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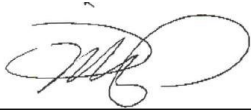
I served as Chief Examiner of the certified court interpreter test for the State of California and as a contract translator and interpreter for various federal agencies through the U.S. Department of State for more than a decade. I served as an instructor at the University of California at Berkeley and the Middlebury Institute of International Studies at Monterey (MIIS) Graduate Program in Translation.

I have more than 30 years of experience reviewing thousands of technical, legal, and business documents from Japanese to English submitted to, among others, Japanese judicial authorities, U.S. federal courts, the U.S. International Trade Commission (ITC), and the USPTO Patent Trial and Appeal Board (PTAB).

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Executed this 17th day of May 2024 in Contra Costa County of the State of California.



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54) [Title of the Invention] ORGANIC LIGHT-EMITTING
DEVICE

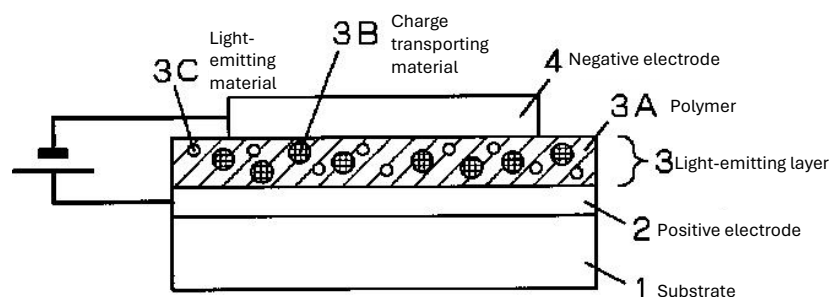
(57) ABSTRACT

[PROBLEM]

To provide a polymer-dispersed organic light-emitting device
that has high light-emitting efficiency.

[RESOLUTION MEANS]

A polymer-dispersed organic light-emitting device having
high light-emitting efficiency can be provided by a light-
emitting layer containing a charge transporting polymer 3A
having a specific hole transporting capacity, a charge
transporting material 3B having a specific electron
transporting capacity, and a light-emitting material 3C.



SCOPE OF PATENT CLAIMS

[Claim 1]

An organic light-emitting device, comprising:
at least one light-emitting layer between a positive electrode and a negative electrode, the light-emitting layer including a charge transporting material, a light-emitting material, and a polymer for dispersing these materials.

[Claim 2]

The organic light-emitting device according to claim 1, wherein the polymer is a charge transporting polymer.

[Claim 3]

The organic light-emitting device according to claim 1, wherein the polymer is a hole transporting polymer.

[Claim 4]

The organic light-emitting device according to claim 3, wherein the charge transporting material is an electron transporting material.

[Claim 5]

The organic light-emitting device according to claim 3 or 4, wherein a carrier mobility of the hole transporting polymer is $1 \times 10^{-7} \text{cm}^2/\text{V} \cdot \text{s}$ or more.

[Claim 6]

The organic light-emitting device according to claim 4 or 5, wherein the carrier mobility of the electron transporting material is $5 \times 10^{-8} \text{cm}^2/\text{V} \cdot \text{s}$ or more.

[Claim 7]

The organic light-emitting device according to any one of claims 4 to 6, wherein the content of the electron transporting material is 30 to 120 wt% based on the polymer.

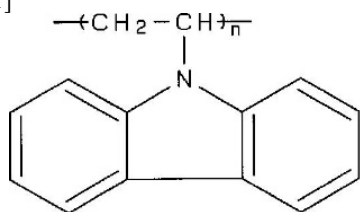
[Claim 8]

The organic light-emitting device according to any of claims 4 to 7, wherein an ionization potential of the hole transporting polymer is greater than an ionization potential of the light-emitting material, and an electron affinity of the electron transporting material is less than an electron affinity of the light-emitting material.

[Claim 9]

The organic light-emitting device according to any of claims 3 to 8, wherein the polymer is poly-N-vinylcarbazole having repeating units expressed by the following general formula (Chem. Fig. 1).

[Chem. Fig. 1]



[Claim 10]

The organic light-emitting device according to any of claims 4 to 9, wherein the electron transporting material includes at least one type selected from oxazole derivatives, oxadiazole derivatives, triazole derivatives, pyrazine derivatives, and aldzine derivatives.

[Claim 11]

The organic light-emitting device according to any of claims 4 to 9, wherein the electron transporting material includes a quinolinol complex or a derivative thereof.

[Claim 12]

The organic light-emitting device according to claim 11, wherein the electron transporting material includes tris(8-quinolinolato)aluminum or a derivative thereof.

[Claim 13]

The organic light-emitting device according to any of claims 1 to 12, comprising, a hole injecting layer between the positive electrode and the light-emitting layer.

[Claim 14]

The organic light-emitting device according to claim 13, wherein the relationship between an ionization potential of the hole injecting layer ($I_p(h)$), an ionization potential of the polymer ($I_p(p)$), and an ionization potential or work function of the positive electrode ($I_p(a)$) is expressed by the following formula.

$$I_p(a) < I_p(h) < I_p(p)$$

[Claim 15]

The organic light-emitting device according to claim 13 or 14, wherein the hole injecting layer includes at least one type selected from polyaniline derivatives, polythiophene derivatives, and amorphous carbon.

[Claim 16]

The organic light-emitting device according to any of claims 1 to 15, comprising: an electron injecting layer between the negative electrode and the light-emitting layer.

[Claim 17]

The organic light-emitting device according to claim 16, wherein an electron affinity or work function of the electron injecting layer is less than a work function of the negative electrode.

