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Inventor(s)	Gao; Rongrong et al.

Organic light-emitting device, light-emitting substrate and light-emitting apparatus

Abstract

An organic light-emitting device includes: an anode, an emitting layer, and a cathode that are stacked; a first functional material layer located between the emitting layer and the anode; and a second functional material layer located between the emitting layer and the cathode. Under a same test condition, a hole mobility of a material of the first functional material layer is at least ten times an electron mobility of a material of the second functional material layer.

Inventors:	Gao; Rongrong (Beijing, CN), Chen; Lei (Beijing, CN)
Applicant:	BOE TECHNOLOGY GROUP CO., LTD. (Beijing, CN)
Family ID:	1000008762514
Assignee:	BOE Technology Group Co., Ltd. (Beijing, CN)
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Primary Examiner: Loewe; Robert S

Attorney, Agent or Firm: Dority & Manning, P.A.

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application is a national phase entry under 35 USC 371 of International Patent Application No. PCT/CN2021/070101, filed on Jan. 4, 2021, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

(2) The present disclosure relates to the field of illumination and display technologies, and in particular, to an organic light-emitting device, a light-emitting substrate and a light-emitting apparatus.

BACKGROUND

(3) Organic light-emitting diodes (OLEDs), which have been hailed as a next-generation "star" display technology, have characteristics of self-luminescence, wide visual angles, fast response time, high luminous efficiencies, low operating voltages, small substrate thicknesses, capabilities of being used to manufacture large-size flexible substrates, simple manufacturing processes and the like.

SUMMARY

(4) In an aspect, an organic light-emitting device is provided, The organic light-emitting device includes: an anode, an emitting layer, and a cathode that are stacked; a first functional material layer located between the emitting layer and the anode; and a second functional material layer located between the emitting layer and the cathode. Under a same test condition, a hole mobility of a material of the first functional material layer is at least ten times an electron mobility of a material of the second functional material layer.

(5) In some embodiments, the second functional material layer includes an electron transport layer and a hole blocking layer. An electron mobility of a material of the electron transport layer is the same as an electron mobility of a material of the hole blocking layer; or under a same test condition, the electron mobility of the material of the hole blocking layer is less than the electron mobility of the material of the electron transport layer.

(6) In some embodiments, a lowest triplet energy of the material of the electron transport layer is greater than a lowest triplet energy of the material of the hole blocking layer.

(7) In some embodiments, the material of the electron transport layer and the material of the hole blocking layer are each independently selected from compounds containing at least one heteroaryl which contains at least two N atoms.

(8) In some embodiments, the material of the electron transport layer is a compound based on a spirocyclic aromatic hydrocarbon structure.

(9) In some embodiments, the material of the electron transport layer is selected from any one or a combination of two or more of structures shown in a general formula (I).

(10) ##STR00001##

(11) In the general formula (I), X is selected from any of C(R).sub.2, O, S, N(R), and a single bond, Ar.sub.1 to Ar.sub.4 are able to exist simultaneously or separately, and are each independently selected from aryl or heteroaryl with 5 to 30 ring atoms substituted or unsubstituted by a substituent R.sub.1, at least one of Ar.sub.1 to Ar.sub.4 is selected from any of structures as shown in a following general formula (II), and the substituent R.sub.1 is selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n.

(12) ##STR00002##

(13) In the general formula (II), X.sub.1, X.sub.2, and X.sub.3 are each independently selected from any of C(R.sub.2) and N, and at least two of X.sub.1, X.sub.2, and X.sub.3 are selected from N.

(14) Each R.sub.2 is the same or different, and is independently selected from any of H and aryl or heteroaryl with 5 to 30 ring atoms. In a case where R.sub.2 is selected from the aryl or heteroaryl with 5 to 30 ring atoms, the aryl or heteroaryl has or has no the substituent R1.

(15) Y.sub.1 is selected from any of carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), and n is an integer greater than or equal to 1. Each Ar is the same or different, and is independently selected from aryl or heteroaryl, or in a case where n is an integer greater than or equal to 2, at least two Ars are connected into a ring through the single bond or a first bridging group. The first bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R), R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl or heteroaryl.

(16) In some embodiments, the material of the electron transport layer is selected from any one or a combination of two or more of following compounds:

(17) ##STR00003## ##STR00004## ##STR00005## ##STR00006## ##STR00007##

(18) In some embodiments, the material of the hole blocking layer is selected from any one or a combination of two or more of structures as shown in a general formula (III).

(19) ##STR00008##

(20) In the general formula (III), X.sub.4, X.sub.5, and X.sub.6 are each independently selected from any of C(R) and N, and at least two of X.sub.4, X.sub.5, and X.sub.6 are selected from N; and Ar.sub.5, Ar.sub.6, and L.sub.2 are each independently selected from aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R1.

(21) L.sub.1 is selected from the single bond, divalent aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or divalent heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1.

(22) R.sub.1 is independently selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n, Y.sub.1 is selected from carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), and n is an integer greater than or equal to 1. Each Ar is the same or different, and is independently selected from aryl or heteroaryl, or Ar and the aryl or heteroaryl substituted by the substituent R.sub.1 are connected as a ring through a single bond or a second bridging group, and/or at least two Ars, in a case where n is an integer greater than or equal to 2, are connected into a ring through the single bond or a second bridging group, and each second bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, O(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R).

(23) R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl and heteroaryl.

(24) In some embodiments, in the general formula (III), in a case where L.sub.1 is selected from bivalent bicyclic aryl substituted or unsubstituted by the substituent R.sub.1, at least one single ring in the divalent bicyclic aryl has a group attached at a meta position and/or an ortho position; and in a case where L.sub.1 is selected from monocyclic aryl substituted or unsubstituted by the substituent R.sub.1, L.sub.2 and azine are attached at a meta position or an ortho position of L.sub.1.

(25) In some embodiments, the material of the hole blocking layer is selected from any one or a combination of two or more of following structures:

(26) ##STR00009## ##STR00010##

(27) In some embodiments, the first functional material layer includes a hole transport layer and an electron blocking layer. A hole mobility of a material of the hole transport layer is the same as a hole mobility of a material of the electron blocking layer; or under a same test condition, the hole mobility of the material of the electron blocking layer is not less than one tenth of the hole mobility of the material of the hole transport layer.

(28) In some embodiments, a difference between a HOMO energy level of the material of the hole transport layer and a HOMO energy level of the material of the electron blocking layer is greater than or equal to -0.5 eV, and is less than or equal to 0.3 eV.

(29) In some embodiments, a lowest triplet energy of the hole transport layer is greater than a lowest triplet energy of the electron blocking layer.

(30) In some embodiments, a material of the emitting layer includes a host material, A difference between a highest occupied molecular orbital (HOMO) energy level of the material of the hole blocking layer and a HOMO energy level of the host material is greater than or equal to 0.1 eV.

(31) In some embodiments, a lowest triplet energy of the hole blocking layer is greater than a lowest triplet energy of the host material.

(32) In some embodiments, the first functional material layer includes an electron blocking layer. A difference between the HOMO energy level of the host material and a HOMO energy level of the electron blocking layer is less than or equal to 0.3 eV.

(33) In some embodiments, a lowest triplet energy of the electron blocking layer is greater than the lowest triplet energy of the host material.

(34) In some embodiments, the material of the hole transport layer and the material of the electron blocking layer are each independently selected from any of aromatic amine compounds.

(35) In another aspect, a light-emitting substrate is provided, including: a base and a plurality of light-emitting devices disposed on the base. At least one light-emitting device is selected from the organic light-emitting device as described above.

(36) In yet another aspect, a light-emitting apparatus is provided, including the light-emitting substrate as described above.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) In order to describe technical solutions in the present disclosure more clearly, accompanying drawings to be used in some embodiments of the present disclosure will be introduced briefly below. However, the accompanying drawings to be described below are merely accompanying drawings of some embodiments of the present disclosure, and a person of ordinary skill in the art may obtain other drawings according to these drawings. In addition, the accompanying drawings to be described below may be regarded as schematic diagrams, and are not limitations on actual sizes of products, actual processes of methods and actual timings of signals involved in the embodiments of the present disclosure.

