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LIGHT-EMITTING DEVICE AND ELECTRONIC APPARATUS INCLUDING THE SAME

Abstract

A light-emitting device having an emission layer that includes a hole-transporting host, an electron-transporting host, a sensitizer, and a delayed fluorescence dopant is provided. The hole-transporting host and the electron-transporting host form an exciplex, ΔE.sub.ST indicating an energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex is 0.3 eV or more, and a ratio of a delayed fluorescence photoluminescence quantum yield (PLQY) to a PLQY of the exciplex is 20% or less.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is claims priority to and the benefit of Korean Patent Application No. 10-2024-0020900, filed on Feb. 14, 2024, in the Korean Intellectual Property Office, the entire content of which is incorporated by reference herein.

BACKGROUND

1. Field

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

2. Description of the Related Art

[0003] From among light-emitting devices, self-emissive devices have relatively wide viewing angles, high contrast ratios, short response times, and excellent or suitable characteristics in terms of luminance, driving voltage, and response speed.

[0004] In a light-emitting device, 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 arranged 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 the holes and electrons, may recombine in the emission layer to produce excitons. The excitons 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 light-emitting device having improved lifetime and an electronic apparatus including the same.

[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, a light-emitting device includes [0008] a first electrode, [0009] a second electrode opposite to (e.g facing) the first electrode, and [0010] an interlayer arranged between the first electrode and the second electrode and including an emission layer, [0011] wherein the emission layer may include a hole-transporting host, an electron-transporting host, a sensitizer, and a delayed fluorescence dopant, [0012] the hole-transporting host and the electron-transporting host may (e.g., be configured to) form an exciplex, [0013] the sensitizer may include an organometallic compound, [0014] the delayed fluorescence dopant may not include a (e.g., may exclude any) metal atom, [0015] ΔE.sub.ST may be (e.g., indicating) an energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex may be at least 0.3 electron volt (eV) (e.g., 0.3 eV or more), and [0016] a ratio of a delayed fluorescence photoluminescence quantum yield (PLQY) to a PLQY of the exciplex may be at most 20% (e.g., 20% or less), [0017] wherein E(.sup.1CT) may be (e.g., indicates) an energy level (eV) of a singlet charge-transfer state (.sup.1CT) of the exciplex, and [0018] E(.sup.3CT) may be (e.g., indicates) an energy level (eV) of a triplet charge-transfer state (.sup.3CT) of the exciplex.

[0019] According to one or more embodiments, an electronic apparatus includes the light-emitting device.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] 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:

[0021] FIG. **1** is a schematic view of the structure of a light-emitting device according to one or more embodiments;

[0022] FIG. **2** is a schematic view of the structure of an electronic apparatus according to one or more embodiments;

[0023] FIG. **3** is a schematic view of the structure of an electronic apparatus according to one or more embodiments; and

[0024] FIG. **4** is a graph showing a time-resolved photoluminescence (TRPL) spectrum curve of a single-host thin film.

DETAILED DESCRIPTION

[0025] 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 in 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, by referring to the drawings, to explain aspects of the present description.

[0026] 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.

[0027] Because the disclosure may have diverse modified embodiments, embodiments are illustrated in the drawings and are described in the detailed description. An aspect and a characteristic of the disclosure, and a method of accomplishing these will be apparent if (e.g., when) referring to one or more embodiments described with reference to the drawings. The disclosure may, however, be embodied in many different forms and should not be construed as limited to one or more embodiments set forth herein.

[0028] Hereinafter, embodiments of the disclosure will be described in more detail with reference to the accompanying drawings. The same or corresponding components will be denoted by the same reference numerals, and thus, redundant description thereof will not be provided.

[0029] 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.
[0030] As used herein, the terms “use,” “using,” and “used” may be considered synonymous with the terms “utilize,” “utilizing,” and “utilized,” respectively.
[0031] 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.
[0032] In the following embodiments, an expression used in the singular form (e.g., “a,” “an,” and “the”) also encompasses the expression of the plural forms, unless it has a clearly different meaning in the context.
[0033] In the following embodiments, the terms “comprise,” “comprises,” “comprising,” “include,” “includes,” “including,” “have,” “has,” “having,” and/or the like specify the presence of stated features and/or components, and do not exclude the presence of addition of one or more other features and/or components.
[0034] In the following embodiments, if (e.g., when) a layer, region, or component is referred to as being “on” or “onto” another layer, region, or component, it may be directly or indirectly formed on the other layer, region, or component. For example, for example, intervening layers, regions, or components may be present.
[0035] Sizes of components in the drawings may be exaggerated for convenience of explanation. For example, because sizes and thicknesses of components in the drawings are arbitrarily illustrated for convenience of explanation, the following embodiments are not limited thereto.
[0036] 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.
[0037] In this context, “consisting essentially of” indicates that any additional components will not materially affect the chemical, physical, optical or electrical properties of the semiconductor film.
[0038] As used herein, the term “major component” refers to a component that is present in a composition, polymer, or product in an amount greater than an amount of any other single component in the composition or product. In contrast, the term “primary component” refers to a component that makes up at least 50% (wt % or at %) or more of the composition, polymer, or product.
[0039] 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.
[0040] The term “interlayer” as used herein refers to a single layer and/or all of a plurality of layers between a first electrode and a second electrode of a light-emitting device.
[0041] Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.
Light-Emitting Device
[0042] An aspect of the disclosure provides a light-emitting device including: [0043] a first electrode; [0044] a second electrode opposite to (e.g., facing) the first electrode; and [0045] an interlayer arranged between the first electrode and the second electrode and including an emission layer, [0046] wherein the emission layer may include a hole-transporting host, an electron-

transporting host, a sensitizer, and a delayed fluorescence dopant, [0047] the hole-transporting host and the electron-transporting host may (e.g., be configured to) form an exciplex, the sensitizer may include an organometallic compound, [0048] the delayed fluorescence dopant may not include a (e.g., may exclude any) metal atom, [0049] ΔE.sub.ST may be (e.g., indicating) an energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex may be at least 0.3 electron volt (eV) (e.g., 0.3 eV or more), and [0050] a ratio of a delayed fluorescence photoluminescence quantum yield (PLQY) to a PLQY of the exciplex may be at most 20% (e.g., 20% or less), [0051] wherein E(.sup.1CT) may be (e.g., indicates) an energy level (eV) of a singlet charge-transfer state (.sup.1CT) of the exciplex, and [0052] E(.sup.3CT) may be (e.g., indicates) an energy level (eV) of a triplet charge-transfer state (.sup.3CT) of the exciplex.

[0053] The hole-transporting host and the electron-transporting host included in the emission layer of the light-emitting device may be to form an exciplex (hereinafter, also referred to as an exciplex host).

[0054] A charge-transfer excited state of the exciplex may have a singlet state and a triplet state. For example, the exciplex may have an excited state including a singlet charge-transfer state (.sup.1CT) and a triplet charge-transfer state (.sup.3CT).

[0055] Herein, ".sup.1" in ".sup.1CT" indicates a singlet state, and ".sup.3" in ".sup.3CT" indicates a triplet state.

[0056] In general, if (e.g., when) ΔE.sub.ST, which may be, or indicates, the energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex, is large, for example, at least 3 eV (e.g., 3 eV or more), the lifetime of the light-emitting device may be short.

[0057] Regarding the correlation between the photophysical characteristics of the exciplex host and the lifetime of the light-emitting device, the lifetime of the light-emitting device is usually improved if (e.g., when) the emission lifetime by triplet excitons of the exciplex host is short. When the emission lifetime of the triplet excitons is short, Förster energy transfer to an emitter (e.g., a dopant) may be induced and Dexter energy transfer to the emitter may be suppressed or reduced, and thus, the amount of triplet excitons of the emitter may be reduced, thereby improving the efficiency and lifetime of the light-emitting device.

[0058] In one or more embodiments, even in a case where the emission lifetime of the triplet excitons is short, if (e.g., when) an intersystem crossing (ISC) process from S.sub.1 to T.sub.1 occurs quickly, the triplet exciton density may increase, thus having a negative impact in terms of (e.g., reducing) lifetime.