[Claim 18]

The organic light-emitting device according to claim 17, wherein the electron injecting layer includes at least one type selected from dilithium phthalocyanine, disodium phthalocyanine, and organic boron complex compounds.

[Claim 19]

The organic light-emitting device according to claim 18, wherein the electron injecting layer contains 4,4,8,8-tetrakis(1H-pyrazol-1-yl)pyrazabole.

[Claim 20]

The organic light-emitting device according to any of claims 1 to 19, wherein the charge transporting material contains at least one or more each of a hole transporting material and an electron transporting material.

[Claim 21]

The organic light-emitting device according to claim 20, wherein an ionization potential of the hole transporting material is less than an ionization potential of the polymer.

[Claim 22]

The organic light-emitting device according to claim 20 or 21, wherein the content of the hole transporting material is 10 to 120 wt% based on the polymer.

DETAILED DESCRIPTION OF THE INVENTION

[0001]

TECHNOLOGICAL FIELD OF THE PRESENT INVENTION

The present invention relates to an organic light-emitting device used in a flat light source or a flat display.

[0002]

CONVENTIONAL TECHNOLOGY

Electroluminescent devices are attracting attention as display devices for flat displays and the like due to being self-luminous, and therefore highly visible, as well as their ability to be made thin. Among these, organic EL devices, in which an organic compound forms a light-emitting body, and which have features such as the ability to be driven at a lower voltage than inorganic EL devices, easy surface area enlargement, and easy acquisition of a desired color at which light is emitted via the selection of an appropriate dye, are being actively developed for next-generation displays.

[0003] As an example of an EL device that uses an organic light-emitting body, a blue emitted light is obtained by applying a voltage of 30 V to an anthracene-deposited film that is 1 μm or thinner (Thin Solid Films, 94 (1982) 171). However, even when this device has a high voltage applied thereto, sufficient luminance cannot be obtained, and there is a need for the light-emitting efficiency to be further improved.

[0004] In response to this, Tang et al. attempted to improve the light-emitting efficiency by laminating a transparent electrode (anode), a hole transporting layer, a light-emitting layer having electron transference, and a cathode that utilizes a metal having a low work function, and thereby achieved a luminance of 1,000 cd/m^2 at an applied voltage of 10 V or less (Appl. Phys. Lett., 51 (1987) 913).

[0005] Furthermore, there are reports of a three-layer-structured device having a light-emitting layer interposed between a hole transporting layer and an electron transporting layer (Jpn. J. Appl. Phys., 27 (1988) L269) and an device in which light-emission from a dye-doped light-emitting layer is obtained (J. Appl. Phys., 65 (1989) 3610).

[0006] On the other hand, whereas for every device having the above configuration, each film is formed by a dry process such as a vacuum deposition method, there are methods for forming devices by so-called wet film formation methods such as spin coating methods and casting methods (for example, Japanese Unexamined Patent Application No. H3-790 and Japanese Unexamined Patent Application No. H3-171590).

[0007] In other words, an device is formed by: dissolving at least one or more types of a material forming the hole transporting layer, electron transporting layer, and light-emitting layer, along with a polymer binder, in an appropriate solvent, coating this onto an electrode surface to form a light-emitting layer, and then further forming an electrode on the light-emitting layer using a vapor deposition method or the like. Hereinafter, an organic light-emitting device fabricated in this manner will be referred to as a polymer-dispersed light-emitting device, in contrast to conventional laminated light-emitting devices.

[0008] Examples of advantages of polymer-dispersed light-emitting devices over organic light-emitting devices fabricated by a dry process include the following points:

- (1) Materials can be used that are difficult to form into a film by a dry process such as deposition.
- (2) A trace amount of doping, which is difficult to control in a dry process, can also be easily achieved.
- (3) Surface area enlargement is easy.
- (4) Fabrication can be carried out at a low cost.
- (5) Simultaneous light emission from a plurality of light-emitting materials can be easily obtained by introducing the respective light-emitting materials (emission of white light is possible).
- (6) Polymer-dispersed light-emitting devices are thermally stable because respective materials are dispersed in a polymer binder, in contrast to conventional laminated light-emitting devices in which respective layers are in an amorphous state.

[0009] Configurations of the light-emitting layer of conventional polymer-dispersed light-emitting devices include those in which a perinone derivative or tris(8-quinolinolato)aluminum is dispersed as a light-emitting material in polyvinylcarbazole, those in which tris(8-quinolinolato)aluminum and tetraphenylbenzidine are dispersed as light-emitting materials in polycarbonate, and the like (for example, Japanese Unexamined Patent Application H3-790, Japanese Unexamined Patent Application H3-171590, and the like).

[0010]

PROBLEMS TO BE SOLVED BY THE INVENTION

Although polymer-dispersed light-emitting devices have the advantages described above, a problem exists in that light-emitting efficiency thereof is low compared to the conventional laminated light-emitting devices.

[0011] In other words, in a laminated light-emitting device, holes are injected from an anode into a hole transporting layer, and electrons are injected from a cathode into an electron transporting layer or an electron transporting layer.

Furthermore, when these holes and electrons are recombined inside the light-emitting layer, excitons are formed, and light is emitted when these excitons transition to their ground state. Here, since electron transport and hole transport are functionally separate, recombination of electrons and holes occurs only near an interface of each layer. Therefore, excitons are generated efficiently, and light-emitting efficiency is also improved.

[0012] Furthermore, regarding the injection of holes and electrons, if the materials of layers in contact with each electrode are selected such that an injection barrier is reduced between the anode and cathode, injection can be easily performed, which allows for driving at a low voltage.