(2) FIG. 1 is a sectional structural view of a light-emitting substrate, in accordance with some

embodiments;

(3) FIG. 2 is a distribution diagram of recombination zones of excitons in an emitting layer, in accordance with some embodiments; and

(4) FIG. 3 is a diagram showing a relationship between HOMO energy levels and LUMO energy levels of a hole transport layer, an electron blocking layer, an emitting layer, a hole blocking layer, and an electron transport layer, in accordance with some embodiments.

DETAILED DESCRIPTION

(5) Technical solutions in some embodiments of the present disclosure will be described clearly and completely below with reference to the accompanying drawings. However, the described embodiments are merely some but not all embodiments of the present disclosure. All other embodiments obtained based on the embodiments of the present disclosure by a person of ordinary skill in the art shall be included in the protection scope of the present disclosure.

(6) Unless the context requires otherwise, throughout the description and the claims, the term “comprise” and other forms thereof such as the third-person singular form “comprises” and the present participle form “comprising” are construed as an open and inclusive meaning, i.e., “including, but not limited to”. In the description of the specification, the terms such as “one embodiment”, “some embodiments”, “exemplary embodiments”, “example”, “specific example” or “some examples” are intended to indicate that specific features, structures, materials or characteristics related to the embodiment(s) or example(s) are included in at least one embodiment or example of the present disclosure. Schematic representations of the above terms do not necessarily refer to the same embodiment(s) or example(s). In addition, the specific features, structures, materials, or characteristics may be included in any one or more embodiments or examples in any suitable manner.

(7) Hereinafter, the terms “first” and “second” are used for descriptive purposes only, and are not to be construed as indicating or implying relative importance or implicitly indicating the number of indicated technical features. Thus, a feature defined with “first” or “second” may explicitly or implicitly include one or more of the features. In the description of the embodiments of the present disclosure, the term “a plurality of”, “the plurality of” or “multiple” means two or more unless otherwise specified.

(8) The phrase “at least one of A, B and C” has a same meaning as the phrase “at least one of A, B or C”, and they both include the following combinations of A, B and C: only A, only B, only C, a combination of A and B, a combination of A and C, a combination of B and C, and a combination of A, B and C.

(9) The phrase “A and/or B” includes the following three combinations: only A, only B, and a combination of A and B.

(10) The phrase “applicable to” or “configured to” used herein has an open and inclusive meaning, which does not exclude devices that are applicable to or configured to perform additional tasks or steps.

(11) In addition, the phrase “based on” used herein is meant to be open and inclusive, since a process, step, calculation or other action that is “based on” one or more of the stated conditions or values may, in practice, be based on additional conditions or values exceeding those stated.

(12) Exemplary embodiments are described herein with reference to sectional views and/or plan views as idealized exemplary drawings. In the drawings, thicknesses of layers and regions are enlarged for clarity. Thus, variations in shapes relative to the accompanying drawings due to, for example, manufacturing technologies and/or tolerances may be envisaged. Therefore, the exemplary embodiments should not be construed as being limited to the shapes of the regions shown herein, but including shape deviations due to, for example, manufacturing. For example, an etched region shown to have a rectangular shape generally has a feature of being curved. Therefore, the regions shown in the accompanying drawings are schematic in nature, and their shapes are not intended to show actual shapes of the regions in a device, and are not intended to limit the scope of

the exemplary embodiments.

(13) Some embodiments of the present disclosure provide a light-emitting apparatus which includes a light-emitting substrate. Of course, the light-emitting apparatus may further include other components. For example, it may include a circuit for providing electrical signals to the light-emitting substrate, so as to drive the light-emitting substrate to emit light. The circuit may be referred to as a control circuit, and may include a circuit board electrically connected to the light-emitting substrate and/or an integrated circuit (IC) electrically connected to the light-emitting substrate.

(14) In some embodiments, the light-emitting apparatus may be an illumination apparatus. In this case, the light-emitting substrate may be an illumination substrate. For example, the light-emitting substrate may be used as a light source to achieve an illumination function. For example, the light-emitting substrate may be a backlight module in a liquid crystal display apparatus, a lamp for internal or external illumination, or a signal lamp.

(15) In some other embodiments, the light-emitting apparatus may be a display apparatus. In this case, the light-emitting substrate is a display substrate, and is used to achieve a function of displaying images (i.e., pictures). The light-emitting apparatus may include a display or a product including the display. The display may be a flat panel display (FPD), a micro display, etc. If classified according to whether users can see a scene behind the display, the display may be a transparent display or an opaque display. If classified according to whether the display can be bent or curled, the display may be a flexible display or a common display (which may be referred to as a rigid display). For example, the product including the display may include a computer display, a television, a billboard, a laser printer with a display function, a telephone, a mobile phone, a personal digital assistant (PDA), a laptop computer, a digital camera, a portable camcorder, a viewfinder, a vehicle, a large-area wall, a screen in a theater, or a sign in a stadium.

(16) In some embodiments, as shown in FIG. 1, the light-emitting substrate **1** may include a base **11** and a plurality of organic light-emitting devices **12** disposed on the base **11**. The base **11** may be a flexible base or a rigid base. In a case where the base **11** is the flexible base, the base **11** may be made of polyimide (PI). In a case where the base **11** is the rigid base, the base **11** may be made of glass. Herein, the base **11** may be a base on which pixel driver circuits have been formed.

(17) The light-emitting substrate **1** may be a top-emission light-emitting substrate (light emitted by the organic light-emitting device **12** is emitted from a side thereof away from the base **11**), a bottom-emission light-emitting substrate (the light emitted by the organic light-emitting device **12** is emitted from a side of the base **11**), or a double-sided emission light-emitting substrate.

(18) For example, as shown in FIG. 1, in an example in which the light-emitting substrate **1** is the top-emission light-emitting substrate, the light-emitting substrate **1** may further include a light extraction layer **13** disposed on a side of the organic light-emitting devices **12** away from the base **11**. The light extraction layer **13** is configured to extract light emitted by each organic light-emitting device **12**.

(19) In some embodiments, at least one organic light-emitting device **12** may include an anode **121**, an emitting layer (EML) **122**, and a cathode **123** that are stacked, a first functional material layer **124** located between the emitting layer **122** and the anode **121**, and a second functional material layer **125** located between the emitting layer **122** and the cathode **123**.

(20) The first functional material layer **124** may include a hole inject layer (HIL) **124a** and a hole transport layer (HTL) **124b**, and may further include an electron blocking layer (EBL) **124c**, which is not specifically limited herein, as long as the first functional material layer **124** can realize injection and transport of holes. The second functional material layer **125** may include an electron inject layer (EIL) **125a** and an electron transport layer (ETL) **125b**, and may further include a hole blocking layer (HBL) **125c**, which is not specifically limited herein, as long as the second functional material layer **125** can realize injection and transport of electrons.

(21) According to structures and functions of the first functional material layer **124** and the second

functional material layer **125**, it will be seen that a light-emitting principle of the organic light-emitting device **12** is that: when a voltage is applied across the anode **121** and the cathode **123**, electrons are injected through the electron inject layer **125a**, and are transported to the emitting layer **122** through the electron transport layer **125b** and the hole blocking layer **125c**; holes are injected through the hole inject layer **124a**, and are transported to the emitting layer **122** through the hole transport layer **124b** and the electron blocking layer **124c**; and the electrons and the holes recombine in the emitting layer **122** to generate singlet excitons and triplet excitons, and light is emitted through de-excitation and radiation of excitons.

(22) In this process, characteristics of materials of the functional material layers and a matching degree of mobilities and a matching degree of energy levels between the functional material layers will affect injection and transport of carriers inside the organic light-emitting device **12**, a formation and quenching of excitons and other characteristics, thus affecting a light-emitting characteristic of the organic light-emitting device **12**.

(23) A mobility refers to an average drift velocity of carriers (the electrons and the holes) under the influence of a unit electric field, i.e., a magnitude of a velocity of movement of carriers under action of an electric field. The faster the carriers move, the greater the mobility will be; and the slower the carriers move, the smaller the mobility will be.

