas (or the plurality of color conversion areas) may include quantum dots. In particular, the first area may include red quantum dots, the second area may include green quantum dots, and the third area may not include (e.g., may exclude any) quantum dots. For descriptions of the quantum dots, reference may be made to the present specification. Each of the first area, the second area, and/or the third area may further include a scatter.

[0436] For example, the organic light-emitting device may be to emit first light, the first area may be to absorb the first light to emit first-first color light, the second area may be to absorb the first light to emit second-first color light, and the third area may be to absorb the first light to emit third-first color light. Here, the first-1 color light, the second-1 color light, and the third-1 color light

may have different maximum emission wavelengths from one another. In particular, the first light may be blue light, the first-1 color light may be red light, the second-1 color light may be green light, and the third-1 color light may be blue light.

[0437] The electronic apparatus may further include a thin-film transistor in addition to the aforementioned organic light-emitting device. The thin-film transistor may include a source electrode, a drain electrode, and an activation layer, wherein any one selected from among the source electrode and the drain electrode may be electrically connected to any one selected from among the first electrode and the second electrode of the organic light-emitting device.

[0438] The thin-film transistor may further include a gate electrode, a gate insulating film, and/or the like.

[0439] The activation layer may include crystalline silicon, amorphous silicon, an organic semiconductor, an oxide semiconductor, and/or the like.

[0440] The electronic apparatus may further include a sealing portion for sealing the organic light-emitting device. The sealing portion may be arranged between the color filter and/or the color conversion layer and the organic light-emitting device. The sealing portion allows light from the organic light-emitting device to be extracted to the outside, and concurrently (e.g., simultaneously) prevents ambient air and moisture from penetrating into the organic light-emitting device. The sealing portion may be a sealing substrate including a transparent glass substrate or a plastic substrate. The sealing portion may be a thin-film encapsulation layer including at least one layer of an organic layer and/or an inorganic layer. When the sealing portion is a thin-film encapsulation layer, the electronic apparatus may be flexible.

[0441] Various functional layers may be additionally arranged on the sealing portion, in addition to the color filter and/or the color conversion layer, according to the use of the electronic apparatus. The functional layers may include a touch screen layer, a polarizing layer, and/or the like. The touch screen layer may be a pressure-sensitive touch screen layer, a capacitive touch screen layer, or an infrared touch screen layer.

[0442] The authentication apparatus may further include, in addition to the organic light-emitting device as described herein, a biometric information collector. The authentication apparatus may be, for example, a biometric authentication apparatus that authenticates an individual by using biometric information of a living body (e.g., fingertips, pupils, and/or the like).

[0443] The electronic apparatus may be applied to one or more suitable displays, light sources, lighting, personal computers (e.g., mobile personal computers), mobile phones, digital cameras, electronic organizers, electronic dictionaries, electronic game machines, medical instruments (e.g., electronic thermometers, sphygmomanometers, blood glucose meters, pulse measurement devices, pulse wave measurement devices, electrocardiogram displays, ultrasonic diagnostic devices, or endoscope displays), fish finders, one or more suitable measuring instruments, meters (e.g., meters for a vehicle, an aircraft, and a vessel), projectors, and/or the like.

Description of FIGS. **2** and **3**

[0444] FIG. **2** is a cross-sectional view showing a light-emitting apparatus according to one or more embodiments.

[0445] The electronic apparatus (e.g. light-emitting apparatus) of FIG. **2** includes a substrate **100**, a thin-film transistor (TFT), an organic light-emitting device, and an encapsulation portion that encapsulates the organic light-emitting device.

[0446] The substrate **100** may be a flexible substrate, a glass substrate, or a metal substrate. A buffer layer **210** may be arranged on the substrate **100**. The buffer layer **210** may prevent or reduce penetration of impurities through the substrate **100**, and provide a flat surface on the substrate **100**.

[0447] A TFT may be arranged on the buffer layer **210**. The TFT may include an activation layer **220**, a gate electrode **240**, a source electrode **260**, and a drain electrode **270**.

[0448] The activation layer **220** may include an inorganic semiconductor, such as silicon or polysilicon, an organic semiconductor, or an oxide semiconductor, and may include a source

region, a drain region, and a channel region.
[0449] A gate insulating film **230** for insulating the activation layer **220** from the gate electrode **240** may be arranged on the activation layer **220**, and the gate electrode **240** may be arranged on the gate insulating film **230**.
[0450] An interlayer insulating film **250** may be arranged on the gate electrode **240**. The interlayer insulating film **250** may be arranged between the gate electrode **240** and the source electrode **260** and between the gate electrode **240** and the drain electrode **270**, to insulate these electrodes from one another.
[0451] The source electrode **260** and the drain electrode **270** may be arranged on the interlayer insulating film **250**. The interlayer insulating film **250** and the gate insulating film **230** may be formed to expose the source region and the drain region of the activation layer **220**, and the source electrode **260** and the drain electrode **270** may be arranged in contact with the exposed portions of the source region and the drain region of the activation layer **220**.
[0452] The TFT may be electrically connected to an organic light-emitting device to drive the organic light-emitting device, and may be covered and protected by a passivation layer **280**. The passivation layer **280** may include an inorganic insulating film, an organic insulating film, and/or a (e.g., any suitable) combination thereof. An organic light-emitting device may be provided on the passivation layer **280**. The organic light-emitting device may include the first electrode **110**, the interlayer **130**, and the second electrode **150**.
[0453] The first electrode **110** may be arranged on the passivation layer **280**. The passivation layer **280** may be arranged to expose a portion of the drain electrode **270** without fully covering the drain electrode **270**, and the first electrode **110** may be arranged to be connected to the exposed portion of the drain electrode **270**.
[0454] A pixel defining layer **290** including an insulating material may be arranged on the first electrode **110**. The pixel defining layer **290** may expose a certain region of the first electrode **110**, and the interlayer **130** may be formed in the exposed region of the first electrode **110**. The pixel defining layer **290** may be a polyimide-based organic film or a polyacrylic-based organic film. In one or more embodiments, at least some layers of the interlayer **130** may extend beyond the upper portion of the pixel defining layer **290** to be arranged in the form of a common layer.
[0455] The second electrode **150** may be arranged on the interlayer **130**, and a capping layer **170** may be additionally formed on the second electrode **150**. The capping layer **170** may be formed to cover the second electrode **150**.
[0456] The encapsulation portion **300** may be located on the capping layer **170**. The encapsulation portion **300** may be arranged on an organic light-emitting device to protect the organic light-emitting device from moisture or oxygen. The encapsulation portion **300** may include: an inorganic film including silicon nitride (SiNx), silicon oxide (SiOx), indium tin oxide, indium zinc oxide, or any combination thereof; an organic film including polyethylene terephthalate, polyethylene naphthalate, polycarbonate, polyimide, polyethylene sulfonate, polyoxymethylene, polyarylate, hexamethyldisiloxane, an acrylic resin (e.g., polymethyl methacrylate, polyacrylic acid, and/or the like), an epoxy-based resin (e.g., aliphatic glycidyl ether (AGE), and/or the like), or any combination thereof; or any combination of the inorganic films and the organic films.
[0457] FIG. **3** shows a cross-sectional view showing an electronic apparatus (e.g. a light-emitting apparatus) according to one or more embodiments.
[0458] The light-emitting apparatus of FIG. **3** is substantially the same as the light-emitting apparatus of FIG. **2**, except that a light-shielding pattern **500** and a functional region **400** are additionally arranged on the encapsulation portion **300**. The functional region **400** may be i) a color filter area, ii) a color conversion area, or iii) a combination of the color filter area and the color conversion area. In one or more embodiments, the organic light-emitting device included in the light-emitting apparatus of FIG. **3** may be a tandem organic light-emitting device.
Description of FIG. **4**

[0459] FIG. **4** is a schematic perspective view of electronic equipment **1** including an organic light-emitting device according to one or more embodiments. The electronic equipment **1** may be, as an apparatus that displays a moving image or a still image, portable electronic equipment, such as a mobile phone, a smart phone, a tablet personal computer (PC), a mobile communication terminal, an electronic notebook, an electronic book, a portable multimedia player (PMP), a navigation, or a ultra-mobile PC (UMPC), as well as one or more suitable products or a part thereof, such as a television, a laptop, a monitor, a billboard, or an Internet of things (IoT). In some embodiments, the electronic equipment **1** may be a wearable device or a part thereof, such as a smart watch, a watch phone, a glasses-type or kind display, or a head mounted display (HMD). However, embodiments are not limited thereto. For example, the electronic equipment **1** may include a dashboard of a vehicle, a center fascia of a vehicle, a center information display arranged on a dashboard of a vehicle, a room mirror display replacing a side mirror of a vehicle, an entertainment display for the rear seat of a vehicle or a display arranged on the back of the front seat, or a head up display (HUD) installed in the front of a vehicle or projected on a front window glass, a computer generated hologram augmented reality head up display (CGH AR HUD). FIG. **4** illustrates a case in which the electronic equipment **1** is a smartphone for convenience of explanation.