[0013] In contrast, in the case of polymer-dispersed light-emitting devices, since they are mainly configured of a single layer, the recombination of holes and electrons / the generation of excitons does not occur locally as in the laminated light-emitting devices described above, and the injection barrier for the holes / electrons from the electrodes is also large, making it difficult to improve light-emitting efficiency.

[0014] The present invention solves the problems described above, realizing a high light-emitting efficiency and low driving voltage even in a polymer-dispersed organic light-emitting device.

[0015]

MEANS FOR SOLVING THE PROBLEM

As a result of intensive research into achieving the above object, the present inventors have found that current-luminance efficiency can be improved in a polymer-dispersed light-emitting device by including a charge transporting material having a specific carrier mobility in the polymer, or by using a charge transporting polymer having a specific carrier mobility.

Furthermore, the present inventors found that the driving voltage can be reduced by inserting a hole injecting layer having a specific ionization potential between a positive electrode and a light-emitting layer, or by including a hole transporting material having a specific ionization potential inside the light-emitting layer.

[0016] Specifically, the organic light-emitting device of the invention of claim 1 of the present application is an organic light-emitting device containing at least one of a light-emitting layer between a positive electrode and a negative electrode, containing the light-emitting layer, a charge transporting material, a light-emitting material, and a polymer for dispersing materials.

[0017] In addition, the invention of claim 2 of the present application is an organic light-emitting device wherein the polymer according to claim 1 is a charge transporting polymer.

[0018] In addition, the invention of claim 3 of the present application is an organic light-emitting device wherein the polymer according to claim 1 is a hole transporting polymer.

[0019] In addition, the invention of claim 4 of the present application is an organic light-emitting device wherein, in the organic light-emitting device according to claim 3, the charge transporting material is an electron transporting material.

[0020] In addition, the invention according to claim 5 of the present application is an organic light-emitting device wherein a carrier mobility of the hole transporting polymer according to claim 3 or 4 is $1 \times 10^{-7} \text{cm}^2/\text{V}\cdot\text{s}$ or more.

[0021] In addition, the invention according to claim 6 of the present application is an organic light-emitting device wherein the carrier mobility of the electron transporting material according to claim 4 or 5 is $5 \times 10^{-8} \text{cm}^2/\text{V}\cdot\text{s}$ or more.

[0022] In addition, the invention of claim 7 of the present application is an organic light-emitting device wherein the content of the electron transporting material according to claims 4 to 6 is 30 to 120% by weight based on the polymer.

[0023] In addition, the invention of claim 8 of the present application is an organic light-emitting device wherein an ionization potential of the hole transporting polymer according to claims 4 to 7 is greater than an ionization potential of the light-emitting material, and an electron affinity of the electron transporting material is less than an electron affinity of the light-emitting material.

[0024] In addition, the invention of claim 9 of the present application is an organic light-emitting device wherein the polymer according to claims 3 to 8 is a poly-N-vinylcarbazole having the repeating unit expressed by the general formula (Chem. Fig. 1).

[0025] In addition, the invention of claim 10 of the present application is an organic light-emitting device wherein the electron transporting material according to one of claims 4 to 9 contains at least one type from among oxazole derivatives, oxadiazole derivatives, triazole derivatives, pyrazine derivatives, and aldazine derivatives.

[0026] In addition, the invention of claim 11 of the present application is an organic light-emitting device wherein the electron transporting material according to one of claims 4 to 9 contains a quinolinol complex or a derivative thereof.

[0027] In addition, the invention of claim 12 of the present application is an organic light-emitting device wherein the electron transporting material according to claim 11 contains tris(8-quinolinolato)aluminum or a derivative thereof.

[0028] In addition, the invention of claim 13 of the present application is an organic light-emitting device having, in the organic light-emitting device according to claims 1 to 12, a hole injecting layer between the positive electrode and the light-emitting layer.

[0029] In addition, the invention of claim 14 of the present application is an organic light-emitting device wherein the relationship between an ionization potential of the hole injecting layer according to claim 13 ($I_p(h)$), an ionization potential of the polymer ($I_p(p)$), and an ionization potential or work function of the positive electrode ($I_p(a)$) is expressed by the following formula.

[0030] $I_p(a) < I_p(h) < I_p(p)$

In addition, the invention of claim 15 of the present application is an organic light-emitting device wherein the hole injecting layer according to claim 13 or 14 contains at least one type selected from polyaniline derivatives, polythiophene derivatives, and amorphous carbon.

[0031] In addition, the invention of claim 16 of the present application is an organic light-emitting device having, in the organic light-emitting device according to one of claims 1 to 15, an electron injecting layer between the negative electrode and the light-emitting layer.

[0032] In addition, the invention of claim 17 of the present application is an organic light-emitting device wherein an electron affinity or work function of the electron injecting layer according to claim 16 is less than a work function of the negative electrode.

[0033] In addition, the invention of claim 18 of the present application is an organic light-emitting device wherein the electron injecting layer according to claim 17 contains at least one type selected from dilithium phthalocyanine, disodium phthalocyanine, and organic boron complex compounds.

[0034] In addition, the invention of claim 19 of the present application is an organic light-emitting device wherein the electron injecting layer according to claim 18 contains 4,4,8,8-tetrakis(1H-pyrazol-1-yl)pyrazabole.

[0035] In addition, the invention of claim 20 of the present application is an organic light-emitting device wherein, in the organic light-emitting device according to any one of claims 1 to 19, the charge transporting material contains at least one or more type of a hole transporting material and an electron transporting material.