(24) The mobility is related to the characteristics of the material, but has little relation to the number and thicknesses of layers in the first functional material layer **124** and the second functional material layer **125**. It can be seen from the above that in the embodiments provided in the present disclosure, descriptions are made by taking examples in which the first functional material layer **124** includes the hole inject layer **124a**, the hole transport layer **124b**, and the electron blocking layer **124c**, and the second functional material layer **125** includes the electron inject layer **125a**, the electron transport layer **125b**, and the hole blocking layer **125c**, and those skilled in the art can understand that the following descriptions of materials of the first functional material layer **124** and the second functional material layer **125** are also applicable to a case where the first functional material layer **124** only includes the hole inject layer **124a** and the hole transport layer **124b**, and/or the second functional material layer **125** only includes the electron inject layer **125a** and the electron transport layer **125b**. The number of layers and a thickness of each layer of the first functional material layer **124** and the second functional material layer **125** is not limited.

(25) Driver circuits connected to the organic light-emitting devices may further be provided in the light-emitting substrate **1**. The driver circuits may be connected to the control circuit, so as to drive, according to electrical signals input by the control circuit, the organic light-emitting devices to emit light. The driver circuit may be an active driver circuit or a passive driver circuit.

(26) The light-emitting substrate **1** may emit monochromatic light (i.e., light of a single color) or color-adjustable light.

(27) In a first example, the light-emitting substrate **1** may emit the monochromatic light. In this example, the plurality of organic light-emitting devices (e.g., all organic light-emitting devices) included in the light-emitting substrate **1** all emit the monochromatic light (e.g., red light). The light-emitting substrate **1** may be used for illumination. That is, the light-emitting substrate **1** may be applied to the illumination apparatus. The light-emitting substrate **1** may also be used to display a single-color image or picture. That is, the light-emitting substrate **1** may be applied to the display apparatus.

(28) In a second example, the light-emitting substrate **1** may emit the color-adjustable light (i.e., colored light). In this example, the plurality of organic light-emitting devices included in the light-emitting substrate **1** emit light of different colors. By controlling a brightness of each organic light-emitting device, a color and a brightness of mixed light emitted by the light-emitting substrate **1** may be controlled, and colored light may be emitted.

(29) In this example, the light-emitting substrate may be used to display images or pictures. That is, the light-emitting substrate may be applied to the display apparatus. Of course, the light-emitting

substrate may also be used in the illumination apparatus.

(30) Herein, as shown in FIG. 1, in an example in which at least three organic light-emitting devices **12** in the light-emitting substrate each include an anode **121**, an emitting layer **122**, and a cathode **123** that are stacked, a first functional material layer **124** located between the emitting layer **122** and the anode **121**, and a second functional material layer **125** located between the emitting layer **122** and the cathode **123**, the at least three organic light-emitting devices may include a light-emitting device R that emits red light, a light-emitting device G that emits green light, and a light-emitting device B that emits blue light.

(31) In some embodiments, a material of the emitting layer **122** may include a host material and a dopant material.

(32) According to a different color of light emitted by an emitting layer **122**, the emitting layer **122** may include a different host material and a different dopant material.

(33) In some embodiments, under a same test condition, a hole mobility of a host material of the emitting layer **122** in the light-emitting device R that emits red light is substantially the same as a hole mobility of a host material of the emitting layer **122** in the light-emitting device G that emits green light, and an electron mobility of the host material of the emitting layer **122** in the light-emitting device R that emits red light is slightly greater than an electron mobility of the host material of the emitting layer **122** in the light-emitting device G that emits green light. A hole mobility of a host material of the emitting layer **122** in the light-emitting device B that emits blue light is less than the hole mobility of the host material of the emitting layer **122** in the light-emitting device R that emits red light, and an electron mobility of the host material of the emitting layer **122** in the light-emitting device B that emits blue light is comparable to the electron mobility of the host material of the emitting layer **122** in the light-emitting device G that emits green light.

(34) That is, transport velocities of carriers in the emitting layer **122** of the light-emitting device R that emits red light and corresponding transport velocities of carriers in the emitting layer **122** of the light-emitting device G that emits green light are basically the same, and a transport of carriers in the host material of the emitting layer **122** in the light-emitting device B that emits blue light is not balanced, in which a serious problem of a hole transport delay exists.

(35) For example, in a case where the organic light-emitting device **12** is the light-emitting device R that emits red light, the host material of the emitting layer **122** may be a dual-host material. That is, the host material of the emitting layer **122** includes both a compound with a function of transporting electrons and a single-host material with a function of transporting holes. In this case, the emitting layer **122** may be formed by evaporating the dual-host material. Of course, the host material of the emitting layer **122** may also be a single compound with functions of transporting electrons and holes.

(36) Herein, a space-charge-limited-current (SCLC) method may be adopted to test the electron mobility and the hole mobility of the host material of the emitting layer. In some embodiments, under a test condition of an electric field intensity of $5000 \text{ V} \cdot \text{sup.}1/2/\text{m} \cdot \text{sup.}1/2$, in the light-emitting device R that emits red light, the electron mobility of the host material of the emitting layer may be any value from $10 \cdot \text{sup.}-7 \text{ cm} \cdot \text{sup.}2\text{V} \cdot \text{sup.}-1\text{s} \cdot \text{sup.}-1$ to $10 \cdot \text{sup.}-6 \text{ cm} \cdot \text{sup.}2\text{V} \cdot \text{sup.}-1\text{s} \cdot \text{sup.}-1$, inclusive, and the hole mobility of the host material of the emitting layer may be any value from $10 \cdot \text{sup.}-7 \text{ cm} \cdot \text{sup.}2\text{V} \cdot \text{sup.}-1\text{s} \cdot \text{sup.}-1$ to $10 \cdot \text{sup.}-6 \text{ cm} \cdot \text{sup.}2\text{V} \cdot \text{sup.}-1\text{s} \cdot \text{sup.}-1$, inclusive.

(37) In a case where the organic light-emitting device **12** is the light-emitting device G that emits green light, the host material of the emitting layer **122** may also be a dual-host material, or the single compound with functions of transporting electrons and holes. In this case, under a same test condition, the electron mobility and the hole mobility of the host material of the emitting layer **122** are also substantially the same.

(38) Herein, the electron mobility and the hole mobility of the host material of the emitting layer may also be tested adopting the SCLC method. In some embodiments, under the test condition of the electric field intensity of $5000 \text{ V} \cdot \text{sup.}1/2/\text{m} \cdot \text{sup.}1/2$, in the light-emitting device G that emits

green light, the electron mobility of the host material of the emitting layer may be any value from $10 \times 10^{-8} \text{ cm}^2/\text{Vs}$ to $10 \times 10^{-7} \text{ cm}^2/\text{Vs}$, inclusive; and the hole mobility of the host material of the emitting layer may be any value from $10 \times 10^{-7} \text{ cm}^2/\text{Vs}$ to $10 \times 10^{-6} \text{ cm}^2/\text{Vs}$, inclusive.

(39) In a case where the organic light-emitting device **12** is the light-emitting device B that emits blue light, the host material of the emitting layer **122** is a single-host material. In this case, under the same test condition, the electron mobility of the host material of the emitting layer **122** is greater than the hole mobility of the host material of the emitting layer **122**.

(40) Herein, the electron mobility and the hole mobility of the host material of the emitting layer **122** may also be tested adopting the SCLC method. In some embodiments, under the test condition of the electric field intensity of $5000 \text{ V}^{1/2}/\text{m}^{1/2}$, in the light-emitting device B that emits blue light, the electron mobility of the host material of the emitting layer **122** is any value from $10 \times 10^{-7} \text{ cm}^2/\text{Vs}$ to $10 \times 10^{-8} \text{ cm}^2/\text{Vs}$, inclusive; and the hole mobility of the host material of the emitting layer **122** is any value from $10 \times 10^{-8} \text{ cm}^2/\text{Vs}$ to $10 \times 10^{-9} \text{ cm}^2/\text{Vs}$, inclusive.

(41) Based on this, researches on recombination zones of excitons of currently existing organic light-emitting devices (e.g., the light-emitting device that emits blue light) show that in the material selection of currently existing functional material layers, a distribution diagram of recombination zones of the excitons in the emitting layer **122** is as shown in FIG. 2. It will be seen from FIG. 2 that the closer to the electron blocking layer **124c**, the greater an intensity of the excitons, which indicates that the recombination zone of most of the excitons is at an interface between the electron blocking layer **124c** and the emitting layer **122**.