[0460] The electronic equipment **1** may include a display area DA and a non-display area NDA outside the display area DA. A display apparatus may implement an image through an array of a plurality of pixels that are two-dimensionally arranged in the display area DA.

[0461] The non-display area NDA may be an area that does not display an image, and may entirely be around (e.g., surround)the display area DA. On the non-display area NDA, a driver for providing electrical signals or power to display devices arranged on the display area DA may be arranged. On the non-display area NDA, a pad, which is an area to which an electronic element or a printed circuit board, may be electrically connected may be arranged.

[0462] In the electronic equipment **1**, the length in an x-axis direction and the length in a y-axis direction may be different from each other. In one or more embodiments, as shown in FIG. **4**, the length in the x-axis direction may be shorter than the length in the y-axis direction. In one or more embodiments, the length in the x-axis direction may be substantially the same as the length in the y-axis direction. In one or more embodiments, the length in the x-axis direction may be greater than the length in the y-axis direction.

Descriptions of FIGS. **5** and **6**A to **6**C

[0463] FIG. **5** is a schematic view of the exterior of a vehicle **1000** as electronic equipment including an organic light-emitting device according to one or more embodiments. FIGS. **6**A to **6**C are each a schematic view of the interior of the vehicle **1000** according to one or more embodiments.

[0464] Referring to FIGS. **5**, **6**A, **6**B, and **6**C, the vehicle **1000** may refer to one or more suitable apparatuses for moving a subject to be transported, such as a human, an aspect, or an animal, from a departure point to a destination point. The vehicle **1000** may include a vehicle traveling on a road or a track, a vessel moving over the sea or river, an airplane flying in the sky using the action of air, and/or the like.

[0465] The vehicle **1000** may travel on a road or a track. The vehicle **1000** may move in a certain direction according to rotation of at least one wheel. In one or more embodiments, the vehicle **1000** may include a three-wheeled or four-wheeled vehicle, a construction machine, a two-wheeled vehicle, a prime mover device, a bicycle, and a train running on a track.

[0466] The vehicle **1000** may include a vehicle body having an interior and an exterior, and a chassis in which mechanical apparatuses necessary for driving are installed as other parts except for the vehicle body. The exterior of the body may include a front panel, a bonnet, a roof panel, a rear panel, a trunk, a pillar provided at a boundary between doors, and/or the like. The chassis of the vehicle **1000** may include a power generating device, a power transmitting device, a driving device, a steering device, a braking device, a suspension device, a transmission device, a fuel device, front

and rear wheels, left and right wheels, and/or the like.
[0467] The vehicle **1000** may include a side window glass **1100**, a front window glass **1200**, a side-view mirror **1300**, a cluster **1400**, a center fascia **1500**, a passenger seat dashboard **1600**, and a display apparatus **2**.
[0468] The side window glass **1100** and the front window glass **1200** may be partitioned by a pillar arranged between the side window glass **1100** and the front window glass **1200**.
[0469] The side window glass **1100** may be installed on the side of the vehicle **1000**. In one or more embodiments, the side window glass **1100** may be installed on a door of the vehicle **1000**. A plurality of side window glasses **1100** may be provided and may face each other. In one or more embodiments, the side window glass **1100** may include a first side window glass **1110** and a second side window glass **1120**. In one or more embodiments, the first side window glass **1110** may be arranged adjacent to the cluster **1400**. The second side window glass **1120** may be arranged adjacent to the passenger seat dashboard **1600**.
[0470] In one or more embodiments, the side window glasses **1100** may be spaced and/or apart (e.g., spaced apart or separated) from each other in an x direction or a −x direction. In one or more embodiments, the first side window glass **1110** and the second side window glass **1120** may be spaced and/or apart (e.g., spaced apart or separated) from each other in the x direction or the −x direction. For example, an imaginary straight line L connecting the side window glasses **1100** may extend in the x direction or the −x direction. In one or more embodiments, an imaginary straight line L connecting the first side window glass **1110** and the second side window glass **1120** to each other may extend in the x direction or the −x direction.
[0471] The front window glass **1200** may be installed in front of the vehicle **1000**. The front window glass **1200** may be arranged between the side window glasses **1100** opposite to (e.g., facing) each other.
[0472] The side-view mirror **1300** may provide a rear view of the vehicle **1000**. The side-view mirror **1300** may be installed on the exterior of the vehicle body. In one or more embodiments, a plurality of side-view mirrors **1300** may be provided. Any one selected from among the plurality of side-view mirrors **1300** may be arranged outside the first side window glass **1110**. The other one selected from among the plurality of side-view mirrors **1300** may be arranged outside the second side window glass **1120**.
[0473] The cluster **1400** may be arranged in front of the steering wheel. The cluster **1400** may include a tachometer, a speedometer, a coolant thermometer, a fuel gauge turn indicator, a high beam indicator, a warning lamp, a seat belt warning lamp, an odometer, a tachograph, an automatic shift selector indicator lamp, a door open warning lamp, an engine oil warning lamp, and/or a low fuel warning light.
[0474] The center fascia **1500** may include a control panel on which a plurality of buttons for adjusting an audio device, an air conditioning device, and a heater of a seat are arranged. The center fascia **1500** may be arranged on one side of the cluster **1400**.
[0475] The passenger seat dashboard **1600** may be spaced and/or apart (e.g., spaced apart or separated) from the cluster **1400** with the center fascia **1500** arranged therebetween. In one or more embodiments, the cluster **1400** may be arranged to correspond to a driver seat, and the passenger seat dashboard **1600** may be arranged to correspond to a passenger seat. In one or more embodiments, the cluster **1400** may be adjacent to the first side window glass **1110**, and the passenger seat dashboard **1600** may be adjacent to the second side window glass **1120**.
[0476] In one or more embodiments, the display apparatus **2** may include a display panel **3**, and the display panel **3** may display an image. The display apparatus **2** may be arranged inside the vehicle **1000**. In one or more embodiments, the display apparatus **2** may be arranged between the side window glasses **1100** opposite to (e.g., facing) each other. The display apparatus **2** may be arranged on at least one selected from the cluster **1400**, the center fascia **1500**, and the passenger seat dashboard **1600**.

[0477] The display device **2** may include an organic light-emitting display device, an inorganic electroluminescent display device, a quantum dot display device, and/or the like. Hereinafter, as the display device **2** according to one or more embodiments, an organic light-emitting display apparatus including the aforementioned organic light-emitting device will be described as an example, but one or more suitable types (kinds) of the aforementioned display apparatus may be used in embodiments.
[0478] Referring to FIG. **6**A, the display apparatus **2** may be arranged on the center fascia **1500**. In one or more embodiments, the display apparatus **2** may display navigation information. In one or more embodiments, the display apparatus **2** may display audio, video, or information regarding vehicle settings.
[0479] Referring to FIG. **6**B, the display apparatus **2** may be arranged on the cluster **1400**. In this case, the cluster **1400** may display driving information and/or the like through the display apparatus **2**. For example, the cluster **1400** may be implemented digitally. The cluster **1400** implemented digitally may display vehicle information and driving information as images. In one or more embodiments, a needle and a gauge of a tachometer and one or more suitable warning light icons may be displayed by a digital signal.
[0480] Referring to FIG. **6**C, the display device **2** may be arranged on the passenger seat dashboard **1600**. The display apparatus **2** may be embedded in the passenger seat dashboard **1600** or arranged on the passenger seat dashboard **1600**. In one or more embodiments, the display device **2** arranged on the passenger seat dashboard **1600** may display an image related to information displayed on the cluster **1400** and/or information displayed on the center fascia **1500**. In one or more embodiments, the display apparatus **2** arranged on the passenger seat dashboard **1600** may display information different from information displayed on the cluster **1400** and/or information displayed on the center fascia **1500**.

Manufacturing Method

[0481] Layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region may be formed in a certain region by using one or more suitable methods such as vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, ink-jet printing, laser-printing, laser-induced thermal imaging, and/or the like.
[0482] When layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region are formed by vacuum deposition, the deposition may be performed at a deposition temperature in a range of about 100° C. to about 500° C., at a vacuum degree in a range of about 10.sup.−8 torr to about 10.sup.−3 torr, and at a deposition speed in a range of about 0.01 angstrom per second (Å/sec) to about 100 Å/sec, depending on a material to be included in a layer to be formed and the structure of a layer to be formed.