[0036] In addition, the invention of claim 21 of the present application is an organic light-emitting device wherein the ionization potential of the hole transporting material according to claim 20 is less than the ionization potential of the polymer.

[0037] In addition, the invention of claim 22 of the present application is an organic light-emitting device wherein the amount of hole transporting material according to claims 20 or 21 is 10 to 120 wt% based on the polymer.

[0038]

EMBODIMENTS OF THE INVENTION

Embodiments of the present invention will be described below. FIG. 1 is a cross-sectional view depicting one example of the organic light-emitting device of the present invention. In FIG. 1, 1 is substrate, 2 is a positive electrode, 3 is a light-emitting layer, and 4 is a negative electrode.

[0039] The substrate 1 may be any substrate capable of carrying the organic light-emitting device of the present invention, and may be a transparent substrate such as glass or a resin film such as polycarbonate, polymethyl methacrylate, or polyethylene terephthalate, or a non-transparent substrate such as silicon.

[0040] At least one of the positive electrode 2 and the negative electrode 4 must be transparent or semi-transparent, and light emitted from the light-emitting layer is ejected to the outside through one or both of these electrodes. The positive electrode 2 typically is a transparent electrode such as indium tin oxide (ITO) or tin oxide, however, a metal electrode such as Ni, Au, Pt, or Pd may be used. For the purpose of improving transparency or reducing resistivity of the ITO film, a film forming method such as sputtering, electron beam deposition, or ion plating is used. In addition, film thickness is determined based on a required sheet resistance value and visible light transmittance, but since the driving current density of an organic light-emitting device is relatively high, a thickness of 1,000 Å or more is often used to reduce sheet resistance value.

The negative electrode 4 can be a metal such as Al, Ag, or Au, an alloy of a metal having a low work function and a metal having a relatively large and stable work function, such as an MgAg alloy or an AlLi alloy, or a laminated electrode of a metal having a low work function and a metal having a high work function, such as Li/Al or LiF/Al. Vapor deposition methods and sputtering methods are preferable for forming these negative electrodes.

Note that in FIG. 1, the order of configuration from the bottom is: substrate / positive electrode / light-emitting layer / negative electrode. However, it is not necessarily required that lamination be done in this order, and the order from the bottom may be: substrate / negative electrode / light-emitting layer / positive electrode. In addition, in FIG. 1, when only the electrode on the substrate 1 side, that is, only the positive electrode 2, is transparent, and the negative electrode 4 is non-transparent, the substrate 1 must also be a transparent substrate in order for emitted light to be ejected to the outside.

[0041] The light-emitting layer includes a charge transporting material 3B, a light-emitting material 3C, and a polymer 3A for dispersing these. For the polymer material, charge transporting polymers are preferable, among which, hole transporting polymers are preferred. The hole transporting polymer preferably has a carrier mobility of $1 \times 10^{-7} \text{cm}^2/\text{V} \cdot \text{s}$ or more, where a poly-N-vinylcarbazole having the repeating unit expressed by the general formula (Chem. Fig. 1) is particularly preferable. When a hole transporting polymer is used, it is preferable that an electron transporting material be used as the charge transporting material. Furthermore, it is preferable that the carrier mobility of the electron transporting material be $5 \times 10^{-8} \text{cm}^2/\text{V} \cdot \text{s}$ or more. In particular, oxazole derivatives, oxadiazole derivatives, triazole derivatives, pyrazine derivatives, aldazine derivatives, quinolinol complexes, and derivatives thereof are preferred. In addition, the content of the electron transporting material is preferably 30 to 120 wt% based on the polymer. In other words, with a content at less than 30%, electron transporting capacity is insufficient, and if greater than 120 wt%, dispersibility in the polymer worsens. For the light-emitting material, a fluorescent substance or a phosphorescent substance that exhibits light emission in response to hole/electron recombination may be used, and as for a substance that exhibits particularly strong fluorescence or phosphorescence, a dye such as a cyanine dye, merocyanine dye, styryl dye, anthracene derivative, porphyrin derivative, phthalocyanine derivative, coumarin, DCM, and Nile Red, and a laser dye may be used. In addition, for the light-emitting material, a substance having an ionization potential of the light-emitting material less than an ionization potential of the hole transporting polymer, and an electron affinity of the light-emitting material greater than an electron affinity of the electron transporting material is preferable.

[0042] The light-emitting mechanism of the organic light-emitting device of the present invention is as follows. That is, in an organic light-emitting device of the configuration in FIG. 1, when a voltage is applied between the positive electrode 2 and the negative electrode 4 in the direction depicted in the drawing, holes injected from the positive electrode 2 and electrons from the negative electrode 4 are injected into the light-emitting layer 3. Furthermore, the injected holes flow toward the negative electrode 4, and the electrons flow toward the positive electrode 2. The holes and electrons recombine inside the light-emitting layer, and in response to this, fluorescence or phosphorescence is emitted from the light-emitting material inside the light-emitting layer. Here, examples of primary factors determining the current efficiency of light emission (efficiency of light emission relative to injected current) include the following.