(42) Herein, the intensity of excitons, different from a concentration of excitons, is a measure of a luminous intensity of excitons when the excitons are deexcited. The intensity of excitons is not only related to the concentration of excitons, but also related to other factors such as lifetimes of excitons. However, in a case where other influencing factors are certain, the concentration of excitons is a main factor that affects the intensity of excitons. Therefore, in an entire device, the intensity of excitons and the concentration of excitons have a same or similar changing trend. Based on this, according to a case where the intensity of the excitons gradually decreases as the emitting layer is farther away from the electron blocking layer **124c** as shown in FIG. 2, it will be seen that the concentration of the excitons also gradually decreases as the emitting layer is farther away from the electron blocking layer **124c**. That is, in a case where the number of excitons is certain, the recombination zone of most of the excitons is at the interface between the electron blocking layer **124c** and the emitting layer **122**. This indicates that during an entire transport process (i.e., an entire process from the injection to the transport) of holes and electrons, an electron transport rate of the material of the second functional material layer **125** is greater than a hole transport rate of the material of the first functional material layer **124**, which causes the recombination zones of excitons to be more biased toward the electron blocking layer **124c**, resulting in accumulation of the electrons at the interface between the electron blocking layer **124c** and the emitting layer **122**. As a result, the materials are deteriorated by charges, and a performance of the device is further affected.

(43) Based on this, in some embodiments, under the same test condition, the hole mobility of the material of the first functional material layer **124** is at least ten times the electron mobility of the material of the second functional material layer **125**.

(44) That is, the material of the first functional material layer **124** and the material of the second functional material layer **125** are reasonably selected, so that the hole transport rate of the material of the first functional material layer **124** and the electron transport rate of the material of the second functional material layer **125** in the organic light-emitting device **12** are adjusted in a way that the hole transport rate in the organic light-emitting device **12** is accelerated, and the electron transport rate in the organic light-emitting device **12** is reduced. As a result, the recombination zones are

adjusted such that the recombination zones shift to a region of the emitting layer **122** away from the electron blocking layer **124c**, which reduces accumulation of the excitons at the interface between the electron blocking layer **124c** and the emitting layer **122**, and avoids the accumulation of the electrons at the interface between the electron blocking layer **124c** and the emitting layer **122**. Therefore, it is possible to slow down the deterioration of the materials caused by accumulation of the charges, so that a stability of the device can be improved and a service life of the device can be improved.

(45) In some embodiments, according to a case where the first functional material layer **124** includes the hole inject layer **124a**, the hole transport layer **124b**, and the electron blocking layer **124c**, it will be seen that as for the first functional material layer **124**, in a case where a material of the hole inject layer **124a** is certain, materials of the hole transport layer **124b** and the electron blocking layer **124c** are the same or different. In a case where the materials of the hole transport layer **124b** and the electron blocking layer **124c** are the same, a hole mobility of the material of the hole transport layer **124b** is the same as a hole mobility of the material of the electron blocking layer **124c**. In a case where the materials of the hole transport layer **124b** and the electron blocking layer **124c** are different, the hole mobility of the material of the hole transport layer **124b** is different from the hole mobility of the material of the electron blocking layer **124c**. In this case, the hole mobility of the material of the electron blocking layer **124c** is generally less than the hole mobility of the material of the hole transport layer **124b**. In order to improve the hole transport rate as much as possible, for example, under the same test condition, the hole mobility of the material of the electron blocking layer **124c** is not less than one tenth of the hole mobility of the material of the hole transport layer **124b**.

(46) In some embodiments, under the test condition of the electric field intensity of $5000 \text{ V}\cdot\text{sup.}1/2/\text{m}\cdot\text{sup.}1/2$, the hole mobility of the material of the hole transport layer **124b** is $10\cdot\text{sup.}-6 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$ to $10 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$, inclusive; and the hole mobility of the material of the electron blocking layer **124c** is $10\cdot\text{sup.}-7 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$ to $10\cdot\text{sup.}-4 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$, inclusive.

(47) For example, the hole mobilities of the materials of the hole transport layer **124b** and the electron blocking layer **124c** may be tested adopting the SCLC method.

(48) According to the case where the hole mobility of the material of the first functional material layer **124** is at least ten times the electron mobility of the material of the second functional material layer **125**, it will be seen that, in a case where the hole mobility of the material of the first functional material layer **124** is $10\cdot\text{sup.}-4 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$, the electron mobility of the material of the second functional material layer **125** is less than or equal to $10\cdot\text{sup.}-5 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$; in a case where the hole mobility of the material of the first functional material layer **124** is $10\cdot\text{sup.}-5 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$, the electron mobility of the material of the second functional material layer **125** is less than or equal to $10\cdot\text{sup.}-6 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$; and by analogy, in a case where the hole mobility of the material of the first functional material layer **124** is $10\cdot\text{sup.}-6 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$, the electron mobility of the material of the second functional material layer **125** is less than or equal to $10\cdot\text{sup.}-7 \text{ cm}\cdot\text{sup.}2\text{V}\cdot\text{sup.}-1\text{s}\cdot\text{sup.}-1$.

(49) The first functional material layer **124** includes the hole transport layer **124b** and the electron blocking layer **124c**, and in the case where the hole mobility of the material of the hole transport layer **124b** is different from the hole mobility of the material of the electron blocking layer **124c**, the hole mobility of the material of the electron blocking layer **124c** is generally less than the hole mobility of the material of the hole transport layer **124b**, and the hole mobility of the material of the electron blocking layer **124c** is not less than one tenth of the hole mobility of the material of the hole transport layer **124b**. It will be seen from the above that in the case where the hole mobility of the material of the first functional material layer **124** is at least ten times the electron mobility of the material of the second functional material layer **125**, the comparison is made based on a larger hole mobility in the first functional material layer **124**. For example, in a case where the hole

mobility of the material of the hole transport layer **124b** in the first functional material layer **124** is $10.\text{sup.}-4\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$, and the hole mobility of the material of the electron blocking layer **124c** in the first functional material layer **124** is $10.\text{sup.}-5\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$, the hole mobility of the material of the hole transport layer **124b** in the first functional material layer **124** is at least ten times the electron mobility of the material of the second functional material layer **125**. In this case, the electron mobility of the material of the second functional material layer **125** is less than or equal to $10.\text{sup.}-5\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$.

(50) In this case, according to the case where the second functional material layer **125** includes the electron inject layer **125a**, the electron transport layer **125b**, and the hole blocking layer **125c**, it will be seen that as for the second functional material layer **125**, in a case where a material of the electron inject layer **125a** is certain, materials of the electron transport layer **125b** and the hole blocking layer **125c** may also be the same or different. In a case where the materials of the electron transport layer **125b** and the hole blocking layer **125c** are the same, an electron mobility of the material of the electron transport layer **125b** is the same as an electron mobility of the material of the hole blocking layer **125c**. In a case where the materials of the electron transport layer **125b** and the hole blocking layer **125c** are different, the electron mobility of the material of the electron transport layer **125b** is different from the electron mobility of the material of the hole blocking layer **125c**. In this case, the electron mobility of the material of the hole blocking layer **125c** is less than the electron mobility of the material of the electron transport layer **125b**.

(51) In the above, the comparison is made based on the larger hole mobility in the first functional material layer **124** when the hole mobility of the material of the first functional material layer **124** is compared with the electron mobility of the material of the second functional material layer **125**, and in the second functional material layer **125**, the electron mobility of the material of the hole blocking layer **125c** is less than the electron mobility of the material of the electron transport layer **125b**. In a case where the materials of the hole blocking layer **125c** and the electron transport layer **125b** in the second functional material layer **125** are different, a larger electron mobility in the second functional material layer **125** is also used when the hole mobility of the material of the first functional material layer **124** is compared with the electron mobility of the material of the second functional material layer **125**.

(52) That is, in a case where the material of the first functional material layer **124** is certain, that the hole mobility of the material of the first functional material layer **124** is at least ten times the electron mobility of the material of the second functional material layer **125** means that the hole mobility of the material of the first functional material layer **124** is at least ten times the electron mobility of the electron transport layer **125b**. In the specific case where the first functional material layer **124** includes the hole transport layer **124b** and the electron blocking layer **124c**, and the second functional material layer **125** includes the electron transport layer **125b** and the hole blocking layer **125c**, the hole mobility of the material of the hole transport layer **124b** is at least ten times the electron mobility of the electron transport layer **125b**. Herein, still considering the hole mobility of the material of the hole transport layer **124b** being $10.\text{sup.}-4\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$ as an example, the electron mobility of the material of the electron transport layer **125b** is less than or equal to $10.\text{sup.}-5\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$, and in this case, the electron mobility of the material of the hole blocking layer **125c** is less than $10.\text{sup.}-5\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$. For example, it may be $10.\text{sup.}-6\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$.