[0059] After long research, the inventors of the present disclosure have found that, even in a case where ΔE.sub.ST, which may be, or indicates, the energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex, is large, if (e.g., when) ϕ.sub.delayed/ϕ.sub.PLQY of the host exciplex is small (e.g., at most 20% (e.g., 20% or less)), the triplet exciton density may be reduced, and thus, Forster energy transfer may be accelerated, thereby improving the lifetime of the light-emitting device. [0060] ϕ.sub.PLQY: total photoluminesence quantum yield (PLQY) [0061] ϕ.sub.delayed: PLQY of delayed fluorescence of exciplex

[0062] In one or more embodiments, the PLQY of the delayed fluorescence of the exciplex may be obtained, for example, from a PL spectrum and a time-resolved photoluminescence (TRPL) spectrum measured at room temperature for a thin film formed by co-depositing the hole-transporting host and the electron-transporting host on a substrate, and may be understood by referring to the Examples and Evaluation Examples described herein.

[0063] In one or more embodiments, E(.sup.1CT) may be greater than E(.sup.3CT). When E(.sup.3CT) is greater than or equal to E(.sup.1CT), the device lifetime may be short.

[0064] In one or more embodiments, a difference between a highest occupied molecular orbital (HOMO) energy level of the hole-transporting host and a HOMO energy level of the electron-transporting host may be at least 0.2 eV (e.g., 0.2 eV or more), and [0065] a difference between a lowest unoccupied molecular orbital (LUMO) energy level of the hole-transporting host and a

LUMO energy level of the electron-transporting host may be at least 0.2 eV (e.g., 0.2 eV or more).
[0066] When the energy level conditions of the hole-transporting host and the electron-transporting host are as described herein, exciplex formation by intermolecular charge transfer may be facilitated.
[0067] In one or more embodiments, a difference between a lowest singlet energy level of the delayed fluorescence dopant and a lowest triplet energy level of the delayed fluorescence dopant may be at most 0.2 eV (e.g., 0.2 eV, or less).
[0068] For example, the delayed fluorescence dopant may satisfy Expression (1):
[00001] $E_{ST} = E_D(S1) - E_D(T1) \leq 0.2\text{eV}$ (1) [0069] wherein, in Expression (1), [0070] E.sub.D(S1) may be, or indicates, a lowest singlet energy level (eV) of the delayed fluorescence dopant, and [0071] E.sub.D(T1) may be, or indicates, a lowest triplet energy level (eV) of the delayed fluorescence dopant.
[0072] When the difference between the lowest triplet energy level of the delayed fluorescence dopant and the lowest singlet energy level of the delayed fluorescence dopant satisfies Expression (1), up-conversion from the triplet state of the delayed fluorescence dopant to the singlet state of the delayed fluorescence dopant may effectively occur, and thus, the luminescence efficiency of the light-emitting device may be improved.
[0073] In one or more embodiments, a lowest triplet energy level of the sensitizer may be present between a lowest triplet energy level of the exciplex and a lowest triplet energy level of the delayed fluorescence dopant.
[0074] For example, the light-emitting device according to one or more embodiments may satisfy Expression (2):
[00002] $E_{EX}(T1) > E_S(T1) > E_D(T1)$ (2) [0075] wherein, in Expression (2), [0076] E.sub.EX(T1) may be, or indicates, a lowest triplet energy level (eV) of the exciplex, [0077] E.sub.S(T1) may be, or indicates, a lowest triplet energy level (eV) of the sensitizer, and [0078] E.sub.D(T1) may be, or indicates, a lowest triplet energy level (eV) of the delayed fluorescence dopant.
[0079] When the light-emitting device according to one or more embodiments satisfies Expression (2), back energy transfer may be effectively prevented or reduced, and thus, energy may be effectively transferred from the exciplex to the delayed fluorescence dopant.
[0080] The compounds selected as the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant included in the emission layer are not limited as long as they are compounds satisfying the conditions described herein.
[0081] Details on the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant may each independently be as described herein.

Description of FIG. **1**

[0082] FIG. **1** is a schematic cross-sectional view of a light-emitting device **10** according to one or more embodiments. The light-emitting device **10** may include a first electrode **110**, an interlayer **130**, and a second electrode **150**.
[0083] Hereinafter, the structure of the light-emitting device **10** according to one or more embodiments and a method of manufacturing the light-emitting device **10** will be described with reference to FIG. **1**.

First Electrode **110**

[0084] In FIG. **1**, a substrate may be additionally arranged under the first electrode **110** or on the second electrode **150**. 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.

[0085] The first electrode **110** may be formed by, for example, depositing or sputtering a material for forming the first electrode **110** on the substrate. 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.
[0086] The first electrode **110** may be a reflective electrode, a transflective electrode, or a transmissive electrode. 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 (AI), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or any combination thereof.
[0087] The first electrode **110** may have a single-layer structure including (e.g., consisting of) a single layer or a multilayer structure including a plurality of layers. For example, the first electrode **110** may have a three-layer structure of ITO/Ag/ITO.

Interlayer **130**

[0088] The interlayer **130** may be arranged on the first electrode **110**. The interlayer **130** may include an emission layer.
[0089] The interlayer **130** may further include a hole transport region arranged between the first electrode **110** and the emission layer and an electron transport region arranged between the emission layer and the second electrode **150**.
[0090] The interlayer **130** may further include, in addition to one or more suitable organic materials, a metal-containing compound such as an organometallic compound, an inorganic material such as a quantum dot, and/or the like.
[0091] In one or more embodiments, the interlayer **130** may include i) two or more emission layers sequentially stacked between the first electrode **110** and the second electrode **150** and ii) a charge generation layer arranged between the two or more emission layers. When the interlayer **130** includes the emission layers and the charge generation layer as described herein, the light-emitting device **10** may be a tandem light-emitting device.

Hole Transport Region in Interlayer **130**

[0092] 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 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.
[0093] 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.
[0094] 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 constituent layers of each structure are stacked sequentially from the first electrode **110**.
[0095] The hole transport region may include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof:
##STR00001## [0096] wherein, in Formulae 201 and 202, [0097] L.sub.201 to L.sub.204 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, [0098] 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, [0099] xa1 to xa4 may each independently be an integer from 0 to 5, [0100] xa5 may be an integer from 1 to 10, [0101] 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, [0102] 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), [0103] 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 [0104] na1 may be an integer from 1 to 4.

[0105] For example, each of Formulae 201 and 202 may include at least one of (e.g., may be any one selected from among) groups represented by Formulae CY201 to CY217:

##STR00002## ##STR00003## ##STR00004## ##STR00005## ##STR00006## ##STR00007## ##STR00008## [0106] wherein, in Formulae CY201 to CY217, R.sub.10b and R.sub.10c are each the same as described in connection with R.sub.10a, ring CY.sub.201 to ring CY.sub.204 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.

[0107] In one or more embodiments, ring CY.sub.201 to ring CY.sub.204 in Formulae CY201 to CY217 may each independently be a benzene group, a naphthalene group, a phenanthrene group, or an anthracene group.

[0108] In one or more embodiments, each of Formulae 201 and 202 may include at least one of groups represented by Formulae CY201 to CY203.

[0109] 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.

[0110] In one or more embodiments, in Formula 201, xa1 may be 1, R.sub.201 may be a group represented by one of Formulae CY201 to CY203, xa2 may be 0, and R.sub.202 may be a group represented by one of Formulae CY204 to CY207.

[0111] 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.

[0112] 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, and may include at least one of groups represented by Formulae CY204 to CY217.

[0113] 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 CY217.