- (1) Recombination efficiency of holes and electrons relative to the injected current
 - (2) Efficiency of exciton generation in a light-emitting material accompanying recombination
 - (3) Quantum efficiency of light-emission from excitons in the light-emitting material
- Of the above, (2) and (3) are determined almost entirely by the properties of the light-emitting material itself. On the other hand, the recombination efficiency of holes and electrons in (1) is most affected by the balance between holes and electrons. In other words, if the balance between holes and electrons is poor, even if an excess of carriers is injected from an electrode, the excess of carriers will reach the opposite electrode with no recombination inside the light-emitting layer, resulting in wasted current that does not contribute to light emission. Therefore, if the mobility of each carrier inside the light-emitting layer is increased, the holes and electrons will flow in a balanced manner, and the light-emitting efficiency will also improve. Specifically, it is preferable that the hole mobility be $1 \times 10^{-7} \text{cm}^2/\text{V} \cdot \text{s}$ or more, and that the electron mobility be $5 \times 10^{-8} \text{cm}^2/\text{V} \cdot \text{s}$ or more.
- [0043] FIGS. 2 to 4 are cross-sectional views depicting separate examples of the organic light-emitting device of the present invention. In FIGS. 2 to 4, 5 is a hole injecting layer, 6 is an electron injecting layer, 3D is a hole transporting material, and 3E is an electron transporting material.
- [0044] The hole injecting layer 5 is inserted for the purpose of assisting hole injection from the positive electrode 2 to the light-emitting layer 3. For the hole injecting layer 5, it is preferable that a material be used wherein the relationship between an ionization potential ($I_p(h)$) thereof, an ionization potential of the polymer ($I_p(p)$), and an ionization potential or work function of the positive electrode ($I_p(a)$) satisfies: $I_p(a) < I_p(h) < I_p(p)$. In particular, it is preferable that the material includes at least one type from among polyaniline derivatives, polythiophene derivatives, and amorphous carbon.
- [0045] The electron injecting layer 6 is inserted for the purpose of assisting electron injection from the negative electrode 4 to the light-emitting layer 3. For the electron injecting layer 6, it is desirable that a material be used wherein an electron affinity or work function thereof is less than a work function of the negative electrode. In particular, it is preferable that the electron injecting layer contains at least one type from among dilithium phthalocyanine, disodium phthalocyanine, and organic boron complex compounds. The hole transporting material 3D is introduced for the purpose of assisting hole injection from the positive electrode 2 to the light-emitting layer 3, as with the hole injecting layer. However, unlike the hole injecting layer 5, the hole transporting material is not inserted as a film between the positive electrode 2 and the light-emitting layer 3, but is directly dispersed inside the light-emitting layer. For the hole transporting material 3D, it is preferable that an ionization potential thereof be less than an ionization potential of the polymer. In addition, the content of the hole transporting material is preferably 10 to 120% by weight based on the polymer. In other words, at less than 10% by weight, sufficient hole injection cannot be obtained, and if greater than 120% by weight, dispersibility in the polymer worsens.
- [0046] The effects of introducing the hole injecting layer 5, the electron injecting layer 6, and the hole transporting material 3D will be described with reference to the drawings.

FIGS. 5 to 8 are energy diagrams of the organic light-emitting device of the present invention.

[0047] FIG. 5, being of an organic light-emitting device configured of a positive electrode / light-emitting layer (hole transporting polymer + electron transporting material + light-emitting material) / negative electrode, and FIG. 6, being of an organic light-emitting device configured of a positive electrode / hole injecting layer / light-emitting layer (hole transporting polymer + electron transporting material + light-emitting material) / negative electrode, represent energy diagrams and operating mechanisms thereof. As described above, when a voltage is applied to an organic light-emitting device, holes from the positive electrode and electrons from the negative electrode are injected into the light-emitting layer. More specifically, as depicted in FIG. 5, both carriers are injected into substances having a lower injection barrier, that is, holes are injected into the hole transporting polymer inside the light-emitting layer, and electrons are injected into the electron transporting material inside the light-emitting layer. Here, the lower the injection barrier for both carriers (holes and electrons), the more easily injection occurs, and the lower the driving voltage. Therefore, even if current efficiencies are the same, the power efficiency of light emission (efficiency of light emission relative to input power) can be improved by reducing the driving voltage. Therefore, for example, when a hole injecting layer having an ionization potential between the positive electrode and the hole transporting polymer is inserted, the hole injection barrier is relaxed, as depicted in FIG. 6, and the driving voltage can also be reduced. Furthermore, when the hole injection barrier is large compared to the electron injection barrier, as depicted in FIG. 5, by reducing the hole injection barrier, the balance between hole injection quantity and electron injection quantity improves, and as a result of effects such as those described above, current efficiency improvement can also be expected.

[0048] In addition, FIG. 7 is an energy diagram of an organic light-emitting device having the configuration: positive electrode / light-emitting layer (hole transporting polymer + electron transporting material + light-emitting material) / electron injecting layer / negative electrode. As with the hole injection barrier, the electron injection barrier can also be decreased, as depicted in FIG. 7, by inserting an electron injecting layer having a small electron affinity compared to the negative electrode, the driving voltage can be reduced, and light-emitting efficiency can be improved.

[0049] On the other hand, FIG. 8 is an energy diagram of an organic light-emitting device having the configuration: positive electrode / light-emitting layer (hole transporting polymer + hole transporting material + electron transporting material + light-emitting material) / negative electrode. In this case, since the ionization potential of the hole transporting material is less than that of the hole transporting polymer, holes are injected directly from the positive electrode into the hole transporting material inside the light-emitting layer, as depicted in the drawing, and the injection barrier decreases compared to when injected into the hole transporting polymer. Therefore, as in the case where a hole injecting layer is inserted, the driving voltage can be reduced, while at the same time, current efficiency improvement can also be expected.

[0050] Of course, configurations may also include incorporation of a configuration described above, that is, insertion of both a hole injecting layer and an electron injecting layer, further insertion of an electron injecting layer, with the light-emitting layer as: hole transporting polymer + hole transporting material + electron transporting material + light-emitting material, or the like.