DEFINITION OF TERMS

[0483] The term “C.sub.3-C.sub.60 carbocyclic group” as used herein refers to a cyclic group including (e.g., consisting of) carbon only as a ring-forming atom and having three to sixty carbon atoms, and the term “C.sub.1-C.sub.60 heterocyclic group” as used herein refers to a cyclic group that has 1 to 60 carbon atoms and further has, in addition to carbon, a heteroatom as a ring-forming atom. The C.sub.3-C.sub.60 carbocyclic group and the C.sub.1-C.sub.60 heterocyclic group may each be: a monocyclic group including (e.g., consisting of) one ring; or a polycyclic group in which two or more rings are condensed with each other. For example, the number of ring-forming atoms of the C.sub.1-C.sub.60 heterocyclic group may be from 3 to 61.
[0484] The term “cyclic group” as used herein may include both (e.g., simultaneously) the C.sub.3-C.sub.60 carbocyclic group and the C.sub.1-C.sub.60 heterocyclic group.
[0485] The term “π electron-rich C.sub.3-C.sub.60 cyclic group” as used herein refers to a cyclic group that has three to sixty carbon atoms and does not include *—N=*′ as a ring-forming moiety, and the term “π electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group” as used herein refers to a heterocyclic group that has one to sixty carbon atoms and includes *—N=*′ as a

ring-forming moiety.

[0486] In one or more embodiments, [0487] the C.sub.3-C.sub.60 carbocyclic group may be i) Group T1 or ii) a condensed cyclic group in which two or more of Group T1 are condensed with each other (e.g., a cyclopentadiene group, an adamantane group, a norbornane group, a benzene group, a pentalene group, a naphthalene group, an azulene group, an indacene group, an acenaphthylene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a perylene group, a pentaphene group, a heptalene group, a naphthacene group, a picene group, a hexacene group, a pentacene group, a rubicene group, a coronene group, an ovalene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, an indenophenanthrene group, or an indenoanthracene group), [0488] the C.sub.1-C.sub.60 heterocyclic group may be i) Group T2, ii) a condensed cyclic group in which at least two of Group T2 are condensed with each other, or iii) a condensed cyclic group in which at least one Group T2 and at least one Group T1 are condensed with each other (e.g., a pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoindole group, an isoindole group, a benzoisoindole group, a naphthoisoindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, an indolocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthothiophene group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzisoxazole group, a benzothiazole group, a benzisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoisoquinoline group, a quinoxaline group, a benzoquinoxaline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, and/or the like), [0489] the π electron-rich C.sub.3-C.sub.60 cyclic group may be i) Group T1, ii) a condensed cyclic group in which two or more of Group T1 are condensed with each other, iii) Group T3, iv) a condensed cyclic group in which two or more of Group T3 are condensed with each other, or v) a condensed cyclic group in which at least one Group T3 and at least one Group T1 are condensed with each other (e.g., the C3-C60 carbocyclic group, a 1H-pyrrole group, a silole group, a borole group, a 2H-pyrrole group, a 3H-pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoindole group, an isoindole group, a benzoisoindole group, a naphthoisoindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, an indolocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthothiophene group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, and/or the like), [0490] the π electron-deficient nitrogen-containing C1-C60 cyclic group may be i) Group T4, ii) a condensed cyclic group in which at least two of Groups T4 are condensed with each other, iii) a condensed cyclic group in which at least one Group T4 and at least one Group T1 are condensed with each other, iv) a condensed cyclic group in which at least one Group T4 and at least one Group T3 are condensed with each other, or

v) a condensed cyclic group in which at least one Group T4, at least one Group T1, and at least one Group T3 are condensed with one another (e.g., a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzisoxazole group, a benzothiazole group, a benzisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoisoquinoline group, a quinoxaline group, a benzoquinoxaline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, and/or the like), [0491] Group T1 may be a cyclopropane group, a cyclobutane group, a cyclopentane group, a cyclohexane group, a cycloheptane group, a cyclooctane group, a cyclobutene group, a cyclopentene group, a cyclopentadiene group, a cyclohexene group, a cyclohexadiene group, a cycloheptene group, an adamantane group, a norbornane (or bicyclo[2.2.1]heptane) group, a norbornene group, a bicyclo[1.1.1]pentane group, a bicyclo[2.1.1]hexane group, a bicyclo[2.2.2]octane group, or a benzene group, [0492] Group T2 may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, a borole group, a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a tetrazine group, a pyrrolidine group, an imidazolidine group, a dihydropyrrole group, a piperidine group, a tetrahydropyridine group, a dihydropyridine group, a hexahydropyrimidine group, a tetrahydropyrimidine group, a dihydropyrimidine group, a piperazine group, a tetrahydropyrazine group, a dihydropyrazine group, a tetrahydropyridazine group, or a dihydropyridazine group, [0493] Group T3 may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, or a borole group, and [0494] Group T4 may include a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or a tetrazine group.
[0495] The term “the cyclic group, the C.sub.3-C.sub.60 carbocyclic group, the C.sub.1-C.sub.60 heterocyclic group, the π electron-rich C.sub.3-C.sub.60 cyclic group, or the π electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group” as used herein may refer to a group condensed to any cyclic group or a group not condensed to any cyclic group, and may be a monovalent group, or a polyvalent group (e.g., a divalent group, a trivalent group, a tetravalent group, and/or the like.) according to the structure of a formula for which the corresponding term is used.
[0496] In one or more embodiments, the term “benzene group” as used herein may be a benzo group, a phenyl group, a phenylene group, and/or the like, which may be easily understand by one of ordinary skill in the art according to the structure of a formula including the “benzene group.”
[0497] Depending on context, a divalent group may refer or be a polyvalent group (e.g., trivalent, tetravalent, etc., and not just divalent) per, e.g., the structure of a formula in connection with which of the terms are utilized.
[0498] Examples of the monovalent C.sub.3-C.sub.60 carbocyclic group and monovalent C.sub.1-C.sub.60 heterocyclic group may include 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, and a monovalent non-aromatic condensed heteropolycyclic group, and examples of the divalent C.sub.3-C.sub.60 carbocyclic group and the

divalent C.sub.1-C.sub.60 heterocyclic group may include a C.sub.3-C.sub.10 cycloalkylene group, a C.sub.1-C.sub.10 heterocycloalkylene group, a C.sub.3-C.sub.10 cycloalkenylene group, a C.sub.1-C.sub.10 heterocycloalkenylene group, a C.sub.6-C.sub.60 arylene group, a C.sub.1-C.sub.60 heteroarylene group, a divalent non-aromatic condensed polycyclic group, and a divalent non-aromatic condensed heteropolycyclic group.

[0499] The term "C.sub.1-C.sub.60 alkyl group" as used herein refers to a linear or branched aliphatic hydrocarbon monovalent group that has 1 to 60 carbon atoms, and specific examples thereof may include a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, a sec-butyl group, an isobutyl group, a tert-butyl group, an n-pentyl group, a tert-pentyl group, a neopentyl group, an isopentyl group, a sec-pentyl group, a 3-pentyl group, a sec-isopentyl group, an n-hexyl group, an isohexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an isoheptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an isooctyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an isononyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an isodecyl group, a sec-decyl group, and a tert-decyl group. The term "C.sub.1-C.sub.60 alkylene group" as used herein refers to a divalent group having the same structure as the C.sub.1-C.sub.60 alkyl group.

[0500] The term "C.sub.2-C.sub.60 alkenyl group" as used herein refers to a monovalent 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, and examples thereof may include an ethenyl group, a propenyl group, a butenyl group, and/or the like. The term "C.sub.2-C.sub.60 alkenylene group" as used herein refers to a divalent group having the same structure as the C.sub.2-C.sub.60 alkenyl group.

[0501] The term "C.sub.2-C.sub.60 alkynyl group" as used herein refers to a monovalent 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, and examples thereof may include an ethynyl group, a propynyl group, and/or the like. The term "C.sub.2-C.sub.60 alkynylene group" as used herein refers to a divalent group having the same structure as the C.sub.2-C.sub.60 alkynyl group.

[0502] 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 the C.sub.1-C.sub.60 alkyl group), and examples thereof may include a methoxy group, an ethoxy group, an isopropyloxy group, and/or the like.

[0503] The term "C.sub.3-C.sub.10 cycloalkyl group" as used herein refers to a monovalent saturated hydrocarbon cyclic group having 3 to 10 carbon atoms, and examples thereof may include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group (or bicyclo[2.2.1]heptyl group), a bicyclo[1.1.1]pentyl group, a bicyclo[2.1.1]hexyl group, a bicyclo[2.2.2]octyl group, and/or the like. The term "C.sub.3-C.sub.10 cycloalkylene group" as used herein refers to a divalent group having the same structure as the C.sub.3-C.sub.10 cycloalkyl group.

[0504] The term "C.sub.1-C.sub.10 heterocycloalkyl group" as used herein refers to a monovalent cyclic group of 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms, and specific examples thereof may include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuranyl group, a tetrahydrothiophenyl group, and/or the like. The term "C.sub.1-C.sub.10 heterocycloalkylene group" as used herein refers to a divalent group having the same structure as the C.sub.1-C.sub.10 heterocycloalkyl group.