[0114] For example, the hole transport region may include: at least one of (e.g., 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:

##STR00009## ##STR00010## ##STR00011## ##STR00012## ##STR00013## ##STR00014##

##STR00015## ##STR00016## ##STR00017## ##STR00018##
##STR00019## ##STR00020## ##STR00021## ##STR00022## ##STR00023## ##STR00024##
[0115] The thickness of the hole transport region may be in a range of about 50 angstrom (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, the 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 the thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, for example, about 100 Å to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within the ranges described herein, satisfactory hole-transporting characteristics may be obtained without a substantial increase in driving voltage.
[0116] The emission auxiliary layer may increase light-emission efficiency by compensating for an optical resonance distance according to the wavelength of light emitted from 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
[0117] The hole transport region may further include, in addition to the materials described herein, 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) a charge-generation material).
[0118] The charge-generation material may be, for example, a p-dopant.
[0119] For example, the p-dopant may have a LUMO energy level (or a work function) of at most −3.5 eV (e.g., −3.5 eV or less).
[0120] 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.
[0121] Examples of the quinone derivative may include TCNQ and F4-TCNQ.
[0122] Examples of the cyano group-containing compound may include TCNQ, F4-TCNQ, HAT-CN, a compound represented by Formula 221, and/or the like:
##STR00025## [0123] wherein, in Formula 221, [0124] R.sub.221 to R.sub.223 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, and [0125] at least one of (e.g., one or more selected from among) R.sub.221 to R.sub.223 may each independently be a C.sub.3-C.sub.60 carbocyclic group 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; or any combination thereof.
[0126] In the compound including element EL1 and element EL2, element EL1 may be metal, metalloid, or any combination thereof, and element EL2 may be non-metal, metalloid, or any combination thereof.
[0127] 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 (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.
[0128] Examples of the metalloid may include silicon (Si), antimony (Sb), tellurium (Te), and/or the like.
[0129] Examples of the non-metal may include oxygen (O), halogen (e.g., F, C.sub.1, Br, I, and/or the like), and/or the like.
[0130] Examples of 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.
[0131] 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., ReOs, and/or the like), and/or the like.
[0132] 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.
[0133] 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.
[0134] 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, MgI.sub.2, CaI.sub.2, SrI.sub.2, BaI.sub.2, and/or the like.
[0135] 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, HfCl.sub.4, HfBr.sub.4, HfI.sub.4, and/or the like), vanadium halide (e.g., VF.sub.3, VCl.sub.3, VBr.sub.3, VI.sub.3, 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, OsCl.sub.2, OsBr.sub.2, OsI.sub.2, and/or the like), cobalt halide (e.g., CoF.sub.2, CoCl.sub.2, CoBr.sub.2, CoI.sub.2, 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.
[0136] Examples of the post-transition metal halide may include zinc halide (e.g., ZnF.sub.2, ZnCl.sub.2, ZnBr.sub.2, ZnI.sub.2, and/or the like), indium halide (e.g., InI.sub.3, and/or the like), tin halide (e.g., SnI.sub.2, and/or the like), and/or the like.
[0137] 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.
[0138] Examples of the metalloid halide may include antimony halide (e.g., SbCl.sub.5, and/or the like) and/or the like.
[0139] Examples of the metal telluride may include alkali metal telluride (e.g., Li.sub.2Te, NazTe, 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**

[0140] When the light-emitting device **10** is a full-color light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, and/or a blue emission layer, according to a subpixel. In one or more embodiments, the emission layer may have a stacked structure of at least two (e.g., two or more) layers of a red emission layer, a green emission layer, and a blue emission layer, in which the two or more layers contact each other or are separated from each other, to emit white light. In one or more embodiments, the emission layer may include at least two (e.g., two or more) materials of a red light-emitting material, a green light-emitting material, and a blue light-emitting material, in which the at least two (e.g., two or more) materials are mixed with each other in a single layer, to emit white light.
[0141] The emission layer may include a hole-transporting host, an electron-transporting host, a sensitizer, and a delayed fluorescence dopant.
[0142] The total amount of the sensitizer and the delayed fluorescence dopant in the emission layer may be in a range of about 0.01 wt % to about 25 wt % based on 100 wt % of the total amount of the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant.
[0143] For example, the total amount of the sensitizer and delayed fluorescence dopant in the emission layer may be in a range of about 0.01 wt % to about 25 wt %.
[0144] In one or more embodiments, the weight ratio of the hole-transporting host to the electron-transporting host in the emission layer may be in a range of about 1:9 to about 9:1. For example, the weight ratio of the hole-transporting host to the electron-transporting host may be in a range of about 3:7 to about 7:3. The weight ratio of the hole-transporting host to the electron-transporting host may be in a range of about 4:5 to about 5:4.
[0145] In one or more embodiments, the weight ratio of the sensitizer to the delayed fluorescence dopant may be in a range of about 100:1 to about 10:1. For example, the weight ratio of the sensitizer to the delayed fluorescence dopant may be in a range of about 50:1 to about 7:1. For example, the weight ratio of the sensitizer to the delayed fluorescence dopant may be in a range of about 30:1 to about 5:1.
[0146] When the weight ratios of the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant in the emission layer are within the ranges described herein, the lifetime of the light-emitting device may be long.
[0147] The 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 range described herein, excellent or suitable luminescence characteristics may be obtained without a substantial increase in driving voltage.
[0148] The compounds selected as the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant included in the emission layer are not limited as

long as they are compounds satisfying the conditions described herein. Hereinafter, the hole-transporting host, the electron-transporting host, the sensitizer, and the delayed fluorescence dopant included in the emission layer are described in more detail.

Host

[0149] The hole-transporting host may be a compound having strong hole characteristics. The expression “a compound having strong hole characteristics” refers to a compound that is easy to accept holes, and such characteristics may be obtained by including a hole-receiving moiety (also referred to as a hole-transporting moiety).

[0150] The hole-receiving moiety may be, or include, for example, a π electron-rich heteroaromatic compound (e.g., a carbazole derivative or an indole derivative) or an aromatic amine compound.

[0151] The electron-transporting host may be a compound having strong electron characteristics. The expression “a compound having strong electron characteristics” refers to a compound that is easy to accept electrons, and such characteristics may be obtained by including an electron-receiving moiety (also referred to as an electron-transporting moiety).

[0152] The electron-receiving moiety may be, or include, for example, a π electron-deficient heteroaromatic compound. For example, the electron-receiving moiety may include a nitrogen-containing heteroaromatic compound.

[0153] A host of the emission layer of the light-emitting device according to one or more embodiments may be a mixed host, and may include the electron-transporting host and the hole-transporting host.

[0154] When a compound includes only a hole-transporting moiety or only an electron-transporting moiety, it should be understood (e.g., is clear to) by the ordinary skilled artisan whether the nature of the compound has hole-transporting characteristics or electron-transporting characteristics.

[0155] A compound may include both (e.g., simultaneously) a hole-transporting moiety and an electron-transporting moiety. In this case, a (e.g., simple) comparison between the total number of hole-transporting moieties and the total number of electron-transporting moieties in the compound may be a criterion for predicting whether the compound is a hole-transporting compound or an electron-transporting compound. However, such comparison may or should not (e.g., cannot) be considered as being an absolute criterion. One of the reasons why the (e.g., such a simple) comparison may or should not (e.g., cannot) be an absolute criterion is that one or more suitable hole-transporting moiety (ies) and one or more suitable electron-transporting moiety (ies) may or should (e.g., do) not, respectively, have (e.g., exactly) the same ability to attract holes and electrons, respectively.

[0156] Accordingly, a relatively reliable way to determine whether a compound having a certain or suitable structure may be configured as a hole-transporting compound or an electron-transporting compound is to directly implement the compound in a device.

[0157] For example, the hole-transporting host of the emission layer of the light-emitting device according to one or more embodiments may include a compound including at least one carbazole group.

[0158] In one or more embodiments, the hole-transporting host may include a compound represented by Formula 1:

##STR00026## [0159] wherein, in Formula 1,

R.sub.1, R.sub.2, and Ar.sub.1 may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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.1)(Q.sub.2)(Q.sub.3), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), or —P(═O)(Q.sub.1)(Q.sub.2),
[0160] L.sub.1 may be a C.sub.4-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, [0161] a1 and a2 may each independently be an integer from 1 to 4, [0162] b1 may be an integer from 0 to 3, [0163] R.sub.10a may be: [0164] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group; [0165] 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.5-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, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(═O)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(Q.sub.11)(Q.sub.12), or any combination thereof; [0166] 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, or a C.sub.2-C.sub.60 heteroarylalkyl 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.5-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, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(═O)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), or any combination thereof; or [0167] —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(═O)(Q.sub.31), —S(═O).sub.2(Q.sub.31), or —P(═O)(Q.sub.31)(Q.sub.32), and [0168] 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; 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 [0169] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.7-C.sub.60 arylalkyl group, or a C.sub.2-C.sub.60 heteroarylalkyl 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.
[0170] In one or more embodiments, the hole-transporting host may include a compound represented by Formula 301-1, a compound represented by Formula 301-2, or any combination thereof:
##STR00027## [0171] wherein, in Formulae 301-1 and 301-2, [0172] 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, [0173] 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), [0174] xb22 and xb23 may each independently be 0, 1, or 2, [0175] xb1 may be an integer from 0 to 5, [0176] xb2 to xb4 may each independently be the same as described in connection with xb1, [0177] L.sub.301 to L.sub.304 may each independently be the same as described in connection with L.sub.1, and [0178] R.sub.301 to R.sub.305 and R.sub.311 to R.sub.314 are each the same as describe in connection with R.sub.1.
[0179] In one or more embodiments, the electron-transporting host may include a compound including at least one π electron-deficient nitrogen-containing 6-membered ring.
[0180] In one or more embodiments, the electron-transporting host may include a compound