(53) In some embodiments, under the test condition of the electric field intensity of $5000\text{ V.sup.}1/2/\text{m.sup.}1/2$, the electron mobility of the material of the electron transport layer **125b** is $10.\text{sup.}-7\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$ to $10.\text{sup.}-5\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$, inclusive, and the electron mobility of the material of the hole blocking layer **125c** is $10.\text{sup.}-9\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$ to $10.\text{sup.}-7\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$, inclusive. That is, still under the test condition of the electric field intensity of $5000\text{ V.sup.}1/2/\text{m.sup.}1/2$, in a case where the hole mobility of the material of the hole transport layer **124b** is $10.\text{sup.}-6\text{ cm.sup.}2\text{V.sup.}-1\text{s.sup.}-1$ to $10.\text{sup.}-4$

cm.sup.2V.sup.-1s.sup.-1, inclusive, and the hole mobility of the material of the electron blocking layer **124c** is 10.sup.-7 cm.sup.2V.sup.-1s.sup.-1 to 10.sup.-4 cm.sup.2V.sup.-1s.sup.-1, inclusive, the electron mobility of the material of the electron transport layer **125b** is any value from 10.sup.-7 cm.sup.2V.sup.-1s.sup.-1 to 10.sup.-5 cm.sup.2V.sup.-1s.sup.-1, inclusive, and the electron mobility of the material of the hole blocking layer **125c** is any value from 10.sup.-9 cm.sup.2V.sup.-1s.sup.-1 to 10.sup.-7 cm.sup.2V.sup.-1s.sup.-1, inclusive. It is possible to increase the hole transport rate, reduce the electron transport rate, and improve an efficiency and the service life of the device.

(54) In some embodiments, the hole transport layer **124b** and the electron blocking layer **124c** are each independently selected from any of aromatic amine compounds. The aromatic amine compounds have good hole transport properties, and as the number of aromatic amines increases, the hole mobility becomes faster.

(55) For example, the material of the hole transport layer **124b** may be selected from the aromatic amine compounds, such as N,N'-Bis(naphthalen-1-yl)-N,N'-bis(phenyl)benzidine (NPB), 4,4',4''-Tris(N-3-methylphenyl-N-phenylamino)triphenylamine (m-MTDATA), and N,N'-diphenyl-N,N'-bis(3-methylphenyl)-[1,1'-biphenyl]-4,4'-diamine (TPD). The material of the electron blocking layer **124c** may be selected from 3,3'-Di(9H-carbazol-9-yl)biphenyl (mCBP), 3,6-Bis(N-phenyloxazol-3-yl)-N-phenylcarbazole (Tris-PCz), etc.

(56) In a case where the hole mobilities of the hole transport layer **124b** and the electron blocking layer **124c** in the first functional material layer **124** are certain, in order to further increase the hole transport rate, for example, as shown in FIG. 3, a difference between a highest occupied molecular orbital (HOMO) energy level of the hole transport layer **124b** and a HOMO energy level of the material of the electron blocking layer **124c** is greater than or equal to -0.5 eV, and is less than or equal to 0.3 eV, which may eliminate the slow hole transport rate caused by an energy level barrier.

(57) In some embodiments, the material of the hole inject layer **124a** may be selected from MoO.sub.3, 2,3,5,6-Tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ), dipyrazino[2,3f:2',3'-h]quinoxaline-2,3,6,7,10,11-hexacarbonitrile (HAT-CN), etc. A thickness of the hole inject layer **124a** may be 5 nm to 30 nm, inclusive, a thickness of the hole transport layer **124b** may be 1000 nm to 1300 nm, inclusive, and a thickness of the electron blocking layer **124c** may be 10 nm to 80 nm, inclusive.

(58) In some embodiments, a lowest triplet exciton energy T1 of the material of the hole transport layer **124b** is greater than a lowest triplet exciton energy T1 of the material of the electron blocking layer **124c**.

(59) According to a recombination mechanism of electrons and holes, in order to avoid a case where the electrons are quenched on a surface of the anode after passing through the electron blocking layer **124c** because the electron blocking layer **124c** is too thin, by making the lowest triplet exciton energy of the material of the hole transport layer **124b** greater than the lowest triplet exciton energy of the material of the electron blocking layer **124c**, it is possible to further block the electrons through the hole transport layer **124b** after the electrons pass through the electron blocking layer **124c**.

(60) In some embodiments, in a case where the host material and the dopant material of the emitting layer **122** are certain, in order to further increase the hole transport rate, for example, a difference between a HOMO energy level of the host material and a HOMO energy level of the material of the electron blocking layer **124c** is less than or equal to 0.3 eV, which can also improve the slow hole transport rate caused by the energy level barrier.

(61) In some embodiments, the lowest triplet exciton energy T1 of the material of the electron blocking layer **124c** is greater than a lowest triplet exciton energy T1 of the host material.

(62) Similarly, by making the lowest triplet exciton energy of the material of the electron blocking layer **124c** greater than the lowest triplet exciton energy of the host material, it is possible to confine the triplet excitons in the emitting layer **122** to effectively utilize the triplet excitons.

(63) Herein, in an example in which the organic light-emitting device is the light-emitting device that emits blue light, in some embodiments, the host material of the emitting layer **122** may be selected from 9,10-di(2-naphthyl)anthracene (AND), 2-(tert-Butyl)-9,10-di(2-naphthalenyl)anthracene (TBADN), 2-Methyl-9,10-bis(naphthalen-2-yl)anthracene (MADN), 1,3,5-Tri-(pyren-1-yl)-benzene (TPB3), etc. The dopant material may be selected from 4,4'-Bis(2,2-diphenylvinyl)-1,1'-biphenyl (Dpvtb). A thickness of the emitting layer **122** may be 20 nm to 40 nm, inclusive.

(64) In some embodiments, the material of the electron transport layer **125b** and the material of the hole blocking layer **125c** are each independently selected from compounds containing at least one heteroaryl which contains at least two N atoms, such as 2,9-Dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 1,10-Phenanthroline monohydrate (Bphen), azine, etc. These compounds have good electron transport properties.

(65) In some embodiments, the material of the electron transport layer **125b** may be a compound based on a spirocyclic aromatic hydrocarbon structure. That is, the material of the electron transport layer **125b** is selected from compounds having a spirocyclic aromatic hydrocarbon structure (e.g., spirofluorene, or spirofluorene xanthene). In this case, in one aspect, the spirocyclic aromatic hydrocarbon has a good electron withdrawing property, which may further improve an electron transport property of the electron transport layer **125b**. In another aspect, the spirocyclic aromatic hydrocarbon structure has a relatively high T1 and is a group with a good steric configuration, which may suppress crystallization of the material to a certain extent. In this way, in a case where the host material of the emitting layer **122** and the material of the hole blocking layer **125c** are certain, it is also possible to confine the triplet excitons to a region proximate to the emitting layer **122**, so as to further block the electrons and prevent the electrons from being quenched.

(66) In some embodiments, the material of the electron transport layer **125b** is selected from any one or a combination of two or more of structures shown in a general formula (I):

(67) ##STR00011##

(68) In the general formula (I), X is selected from any of C(R).sub.2, O, S, N(R), and a single bond. In a case where X is selected from the single bond, the general formula (I) is spirofluorene.

Ar.sub.1 to Ar.sub.4 may exist simultaneously or separately, and are each independently selected from aryl or heteroaryl with 5 to 30 ring atoms substituted or unsubstituted by a substituent R.sub.1, at least one of Ar.sub.1 to Ar.sub.4 is selected from any of structures shown in a following general formula (II), and the substituent R.sub.1 is selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n.

(69) ##STR00012##

(70) In the general formula (II), X.sub.1, X.sub.2, and X.sub.3 are each independently selected from any of C(R.sub.2) and N, and at least two of X.sub.1, X.sub.2, and X.sub.3 are selected from N. Each R.sub.2 is the same or different, and is independently selected from any of H and aryl or heteroaryl with 5 to 30 ring atoms. In a case where R2 is selected from the aryl or heteroaryl with 5 to 30 ring atoms, the aryl or heteroaryl has or has no the substituent R.sub.1. Y.sub.1 is selected from any of carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), and n is an integer greater than or equal to 1. Each Ar is the same or different, and is independently selected from the aryl or heteroaryl. Alternatively, in a case where n is an integer greater than or equal to 2, at least two Ars are connected into a ring through a single bond or a first bridging group, and the first bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R). R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl or heteroaryl.