[0051] Next, a more detailed description will be given based on a specific embodiment.

[0052] (Example 1) An organic light-emitting device having the configuration in FIG. 1 was fabricated as follows. For the substrate 1, a glass substrate having a thickness of 0.7 mm was used, and for the positive electrode 2 thereon, ITO was formed into a film by a sputtering method. The ITO film thickness was approximately 1,000 Å, with a sheet resistance of approximately 15 Ω/□, and was patterned into a desired shape by photolithography. For the light-emitting layer 3, poly-N-vinylcarbazole (PVK) (molecular weight of approximately 28,000) was used for the polymer 3A, tris(8-quinolinolato)aluminum (Alq₃) was used for the charge transporting material 3B, and Nile Red, a laser dye, was used for the light-emitting material 3C. PVK is a hole transporting polymer with a carrier mobility of approximately $2 \times 10^{-6} \text{ cm}^2/\text{V} \cdot \text{s}$. In addition, Alq₃ is an electron transporting material with a carrier mobility of approximately $2 \times 10^{-6} \text{ cm}^2/\text{V} \cdot \text{s}$. The mixing ratio of each material was: PVK:Alq₃:Nile Red = 100:60:0.2 (weight ratio). The light-emitting layer was formed by performing the following method. 300 mg of PVK, 180 mg of Alq₃, and 0.6 mg of Nile Red were dissolved in 30 mL of a 1:1 mixed solvent of toluene and chloroform, and the solution was stirred for one day. This solution was spin-coated onto the ITO-affixed glass substrate described above, which was cleaned and treated with oxygen plasma in advance, to obtain the light-emitting layer 3. The spin coating was performed using a spinner, in a sealed state, and under the conditions: 500 rpm for 10 seconds and 1,000 rpm for 30 seconds, then heat treatment was performed at 110° C for 1 minute using a hot plate. The film thickness of the light-emitting layer 3 was approximately 1,000 Å. Next, for the negative electrode 4, a Li/Al laminated electrode was formed into a film by a vacuum deposition method. The film was formed under a vacuum of approximately 5×10^{-6} Torr, where first, Li was deposited over 10 Å at a rate of approximately 0.5 Å/sec, then Al was deposited over 1,500 Å at approximately 30 Å/sec. For the shape of the negative electrode, a desired pattern was obtained using a mask.

[0053] On the other hand, with regard to the energy level of each material, the ionization potential of ITO is 4.9 eV, the ionization potential of PVK is 5.6 eV and the electron affinity is 2.0 eV, the ionization potential of Alq₃ is 5.7 eV and the electron affinity is 3.0 eV, the ionization potential of Nile Red is 5.3 eV and the electron affinity is 3.5 eV, the work function of Li is 2.9 eV, and the work function of Al is 4.3 eV.

[0054] When a voltage was applied to the organic light-emitting device fabricated in this manner in the direction depicted in FIG. 1, the device emitted orange light. The current efficiency (cd/A), driving voltage at a luminance of 100 cd/m², and power efficiency (lm/W) at a luminance of 100 cd/m² at this time are shown in Table 1.

[0055]

[Table 1]

	Current Efficiency (cd/A)	Driving Voltage (at 100 cd/m ²) (V)	Power Efficiency (at 100 cd/m ²) (lm/W)
Example 1	3.0	10.0	0.9
Example 2	4.0	8.0	1.6
Example 3	3.8	8.0	1.5
Example 4	4.0	7.6	1.7
Example 5	3.0	9.0	1.0
Example 6	3.1	9.0	1.1
Example 7	3.1	9.0	1.1
Example 8	4.0	8.0	1.6
Example 9	4.0	7.6	1.7
Comparative Example 1	0.4	20.0	0.06
Comparative Example 2	0.4	18.0	0.07

[0056] (Example 2) An organic light-emitting device having the configuration in FIG. 2 was fabricated and evaluated. The substrate 1, the positive electrode 2, the light-emitting layer 3, and the negative electrode 4 had the same configuration and thickness as in Example 1, and a commercially available polythiophene derivative was inserted as the hole injecting layer 5. The film of the hole injecting layer was formed using a spin coating method, as with the light-emitting layer, and made to a film thickness of 150 Å. The ionization potential of the polythiophene derivative used here is 5.3 eV. The evaluation results of this device are presented in Table 1.

[0057] (Example 3) For the hole injecting layer 5, in place of the polythiophene derivative in Example 2, a commercially available polyaniline derivative exhibiting an ionization potential equivalent to that of the polythiophene derivative was used. A film of the polyaniline derivative was formed in the same manner as in Example 2, and made to a film thickness of 150 Å. The evaluation results of this device are presented in Table 1.

[0058] (Example 4) For the hole injecting layer 5, in place of the polythiophene derivative in Example 2, an amorphous carbon was used. The amorphous carbon was formed by a sputtering method, and made to a film thickness of 100 Å. The ionization potential of amorphous carbon is 5.2 eV. The evaluation results of this device are presented in Table 1.

[0059] (Example 5) An organic light-emitting device having the configuration in FIG. 3 was fabricated and evaluated. The substrate 1, the positive electrode 2, and the light-emitting layer 3 had the same configuration and film thickness as in Example 1, and for the electron injecting layer 6 on the light-emitting layer, a film of dilithium phthalocyanine was formed, and furthermore, for the negative electrode 4, a film of Al was formed. The dilithium phthalocyanine and Al were

formed by a vacuum deposition method, wherein a film of the dilithium phthalocyanine was formed on the light-emitting layer 3 over 10 Å at a rate of approximately 0.3 Å/sec, after which a film of the Al was formed over 1,500 Å at approximately 30 Å/sec. The electron affinity of the dilithium phthalocyanine is 3.0 eV. The evaluation results of this device are presented in Table 1.