represented by Formula 2:
##STR00028## [0181] wherein, in Formula 2, [0182] X.sub.21 may be N or C-(L.sub.24).sub.a24-(R.sub.24).sub.b24, X.sub.22 may be N or C-(L.sub.25).sub.a25-(R.sub.25).sub.b25, and X.sub.23 may be N or C-(L.sub.26).sub.a26-(R.sub.26).sub.b26, wherein at least one of X.sub.21 to X.sub.23 may include N, [0183] L.sub.21 to L.sub.26 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, [0184] a21 to a26 may each independently be an integer from 0 to 5, [0185] R.sub.21 to R.sub.26 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.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, 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, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), or —P(═O)(Q.sub.1)(Q.sub.2), [0186] b21 to b26 may each independently be an integer from 1 to 5, and [0187] R.sub.10a and Q.sub.1 to Q.sub.3 are each as described in Formula 1.
[0188] In one or more embodiments, the hole-transporting host and the electron-transporting host may each independently include at least one selected from among Compounds HT-01 to HT-17, at least one selected from among ET-01 to ET-015, 1,3,5-tri(carbazol-9-yl)benzene (TCP), or any combination thereof:
##STR00029## ##STR00030## ##STR00031## ##STR00032## ##STR00033## ##STR00034## ##STR00035## ##STR00036## ##STR00037##
Sensitizer
[0189] The sensitizer may include an organometallic compound.
[0190] The sensitizer may not emit (e.g., not be configured to emit) light to the outside of the light-emitting device, and may transfer energy between the exciplex host and the delayed fluorescence dopant.
[0191] For example, singlet excitons of the exciplex may be transferred to the singlet state of the sensitizer through Förster energy transfer, and triplet excitons of the exciplex may be transferred to the triplet state of the sensitizer through Dexter energy transfer.
[0192] The sensitizer may transfer energy to the delayed fluorescence dopant. For example, the sensitizer may serve as an energy donor, and the delayed fluorescence dopant may serve as an energy acceptor. A method of transferring energy from the sensitizer to the delayed fluorescence dopant may include both (e.g., simultaneously) a Forster energy transfer mechanism and a Dexter energy transfer mechanism. Accordingly, energy transfer for emission may occur effectively in the emission layer.
[0193] Because singlet excitons are mostly transferred to triplet excitons through intersystem crossing (ISC), and the triplet excitons may be used in emission due to the “heavy atom effect” of metal atoms, the sensitizer may effectively transfer excitons transferred from the exciplex to the delayed fluorescence dopant.
[0194] In one or more embodiments, the sensitizer may include an organometallic compound represented by Formula 401:
##STR00038## [0195] wherein, in Formulae 401 and 402, [0196] M may be a transition metal, [0197] 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, at least two (e.g., two or more) of L.sub.401 may be substantially

identical to or different from each other, [0198] 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, at least two (e.g., two or more) of L.sub.402 may be substantially identical to or different from each other, [0199] X.sub.401 and X.sub.402 may each independently be nitrogen or carbon, [0200] ring A.sub.401 and ring A.sub.402 may each independently a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, [0201] 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═, [0202] X.sub.403 and X.sub.404 may each independently be a chemical 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), [0203] 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), [0204] R.sub.401 and R.sub.402 may optionally be linked to each other to form a ring, [0205] R.sub.10a is as described in Formula 1, and Q.sub.411 to Q.sub.414 and Q.sub.401 to Q.sub.403 are each as described in connection with Q.sub.1 in Formula 1, xc11 and xc12 may each independently be an integer from 0 to 10, and [0206] * and *′ in Formula 402 each indicate a binding site to M in Formula 401.

[0207] In one or more embodiments, at least one of (e.g., one or more selected from among) A.sub.401 and A.sub.402 may be a group represented by Formula 3A-1 or Formula 3A-2:

##STR00039## [0208] wherein, in Formulae 401 and 402, [0209] R.sub.37 is the same as described in connection with R.sub.401, [0210] *indicates a binding site to M, and [0211] ** indicates a binding site to a neighboring atom.

[0212] For example, the sensitizer may include at least one of (e.g., one or more selected from among) Compounds Pt-1 to Pt-16, but embodiments are not limited thereto:

##STR00040## ##STR00041## ##STR00042## ##STR00043##

Delayed Fluorescence Dopant

[0213] The delayed fluorescence dopant may be any suitable compound that may be to emit delayed fluorescence according to a delayed fluorescence emission mechanism.

[0214] When triplet excitons are transferred to a singlet state through reverse ISC (RISC), and the excitons in the singlet state are transferred to a ground state, the delayed fluorescence dopant may be to emit delayed fluorescence. Accordingly, the delayed fluorescence dopant may theoretically have internal quantum efficiency of 100%.

[0215] For example, the delayed fluorescence dopant may be a thermally activated delayed fluorescence dopant.

[0216] For example, the delayed fluorescence dopant 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), 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), and/or iii) the like.

[0217] In one or more embodiments, the delayed fluorescence dopant may include a condensed cyclic compound represented by Formula 3:

##STR00044## [0218] wherein, in Formula 3, [0219] Y.sub.1 to Y.sub.3 may each independently be S, N(R.sub.24), B(R.sub.24), C(R.sub.24)(R.sub.25), or Si(R.sub.24)(R.sub.25), [0220] c may be 0 or 1, [0221] A.sub.11 to A.sub.13 may each independently be selected from among a C.sub.5-C.sub.30 carbocyclic group and a C.sub.1-C.sub.30 heterocyclic group, [0222] R.sub.21 to

R.sub.25 may each independently be selected from among hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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 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), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), and —P(═O)(Q.sub.1)(Q.sub.2), [0223] R.sub.21 to R.sub.25 may optionally be linked to each other to form a substituted or unsubstituted C.sub.5-C.sub.30 carbocyclic group or a substituted or unsubstituted C.sub.1-C.sub.30 heterocyclic group, [0224] a21 to a23 may each independently be an integer from 0 to 10, and [0225] R.sub.10a and Q.sub.1 to Q.sub.3 are each as described in Formula 1.

[0226] For example, the delayed fluorescence dopant may be a condensed cyclic compound represented by Formula 3-1:

##STR00045## [0227] wherein, in Formula 3-1, [0228] R.sub.411 to R.sub.414 may each independently be the same as described in connection with R.sub.21, R.sub.421 to R.sub.424 may each independently be the same as described in connection with R.sub.22, and R.sub.431 to R.sub.433 may each independently be the same as described in connection with R.sub.23, and [0229] X.sub.41 is as described in connection with Y.sub.2, and X.sub.42 is as described in connection with Y.sub.3.

[0230] For example, the delayed fluorescence dopant may include at least one of (e.g., one or more selected from among) Compounds D1 to D12, but embodiments are not limited thereto.

##STR00046## ##STR00047## ##STR00048##

[0231] The condensed cyclic compound represented by Formula 3 or 3-1 may have a structure in which cyclic groups are condensed around boron, and thus, the overall structural flexibility (e.g., fluidity) of the compound may be low, and changes in geometry may be small. Thus, the condensed cyclic compound may have small Stoke's shift characteristics, thereby having a small full width of half maximum (FWHM). Accordingly, a light-emitting device using the condensed cyclic compound as a dopant in an emission layer may have improved color purity and color reproducibility, as compared with a light-emitting device using a sensitizer as a dopant in an emission layer.

[0232] In one or more embodiments, the emission layer may be a fluorescent emission layer.

[0233] In one or more embodiments, the emission layer may be a blue emission layer.