(71) According to the case where in the general formula (II), X.sub.1, X.sub.2, and X.sub.3 are each independently selected from any of C(R.sub.2) and N, and at least two of X.sub.1, X.sub.2,

and X.sub.3 are selected from N, it will be seen that the general formula (II) is a general formula of azine. In this case, in an example in which Ar.sub.3 in the general formula (I) is selected from the general formula (II), Ar.sub.4 is selected from phenyl substituted by the substituent R.sub.1, and Ar.sub.1 and Ar.sub.2 do not exist, a structural formula of the general formula (I) may be expressed as follows.

(72) ##STR00013##

(73) In this case, in an example in which X.sub.1, X.sub.2, and X.sub.3 are all selected from N, according to a case where R.sub.2 may be selected from any of H and aryl or heteroaryl with 5 to 30 ring atoms, and the aryl or heteroaryl has or has no the substituent R1 in a case where R.sub.2 is selected from the aryl or heteroaryl with 5 to 30 ring atoms, it will be seen that the general formula (I) may be selected from any of following compounds:

(74) ##STR00014##

(75) According to a case where X may be selected from any of C(R).sub.2, O, S, N(R), and the single bond, and R.sub.1 is independently selected from any of the tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n, it will be seen that the general formula (I) may be selected from any of following compounds. In this case, the material of the electron transport layer may be selected from any one or a combination of two or more of following compounds:

(76) ##STR00015## ##STR00016## ##STR00017## ##STR00018## ##STR00019##

(77) Herein, it will be noted that the compounds shown above are only examples. Herein, those skilled in the art will understand that all the compounds cannot be exhaustively listed, and combinations that meet the above description are all within the protection scope of the present disclosure.

(78) In some embodiments, the material of the hole blocking layer **125c** is selected from any one or a combination of two or more of structures shown in a general formula (III).

(79) ##STR00020##

(80) In the general formula (III), X.sub.4, X.sub.5, and X.sub.6 are each independently selected from any of C(R) and N, and at least two of X.sub.4, X.sub.5, and X.sub.6 are selected from N. Ar.sub.5, Ar.sub.6, and L.sub.2 are each independently selected from aryl with 6 to 60 carbon atoms substituted or unsubstituted by a substituent R.sub.1, or heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1. L.sub.1 is selected from a single bond, divalent aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or divalent heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1. R.sub.1 is independently selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n. Y.sub.1 is selected from any of carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), and n is an integer greater than or equal to 1. Each Ar is the same or different, and is independently selected from the aryl or heteroaryl. Alternatively, Ar and the aryl or heteroaryl substituted by the substituent R1 are connected into a ring through a single bond or a second bridging group, and/or in a case where n is an integer greater than or equal to 2, at least two Ars are connected into a ring through a single bond or a second bridging group. The second bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R). R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl and heteroaryl.

(81) According to the case where Ar.sub.5, Ar.sub.6, and L.sub.2 are each independently selected from the aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or the heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, it will be seen that Ar.sub.5, Ar.sub.6, and L.sub.2 may each be independently selected from any of phenyl, biphenyl, naphthyl, anthryl, fluorenyl, spirocyclic aryl, thienyl, pyridyl, quinolyl, imidazolyl, indolyl, benzofuranyl, and benzothiophene that are each substituted or unsubstituted by

the substituent R.sub.1.

(82) According to the case where L.sub.1 is selected from the single bond, the divalent aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or the divalent heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, it will be seen that in a case where L.sub.1 is selected from the single bond, the general formula (III) may be expressed as:

(83) ##STR00021##

(84) In a case where L.sub.1 is selected from the divalent aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or the divalent heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, L.sub.1 may be selected from any of divalent phenyl, divalent biphenyl, divalent naphthyl, divalent anthryl, divalent fluorenyl, divalent spirocyclic aryl, divalent thienyl, divalent pyridyl, divalent quinolinyl, divalent imidazolyl, divalent indolyl, divalent benzofuranyl, and divalent benzothiophene that are each substituted or unsubstituted by the substituent R.sub.1.

(85) In some embodiments, in the general formula (III), in a case where L.sub.1 is selected from divalent bicyclic aryl substituted or unsubstituted by the substituent R.sub.1, at least one single ring in the divalent bicyclic aryl has a group attached at a meta position and/or an ortho position. In a case where L.sub.1 is selected from monocyclic aryl substituted or unsubstituted by the substituent R.sub.1, L.sub.2 and azine are attached at a meta position or an ortho position of L.sub.1.

(86) That at least one single ring in the divalent bicyclic aryl has a group attached at the meta position and/or the ortho position means that there is a substituent R.sub.1 in the meta position and/or the ortho position of the at least one single ring in the divalent bicyclic aryl, or the remaining aromatic rings in the divalent bicyclic aryl apart from the single ring are attached at the meta position and/or the ortho position of the single ring, or the remaining aromatic rings and the azine in the divalent bicyclic aryl apart from the single ring are attached at the meta position and/or the ortho position of the single ring, or the remaining aromatic rings and the substituent R.sub.1 in the divalent bicyclic aryl apart from the single ring are attached at the meta position and/or the ortho position of the single ring, or the substituent R.sub.1 and the azine in the divalent bicyclic aryl are attached at the meta position and/or the ortho position of the single ring.

(87) For example, in an example in which L.sub.1 is selected from the unsubstituted biphenyl, the general formula (III) may be selected from any of following structures:

(88) ##STR00022##

(89) In an example in which L.sub.1 is selected from the biphenyl substituted by the substituent the general formula (III) may be selected from any of following structures:

(90) ##STR00023##

(91) In an example in which L.sub.1 is selected from unsubstituted monocyclic aryl, the general formula (III) may be selected from any of following structures:

(92) ##STR00024##

(93) In an example in which L.sub.1 is selected from the monocyclic aryl substituted by the substituent R.sub.1, the general formula (III) may be selected from any of following structures:

(94) ##STR00025##

(95) In the above structures, by arranging the meta-position or ortho-position connection among the groups, it may greatly increase the steric twist of molecules to a great extent, and reduce a degree of conjugation of the molecules, thus reducing the mobility of the material and helping to slow down the transport of electrons. In addition, a compound with a large steric twist has a relatively high T1, which may confine the triplet excitons in the emitting layer **122**, and can suppress the crystallization of the material to a certain extent.

(96) In the above description, R.sub.1 is independently selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n, Y.sub.1 is selected from any of carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR),

C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), n is the integer greater than or equal to 1, each Ar is the same or different, and is independently selected from the aryl or heteroaryl, or Ar and the aryl or heteroaryl substituted by the substituent R.sub.1 are connected as the ring through the single bond or the second bridging group, and/or at least two Ars, in a case where n is the integer greater than or equal to 2, are connected as the ring through the single bond or the second bridging group, the second bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R), R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl and heteroaryl. The aryl or heteroaryl with 5 to 30 ring atoms is referred to as A. It will be seen from the above that in a case where L.sub.2 is selected from the aryl or heteroaryl with 5 to 30 ring atoms substituted by the substituent R.sub.1, and R.sub.1 is selected from —Y.sub.1(Ar).sub.n, a structural formula of L.sub.2 may be as shown below, and L.sub.2 is connected to L.sub.1 by a dotted line.

(97) ##STR00026##

(98) In an example in which A is selected from benzene ring, Ar is selected from benzene ring, Y.sub.1 is selected from C(R.sub.3).sub.2, R.sub.3 is selected from methyl, and in this case, n is equal to 1, and Ar and A are connected as a ring through a single bond, the structural formula of L.sub.2 may be expressed as follows.

(99) ##STR00027##

(100) In an example in which A is selected from benzene ring, Ar is selected from benzene ring, Y.sub.1 is selected from carbon, and in this case, n is equal to 3, the structural formula of L.sub.2 may be expressed as follows.

(101) ##STR00028##

(102) In an example in which A is selected from benzene ring, Ar is selected from benzene ring, Y.sub.1 is selected from carbon, and in this case, n is equal to 3, and one Ar and A are connected as a ring through a single bond, the structural formula of L.sub.2 may be expressed as follows.