[0505] The term "C.sub.3-C.sub.10 cycloalkenyl group" as used herein refers to a monovalent cyclic group that 3 to 10 carbon atoms, at least one carbon-carbon double bond in the ring thereof, and no aromaticity, and specific examples thereof may include a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, and/or the like. The term "C.sub.3-C.sub.10 cycloalkenylene group" as used herein refers to a divalent group having the same structure as the

C.sub.3-C.sub.10 cycloalkenyl group.
[0506] The term “C.sub.1-C.sub.10 heterocycloalkenyl group” as used herein refers to a monovalent cyclic group of 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms and at least one carbon-carbon double bond in the cyclic structure thereof. Examples of the C.sub.1-C.sub.10 heterocycloalkenyl group may include a 4,5-dihydro-1,2,3,4-oxatriazolyl group, a 2,3-dihydrofuranyl group, a 2,3-dihydrothiophenyl group, and/or the like. The term “C.sub.1-C.sub.10 heterocycloalkylene group” as used herein refers to a divalent group having the same structure as the C.sub.1-C.sub.10 heterocycloalkyl group.
[0507] The term “C.sub.6-C.sub.60 aryl group” as used herein refers to a monovalent group having a carbocyclic aromatic system of six to sixty carbon atoms, and the term “C.sub.6-C.sub.60 arylene group” as used herein refers to a divalent group having a carbocyclic aromatic system of six to sixty carbon atoms. Examples of the C.sub.6-C.sub.60 aryl group may include a phenyl group, a pentalenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a heptalenyl group, a naphthacenyl group, a picenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, and/or the like. When the C.sub.6-C.sub.60 aryl group and the C.sub.6-C.sub.60 arylene group each include two or more rings, the two or more rings may be condensed with each other.
[0508] The term “C.sub.1-C.sub.60 heteroaryl group” as used herein refers to a monovalent group having a heterocyclic aromatic system of 1 to 60 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms. The term “C.sub.1-C.sub.60 heteroarylene group” as used herein refers to a divalent group having a heterocyclic aromatic system of 1 to 60 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms. Examples of the C.sub.1-C.sub.60 heteroaryl group may include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a benzoisoquinolinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthrolinyl group, a phthalazinyl group, a naphthyridinyl group, and/or the like. When the C.sub.1-C.sub.60 heteroaryl group and the C.sub.1-C.sub.60 heteroarylene group each include two or more rings, the two or more rings may be condensed with each other.
[0509] The term “monovalent non-aromatic condensed polycyclic group” as used herein refers to a monovalent group (e.g., having 8 to 60 carbon atoms) having two or more rings condensed to each other, only carbon atoms as ring-forming atoms, and no aromaticity in the entire molecular structure. Examples of the monovalent non-aromatic condensed polycyclic group may include an indenyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, an indenophenanthrenyl group, an indeno anthracenyl group, and/or the like. The term “divalent non-aromatic condensed polycyclic group” as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed polycyclic group described herein.
[0510] The term “monovalent non-aromatic hetero-condensed polycyclic group” as used herein refers to a monovalent group (e.g., having 1 to 60 carbon atoms) having two or more rings condensed to each other, further including, in addition to carbon atoms, at least one heteroatom, as ring-forming atoms, and having non-aromaticity in its entire molecular structure. Examples of the monovalent non-aromatic hetero-condensed polycyclic group may include a pyrrolyl group, a thiophenyl group, a furanyl group, an indolyl group, a benzoindolyl group, a naphthoindolyl group, an isoindolyl group, a benzoisoindolyl group, a naphthoisoindolyl group, a benzosilolyl group, a benzothiophenyl group, a benzofuranyl group, a carbazolyl group, a dibenzosilolyl group, a dibenzothiophenyl group, a dibenzofuranyl group, an azacarbazolyl group, an azafluorenyl group, an azadibenzosilolyl group, an azadibenzothiophenyl group, an azadibenzofuranyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, a tetrazolyl group, an oxazolyl group, an

isoxazolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, a benzoxazolyl group, a benzothiazolyl group, a benzoxadiazolyl group, a benzothiadiazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an imidazotriazinyl group, an imidazopyrazinyl group, an imidazopyridazinyl group, an indeno carbazolyl group, an indolocarbazolyl group, a benzofurocarbazolyl group, a benzothienocarbazolyl group, a benzosilolocarbazolyl group, a benzoindolocarbazolyl group, a benzocarbazolyl group, a benzonaphthofuranyl group, a benzonaphthothiophenyl group, a benzonaphthosilolyl group, a benzofurodibenzofuranyl group, a benzofurodibenzothiophenyl group, and a benzothienodibenzothiophenyl group. The term “divalent non-aromatic condensed heteropolycyclic group” as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0511] The term “C.sub.6-C.sub.60 aryloxy group” as used herein refers to —OA.sub.102 (wherein A.sub.102 is the C.sub.6-C.sub.60 aryl group), and the term “C.sub.6-C.sub.60 arylthio group” as used herein refers to —SA.sub.103 (wherein A.sub.103 is the C.sub.6-C.sub.60 aryl group).

[0512] The term “C.sub.7-C.sub.60 arylalkyl group” as used herein refers to -A.sub.104A.sub.105 (wherein A.sub.104 is a C.sub.1-C.sub.54 alkylene group, and A.sub.105 is a C.sub.6-C.sub.59 aryl group), and the term “C.sub.2-C.sub.60 heteroarylalkyl group” as used herein refers to -A.sub.106A.sub.107 (wherein A.sub.106 is a C.sub.1-C.sub.59 alkylene group, and A.sub.107 is a C.sub.1-C.sub.59 heteroaryl group).

[0513] The term “R.sub.10a” as used herein may be: [0514] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group; [0515] 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, or a C.sub.1-C.sub.60 alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, or a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), —P(═S)(Q.sub.11)(Q.sub.12), or any combination thereof; [0516] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 aryl alkyl group, or a C.sub.2-C.sub.60 heteroaryl alkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro 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.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 aryl alkyl group, a C.sub.2-C.sub.60 heteroaryl alkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), —P(═S)(Q.sub.21)(Q.sub.22), or any combination thereof; or [0517] —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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), or —P(═S)(Q.sub.31)(Q.sub.32).

[0518] In the present specification, 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: 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.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, each unsubstituted or substituted with deuterium, —F, a

cyano group, a C.sub.1-C.sub.60 alkyl group, a C.sub.1-C.sub.60 alkoxy group, a phenyl group, a biphenyl group, or any combination thereof; a C.sub.7-C.sub.60 arylalkyl group; or a C.sub.2-C.sub.60 heteroarylalkyl group.
[0519] The term “heteroatom” as used herein refers to any atom other than a carbon atom. Examples of the heteroatom may include O, S, N, P, Si, B, Ge, Se, and any combination thereof.
[0520] 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 “tert-Bu” or “Bu.sup.t” as used herein refers to a tert-butyl group, and the term “OMe” as used herein refers to a methoxy group.
[0521] The term “biphenyl group” as used herein refers to “a phenyl group substituted with a phenyl group.” For example, the “biphenyl group” is a substituted phenyl group having a C.sub.6-C.sub.60 aryl group as a substituent.
[0522] The term “terphenyl group” as used herein refers to “a phenyl group substituted with a biphenyl group”. For example, the “terphenyl group” is a substituted phenyl group having, as a substituent, a C.sub.6-C.sub.60 aryl group substituted with a C.sub.6-C.sub.60 aryl group.
[0523] In the specification, the x-axis, y-axis, and z-axis are not limited to three axes in an orthogonal coordinate system, and may be interpreted in a broad sense including these axes. For example, the x-axis, y-axis, and z-axis may refer to those orthogonal to each other, or may refer to those in different directions that are not orthogonal to each other. [0524] *, *′, and *″ as used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula or moiety.
[0525] Terms such as “substantially,” “about,” and “approximately” are used as relative terms 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. They may be inclusive of the stated value and an acceptable range of deviation as determined by one of ordinary skill in the art, considering the limitations and error associated with measurement of that quantity. For example, “about” may refer to one or more standard deviations, or ±30%, 20%, 10%, 5% of the stated value.
[0526] Numerical ranges disclosed herein include and are intended to disclose all subsumed sub-ranges of the same numerical precision. For example, a range of “1.0 to 10.0” includes all subranges 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. Applicant therefore reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein.
[0527] The organic light-emitting device, the electronic apparatus, the consumer product (e.g. electronic equipment), and/or any other relevant devices or components according to embodiments of the present disclosure described herein may be implemented utilizing any suitable hardware, firmware (e.g., an application-specific integrated circuit), software, or a combination of software, firmware, and hardware. For example, the various components of the light-emitting device and/or the electronic apparatus or equipment may be formed on one integrated circuit (IC) chip or on separate IC chips. Further, the various components of the light-emitting device, the electronic apparatus, and/or the consumer product may be implemented on a flexible printed circuit film, a tape carrier package (TCP), a printed circuit board (PCB), or formed on one substrate. Further, the various components of the device, apparatus, and/or product may be a process or thread, running on one or more processors, in one or more computing devices, executing computer program instructions and interacting with other system components for performing the various functionalities described herein. The computer program instructions are stored in a memory which may be implemented in a computing device using a standard memory device, such as, for example, a random access memory (RAM). The computer program instructions may also be stored in other non-transitory computer readable media such as, for example, a CD-ROM, flash drive, or the like.