Electron Transport Region in Interlayer **130**

[0234] 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 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.
[0235] The electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.
[0236] For example, the electron transport region may have an electron transport layer/electron injection layer structure or a hole blocking layer/electron transport layer/electron injection layer structure, wherein constituent layers of each structure are sequentially stacked from the emission layer.
[0237] The electron transport region (e.g., the hole blocking 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.
[0238] 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 [0239] wherein, in Formula 601, [0240] Ar.sub.601 and L.sub.601 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, [0241] xe11 may be 1, 2, or 3, [0242] xe1 may be 0, 1, 2, 3, 4, or 5, [0243] R.sub.601 may be a C.sub.5-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), [0244] Q.sub.601 to Q.sub.603 are each as described in connection with Q.sub.1, [0245] xe21 may be 1, 2, 3, 4, or 5, and [0246] at least one of (e.g., one or more 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.
[0247] For example, if (e.g., when) xe11 in Formula 601 is 2 or more, at least two (e.g., two or more) of Ar.sub.601 may be linked to each other via a single bond.
[0248] In one or more embodiments, Ar.sub.601 in Formula 601 may be a substituted or unsubstituted anthracene group.
[0249] In one or more embodiments, the electron transport region may include a compound represented by Formula 601-1:
##STR00049## [0250] wherein, in Formula 601-1, [0251] X.sub.614 may be N or C(R.sub.614), X.sub.615 may be N or C(R.sub.615), X.sub.616 may be N or C(R.sub.616), and at least one of (e.g., selected from among) X.sub.614 to X.sub.616 may be N, [0252] L.sub.611 to L.sub.613 are each as described in connection with L.sub.601, [0253] xe611 to xe613 are each as described in connection with xe1, [0254] R.sub.611 to R.sub.613 are each as described in connection with R.sub.601, and [0255] 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.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.
[0256] For example, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.
[0257] 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; BAlq; TAZ; NTAZ; or any combination thereof:
##STR00050## ##STR00051## ##STR00052## ##STR00053## ##STR00054## ##STR00055## ##STR00056## ##STR00057## ##STR00058## ##STR00059## ##STR00060## ##STR00061## ##STR00062## ##STR00063##

##STR00064## ##STR00065##
[0258] The thickness of the electron transport region may be in a range of about 100 Å to about 5,000 Å, for example, about 160 Å to about 4,000 Å. When the electron transport region includes a hole blocking layer, an electron transport layer, or any combination thereof, the thickness of the hole blocking layer or the electron transport layer may be in a range of about 20 Å to about 1,000 Å, for example, about 30 Å to about 300 Å. The 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 hole blocking layer and/or the electron transport layer are within the ranges described herein, satisfactory electron-transporting characteristics may be obtained without a substantial increase in driving voltage.
[0259] The electron transport region (e.g., the electron transport layer in the electron transport region) may further include, in addition to the materials described herein, a metal-containing material.
[0260] 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 alkaline earth-metal complex may include hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, cyclopentadiene, or any combination thereof.
[0261] For example, the metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (LiQ) or ET-D2:
##STR00066##
[0262] 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**.
[0263] 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 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.
[0264] 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.
[0265] 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.
[0266] The alkali metal-containing compound, the alkaline earth metal-containing compound, and the rare earth metal-containing compound may include oxides, halides (e.g., fluorides, chlorides, bromides, iodides, and/or the like), or tellurides of the alkali metal, the alkaline earth metal, and the rare earth metal, or any combination thereof.
[0267] The alkali metal-containing compound may include: alkali metal oxide, such as Li.sub.2O, Cs.sub.2O, K.sub.2O, and/or the like; alkali metal halide, such as LiF, NaF, CsF, KF, LiI, NaI, CsI, KI, and/or the like; or any combination thereof. The alkaline earth metal-containing compound may include 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.

[0268] 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 ion(s)), for example, hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenyl benzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, cyclopentadiene, or any combination thereof.

[0269] 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., a compound represented by Formula 601).

[0270] In one or more embodiments, the electron injection layer may include (e.g., consist of) i) an alkali metal-containing compound (e.g., alkali metal halide), ii) a) an alkali metal-containing compound (e.g., alkali metal halide); and b) an alkali metal, an alkaline earth metal, a rare earth metal, or any combination thereof. For example, 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 iii) the like.

[0271] 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.

[0272] The thickness of the electron injection layer may be in a range of about 1 Å to about 100 Å, for example, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within the range described herein, satisfactory electron injection characteristics may be obtained without a substantial increase in driving voltage.

Second Electrode **150**

[0273] The second electrode **150** may be arranged on the interlayer **130** having a structure as described herein. 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.

[0274] The second electrode **150** may include lithium (Li), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ytterbium (Yb), silver-ytterbium (Ag—Yb), ITO, IZO, or any combination thereof. The second electrode **150** may be a transmissive electrode, a transflective electrode, or a reflective electrode.

[0275] The second electrode **150** may have a single-layer structure or a multi-layer structure including multiple layers.

Capping Layer

[0276] A first capping layer may be arranged outside (e.g., and on) the first electrode **110**, and/or a second capping layer may be arranged outside (e.g., and on) the second electrode **150**. For example, the 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.

[0277] Light generated in the emission layer of the interlayer **130** of the 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 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.

[0278] 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 light-emitting device **10** may be increased, and thus, the luminescence efficiency of the light-emitting device **10** may be improved.

[0279] 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).

[0280] 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 a composite capping layer including an organic material and an inorganic material.

[0281] At least one of (e.g., one or more 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. In one or more embodiments, at least one of (e.g., one or more selected from among) the first capping layer and the second capping layer may each independently include an amine group-containing compound.

[0282] For example, at least one of the (e.g., one or more selected from among) first capping layer and the second capping layer may each independently include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof.

[0283] In one or more embodiments, at least one of (e.g., one or more selected from among) the first capping layer and/or the second capping layer may each independently include: at least one of (e.g., one or more selected from among) Compounds HT28 to HT33; at least one of (e.g., one or more selected from among) Compounds CP1 to CP6; β-NPB; or any combination thereof:
##STR00067## ##STR00068##

[0284] Another aspect of the disclosure provides an electronic apparatus including the light-emitting device.

[0285] 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, and the first electrode of the 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 functional layer including a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof. More details on the electronic apparatus may each independently be the same as described herein.

Electronic Apparatus

[0286] The light-emitting device may be included in one or more suitable electronic apparatuses. For example, the electronic apparatus including the light-emitting device may be a light-emitting apparatus, an authentication apparatus, and/or the like.

[0287] The electronic apparatus (e.g., a light-emitting apparatus) may further include, in addition to the 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 light-emitting device. For example, the light emitted from the light-emitting device may be blue light or white light. Details on the light-emitting device may each independently be the same as described herein. In one or more embodiments, the color conversion layer may include a quantum dot. The quantum dot may be, for example, a quantum dot as described herein.

[0288] In some embodiments, 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

[0289] 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 subpixel areas, and the color conversion layer may include a plurality of color conversion areas respectively corresponding to the subpixel areas.

[0290] A pixel-defining film may be arranged among the subpixel areas to define each of the subpixel areas.

[0291] The color filter may further include a plurality of color filter areas and light-shielding patterns arranged among the color filter areas, and the color conversion layer may further include a plurality of color conversion areas and light-shielding patterns arranged among the color conversion areas.

[0292] 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. For example, 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. For example, the plurality of color filter areas (or the plurality of color conversion areas) may include quantum dots. For example, the first area may include a red quantum dot, the second area may include a green quantum dot, and the third area may not include a (e.g., may exclude any) a quantum dot. Details on the quantum dot may each independently be the same as described herein. The first area, the second area, and/or the third area may each further include a scatter.

[0293] For example, the light-emitting device may be to emit first light, the first area may be to absorb the first light to emit first-1 color light, the second area may be to absorb the first light to emit second-1 color light, and the third area may be to absorb the first light to emit third-1 color light. In this regard, the first-1 color light, the second-1 color light, and the third-1 color light may have different maximum emission wavelengths. For example, 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.
[0294] The electronic apparatus may further include a thin-film transistor, in addition to the light-emitting device as described herein. 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 light-emitting device.
[0295] The thin-film transistor (TFT) may further include a gate electrode, a gate insulating film, and/or the like.
[0296] The activation layer may include crystalline silicon, amorphous silicon, an organic semiconductor, an oxide semiconductor, and/or the like.
[0297] The electronic apparatus may further include a sealing portion for sealing the light-emitting device. The sealing portion may be arranged between the color filter and/or the color conversion layer and the light-emitting device. The sealing portion allows light from the light-emitting device to be extracted to the outside, and concurrently (e.g., simultaneously) prevents ambient air and moisture from penetrating into the 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.
[0298] 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.
[0299] 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).
[0300] The authentication apparatus may further include, in addition to the light-emitting device as described herein, a biometric information collector.
[0301] The electronic apparatus may be applied to one or more suitable displays, light sources, lighting, personal computers (e.g., a mobile personal computer), 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/or a vessel), projectors, and/or the like.
Description of FIGS. **2** and **3**
[0302] FIG. **2** is a cross-sectional view of an electronic apparatus according to one or more embodiments.
[0303] The electronic apparatus of FIG. **2** may include a substrate **100**, a thin-film transistor (TFT), a light-emitting device, and an encapsulation portion **300** that seals the light-emitting device.
[0304] 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 may provide a flat surface on the substrate **100**.
[0305] 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**.
[0306] 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.