[0060] (Example 6) For the electron injecting layer 6, in place of the dilithium phthalocyanine in Example 5, disodium phthalocyanine, which exhibits an equivalent electron affinity as dilithium phthalocyanine, was used. A film of the disodium phthalocyanine was formed in the same manner as in Example 5, and made to a film thickness of 10 Å. The evaluation results of this device are presented in Table 1.

[0061] (Example 7) For the electron injecting layer 6, in place of the dilithium phthalocyanine in Example 5, 4,4,8,8-tetrakis(1H-pyrazol-1-yl)pyrazabole was used. A film of the 4,4,8,8-tetrakis(1H-pyrazol-1-yl)pyrazabole was formed in the same manner as in Example 5, and was made to a film thickness of 10 Å. The electron affinity of 4,4,8,8-tetrakis(1H-pyrazol-1-yl)pyrazabole is 2.3 eV. The evaluation results of this device are presented in Table 1.

[0062] (Example 8) An organic light-emitting device having the configuration in FIG. 4 was fabricated and evaluated. The substrate 1, the positive electrode 2, and the negative electrode 4 had the same configuration and thickness as in Example 1. For the light-emitting layer 3, PVK was used for the polymer 3A, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD) was used for the hole transporting material 3D, Alq₃ was used for the electron transporting material 3E, and Nile Red was used for the light-emitting material 3C. The ionization potential of the TPD is 5.4 eV. The mixing ratio of each material was: PVK:Alq₃:TPD:Nile Red = 100:60:80:0.2 (weight ratio).

The light-emitting layer was formed by dissolving 300 mg of PVK, 180 mg of Alq₃, 240 mg of TPD, and 0.6 mg of Nile Red in 50 mL of a 1:1 mixed solvent of toluene and chloroform, stirring the solution for one day, then spin-coating the solution onto the ITO-affixed glass substrate in the same manner as in Example 1. The film thickness of the light-emitting layer 3 was approximately 1,000 Å.

Furthermore, a Li/Al-laminated electrode was vacuum-deposited thereon as the negative electrode 4 in the same manner as in (Example 1). The evaluation results of this device are presented in Table 1.

[0063] (Example 9) An device was fabricated in which both a hole injecting layer and an electron injecting layer were inserted. In other words, formation from the bottom was: substrate / positive electrode / hole injecting layer / light-emitting layer / electron injecting layer / negative electrode, wherein, the hole injecting layer was formed of the polythiophene derivative, and the electron injecting layer was formed of the dilithium phthalocyanine, each using the same fabrication methods and film thicknesses as in Example 2 and Example 5. The light-emitting layer had the same configuration as in Example 1, and for the negative electrode, Al was formed over 1,500 Å. The evaluation results of this device are presented in Table 1.

[0064] (Comparative Example 1) An organic light-emitting device similar to that of Example 1 was fabricated, differing from the configuration in FIG. 1 in that the light-emitting layer was configured only of PVK and Nile Red, and otherwise being the same. The evaluation results of this device are presented in Table 1.

[0065] (Comparative Example 2) An organic light-emitting device similar to that of Example 1 was fabricated, differing from the configuration in FIG. 1 in that the light-emitting layer was configured of PVK, TPD, and Nile Red, and otherwise being the same. TPD exhibits hole transporting properties, but extremely low electron transporting properties. The evaluation results of this device are presented in Table 1.

[0066] In contrast to Comparative Examples 1 and 2, in which a charge transporting material having a high electron transporting capacity was not included, when Alq₃, which has a high electron mobility of approximately $2 \times 10^{-6} \text{ cm}^2/\text{V}\cdot\text{s}$, was included, current efficiency was able to be significantly improved, as depicted in Example 1. In addition, as depicted in Examples 2 to 9, by inserting a hole injecting layer or an electron injecting layer, or by introducing a hole transporting material inside the light-emitting layer to assist in hole injection, further driving voltage reduction and power efficiency improvement were able to be achieved.

[0067]

EFFECTS OF THE INVENTION

As described above, according the organic light-emitting

device of the present invention, the light-emitting layer includes a charge transporting material, a light-emitting material, and a polymer for dispersing these materials, and by having specific carrier transporting properties or ionization potentials, these materials allowing holes and electrons to flow inside the light-emitting layer in a balanced manner, is therefore capable of improving light-emitting efficiency.

[0068] In addition, by inserting a hole injecting layer or an electron injecting layer, or by introducing a hole transporting material into the light-emitting layer to assist in hole injection, the hole or electron injection barrier is relaxed, and further driving voltage reduction and light-emitting efficiency improvement can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[FIG. 1] A cross-sectional view of an organic light-emitting device according to the first example of the present invention.

[FIG. 2] A cross-sectional view of an organic light-emitting device according to the second example of the present invention.

[FIG. 3] A cross-sectional view of an organic light-emitting device according to the third example of the present invention.

[FIG. 4] A cross-sectional view of an organic light-emitting device according to the fourth example of the present invention.

[FIG. 5] A figure depicting an energy diagram of the organic light-emitting device of the first example of the present invention.

[FIG. 6] A figure depicting an energy diagram of the organic light-emitting device of the second example of the present invention.

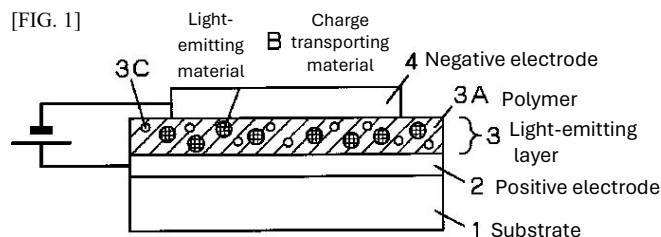
[FIG. 7] A figure depicting an energy diagram of the organic light-emitting device of the third example of the present invention.

[FIG. 8] A figure depicting an energy diagram of the organic light-emitting device of the fourth example of the present invention.

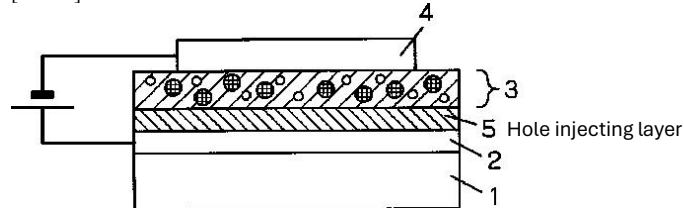
DESCRIPTION OF REFERENTIAL NUMERICALS

1. Substrate
2. Positive electrode
3. Light-emitting layer
 - 3A. Polymer
 - 3B. Charge transporting material
 - 3C. Light-emitting material
 - 3D. Hole transporting material
 - 3E. Electron transporting material
4. Negative electrode
5. Hole injecting layer
6. Electron injecting layer

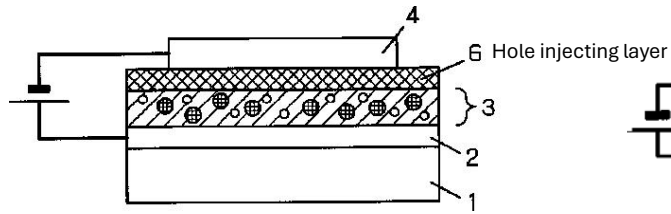
[FIG. 1]



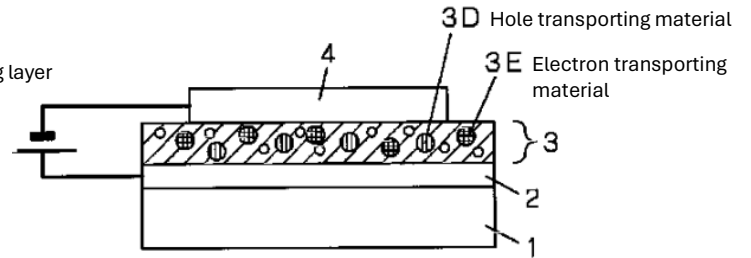
[FIG. 2]



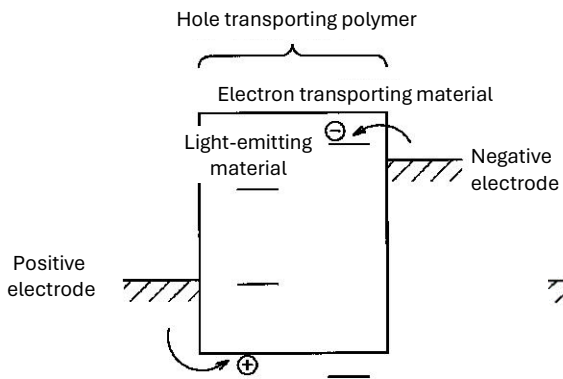
[FIG. 3]



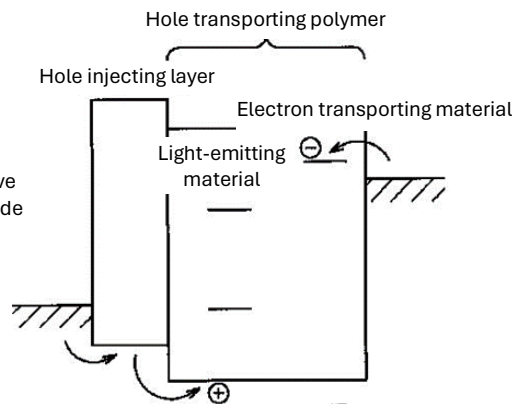
[FIG. 4]



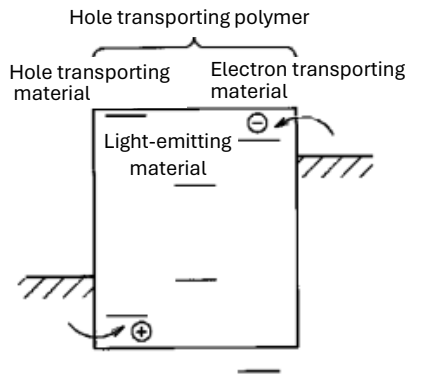
[FIG. 5]



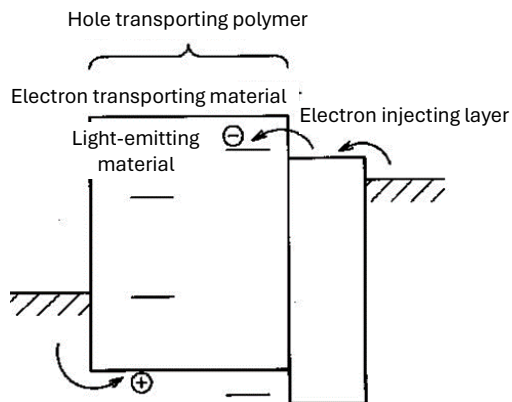
[FIG. 6]



[FIG. 8]



[FIG. 7]



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