(103) ##STR00029##

(104) In an example in which A is selected from benzene ring, Y.sub.1 is selected from nitrogen, Ar is selected from benzene ring, and in this case, n is equal to 2, and two Ars are connected as a ring through a single bond, the structural formula of L.sub.2 may be expressed as follows.

(105) ##STR00030##

(106) In an example in which A is selected from benzene ring, Y.sub.1 is selected from O, Ar is selected from benzene ring, and in this case, n is equal to 1, and Ar and A are connected as a ring through a single bond, a structural formula of L.sub.2 may be expressed as follows.

(107) ##STR00031##

(108) In the above structural formulas, by introducing an atom with relatively large steric configuration such as boron, phosphorus, sulfur, or silicon into the general formula (III), it is possible to increase the steric configuration of the molecule, and make the steric twist of the molecule large, which is beneficial to improve T1. In addition, by introducing an electron-withdrawing group such as boron, nitrogen, sulfur, or phosphorus, it is also possible to increase the electron mobility.

(109) In some embodiments, the material of the hole blocking layer **125c** is selected from any one or a combination of two or more of following structures:

(110) ##STR00032## ##STR00033##

(111) Based on the above structures, in a case where the electron mobilities of the electron transport layer **125b** and the hole blocking layer **125c** in the second functional material layer **125** are certain, in order to further reduce the electron transport rate, for example, a difference between a lowest unoccupied molecular orbital (LUMO) energy level of the hole blocking layer **125c** and a LUMO energy level of the electron transport layer **125b** is greater than or equal to 0.4 eV, and is less than or equal to 1 eV, which may increase an energy level barrier between the hole blocking layer **125c** and the electron transport layer **125b**, so as to further reduce the electron transport rate.

(112) In some embodiments, the material of the electron inject layer **125a** may be selected from alkali metals or metals, such as LiF, Yb, and 8-hydroxyquinoline lithium (LiQ). A thickness of the electron inject layer **125a** may be 1 nm to 3 nm, inclusive, a thickness of the electron transport layer **125b** may be 20 to 35 nm, inclusive, and a thickness of the hole blocking layer **125c** may be 5 nm to 10 nm, inclusive.

(113) In some embodiments, a lowest triplet exciton energy T1 of the material of the electron transport layer **125b** is greater than a lowest triplet exciton energy T1 of the material of the hole blocking layer **125c**.

(114) According to the recombination mechanism of electrons and holes, in order to avoid a case where the holes are quenched on a surface of the cathode after passing through the hole blocking layer **125c** because the hole blocking layer **125c** is too thin, the lowest triplet exciton energy of the material of the electron transport layer **125b** is made greater than the lowest triplet exciton energy of the material of the hole blocking layer **125c**, which is also possible to further block the holes through the electron transport layer **125b** after the holes pass through the hole blocking layer **125c**, thereby preventing the holes from being quenched.

(115) In some embodiments, in order to further reduce the electron transport rate, a difference between a HOMO energy level of the material of the hole blocking layer **125c** and a HOMO energy level of the host material of the emitting layer **122** is greater than or equal to 0.1 eV, which may well block the holes.

(116) In some embodiments, the lowest triplet exciton energy T1 of the material of the hole blocking layer **125c** is greater than the lowest triplet exciton energy T1 of the host material.

(117) Similarly, by making the lowest triplet exciton energy of the material of the hole blocking layer **125c** greater than the lowest triplet exciton energy of the host material, it is possible to confine the triplet excitons in the emitting layer **122**, so as to effectively utilize the triplet excitons.

(118) In order to objectively evaluate the technical effects of the embodiments of the present disclosure, the technical solutions will be exemplarily described in detail below through following experimental examples and comparative examples.

(119) In the following experimental examples and comparative examples, structures and the test conditions of the devices that are adopted are the same. The structure of the device is expressed as: anode (indium tin oxide (ITO)), HIL, HTL, EBL, Host+Dopant, HBL, ETL, EIL, and cathode (Al).

(120) A comparative example 1, a comparative example 2, a comparative example 3, a comparative example 4, a comparative example 5, an experimental example 1, an experimental example 2, an experimental example 3, and an experimental example 4 are provided. In the comparative examples 1 to 5 and the experimental examples 1 to 4, materials of the remaining layers except for the ETLs and the HBLs are the same, and selected from following structures.

(121) ##STR00034##

(122) The material of the hole inject layer **124a** is selected from a mixed material of a structural formula shown in the HTL and a structural formula shown in the P Dopant. The material of the electron inject layer **125a** is selected from lithium fluoride.

(123) In the comparative examples 1 to 5 and the experimental examples 1 to 4, the materials of the ETLs and the HBLs are selected from materials as shown in Table 1 below, respectively, The HOMO energy levels, the LUMO energy levels, and the lowest triplet energies T1 of the materials shown in Table 1 are as shown in Table 2 below. Structural formulas of the materials shown in Table 1 and names of the structural formulas are as shown below.

(124) ##STR00035## ##STR00036##

(125) TABLE-US-00001
TABLE 1 Service life Material Material (LT95@ of ETL of HBL Voltage Efficiency 1000 nit)
Comparative Comparative Comparative 100% 100% 100% example 1 ETL
HBL Comparative ETL1 Comparative 100% 102% 120% example 2 HBL Comparative ETL2
Comparative 95% 105% 129% example 3 HBL Comparative Comparative HBL1 97% 108% 103%
example 4 ETL Comparative Comparative HBL2 96% 109% 104% example 5 ETL Experimental

ETL1 HBL1 96% 119% 131% example 1 Experimental ETL1 HBL2 94% 128% 137% example 2
Experimental ETL2 HBL1 99% 121% 126% example 3 Experimental ETL2 HBL2 97% 120%
130% example 4

(126) TABLE-US-00002 TABLE 2 Name HOMO (eV) LUMO (eV) T1 (eV) ETL1 -6.56 -3.5 2.7
ETL2 -6.50 -3.4 2.75 HBL1 -6.00 -2.71 2.4 HBL2 -5.80 -2.51 2.80

(127) Table 1 further shows test results of driving voltages, current efficiencies, and service lives of devices in the comparative examples 1 to 5 and the experimental examples 1 to 4 under a same test condition.

(128) It will be seen from Table 1 and Table 2 that in a case where the host material of the emitting layer **122**, the material of the HTL, and the material of the EBL are all certain, suitable materials of the ETL and the HBL are chosen such that the electron mobility of the material of the ETL and the electron mobility of the material of the HBL are adjusted, the electron mobility of the organic light-emitting device is appropriately reduced, the energy levels of the materials of the functional material layers are matched simultaneously, the energy level barrier of the electrons among the material of the HBL, the material of the ETL, and the host material of the emitting layer is increased, and the energy level barrier of the holes among the material of the HBL, the material of the ETL, and the host material of the emitting layer is reduced. Therefore, it is possible to generally reduce a transport velocity of electrons, increase a transport velocity of holes, and adjust the recombination zones of the holes and the electrons, so that it is possible to make the recombination zones of the holes and the electrons away from the electron blocking layer **124c**. As a result, the service lives and efficiencies of the obtained devices are improved to various degrees.

(129) It will be seen that the embodiments provided by the present disclosure can solve a defect that the recombination zones are located at the interface between the electron blocking layer **124c** and the emitting layer **122** in the related art, which leads to the accumulation of the electrons at the interface between the electron blocking layer **124c** and the emitting layer **122**, resulting in the deterioration of the materials due to the accumulation of the charges, which is not conducive to the improvement of the efficiencies and service lives of the devices.

(130) The foregoing descriptions are merely specific implementations of the present disclosure, but the protection scope of the present disclosure is not limited thereto. Any person skilled in the art could conceive of changes or replacements within the technical scope of the present disclosure, which shall all be included in the protection scope of the present disclosure. Therefore, the protection scope of the present disclosure shall be subject to the protection scope of the claims.

Claims

1. An organic light-emitting device, comprising: an anode, an emitting layer and a cathode that are stacked; a first functional material layer located between the emitting layer and the anode; and a second functional material layer located between the emitting layer and the cathode; and under a same test condition, a hole mobility of a material of the first functional material layer being at least ten times an electron mobility of a material of the second functional material layer; wherein the second functional material layer includes an electron transport layer and a hole blocking layer; an electron mobility of a material of the electron transport layer is the same as an electron mobility of a material of the hole blocking layer; or, under a same test condition, the electron mobility of the material of the hole blocking layer is less than the electron mobility of the material of the electron transport layer; and the material of the electron transport layer and the material of the hole blocking layer are each independently selected from compounds containing at least one heteroaryl which contains at least two N atoms.

2. The organic light-emitting device according to claim 1, wherein a lowest triplet energy of the material of the electron transport layer is greater than a lowest triplet energy of the material of the hole blocking layer.

3. The organic light-emitting device according to claim 1, wherein the material of the electron transport layer is a compound based on a spirocyclic aromatic hydrocarbon structure.
4. The organic light-emitting device according to claim 3, wherein the material of the electron transport layer is selected from any one or a combination of two or more of structures shown in a general formula (I): ##STR00037## in the general formula (I), X is selected from any of C(R).sub.2, O, S, N(R), and a single bond, Ar.sub.1 to Ar.sub.4 are able to exist simultaneously or separately, and are each independently selected from aryl or heteroaryl with 5 to 30 ring atoms substituted or unsubstituted by a substituent R1, at least one of Ar.sub.1 to Ar.sub.4 is selected from any of structures shown in a following general formula (II), and the substituent R.sub.1 is selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n; ##STR00038## in the general formula (II), X.sub.1, X.sub.2, and X.sub.3 are each independently selected from any of C(R.sub.2) and N, and at least two of X.sub.1, X.sub.2, and X.sub.3 are selected from N; and each R2 is the same or different, and is independently selected from any of H and aryl or heteroaryl with 5 to 30 ring atoms, and in a case where R.sub.2 is selected from the aryl or heteroaryl with 5 to 30 ring atoms, the aryl or heteroaryl has or has no the substituent R.sub.1; wherein Y.sub.1 is selected from carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), n is an integer greater than or equal to 1, each Ar is the same or different, and is independently selected from aryl or heteroaryl, or in a case where n is an integer greater than or equal to 2, at least two Ars are connected as a ring through a single bond or a first bridging group, and the first bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R); and R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl or heteroaryl.
5. The organic light-emitting device according to claim 4, wherein the material of the electron transport layer is selected from any one or a combination of two or more of following compounds: ##STR00039## ##STR00040## ##STR00041## ##STR00042## ##STR00043##
6. The organic light-emitting device according to claim 1, wherein the material of the hole blocking layer is selected from any one or a combination of two or more of structures as shown in a general formula (III): ##STR00044## in the general formula (III), X.sub.4, X.sub.5, and X.sub.6 are each independently selected from any of C(R) and N, and at least two of X.sub.4, X.sub.5, and X.sub.6 are selected from N; and Ar.sub.5, Ar.sub.6, and L.sub.2 are each independently selected from aryl with 6 to 60 carbon atoms substituted or unsubstituted by a substituent R.sub.1, or heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1; L.sub.1 is selected from a single bond, divalent aryl with 6 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1, or divalent heteroaryl with 2 to 60 carbon atoms substituted or unsubstituted by the substituent R.sub.1; R.sub.1 is independently selected from any of tert-butyl, cyano, aryl or heteroaryl with 5 to 30 ring atoms, and —Y.sub.1(Ar).sub.n, Y.sub.1 is selected from carbon, nitrogen, phosphorus, silicon, boron, C(R.sub.3).sub.2, Si(R.sub.3).sub.2, C(=O), C(=NR), C(=C(R).sub.2), S(=O), S(=O).sub.2, and P(=O), n is an integer greater than or equal to 1, each Ar is the same or different, and is independently selected from aryl or heteroaryl, or Ar and the aryl or heteroaryl substituted by the substituent R.sub.1 are connected as a ring through a single bond or a second bridging group, and/or at least two Ars, in a case where n is an integer greater than or equal to 2, are connected as a ring through a single bond or a second bridging group, and each second bridging group is selected from B(R), C(R).sub.2, Si(R).sub.2, C(=O), C(=NR), C(=C(R).sub.2), O, S, S(=O), S(=O).sub.2, N(R), P(R), and P(=O)(R); and R.sub.3 is selected from any of H and methyl, and R is selected from any of H, methyl, aryl, and heteroaryl.
7. The organic light-emitting device according to claim 6, wherein in the general formula (III), in a case where L.sub.1 is selected from divalent bicyclic aryl substituted or unsubstituted by the substituent R.sub.1, at least one single ring in the divalent bicyclic aryl has a group attached at a meta position and/or an ortho position; and in a case where L.sub.1 is selected from monocyclic

aryl substituted or unsubstituted by the substituent R.sub.1, L.sub.2 and azine are attached at a meta position or an ortho position of L.sub.1.

8. The organic light-emitting device according to claim 7, wherein the material of the hole blocking layer is selected from any one or a combination of two or more of following structures:

##STR00045## ##STR00046##

9. The organic light-emitting device according to claim 1, wherein the first functional material layer includes a hole transport layer and an electron blocking layer; and a hole mobility of a material of the hole transport layer is the same as a hole mobility of a material of the electron blocking layer; or under a same test condition, the hole mobility of the material of the electron blocking layer is not less than one tenth of the hole mobility of the material of the hole transport layer.

10. The organic light-emitting device according to claim 9, wherein a difference between a highest occupied molecular orbital (HOMO) energy level of the material of the hole transport layer and a HOMO energy level of the material of the electron blocking layer is greater than or equal to -0.5 eV, and is less than or equal to 0.3 eV.

11. The organic light-emitting device according to claim 9, wherein a lowest triplet energy of the hole transport layer is greater than a lowest triplet energy of the electron blocking layer.

12. The organic light-emitting device according to claim 1, wherein a material of the emitting layer includes a host material, and a difference between a highest occupied molecular orbital (HOMO) energy level of the hole blocking layer and a HOMO energy level of the host material is greater than or equal to 0.1 eV.

13. The organic light-emitting device according to claim 12, wherein a lowest triplet energy of the hole blocking layer is greater than a lowest triplet energy of the host material.

14. The organic light-emitting device according to claim 12, wherein the first functional material layer includes an electron blocking layer, and a difference between the HOMO energy level of the host material and a HOMO energy level of the electron blocking layer is less than or equal to 0.3 eV.

15. The organic light-emitting device according to claim 14, wherein a lowest triplet energy of the electron blocking layer is greater than a lowest triplet energy of the host material.

16. The organic light-emitting device according to claim 9, wherein the material of the hole transport layer and the material of the electron blocking layer are each independently selected from any of aromatic amine compounds.

17. A light-emitting substrate, comprising: a base; and a plurality of light-emitting devices disposed on the base; and at least one light-emitting device being selected from the organic light-emitting device according to claim 1.

18. A light-emitting apparatus, comprising the light-emitting substrate according to claim 17.

19. An organic light-emitting device, comprising: an anode, an emitting layer and a cathode that are stacked; a first functional material layer located between the emitting layer and the anode; and a second functional material layer located between the emitting layer and the cathode; and under a same test condition, a hole mobility of a material of the first functional material layer being at least ten times an electron mobility of a material of the second functional material layer; wherein the second functional material layer includes an electron transport layer and a hole blocking layer; an electron mobility of a material of the electron transport layer is the same as an electron mobility of a material of the hole blocking layer; or, under a same test condition, the electron mobility of the material of the hole blocking layer is less than the electron mobility of the material of the electron transport layer; and a lowest triplet energy of the material of the electron transport layer is greater than a lowest triplet energy of the material of the hole blocking layer.

20. An organic light-emitting device, comprising: an anode, an emitting layer and a cathode that are stacked; a first functional material layer located between the emitting layer and the anode; and a second functional material layer located between the emitting layer and the cathode; and under a

same test condition, a hole mobility of a material of the first functional material layer being at least ten times an electron mobility of a material of the second functional material layer; wherein the first functional material layer includes a hole transport layer and an electron blocking layer; a hole mobility of a material of the hole transport layer is the same as a hole mobility of a material of the electron blocking layer; or, under a same test condition, the hole mobility of the material of the electron blocking layer is not less than one tenth of the hole mobility of the material of the hole transport layer; and a lowest triplet energy of the hole transport layer is greater than a lowest triplet energy of the electron blocking layer.