[0307] 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**.
[0308] 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 from one another.
[0309] 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**.
[0310] The TFT may be electrically connected to a light-emitting device to drive the 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, or any combination thereof. A light-emitting device may be provided on the passivation layer **280**. The light-emitting device may include the first electrode **110**, the interlayer **130**, and the second electrode **150**.
[0311] 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**, not 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**.
[0312] A pixel-defining film **290** including an insulating material may be arranged on the first electrode **110**. The pixel-defining film **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 film **290** may be a polyimide-based organic film or a polyacrylic organic film. In some embodiments, at least some layers of the interlayer **130** may extend beyond the upper portion of the pixel-defining film **290** to be arranged in the form of a common layer.
[0313] 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**.
[0314] The encapsulation portion **300** may be arranged on the capping layer **170**. The encapsulation portion **300** may be arranged on a light-emitting device to protect the 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 film(s) and the organic film(s).
[0315] FIG. **3** is a cross-sectional view of an electronic apparatus according to one or more embodiments.
[0316] The electronic apparatus of FIG. **3** is the same as the electronic 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 light-emitting device included in the electronic apparatus of FIG. **3** may be a tandem light-emitting device.

Manufacturing Method

[0317] The 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.
[0318] When the 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 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
[0319] 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 3 to 60 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.5-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.
[0320] 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.
[0321] The term “π electron-rich C.sub.3-C.sub.60 cyclic group” as used herein refers to a cyclic group that has 3 to 60 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 1 to 60 carbon atoms and includes *—N═*′ as a ring-forming moiety.
[0322] For example, [0323] 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), [0324] the C.sub.1-C.sub.60 heterocyclic group may be i) Group T2, ii) a condensed cyclic group in which two or more 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 benzoisoxazole group, a benzothiazole group, a benzoisothiazole 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), [0325] the π electron-rich C.sub.5-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 C.sub.3-C.sub.60 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), [0326] the π electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group may be i) Group T4, ii) a condensed cyclic group in which two or more of Group 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 benzoisoxazole group, a benzothiazole group, a benzoisothiazole 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), [0327] 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, [0328] 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, [0329] Group T3 may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, or a borole group, and [0330] Group T4 may be 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.

[0331] The term “cyclic group,” “C.sub.3-C.sub.60 carbocyclic group,” “C.sub.1-C.sub.60 heterocyclic group,” “π electron-rich C.sub.3-C.sub.60 cyclic group,” or “π electron-deficient nitrogen-containing C.sub.1-C.sub.60 cyclic group” as used herein refers to a group condensed to any cyclic group, 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.

[0332] For example, the “benzene group” may be a benzo group, a phenyl group, a phenylene group, and/or the like, which may be easily understood by those of ordinary skill in the art according to the structure of a formula including the “benzene group.”

[0333] 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.

[0334] Examples of the monovalent C.sub.3-C.sub.60 carbocyclic group and the monovalent C.sub.1-C.sub.60 heterocyclic group may include a C.sub.5-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 hetero-condensed polycyclic group. 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 hetero-condensed polycyclic group.

[0335] 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 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, a tert-decyl group, and/or the like. 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.

[0336] 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.

[0337] 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.

[0338] 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.

[0339] 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 adamantyl group, a norbornyl (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.

[0340] The term “C.sub.1-C.sub.10 heterocycloalkyl group” as used herein refers to a monovalent cyclic group having 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom, as ring-forming atoms, and 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.

[0341] The term “C.sub.3-C.sub.10 cycloalkenyl group” as used herein refers to a monovalent cyclic group that has 3 to 10 carbon atoms and at least one carbon-carbon double bond in the ring thereof and no aromaticity, and examples thereof 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.

[0342] The term “C.sub.1-C.sub.10 heterocycloalkenyl group” as used herein refers to a monovalent cyclic group having 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom, as ring-forming atoms, and having 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 heterocycloalkenylene group” as used herein refers to a divalent group having the same structure as the C.sub.1-C.sub.10 heterocycloalkenyl group.

[0343] The term “C.sub.6-C.sub.60 aryl group” as used herein refers to a monovalent group having a carbocyclic aromatic system of 6 to 60 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 6 to 60 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.

[0344] 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.
[0345] 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 its 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 indenoanthracenyl 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.
[0346] The term “monovalent non-aromatic condensed heteropolycyclic 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 condensed heteropolycyclic group may include a pyrrolyl group, a thiophenyl group, a furanyl group, an indolyl group, a benzoindolyl group, a naphtho indolyl 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 indenocarbazolyl 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, a benzothienodibenzothiophenyl group, and/or the like. 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.
[0347] 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).
[0348] 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).
[0349] The term “R.sub.10a” as used herein may be: [0350] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group; [0351] 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.5-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, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(═O)(Q.sub.11), —S(═O).sub.2(Q.sub.11),

—P(═O)(Q.sub.11)(Q.sub.12), or any combination thereof; [0352] 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, or a C.sub.2-C.sub.60 heteroarylalkyl 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.5-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, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(═O)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(Q.sub.21)(Q.sub.22), or any combination thereof; or [0353] —Si(Q.sub.31)(Q.sub.32)(Q.sub.33), —N(Q.sub.31)(Q.sub.32), —B(Q.sub.31)(Q.sub.32), —C(═O)(Q.sub.31), —S(═O).sub.2(Q.sub.31), or —P(═O)(Q.sub.31)(Q.sub.32).

[0354] 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; 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 [0355] a C.sub.3-C.sub.60 carbocyclic group, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.7-C.sub.60 arylalkyl group, or a C.sub.2-C.sub.60 heteroarylalkyl group, each unsubstituted or substituted with deuterium, —F, 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.

[0356] 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, or any combination thereof.

[0357] The term “third-row transition metal” as used herein may include hafnium (Hf), tantalum (Ta), tungsten (W), rhenium (Re), osmium (Os), iridium (Ir), platinum (Pt), gold (Au), and/or the like.

[0358] The term “Ph” as used herein refers to a phenyl group, the term “Me” as used herein refers to a methyl group, the term “Et” as used herein refers to an ethyl group, the term “ter-Bu” or “But” as used herein refers to a tert-butyl group, and the term “OMe” as used herein refers to a methoxy group.

[0359] The term “biphenyl group” as used herein refers to “a phenyl group substituted with a phenyl group.” The “biphenyl group” may be a substituted phenyl group having a C.sub.6-C.sub.60 aryl group as a substituent.

[0360] The term “terphenyl group” as used herein refers to “a phenyl group substituted with a biphenyl group.” The “terphenyl group” may be a substituted phenyl group having, as a substituent, a C.sub.6-C.sub.60 aryl group substituted with a C.sub.6-C.sub.60 aryl group.

[0361] The number of carbon atoms in the substituent definition is an example. For example, in the C.sub.1-C.sub.60 alkyl group, the number of carbon atoms, 60, is an example, and the definition for the alkyl group is equally applied to the C.sub.1-C.sub.20 alkyl group. The same applies to other cases.

[0362] Any hydrogen in the compound structures described herein may optionally be substituted with deuterium. [0363] * and *′ as used herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

[0364] 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.

[0365] 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.

[0366] The light-emitting device, the electronic apparatus, 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 may be formed on one integrated circuit (IC) chip or on separate IC chips. Further, the various components of the light-emitting device and/or the electronic apparatus 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 and/or apparatus 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.

[0367] Hereinafter, a light-emitting device according to one or more example embodiments will be described in more detail with reference to Examples and Comparative Examples.