Also, a person of skill in the art should recognize that the functionality of various computing devices may be combined or integrated into a single computing device, or the functionality of a particular computing device may be distributed across one or more other computing devices without departing from the scope of the embodiments of the present disclosure.

[0528] Hereinafter, a compound according to one or more embodiments and an organic 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 substantially identical molar equivalent of B was used in place of A.

EXAMPLES

Synthesis Examples

Synthesis Example 1: Synthesis of Compound 1

##STR00186##

(1) Synthesis of Intermediate Compound 1-a

[0529] In an argon atmosphere, N1-([1,1′-biphenyl]-3-yl)-N1,N3-di([1,1′: 3′,1″-terphenyl]-2′-yl)-5-(tert-butyl)benzene-1,3-diamine (10 9, 13 mmol), 3-(3-bromo-5-iodophenoxy)-1,1′-biphenyl (5.8 9, 13 mmol), Pd.sub.2(dba).sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (5.8 g, 60 mmol) were added to a 2 liter (L) flask and dissolved in 150 milliliter (mL) of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decom pressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 1-a (white solid, 10.6 g, 75%).

[0530] ESI-LCMS for Intermediate Compound 1-a: [M].sup.+: C.sub.76H.sub.59BrN.sub.2O. 1094.3831.

(2) Synthesis of Intermediate Compound 1-b

[0531] In an argon atmosphere, Intermediate Compound 1-a (10 g, 9.1 mmol), 3,5-bis([1,1′-biphenyl]-4-yloxy)phenol (4 g, 9.1 mmol), CuI (1.7 g, 9.1 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (1.1 g, 9.1 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 1-b (white solid, 9.2 g, 70%).

[0532] ESI-LCMS: [M].sup.+: C.sub.106H.sub.80N.sub.2O.sub.4. 1444.6641.

(3) Synthesis of Compound 1

[0533] In an argon atmosphere, Intermediate Compound 1-b (9 g, 6.2 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 1 (yellow solid, 3.9 g, 43%).

[0534] ESI-LCMS for Compound 1: [M].sup.+: C106H71B3N2O4. 1468.5751

[0535] 1H-NMR for Compound 1 (CDCl3): δ=8.55 (d, 1H), 7.75 (d, 8H), 7.67 (d, 4H), 7.55 (m, 12H), 7.43 (m, 5H), 7.41 (m, 4H), 7.28 (m, 12H), 7.21 (s, 1H), 7.11 (d, 2H), 7.05 (m, 8H), 6.93 (s, 2H), 6.88 (s, 1H), 6.55 (s, 1H), 1.32 (s, 9H).

Synthesis Example 2: Synthesis of Compound 13

##STR00187##
(1) Synthesis of Intermediate Compound 13-a
[0536] In an argon atmosphere, Compound N1-([1,1′-biphenyl]-4-yl)-N1,N3-di([1,1:3′,1″-terphenyl]-2′-yl)-5-(tert-butyl)benzene-1,3-diamine (10 g, 13 mmol), 4-(3-bromo-5-iodophenoxy)-1,1′-biphenyl (5.89 g,13 mmol), Pd.sub.2(dba).sub.3 (0.69 g,0.7 mmol), tris-tert-butyl phosphine (0.6 mL, 1.4 mmol), and sodium tert-butoxide (4.4 g, 45 mmol) were added to a 1 L flask and dissolved in in 150 mL of xylene, and the reaction solution was stirred at 1400° C. for 12 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 13-a (white solid, 10.5 g, 74%).
[0537] ESI-LCMS for Intermediate Compound 13-a: [M].sup.+: C76H59BrN2O. 1094.3808
(2) Synthesis of Intermediate Compound 13-b
[0538] In an argon atmosphere, Intermediate Compound 13-a (10 g, 9.1 mmol), 3-([1,1′-biphenyl]-4-yloxy)-5-([1,1′-biphenyl]-4-ylthio)benzenethiol (4.2 g, 9.1 mmol), CuI (1.7 g, 9.1 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (1.1 g, 9.1 mmol) were added to a 2 L flask and dissolved in in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 13-b (white solid, 8 g, 60%).
[0539] ESI-LCMS for Intermediate Compound 13-b: [M].sup.+: C106H80N2O2S2. 1476.5747.
(3) Synthesis of Compound 13
[0540] In an argon atmosphere, Intermediate Compound 1-b (8 g, 5.4 mmol) was added to a 1 L flask and dissolved in 100 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. The reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 13 (yellow solid, 3.8 g, 45%).
[0541] ESI-LCMS for Compound 13: [M].sup.+: C106H71B3N2O2S2. 1500.5243
[0542] 1H-NMR for Compound 13 (CDCl3): δ=8.81 (d, 1H), 7.75 (d, 8H), 7.60 (m, 5H), 7.51 (m, 12H), 7.45 (m, 7H), 7.36 (m, 4H), 7.21 (m, 13H), 7.15 (d, 1H), 7.04 (m, 8H), 6.94 (s, 2H), 6.85 (s, 1H), 1.35 (s, 9H).
Synthesis Example 3: Synthesis of Compound 21
##STR00188##
(1) Synthesis of Intermediate Compound 21-a
[0543] In an argon atmosphere, Intermediate Compound 1-a (10 g, 9.1 mmol), [1,1′-biphenyl]-4-amine (1.5 g, 9.1 mmol), Pd.sub.2dba.sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (11.5 g, 120 mmol) were added into a 2 L flask and dissolved in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 21-a (white solid, 8.3 g, 77%).

[0544] ESI-LCMS for Intermediate Compound 21-a: [M].sup.+: C88H69N3O. 1183.5434.
(2) Synthesis of Intermediate Compound 21-b
[0545] In an argon atmosphere, Intermediate Compound 21-a (8 g, 6.7 mmol), N-([1,1′-biphenyl]-4-yl)-N-(3-([1,1′-biphenyl]-4-yloxy)-5-chlorophenyl)-[1,1′-biphenyl]-4-amine (4 g, 9.1 mmol), Pd.sub.2(dba).sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (2.8 g, 30 mmol) were added to a 2 L flask and dissolved in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 21-b (white solid, 11.9 g, 75%).
[0546] ESI-LCMS for Intermediate Compound 21-b: [M].sup.+: C130H98N4O2. 1746.7718.
(3) Synthesis of Compound 21
[0547] In an argon atmosphere, Intermediate Compound 21-b (10 g, 5.7 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 21 (yellow solid, 3.65 g, 36%).
[0548] ESI-LCMS for Compound 21: [M].sup.+: C130H89B3N4O2. 1770.7373
[0549] 1H-NMR for Compound 21 (CDCl3): δ=8.82 (d, 1H), 7.90 (d, 1H), 7.75 (m, 12H), 7.67 (m, 3H), 7.55 (m, 18H), 7.48 (m, 13H), 7.38 (m, 10H), 7.27 (s, 1H), 7.20 (d, 1H), 7.08 (m, 8H), 6.99 (s, 2H), 6.88 (s, 1H), 1.42 (s, 27H).
Synthesis Example 4: Synthesis of Compound 36
##STR00189##
(1) Synthesis of Intermediate Compound 36-a
[0550] In an argon atmosphere, Intermediate Compound 1-a (10 g, 9.1 mmol), 3,5-bis(4-phenyl-9H-carbazol-9-yl)phenol (4.2 g, 9.1 mmol), CuI (1.7 g, 9.1 mmol), potassium carbonate (4.1 g, 30 mmol), picolinic acid (1.1 g, 9.1 mmol), and sodium tert-butoxide (5.8 g, 60 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 36-a (white solid, 9.8 g, 68%).
[0551] ESI-LCMS for Intermediate Compound 36-a: [M].sup.+: C118H86N4O2. 1590.6836.
(2) Synthesis of Compound 36
[0552] In an argon atmosphere, Intermediate Compound 36-a (9 g, 5.6 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 36 (yellow solid, 1.11 g, 13%).
[0553] ESI-LCMS for Compound 36: [M].sup.+: C118H77B3N4O2. 1614.6340
[0554] 1H-NMR for Compound 36 (CDCl3): δ=8.33 (d, 1H), 7.94 (m, 4H), 7.89 (s, 2H), 7.75 (m, 9H), 7.69 (d, 2H), 7.38 (m, 8H), 7.25 (m, 9H), 7.21 (s, 1H), 7.08 (m, 8H), 7.03 (s, 2H), 6.94 (d,

2H), 6.58 (s, 1H), 1.42 (s, 9H)
Synthesis Example 5: Synthesis of Compound 57
##STR00190##
(1) Synthesis of Intermediate Compound 57-a
[0555] In an argon atmosphere, N1-([1,1′-biphenyl]-3-yl)-N1,N3-di([1,1′:3′,1″-terphenyl]-2′-yl)-5-(9H-carbazol-9-yl)benzene-1,3-diamine (10 g, 11 mmol), 3-(3-bromo-5-iodophenoxy)-1,1′-biphenyl (5.11 g, 11 mmol), Pd.sub.2dba.sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (11.5 g, 120 mmol) were added to a 2 L flask and dissolved in in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 57-a (white solid, 7.9 g, 72%).
[0556] ESI-LCMS for Intermediate Compound 57-a: [M].sup.+: C84H58BrN.sub.3O. 1203.3857.
(2) Synthesis of Intermediate Compound 57-b
[0557] In an argon atmosphere, Intermediate Compound 57-a (7.5 g, 6.2 mmol), 3,5-bis([1,1′-biphenyl]-4-yloxy)phenol (2.7 g, 6.2 mmol), CuI (1.1 g, 6.2 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (0.8 g, 6.2 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 57-b (white solid, 6.7 g, 70%).
[0558] ESI-LCMS for Intermediate Compound 57-b: [M].sup.+: C114H79N3O4. 1553.6161.
(3) Synthesis of Compound 57
[0559] In an argon atmosphere, Intermediate Compound 57-b (6.5 g, 4.2 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 57 (yellow solid, 2.2 g, 33%).
[0560] ESI-LCMS for Compound 57: [M].sup.+: C114H70B3N3O4. 1577.5641
[0561] 1H-NMR for Compound 57 (CDCl3): δ=8.92 (d, 1H), 8.55 (m, 2H), 7.99 (d, 1H), 7.94 (d, 1H), 7.75 (m, 8H), 7.67 (m, 5H), 7.55 (m, 12H), 7.42 (m, 12H), 7.35 (m, 6H), 7.28 (m, 4H), 7.22 (s, 1H), 7.08 (m, 8H), 7.02 (m, 4H), 6.89 (s, 2H), 6.58 (s, 2H), 6.37 (s, 1H)
##STR00191##
Synthesis Example 6: Synthesis of Compound 61
(1) Synthesis of Intermediate Compound 61-a
[0562] In an argon atmosphere, N1-([1,1′-biphenyl]-3-yl)-N1,N3-di([1,1′:3′,1″-terphenyl]-2′-yl)-5-(tert-butyl)benzene-1,3-diamine (10 g, 13 mmol), 3-(3-bromo-5-iodophenoxy)-1,1′-biphenyl (5.11 g, 11 mmol), Pd.sub.2(dba).sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (11.5 g, 120 mmol) were added to a 2 L flask and dissolved in in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing

solvents, so as to obtain Intermediate Compound 61-a (white solid, 10.6 g, 75%).
[0563] ESI-LCMS for Intermediate Compound 61-a: [M].sup.+: C76H59BrN2O. 1094.3857.
(2) Synthesis of Intermediate Compound 61-b
[0564] In an argon atmosphere, Intermediate Compound 61-a (10 g, 9.1 mmol), 3,5-bis([1,1′-biphenyl]-3-yloxy)phenol (4 g, 9.1 mmol), CuI (1.7 g, 9.1 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (1.2 g, 9.1 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 61-b (white solid, 8.5 g, 65%).
[0565] ESI-LCMS for Intermediate Compound 61-b: [M].sup.+: C106H80N2O4. 1444.6191.
(3) Synthesis of Compound 61
[0566] In an argon atmosphere, Intermediate Compound 61-b (8.5 g, 5.8 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 61 (yellow solid, 3.9 g, 45%).
[0567] ESI-LCMS for Compound 61: [M].sup.+: C106H71B3N2O4. 1468.5711
[0568] 1H-NMR for Compound 61 (CDCl3): δ=8.92 (d, 1H), 7.90 (d, 1H), 7.75 (m, 8H), 7.55 (m, 9H), 7.43 (m, 12H), 7.39 (m, 4H), 7.08 (m, 8H), 7.00 (s, 2H), 6.81 (s, 1H), 6.66 (s, 1H), 1.22 (s, 9H)
Synthesis Example 7: Synthesis of Compound 71
##STR00192##
(1) Synthesis of Intermediate Compound 71-a
[0569] In an argon atmosphere, N1-(3-(9H-carbazol-9-yl)phenyl)-5-(tert-butyl)-N1,N3-bis(5′-phenyl-[1,1′:3′,1″-terphenyl]-2′-yl)benzene-1,3-diamine (10 g, 9.9 mmol), 9-(3-(3-bromo-5-iodophenoxy)phenyl)-9H-carbazole (5.3 g, 11 mmol), Pd.sub.2(dba).sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (11.5 g, 120 mmol) were added to a 2 L flask and dissolved in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 71-a (white solid, 10 g, 71%).
[0570] ESI-LCMS for Intermediate Compound 71-a: [M].sup.+: C100H73BrN4O. 1424.5001.
(2) Synthesis of Intermediate Compound 71-b
[0571] In an argon atmosphere, Intermediate Compound 71-a (10 g, 7 mmol), 3,5-bis([1,1′-biphenyl]-3-yloxy)phenol (3 g, 7 mmol), CuI (1.3 g, 7 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (0.8 g, 7 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 71-b (white solid, 7.3 g, 59%).

[0572] ESI-LCMS for Intermediate Compound 71-b: [M].sup.+: C130H94N4O4. 1774.7473.
(3) Synthesis of Compound 71
[0573] In an argon atmosphere, Intermediate Compound 71-b (7.3 g, 4.1 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 71 (yellow solid, 2.4 g, 33%).
[0574] ESI-LCMS for Compound 71: [M].sup.+: C130H85B3N4O4. 1798.6817
[0575] 1H-NMR for Compound 71 (CDCl3): δ=8.61 (d, 1H), 8.55 (d, 4H), 7.85 (m, 8H), 7.71 (m, 8H), 7.55 (m, 8H), 7.49 (m, 14H), 7.41 (m, 10H), 7.36 (m, 4H), 7.25 (m, 8H), 7.11 (m, 13H), 7.01 (s, 2H), 6.87 (s, 1H), 6.56 (s, 1H), 1.29 (s, 9H)
Synthesis Example 8: Synthesis of Compound 78
##STR00193##
(1) Synthesis of Intermediate Compound 78-a
[0576] In an argon atmosphere, N1-([1,1′-biphenyl]-3-yl)-5-(tert-butyl)-N1,N3-bis(5′-phenyl-[1,1′:3′,1″-terphenyl]-2′-yl)benzene-1,3-diamine (10 g, 11 mmol), 3-(3-bromo-5-iodophenoxy)-1,1′-biphenyl (4.9 g, 11 mmol), Pd.sub.2dba.sub.3 (1.6 g, 1.9 mmol), tris-tert-butyl phosphine (1.6 mL, 3.8 mmol), and sodium tert-butoxide (11.5 g, 120 mmol) were added to a 2 L flask and dissolved in in 300 mL of o-xylene, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decom pressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 78-a (white solid, 10 g, 73%).
[0577] ESI-LCMS for Intermediate Compound 78-a: [M].sup.+: C88H67BrN.sub.2O. 1246.4434.
(2) Synthesis of Intermediate Compound 78-b
[0578] In an argon atmosphere, Intermediate Compound 78-a (10 g, 8 mmol), 3-([1,1′-biphenyl]-4-yl([1,1′:3′,1″-terphenyl]-2′-yl)amino)-5-([1,1′-biphenyl]-4-yloxy)phenol (5.3 g, 8 mmol), CuI (1.5 g, 8 mmol), potassium carbonate (4.1 g, 30 mmol), and picolinic acid (1.2 g, 8 mmol) were added to a 2 L flask and dissolved in 100 mL of DMF, and the reaction solution was stirred at 140° C. for 2 hours. After cooling, water (1 L) and ethyl acetate (300 mL) were added thereto for extraction, and an organic layer was collected therefrom, dried with MgSO.sub.4, and filtered. The filtrate was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent, and the resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvents, so as to obtain Intermediate Compound 78-b (white solid, 7.9 g, 62%).
[0579] ESI-LCMS for Intermediate Compound 78-b: [M].sup.+: C136H101N3O3. 1823.7780.
(3) Synthesis of Compound 78
[0580] In an argon atmosphere, Intermediate Compound 78-b (7.9 g, 4.3 mmol) was added to a 1 L flask and dissolved in 200 mL of o-dichlorobenzene, and BBr.sub.3 (3 equiv.) was added thereto. Then, the reaction solution was stirred at 140° C. for 12 hours. After cooling, triethylamine was added thereto to terminate the reaction, and the resulting solution was placed under vacuum (e.g., decompressurized or depressurized) to remove the solvent. The resulting solids were purified by column chromatography by using silica gel using CH.sub.2Cl.sub.2 and hexane as developing solvent, so as to obtain Compound 78 (yellow solid, 3.2 g, 40%).
[0581] ESI-LCMS for Compound 78: [M].sup.+: C136H92B3N3O3. 1847.1572
[0582] 1H-NMR for Compound 78 (CDCl3): δ=8.31 (d, 1H), 8.29 (d, 1H), 7.78 (m, 10H), 7.67 (m,

3H), 7.58 (m, 12H), 7.51 (m, 6H), 7.43 (m, 12H), 7.41 (m, 10H), 7.35 (s, 4H), 7.25 (m, 8H), 7.23 (s, 1H), 7.19 (d, 1H), 7.08 (m, 12H), 7.05 (s, 2H), 6.91 (s, 1H), 1.32 (s, 9H)

Organic Light-Emitting Device Examples

Example 1

[0583] As an anode, a glass substrate (product of Corning Inc.) with a 15 ohm per square centimeter (Ω/cm.sup.2) (1,200 angstrom (Å)) ITO electrode formed thereon was cut to a size of 50 millimeter (mm)×50 mm×0.7 mm, sonicated by using isopropyl alcohol and pure water each for 5 minutes, cleaned by irradiation of ultraviolet rays and exposure of ozone thereto for 30 minutes, and then mounted on a vacuum deposition apparatus.

[0584] NPD was deposited on the anode to form a hole injection layer having a thickness of 300 Å, Compound HT6 was deposited on the hole injection layer to form a hole transport layer having a thickness of 200 Å, and CzSi was deposited on the hole transport layer to form an electron blocking layer having a thickness of 100 Å.

[0585] Afterwards, a host mixture in which Compounds HTH53 and ETH66 were mixed at 1:1, Compound PD33, and Compound 1 were co-deposited at a weight ratio of 85:14:1 on the electron blocking layer to form an emission layer having a thickness of 200 Å, and Compound TSPO1 was deposited on the emission layer to form a hole blocking layer having a thickness of 200 Å. Afterwards, Compound TPBi was deposited on the hole blocking layer to form an electron transport layer having a thickness of 300 Å, and LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å. Afterwards, Al was used to form a cathode having a thickness of 3,000 Å, thereby forming a LiF/Al electrode. Afterwards, HT28 was used to form a capping layer having a thickness of 700 Athereon. Here, each layer was formed by vacuum deposition.

##STR00194## ##STR00195## ##STR00196##

Examples 2 to 8 and Comparative Examples 1 to 5

[0586] Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that compounds shown in Table 1 were used as a dopant in the formation of the emission layer.

##STR00197## ##STR00198## ##STR00199## ##STR00200##

Evaluation Example 1: Evaluation of Properties of Organic Light-Emitting Device

[0587] The driving voltage at luminance of 1,000 candela per square meter (cd/m.sup.2), luminescence efficiency, maximum emission wavelength (λ.sub.max), lifespan (T.sub.95), and color coordinates (CIE y) of the organic light-emitting devices of Examples 1 to 8 and Comparative Examples 1 to 5 were each measured by using a Keithley SMU 236 meter and a luminance meter PR650, and results are shown in Table 1. In Table 1, the lifespan (T95) is a measure of the time (hr) expressed as a relative value to Comparative Example 1, taken for the luminance to reach 95% of the initial luminance.

TABLE-US-00001 TABLE 1 Luminesce Maximum Lifespan Dopant in Driving nce emission (T.sub.95) emission voltage efficiency wavelength (relative layer (V) (cd/A/y) (nm) value) CIE y Example 1 Compound 1 3.8 550 458 11.5 0.048 Example 2 Compound 13 3.7 565 461 12.5 0.050 Example 3 Compound 21 3.8 580 459 9.9 0.049 Example 4 Compound 36 3.7 540 460 10.4 0.050 Example 5 Compound 57 3.8 560 456 11.3 0.046 Example 6 Compound 61 3.8 580 458 9.9 0.048 Example 7 Compound 71 3.7 540 457 10.4 0.046 Example 8 Compound 78 3.8 560 456 11.3 0.045 Comparative Compound A 4.4 350 472 1 0.067 Example 1 Comparative Compound B 4.8 270 485 0.2 0.078 Example 2 Comparative Compound C 5.1 220 440 0.01 0.045 Example 3 Comparative Compound D 4.5 450 480 0.1 0.075 Example 1 Comparative Compound E 4.0 500 465 1.1 0.060 Example 5

[0588] Referring to Table 1, it was confirmed that the organic light-emitting devices of Examples 1 to 8 had low driving voltage, high luminescence efficiency, and significantly excellent or suitable lifespan characteristics, compared to the organic light-emitting devices of Comparative Examples 1

to 5.
[0589] According to the one or more embodiments, an organic light-emitting device including a heterocyclic compound may have low driving voltage, high efficiency, high color purity and long lifespan. In some embodiments, a high-quality electronic apparatus and a consumer product may be manufactured by using this organic light-emitting device.
[0590] 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 one or more 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 one or more suitable 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 heterocyclic compound represented by Formula 1: ##STR00201## wherein, in Formula 1, X.sub.1 is O, S, Se, or N(Ar.sub.3), X.sub.2 is O, S, Se, or N(Ar.sub.4), and A.sub.1 and A.sub.2 are each independently a C.sub.5-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, or a group represented by Formula 2, wherein at least one selected from among A.sub.1 and A.sub.2 is the group represented by Formula 2, ##STR00202## in Formula 2, X.sub.3 is O, S, Se, or N(Ar.sub.5), X.sub.4 is O, S, Se, or N(Ar.sub.6), in Formulae 1 and 2, A.sub.3 to A.sub.5 and A.sub.11 to A.sub.13 are each independently a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, and Ar.sub.1 to Ar.sub.6 are each independently a group represented by Formula 3, 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2), ##STR00203## in Formula 3, A.sub.6 and A.sub.7 are each independently a C.sub.5-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, and * indicates a binding site to a neighboring atom, and in Formulae 1 to 3, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 are each independently 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 unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-C.sub.60 alkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.2-

C.sub.60 alkynyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 alkoxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.3-C.sub.10 cycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.10 heterocycloalkenyl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 aryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.6-C.sub.60 arylthio group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryl group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroaryloxy group unsubstituted or substituted with at least one R.sub.10a, a C.sub.1-C.sub.60 heteroarylthio group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed polycyclic group unsubstituted or substituted with at least one R.sub.10a, a monovalent non-aromatic condensed heteropolycyclic group unsubstituted or substituted with at least one R.sub.10a, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —B(Q.sub.1)(Q.sub.2), —N(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), —P(═O)(Q.sub.1)(Q.sub.2), or —P(═S)(Q.sub.1)(Q.sub.2), at least two selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 are optionally bonded together to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, b10 and b20 are each independently 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, or 18, b30, b40, b50, b60, and b70 are each independently 0, 1, 2, 3, 4, 5, 6, 7, or 8, R.sub.10a is: deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro 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, or a C.sub.1-C.sub.60 alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), —P(═S)(Q.sub.11)(Q.sub.12), or any combination thereof; a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, or a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, or a C.sub.1-C.sub.60 heteroarylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro 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.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.6-C.sub.60 aryloxy group, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, a C.sub.2-C.sub.60 heteroarylalkyl group, a C.sub.1-C.sub.60 heteroaryloxy group, a C.sub.1-C.sub.60 heteroarylthio 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)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), —P(═S)(Q.sub.21)(Q.sub.22), or any combination thereof; or —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)(Q.sub.31), —S(═O).sub.2(Q.sub.31), —P(═O)(Q.sub.31)(Q.sub.32), or —P(═S)(Q.sub.31)(Q.sub.32), and 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 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, or a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C.sub.1-C.sub.60 alkyl group, a C.sub.1-C.sub.60 alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

2. The heterocyclic compound of claim 1, wherein A.sub.1 and A.sub.2 are each independently a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a pyridine group, a pyrimidine group, a furan group, a benzofuran group, a thiophene group, a benzothiophene group, or a group represented by Formula 2A: ##STR00204## in Formula 2A, X.sub.3, X.sub.4, and A.sub.11 to A.sub.13 are each as defined in Formula 2, custom-character indicates a single bond or a double bond, and * and *′ each indicate a binding site to a neighboring atom.

3. The heterocyclic compound of claim 1, wherein a moiety represented by ##STR00205## in Formula 1 is a group represented by Formula 2-1, or a moiety represented by ##STR00206## in Formula 1 is a group represented by Formula 2-2: ##STR00207## wherein, in Formulae 2-1 and 2-2, X.sub.3 and X.sub.4 are each as defined in Formula 2, X.sub.11 is C(R.sub.11) or N, X.sub.12 is C(R.sub.12) or N, X.sub.13 is C(R.sub.13) or N, X.sub.14 is C(R.sub.14) or N, X.sub.15 is C(R.sub.15) or N, X.sub.16 is C(R.sub.16) or N, X.sub.17 is C(R.sub.17) or N, X.sub.18 is C(R.sub.18) or N, and X.sub.19 is C(R.sub.19) or N, X.sub.21 is C(R.sub.21) or N, X.sub.22 is C(R.sub.22) or N, X.sub.23 is C(R.sub.23) or N, X.sub.24 is C(R.sub.24) or N, X.sub.25 is C(R.sub.25) or N, X.sub.26 is C(R.sub.26) or N, X.sub.27 is C(R.sub.27) or N, X.sub.28 is C(R.sub.28) or N, and X.sub.29 is C(R.sub.29) or N, R.sub.11 to R.sub.19 are each independently defined as for R.sub.10 in Formula 1, R.sub.21 to R.sub.29 are each independently defined as for R.sub.20 in Formula 1, at least two selected from among neighboring R.sub.11 to R.sub.19 and R.sub.21 to R.sub.29 are optionally bonded to each other to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, R.sub.10a is as defined in Formula 1, and * and *′ each indicate a binding site to a neighboring atom.

4. The heterocyclic compound of claim 1, wherein A.sub.3 to A.sub.5 and A.sub.11 to A.sub.13 are each independently a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a pyridine group, a pyrimidine 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, or a dinaphthothiophene group.

5. The heterocyclic compound of claim 1, wherein the group represented by Formula 3 is a group represented by any one selected from among Formulae 3A to 3C: ##STR00208## in Formulae 3A to **3**C, A.sub.6, A.sub.7, R.sub.60, R.sub.70, b60, and b70 are each as defined in Formula 1, custom-character indicates a single bond or a double bond, and * indicates a binding site to a neighboring atom.

6. The heterocyclic compound of claim 1, wherein the group represented by Formula 3 is a group represented by any one selected from among Formulae 3-1 to 3-3: ##STR00209## wherein, in Formulae 3-1 to 3-3, X.sub.61 is C(R.sub.61) or N, X.sub.62 is C(R.sub.62) or N, X.sub.63 is C(R.sub.63) or N, X.sub.64 is C(R.sub.64) or N, and X.sub.65 is C(R.sub.65) or N, X.sub.71 is C(R.sub.71) or N, X.sub.72 is C(R.sub.72) or N, X.sub.73 is C(R.sub.73) or N, X.sub.74 is C(R.sub.74) or N, and X.sub.75 is C(R.sub.75) or N, R.sub.61 to R.sub.65 are each independently defined as for R.sub.60 in Formula 1, R.sub.71 to R.sub.75 are each independently defined as for R.sub.70 in Formula 1, at least two selected from among neighboring R.sub.61 to R.sub.65 and

R.sub.71 to R.sub.75 are optionally bonded to each other to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, R.sub.10a is as defined in Formula 1, and * indicates a binding site to a neighboring atom.

7. The heterocyclic compound of claim 1, wherein R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, R.sub.60, and R.sub.70 are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C.sub.1-C.sub.20 alkyl group, a C.sub.1-C.sub.20 alkoxy group, or a group represented by any one selected from among Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55: ##STR00210## ##STR00211## ##STR00212## ##STR00213## ##STR00214## ##STR00215## ##STR00216## ##STR00217## ##STR00218## wherein, in Formulae 5-1 to 5-26 and 6-1 to 6-55, Y.sub.31 and Y.sub.32 are each independently O, S, C(Z.sub.33)(Z.sub.34), N(Z.sub.33), or Si(Z.sub.33)(Z.sub.34), Z.sub.31 to Z.sub.34 are each independently selected from among 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, e2 is 1 or 2, e3 is an integer from 1 to 3, e4 is an integer from 1 to 4, e5 is an integer from 1 to 5, e6 is an integer from 1 to 6, e7 is an integer from 1 to 7, e9 is an integer from 1 to 9, and * indicates a binding site to a neighboring atom.

8. The heterocyclic compound of claim 1, wherein the heterocyclic compound is represented by Formula 11 or 12: ##STR00219## wherein, in Formulae 11 and 12, X.sub.1 to X.sub.4, A.sub.1 to A.sub.5, A.sub.11 to A.sub.13, Ar.sub.1, Ar.sub.2, R.sub.10, R.sub.20, R.sub.30, R.sub.40, R.sub.50, b10, b20, b30, b40 and b50 are each as defined in Formula 1, b11 and b21 are each independently 0, 1, 2, 3, or 4, and b12, b13, b22, and b23 are each independently 0, 1, 2, 3, 4, 5, 6, 7, or 8.

9. The heterocyclic compound of claim 1, wherein the heterocyclic compound is represented by Formula 21 or 22: ##STR00220## wherein, in Formulae 21 and 22, X.sub.1 to X.sub.4, Ar.sub.1, and Ar.sub.2 are each as defined in Formula 1 and Formula 2, R.sub.11 to R.sub.19 are each independently defined as for R.sub.10 in Formula 1, R.sub.21 to R.sub.29 are each independently defined as for R.sub.20 in Formula 1, R.sub.31 is defined as for connection with R.sub.30 in Formula 1, R.sub.41 to R.sub.44 are each independently defined as for R.sub.40 in Formula 1, R.sub.51 to R.sub.53 are each independently defined as for R.sub.50 in Formula 1, at least two selected from among neighboring Ar.sub.1 to Ar.sub.6, R.sub.11 to R.sub.19, R.sub.21 to R.sub.29, R.sub.31, R.sub.41 to R.sub.44, and R.sub.51 to R.sub.53 are optionally bonded together to form a C.sub.5-C.sub.60 carbocyclic group unsubstituted or substituted with at least one R.sub.10a or a C.sub.1-C.sub.60 heterocyclic group unsubstituted or substituted with at least one R.sub.10a, and R.sub.10a is as defined in Formula 1.

10. The heterocyclic compound of claim 1, wherein the heterocyclic compound is selected from among Compounds 1 to 80: ##STR00221## ##STR00222## ##STR00223## ##STR00224## ##STR00225## ##STR00226## ##STR00227## ##STR00228## ##STR00229## ##STR00230## ##STR00231## ##STR00232## ##STR00233## ##STR00234## ##STR00235## ##STR00236## ##STR00237## ##STR00238##

11. An organic light-emitting device comprising: a first electrode; a second electrode opposite to the first electrode; an interlayer between the first electrode and the second electrode and comprising an emission layer; and the heterocyclic compound of claim 1.

12. The organic light-emitting device of claim 11, wherein the first electrode is an anode, the second electrode is a cathode, 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, the hole transport region comprising at least one selected from among a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer, and the electron transport region comprising at least one selected from among a hole blocking layer, an electron transport layer, and an electron injection layer.

13. The organic light-emitting device of claim 11, wherein the emission layer comprises the heterocyclic compound.

14. The organic light-emitting device of claim 13, wherein the emission layer comprises a host and a dopant, and the dopant comprises the heterocyclic compound.

15. The organic light-emitting device of claim 13, wherein the emission layer is configured to emit blue light having a maximum emission wavelength of about 410 nanometer (nm) to about 490 nm.

16. The organic light-emitting device of claim 12, wherein the emission layer further comprises a sensitizer.

17. An electronic apparatus comprising the organic light-emitting device of claim 11.

18. The electronic apparatus of claim 17, further comprising a thin-film transistor, the thin-film transistor comprising a source electrode and a drain electrode, and the first electrode of the organic light-emitting device is electrically connected to the source electrode or the drain electrode.

19. A consumer product comprising the organic light-emitting device of claim 11.

20. The consumer product of claim 19, wherein the consumer product is at least one selected from among a flat panel display, a curved display, a computer monitor, a medical monitor, a television, a billboard, an indoor or outdoor light and/or light for signal, a head-up display, a fully or partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a telephone, a portable phone, a tablet personal computer, a phablet, a personal digital assistant (PDA), a wearable device, a laptop computer, a digital camera, a camcorder, a viewfinder, a micro display, a three-dimensional (3D) display, a virtual reality or augmented reality display, a vehicle, a video wall with multiple displays tiled together, a theater or stadium screen, a phototherapy device, a signboard, and combinations thereof.