EXAMPLES

Evaluation Example 1: Measurement of .SUP.1.CT and .SUP.3.CT Energy Levels of Exciplex

[0368] 50 wt % of a hole-transporting host and 50 wt % of an electron-transporting host were applied onto a quartz substrate to form a thin film having a thickness of 400 angstrom (Å), and the thin film was subjected to i) measurement of the .sup.1CT energy level of the exciplex from a photoluminesence (PL) spectrum at a temperature of 300 Kelvin (K) and ii) measurement of the .sup.3CT energy level of the exciplex from a PL spectrum at a temperature of 4 K. The spectra were measured by using a photomultiplier tube (Acton Research Corporation; PD-471) equipped with a He:Cd laser and a monochromator (Acton Research Corporation; SpectraPro 300i).

[0369] For each of Thin Films A to D, corresponding compounds shown in Table 1 were used as the hole-transporting host and the electron-transporting host.

TABLE-US-00001 TABLE 1 Hole- Electron- trans- trans- porting porting .sup.1CT .sup.3CT ΔE.sub.ST host host (eV) (eV) (eV) Thin Film A HT-07 ET-015 3.05 2.87 0.18 Thin Film B HT-08 ET-015 3.05 2.74 0.31 Thin Film C HT-14 ET-015 3.05 2.75 0.30 Thin Film D HT-17 ET-015 3.05 2.75 0.30

[0370] Referring to Table 1, it was confirmed that Thin Films B to D each had ΔE.sub.ST, which indicates the energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex of the hole-transporting host and the electron-transporting host, of 0.3 electron volt (eV) or more, and Film A had ΔE.sub.ST of 0.18 eV.

Evaluation Example 2: Measurement of PLQY and ΦDF/ΦPLQY

[0371] For each of Thin Films A to D, i) the photoluminesence quantum yield (PLQY), ii) the delayed fluorescence PLQY (ΦDF), and iii) the prompt fluorescence PLQY (ΦPF) were measured, and values thereof are shown in Table 2.

[0372] The PLQY was calculated by measuring a PLQY in an excitation wavelength in a range of

280 nanometer (nm) to 320 nm by using an integrating sphere and taking an average value therefrom. The ratio of the delayed fluorescence PLQY to the prompt fluorescence PLQY based on the total PLQY was measured from an amplitude ratio of a first component to a second component of a TRPL curve (a transient PL decay curve).

TABLE-US-00002 TABLE 2 PLQY (%) Φ.sub.PF (%) Φ.sub.DF (%) Φ.sub.DF/Φ.sub.PLQY (%) Thin Film A 100 78 22 22 Thin Film B 45 40 5 11 Thin Film C 50.7 91.6 8.4 8.4 Thin Film D 48 45 3 6.0

[0373] Referring to Table 2, it was confirmed that Thin Film A had PDF/ΦPLOY of 22% %, and Thin Films B to D each had ΦDF/ΦPLOY of at most 20% (e.g., 20% or less). For example, Thin Films B to D each had ΦDF/ΦPLOY less than 20%.

Evaluation Example 3: Measurement of TRPL Spectrum

[0374] A time-resolved photoluminescence (TRPL) curve was obtained for each of Thin Films A and C, and results thereof shown in FIG. **4**.

[0375] Referring to the TRPL curves in FIG. **4**, Thin Films A and C each include two decay components. The two decay components include a curve of prompt fluorescence components shown in a range of several nanoseconds and a curve of delayed fluorescence components shown in a range of several tens of nanoseconds.

[0376] In FIG. **4**, the slope indicates the rate at which excitons pass through the triplet state, and the area indicates the triplet exciton density. In the case of an exciplex having a relatively large ΔE.sub.ST value (Thin Film C), it was confirmed that while the intersystem crossing (ISC) and reverse intersystem crossing (RISC) rates were low, the triplet exciton density was reduced, as compared with the case of an exciplex having a relatively small ΔE.sub.ST value (Thin Film A) (the area of Thin Film C was about 74% of the area of Thin Film A).

[0377] Accordingly, if (e.g., when) Thin Film C is applied to a light-emitting device, the triplet exciton density is expected to be reduced so that Förster energy transfer is accelerated, thereby improving the lifetime of the device.

Comparative Example 1

[0378] As an anode, a substrate on which indium tin oxide (ITO) were deposited was cut to a size of 50 millimeter (mm)×50 mm×0.5 mm, sonicated with isopropyl alcohol and pure water each for 5 minutes, cleaned by exposure to ultraviolet rays and ozone for 30 minutes, and then mounted on a vacuum deposition apparatus.

[0379] m-MTDATA was deposited on the ITO substrate to form a hole injection layer having a thickness of 40 angstrom (Å), NPB was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 1,000 Å, and then, Compounds HT-07, ET-015, Pt-2, and D3 were co-deposited at a weight ratio of 50:50:13:0.4 on the hole transport layer to form an emission layer having a thickness of 400 Å. As a host of the emission layer, a host combination corresponding to Thin Film A was used.

[0380] Compound ET1 was deposited on the emission layer to form an electron transport layer having a thickness of 300 Å. Al was deposited on the electron transport layer to form a cathode having a thickness of a 1,200 Å, thereby completing the manufacture of an organic light-emitting device.

##STR00069## ##STR00070##

Examples 1 to 3

[0381] Organic light-emitting devices were manufactured in substantially the same manner as in Comparative Example 1, except that compounds shown in Table 3 were each used in forming the emission layer.

[0382] As a host of the emission layer of the organic light-emitting device of Example 2, a host combination corresponding to Thin Film C was used.

[0383] The lifetime of each of the organic light-emitting devices manufactured in Comparative Example 1 and Examples 1 to 3 was measured by using Keithley SMU 236 and luminance meter

PR650, and results thereof are shown in Table 3.
TABLE-US-00003 TABLE 3 Emission layer Hole- Electron- trans- trans- Delayed porting porting Sensi- fluorescence Lifetime host host tizer dopant (%) Compar- HT-07 ET-015 Pt-2 D3 80 ative Example 1 Example 1 HT-08 ET-015 Pt-2 D3 82 Example 2 HT-14 ET-015 Pt-2 D3 100 Example 3 HT-17 ET-015 Pt-2 D3 103
[0384] Referring to Table 3, it was confirmed that the organic light-emitting devices of Examples 1 to 3 each had improved lifetime compared to the organic light-emitting device of Comparative Example 1.
[0385] For example, it was confirmed that, as expected, the organic light-emitting device of Example 2 using a host corresponding to Thin Film C had an improved (e.g., longer) lifetime compared to the organic light-emitting device of Comparative Example 1 using a host corresponding to Thin Film A.
[0386] In some embodiments, regarding the hole-transporting host and the electron-transporting host in each of Examples 1 to 3, it was confirmed that the difference between the HOMO energy level of the hole-transporting host and the HOMO energy level of the electron-transporting host was at least 0.2 eV, (e.g., or more), and that the difference between the LUMO energy level of the hole-transporting host and the LUMO energy level of the electron-transporting host was at elast 0.2 eV, (e.g., or more).
[0387] Regarding the delayed fluorescence dopant in each of Examples 1 to 3, it was confirmed that the lowest singlet energy level value of the delayed fluorescence dopant was greater than the lowest triplet energy level value of the delayed fluorescence dopant, and that the difference therebetween was at most 0.2 eV, (e.g., or less).
[0388] Regarding the emission layer materials in each of Examples 1 to 3, it was confirmed that the lowest triplet energy level of the exciplex was higher than the lowest triplet energy level of the sensitizer, and that the lowest triplet energy level of the sensitizer was higher than the lowest triplet energy level of the delayed fluorescence dopant.
[0389] According to the one or more embodiments, even in a case where ΔE.sub.ST, which indicates an energy gap between E(.sup.1CT) and E(.sup.3CT) of a host exciplex, has a relatively large value of at least 0.3 eV, (e.g., or more), if (e.g., when) ϕ.sub.delayed/ϕ.sub.PLQY is less than 20%, a light-emitting device may have improved lifetime.
[0390] 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 light-emitting device comprising: a first electrode; a second electrode opposite to the first electrode; and an interlayer arranged between the first electrode and the second electrode and comprising an emission layer, the emission layer comprising a hole-transporting host, an electron-transporting host, a sensitizer, and a delayed fluorescence dopant, the hole-transporting host and the electron-transporting host being configured to form an exciplex, the sensitizer comprising an organometallic compound, the delayed fluorescence dopant excluding a metal atom, ΔE.sub.ST indicating an energy gap between E(.sup.1CT) and E(.sup.3CT) of the exciplex being at least 0.3 electron volt (eV), and a ratio of a delayed fluorescence photoluminescence quantum yield (PLQY) to a PLQY of the exciplex being at most 20%, E(.sup.1CT) being an energy level (eV) of a singlet charge-transfer state (.sup.1CT) of the exciplex, and E(.sup.3CT) being an energy level (eV) of a

triplet charge-transfer state (.sup.3CT) of the exciplex.

2. The light-emitting device of claim 1, wherein E(.sup.1CT) is greater than E(.sup.3CT).

3. The light-emitting device of claim 1, wherein a difference between a highest occupied molecular orbital (HOMO) energy level of the hole-transporting host and a HOMO energy level of the electron-transporting host is at least 0.2 eV, and a difference between a lowest unoccupied molecular orbital (LUMO) energy level of the hole-transporting host and a LUMO energy level of the electron-transporting host is at least 0.2 eV.

4. The light-emitting device of claim 1, wherein a difference between a lowest singlet energy level of the delayed fluorescence dopant and a lowest triplet energy level of the delayed fluorescence dopant is at most 0.2 eV.

5. The light-emitting device of claim 1, wherein the delayed fluorescence dopant satisfies Expression (1): $E_{ST} = E_D(S1) - E_D(T1) \leq 0.2\text{eV}$ (1) in Expression (1), E.sub.D(S1) being a lowest singlet energy level (eV) of the delayed fluorescence dopant, and E.sub.D(T1) being a lowest triplet energy level (eV) of the delayed fluorescence dopant.

6. The light-emitting device of claim 1, wherein a lowest triplet energy level of the sensitizer is between a lowest triplet energy level of the exciplex and a lowest triplet energy level of the delayed fluorescence dopant.

7. The light-emitting device of claim 1, wherein the light-emitting device satisfies Expression (2): $E_{EX}(T1) > E_S(T1) > E_D(T1)$ (2) in Expression (2), E.sub.EX(T1) being a lowest triplet energy level (eV) of the exciplex, E.sub.S(T1) being a lowest triplet energy level (eV) of the sensitizer, and E.sub.D(T1) being a lowest triplet energy level (eV) of the delayed fluorescence dopant.

8. The light-emitting device of claim 1, wherein the sensitizer is not configured to emit light, and the delayed fluorescence dopant is configured to emit fluorescence.

9. The light-emitting device of claim 1, wherein a weight ratio of the hole-transporting host to the electron-transporting host is about 1:9 to about 9:1.

10. The light-emitting device of claim 1, wherein a weight ratio of the sensitizer to the delayed fluorescence dopant is about 100:1 to about 10:1.

11. The light-emitting device of claim 1, wherein the emission layer is configured to emit blue light.

12. The light-emitting device of claim 1, wherein the hole-transporting host comprises a compound comprising at least one carbazole group.

13. The light-emitting device of claim 1, wherein the hole-transporting host comprises a compound represented by Formula 1: ##STR00071## wherein, in Formula 1, R.sub.1, R.sub.2, and Ar.sub.1 are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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.1)(Q.sub.2)(Q.sub.3), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), or —P(═O)(Q.sub.1)(Q.sub.2), L.sub.1 is a C.sub.4-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, a1 and a2 are each independently an integer from 1 to 4, b1 is an integer from 0 to 3, 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, —Si(Q.sub.11)(Q.sub.12)(Q.sub.13), —N(Q.sub.11)(Q.sub.12), —B(Q.sub.11)(Q.sub.12), —C(═O)(Q.sub.11), —S(═O).sub.2(Q.sub.11), —P(═O)(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, a C.sub.6-C.sub.60 arylthio group, a C.sub.7-C.sub.60 arylalkyl group, or a C.sub.2-C.sub.60 heteroarylalkyl 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, —Si(Q.sub.21)(Q.sub.22)(Q.sub.23), —N(Q.sub.21)(Q.sub.22), —B(Q.sub.21)(Q.sub.22), —C(═O)(Q.sub.21), —S(═O).sub.2(Q.sub.21), —P(═O)(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).sub.2(Q.sub.31), or —P(═O)(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; 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, a C.sub.1-C.sub.60 heterocyclic group, a C.sub.7-C.sub.60 arylalkyl group, or a C.sub.2-C.sub.60 heteroarylalkyl 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.

14. The light-emitting device of claim 1, wherein the electron-transporting host comprises a compound comprising at least one π electron-deficient nitrogen-containing 6-membered ring.

15. The light-emitting device of claim 1, wherein the electron-transporting host is a compound represented by Formula 2: ##STR00072## wherein, in Formula 2, X.sub.21 is N or C-(L.sub.24).sub.a24-(R.sub.24).sub.b24, X.sub.22 is N or C-(L.sub.25).sub.a25-(R.sub.25).sub.b25, and X.sub.23 is N or C-(L.sub.26).sub.a26-(R.sub.26).sub.b26, wherein at least one of X.sub.21 to X.sub.23 is N, L.sub.21 to L.sub.26 are each independently 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, a21 to a26 are each independently an integer from 0 to 5, R.sub.21 to R.sub.26 are each independently 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, 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, —Si(Q.sub.1)(Q.sub.2)(Q.sub.3), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), or —P(═O)(Q.sub.1)(Q.sub.2), b21 to b26 are each independently an integer from 1 to 5, and R.sub.10a and Q.sub.1 to Q.sub.3 are each as defined in Formula 1.

16. The light-emitting device of claim 1, wherein the sensitizer comprises an organometallic compound represented by Formula 401: ##STR00073## wherein, in Formulae 401 and 402, M is a

transition metal, L.sub.401 is a ligand represented by Formula 402, and xc1 is 1, 2, or 3, wherein, when xc1 is at least 2, at least two of L.sub.401 are each independently identical to or different from each other, L.sub.402 is an organic ligand, and xc2 is 0, 1, 2, 3, or 4, wherein, when xc2 is at least 2, at least two of L.sub.402 are each independently identical to or different from each other, X.sub.401 and X.sub.402 are each independently nitrogen or carbon, ring A.sub.401 and ring A.sub.402 are each independently a C.sub.3-C.sub.60 carbocyclic group or a C.sub.1-C.sub.60 heterocyclic group, T.sub.401 is 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═, X.sub.403 and X.sub.404 are each independently a chemical 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), R.sub.401 and R.sub.402 are each independently 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), R.sub.401 and R.sub.402 are optionally linked to each other to form a ring, R.sub.10a is as defined in Formula 1, and Q.sub.411 to Q.sub.414 and Q.sub.401 to Q.sub.403 are each defined as in connection with Q.sub.1 in Formula 1, xc11 and xc12 are each independently an integer from 0 to 10, and * and *′ in Formula 402 each indicate a binding site to M in Formula 401.

17. The light-emitting device of claim 1, wherein the delayed fluorescence dopant comprises a condensed cyclic compound represented by Formula 3: ##STR00074## wherein, in Formula 3, Y.sub.1 to Y.sub.3 are each independently S, N(R.sub.24), B(R.sub.24), C(R.sub.24)(R.sub.25), or Si(R.sub.24)(R.sub.25), c is 0 or 1, A.sub.11 to A.sub.13 are each independently selected from among a C.sub.5-C.sub.30 carbocyclic group and a C.sub.1-C.sub.30 heterocyclic group, R.sub.21 to R.sub.25 are each independently selected from among hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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 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), —N(Q.sub.1)(Q.sub.2), —B(Q.sub.1)(Q.sub.2), —P(Q.sub.1)(Q.sub.2), —C(═O)(Q.sub.1), —S(═O).sub.2(Q.sub.1), and —P(═O)(Q.sub.1)(Q.sub.2), R.sub.21 to R.sub.25 are optionally linked to each other to form a substituted or unsubstituted C.sub.5-C.sub.30 carbocyclic group or a substituted or unsubstituted C.sub.1-C.sub.30 heterocyclic group, a21 to a23 are each independently an integer from 0 to 10, and R.sub.10a and Q.sub.1 to Q.sub.3 are each as defined in Formula 1.

18. An electronic apparatus comprising the light-emitting device of claim 1.
19. The electronic apparatus of claim 18, further comprising a thin-film transistor, wherein the thin-film transistor comprises a source electrode and a drain electrode, and the first electrode of the light-emitting device is electrically connected to the source electrode or the drain electrode.
20. The electronic apparatus of claim 18, further comprising a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof.