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ORGANIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE

Abstract

An organic compound represented by formula [1-1] or [1-2]:

##STR00001##

where R.sub.1 to R.sub.20 are each independently selected from a hydrogen atom, a halogen atom, an alkyl group, an alkoxy group, an amino group, an aromatic hydrocarbon group, a heterocyclic group, an aryloxy group, a silyl group, and a cyano group, in which at least one of R.sub.1 to R.sub.4 and R6 to R.sub.9 and at least one of R.sub.11 to R.sub.14 and R.sub.16 to R.sub.19 are amino groups; and X.sub.1 to X.sub.4 are each oxygen, sulfur, selenium, or tellurium and are optionally the same or different.

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Background/Summary

CROSS REFERENCE OF RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 17/519,369, filed Nov. 4, 2021 which claims the benefit of Japanese Patent Application No. 2020-187223, filed Nov. 10, 2020, all of which are hereby incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present disclosure relates to an organic compound and an organic light-emitting device containing the organic compound.

Description of the Related Art

[0003] Organic light-emitting devices (hereinafter, also referred to as “organic electroluminescent devices” or “organic EL devices”) are electronic devices each including a pair of electrodes and an organic compound layer disposed between these electrodes. The injection of electrons and holes from these pairs of electrodes generates excitons in the light-emitting organic compound in the organic compound layer, and when the excitons return to the ground state, the organic light-emitting device emits light.

[0004] Recently, organic light-emitting devices have made remarkable progress and have achieved low-driving voltage, various emission wavelengths, and fast response time. The use thereof has enabled the development of thinner and lighter light-emitting apparatuses.

[0005] Regarding the improvement of the efficiency of light-emitting devices, devices containing high-efficiency materials, such as phosphorescent materials and delayed fluorescent materials, have been reported.

[0006] Journal of the Chemical Society (1953), 2434-9 (NPL 1) describes compound 1-a below. Journal of Organic Chemistry (1962), 27, 1211-16 (NPL 2) describes compound 1-b below. Justus Liebigs Annalen der Chemie (1934), 513, 156-79 (NPL 3) describes compound 2-a below.

##STR00002##

[0007] When compounds 1-a, 1-b, and 2-a described in NPLs 1 to 3 are used for light-emitting layers of organic light-emitting devices, there is a disadvantage with luminous efficiency.

SUMMARY OF THE INVENTION

[0008] The present disclosure has been accomplished in light of the foregoing disadvantage. The present disclosure provides an organic compound and an organic light-emitting device that have excellent luminous efficiency. The present disclosure also provides an organic light-emitting device excellent in driving durability characteristics.

[0009] According to one aspect of the present disclosure, there is provided an organic compound

represented by formula [1-1] or [1-2]:

##STR00003##

where in formula [1-1] or [1-2], R.sub.1 to R.sub.20 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted alkoxy group, a substituted or unsubstituted amino group, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted heterocyclic group, a substituted or unsubstituted aryloxy group, a silyl group, and a cyano group, in which at least one of R.sub.1 to R.sub.4 and R.sub.6 to R.sub.9 and at least one of R.sub.11 to R.sub.14 and R.sub.16 to R.sub.19 are substituted or unsubstituted amino groups, and groups bonded to nitrogen atoms of the substituted or unsubstituted amino groups are optionally taken together to form a ring structure; and X.sub.1 to X.sub.4 are each oxygen, sulfur, selenium, or tellurium and are optionally the same or different.

[0010] Further features of the present disclosure will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 illustrates molecular models of HOMO distributions and LUMO distributions of exemplified compounds, and energy differences between Si and Ti levels thereof.

[0012] FIG. 2 illustrates molecular models when viewed in molecular plane directions and in the directions perpendicular to the molecular plane directions.

[0013] FIG. 3 is a schematic cross-sectional view of an example of a display apparatus including organic light-emitting devices according to an embodiment of the present disclosure.

[0014] FIG. 4 is a schematic view of an example of a display apparatus according to an embodiment of the present disclosure.

[0015] FIG. 5A is a schematic view of an example of an image pickup apparatus according to an embodiment of the present disclosure, and FIG. 5B is a schematic view of an example of an electronic apparatus according to an embodiment of the present disclosure.

[0016] FIG. 6A is a schematic view of an example of a display apparatus according to an embodiment of the present disclosure, and FIG. 6B is a schematic view of an example of a foldable display apparatus according to an embodiment of the present disclosure.

[0017] FIG. 7A is a schematic view of an example of a lighting device according to an embodiment of the present disclosure, and FIG. 7B is a schematic view of an example of an automobile including an automotive lighting unit according to an embodiment of the present disclosure.

[0018] FIG. 8 is a schematic view of an example of an image-forming apparatus according to an embodiment of the present disclosure.

[0019] FIGS. 9A and 9B are schematic views of examples of an exposure light source for an image-forming apparatus according to an embodiment of the present disclosure.

[0020] FIG. 10A is a schematic view of an example of a wearable device according to an embodiment of the present disclosure, and FIG. 10B is a schematic view of an example of a wearable device according to an embodiment of the present disclosure, the wearable device including an image pickup device.

DESCRIPTION OF THE EMBODIMENTS

Organic Compound

[0021] An organic compound according to an embodiment will be described. The organic compound according to this embodiment is represented by formula [1-1] or [1-2].

##STR00004##

R.SUB.1 .to R.SUB.20

[0022] R.sub.1 to R.sub.20 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted alkoxy group, a substituted or unsubstituted amino group, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted heterocyclic group, a substituted or unsubstituted aryloxy group, a silyl group, and a cyano group, in which at least one of R.sub.1 to R.sub.4 and R.sub.6 to R.sub.9 and at least one of R.sub.11 to R.sub.14 and R.sub.16 to R.sub.19 are substituted or unsubstituted amino groups, and groups bonded to nitrogen atoms of the substituted or unsubstituted amino groups may be taken together to form a ring structure.

[0023] Non-limiting examples of the halogen atom include fluorine, chlorine, bromine, and iodine.

[0024] Non-limiting examples of the alkyl group include a methyl group, an ethyl group, a n-propyl group, an isopropyl group, a n-butyl group, a tert-butyl group, a sec-butyl group, an octyl group, a cyclohexyl group, a 1-adamantyl group, and a 2-adamantyl group. As the alkyl group, an alkyl group having 1 to 10 carbon atoms can be used.

[0025] Non-limiting examples of the alkoxy group include a methoxy group, an ethoxy group, a propoxy group, a 2-ethyloctyloxy group, and a benzyloxy group. As the alkoxy group, an alkoxy group having 1 to 10 carbon atoms can be used.

[0026] Non-limiting examples of the amino group include an N-methylamino group, an N-ethylamino group, an N,N-dimethylamino group, an N,N-diethylamino group, an N-methyl-N-ethylamino group, an N-benzylamino group, an N-methyl-N-benzylamino group, an N,N-dibenzylamino group, an anilino group, an N,N-diphenylamino group, an N,N-dinaphthylamino group, an N,N-difluorenylamino group, an N-phenyl-N-tolylamino group, an N,N-ditolylamino group, an N-methyl-N-phenylamino group, an N,N-dianisylamino group, an N-mesityl-N-phenylamino group, an N,N-dimesitylamino group, an N-phenyl-N-(4-tert-butylphenyl)amino group, an N-phenyl-N-(4-trifluoromethylphenyl)amino group, an N-piperidyl group, a carbazolyl group, and an acridyl group.

[0027] Examples of the amino group include amino groups each having any of structures illustrated below. In the following structural formulae, each * represents a binding position.

##STR00005## ##STR00006## ##STR00007## ##STR00008##

[0028] Non-limiting examples of the aromatic hydrocarbon group include a phenyl group, a naphthyl group, an indenyl group, a biphenyl group, a terphenyl group, a fluorenyl group, a phenanthryl group, a triphenylenyl group, a pyrenyl group, an anthracenyl group, a perylenyl group, a chrysenyl group, and a fluoranthenyl group. As the aromatic hydrocarbon group, an aromatic hydrocarbon group having 6 to 60 carbon atoms can be used.

[0029] Non-limiting examples of the heterocyclic group include a pyridyl group, a pyrimidyl group, a pyrazinyl group, a triazinyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, an oxazolyl group, an oxadiazolyl group, a thiazolyl group, a thiadiazolyl group, a carbazolyl group, an acridinyl group, and a phenanthrolinyl group. As the heterocyclic group, a heterocyclic group having 3 to 60 carbon atoms can be used.

[0030] A non-limiting example of the aryloxy group is a phenoxy group.

[0031] Non-limiting examples of the silyl group include a trimethylsilyl group and a triphenylsilyl group.

[0032] Non-limiting examples of substituents that may be further contained in the alkyl group, the alkoxy group, the amino group, the aromatic hydrocarbon group, the heterocyclic group, and the aryloxy group include alkyl groups, such as a methyl group, an ethyl group, a n-propyl group, an isopropyl group, a n-butyl group, and a tert-butyl group; aralkyl groups, such as a benzyl group; aromatic hydrocarbon groups, such as a phenyl group, a biphenyl group, and a naphthyl group; heterocyclic groups, such as a pyridyl group, a pyrrolyl group, a pyrazinyl group, and a triazinyl group; amino groups, such as a dimethylamino group, a diethylamino group, a dibenzylamino group, a diphenylamino group, and a ditolylamino group; alkoxy groups, such as a methoxy group, an ethoxy group, and a propoxy group; alkoxy groups, such as a methoxy group, an ethoxy group,

and a propoxy group; aryloxy groups, such as a phenoxy group; halogen atoms, such as fluorine, chlorine, bromine, and iodine atoms; and a cyano group.

X.SUB.1 .to X.SUB.4

[0033] X.sub.1 to X.sub.4 are each oxygen, sulfur, selenium, or tellurium and may be the same or different. In the organic compound according to the embodiment, the chalcogen atom in the basic skeleton has lone pairs and is effective in enhancing the stability of the fused-ring basic skeleton. Thus, when the organic compound according to the embodiment is used for an organic light-emitting device, good durability characteristics can be provided. The basic skeleton according to the embodiment refers to a skeleton in which R.sub.1 to R.sub.20 of the compound represented by formula [1-1] or [1-2] are all hydrogen atoms.

[0034] Examples of the organic compound according to the embodiment include organic compounds represented by formulae [2-1] and [2-2] below, organic compounds represented by formulae [3-1] and [3-2] below, organic compounds represented by formulae [4-1] and [4-2], and organic compounds represented by formulae [5-1] and [5-2].

##STR00009##

[0035] In formula [2-1] or [2-2], R.sub.21 to R.sub.24 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group. R.sub.21 and R.sub.22, or R.sub.23 and R.sub.24 may be taken together to form a ring structure.

##STR00010##

[0036] In formula [3-1] or [3-2], R.sub.25 to R.sub.28 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group. R.sub.25 and R.sub.26, or R.sub.27 and R.sub.28 may be taken together to form a ring structure.

##STR00011##

[0037] In formula [4-1] or [4-2], R.sub.29 to R.sub.32 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group. R.sub.29 and R.sub.30, or R.sub.31 and R.sub.32 may be taken together to form a ring structure.

##STR00012##

[0038] In formula [5-1] or [5-2], R.sub.33 to R.sub.36 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group. R.sub.33 and R.sub.34, or R.sub.35 and R.sub.36 may be taken together to form a ring structure.

[0039] Specific examples of the halogen atom, the alkyl group, the aromatic hydrocarbon group, and the heterocyclic group that are represented by R.sub.21 to R.sub.36 are, but not limited to, the same as those described for R.sub.1 to R.sub.20. As the alkyl group, an alkyl group having 1 to 10 carbon atoms can be used. As the aromatic hydrocarbon group having 6 to 60 carbon atoms can be used. As the heterocyclic group, a heterocyclic group having 3 to 60 carbon atoms can be used. Specific examples of substituents that may further be contained in the alkyl group, the aromatic hydrocarbon group, and the heterocyclic group are, but not limited to, the same as those described for R.sub.1 to R.sub.20.

[0040] A method for synthesizing an organic compound according to the embodiment of the present disclosure will be described below. The organic compound according to the embodiment of the present disclosure is synthesized, for example, by a reaction scheme described below.

##STR00013##

[0041] Here, each of the compounds represented by formulae [1-1] and [1-2] can be synthesized by appropriately changing compounds (a) to (c). The synthesis method is not limited thereto.

[0042] The organic compound according to the embodiment has features described below. The use of the organic compound according to the embodiment for an organic light-emitting device allows

the organic light-emitting device to have high luminous efficiency and excellent driving durability characteristics. The following is an explanation of the features of this embodiment using exemplified compounds AA1, AB1, AC1, AD1, BA1, BB1, BC1, and BD1 in comparison with comparative compounds 1-a described in Non-Patent Literature 1, comparative compounds 1-b described in Non-Patent Literature 2, and comparative compounds 2-a described in Non-Patent Literature 3. [0043] (1) A fused-ring skeleton contains, as a basic skeleton, five 6-membered rings, and contains two electron-withdrawing carbonyl groups and at least one electron-donating amino group, so that the energy gap between S1 and T1 is small.

[0044] For excitons consisting of singlet and triplet excitons in a ratio of 1:3, the triplet excitons, which undergo thermal deactivation normally, can be used for delayed fluorescence from the excited singlet state due to the small energy difference between the excited singlet state S1 and the excited triplet state T1. For reverse intersystem crossing to convert the triplet excitons into the excited singlet state, a smaller energy difference between S1 and T1 is advantageous because of a smaller energy barrier. The compound according to the embodiment is advantageous for that condition. Thus, the device having high luminous efficiency can be provided.

[0045] The inventors have focused on the electron distribution of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of the compound represented by formula [1-1] or [1-2] in creating the organic compound.

[0046] As presented in FIG. 1, in each of exemplified compounds AA1, AB1, AC1, BA1, BB1, and BC1 according to the embodiment, a moiety occupying the electron orbital distribution of HOMO and a moiety occupying the electron orbital distribution of LUMO are separated. It can be seen that there are only a few portions where the HOMO and LUMO overlap. This leads to a small overlap integral and a small energy difference between S1 and T1.

[0047] The above feature is the effect due to the fact that the fused-ring skeleton contains, as a basic skeleton, five 6-membered rings, and contains two electron-withdrawing carbonyl groups and at least one electron-donating amino group. The basic skeleton has the fused-ring structure containing five 6-membered rings and having a strong electron-withdrawing ability because of the presence of two carbonyl groups. Thus, the HOMO on the amino substituent and the LUMO on the basic skeleton are spatially separated. The LUMO extending over the entire fused-ring structure is also effective in stabilizing excitons in the excited state. Accordingly, the use of the organic compound for a light-emitting layer of an organic light-emitting device improves the durability characteristics.

[0048] For structures that are not substituted with amino groups, such as comparative compounds 1-a and 1-b, the HOMO and the LUMO are not separated. This results in a large energy difference between S1 and T1.

[0049] In a structure substituted with an amino group between the two carbonyl groups, such as comparative compound 2-a, the HOMO and the LUMO are close to each other, leading to a low degree of separation. This results in a large energy difference between S1 and T1. That is, the introduction of an amino group into R.sub.5, R.sub.10, R.sub.15, or R.sub.20 in formula [1-1] or [1-2] decreases the efficiency. Regarding the above effects, a comparison of the E.Q.E. of the organic light-emitting devices given in Examples (Table 8) also indicates that exemplified compounds BA1, BB1, and BC1 according to the embodiment have higher efficiency than comparative compounds 1-a, 1-b, and 2-a.

[0050] As described above, the compounds represented by formulae [1-1] and [1-2] are characterized by small energy differences between S1 and T1, and thus can provide light-emitting devices with high efficiency, compared with the cases where comparative compounds 1-a, 1-b, and 2-a are used for light-emitting devices.

[0051] The above electron orbital distributions of the HOMO and the LUMO and the energies of S1 and T1 were visualized using molecular orbital calculations. As the molecular orbital calculation method, the density functional theory (DFT), which is widely used at present, was used with the

B3LYP functional and 6-31G* as the basis function. The molecular orbital calculation method was performed using Gaussian 09 (Gaussian 09, Revision C.01, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, T. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J. M. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, O. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski, and D. J. Fox, Gaussian, Inc., Wallingford CT, 2010), which is widely used at present. In this specification, hereinafter, the same method is employed for molecular orbital calculations. [0052] (2) The presence of an amino group results in a low molecular aspect ratio and reduced molecular association.

[0053] A high degree of flatness easily causes molecular stacking. In other words, molecular association may occur easily. In organic light-emitting devices, molecular association leads to a decrease in efficiency due to concentration quenching. It is also disadvantageous for reverse intersystem crossing. This is because triplet-triplet exciton annihilation (TTA) due to energy transfer of triplet excitons between molecules occurs easily, and reverse intersystem crossing to singlet excitons does not easily occur.

[0054] The inventors have focused on the flatness of the compound represented by the formula [1-1] or [1-2] in creating the organic compound. The basic skeleton of the compound according to the embodiment has a structure in which an electron-withdrawing carbonyl group is fused to a five-membered ring, and thus the structure has a high degree of flatness. The inventors have found that, for example, an amino group is introduced as a substituent. The introduction of an amino group can reduce the molecular aspect ratio and the molecular association.

[0055] The molecular aspect ratio used in the embodiment is defined as the ratio of the maximum molecular length (molecular diameter) in the xy-plane containing the basic skeleton to the molecular length (molecular thickness) in the z-axis direction perpendicular to the xy-plane containing this basic skeleton, i.e., $\text{molecular aspect ratio} = (\text{molecular diameter}) / (\text{molecular thickness})$. In other words, a higher molecular aspect ratio results in a higher degree of flatness. A lower molecular aspect ratio results in a lower degree of flatness and can reduce molecular association. Specifically, the molecular aspect ratio is preferably 5.0 or less, more preferably 3.0 or less. The molecular lengths of the molecular diameters and the molecular thicknesses were calculated from the molecular lengths in ball-and-bond representations using molecular structures determined from optimized structure calculations.

[0056] FIG. 2 presents the comparison results of the molecular aspect ratios. FIG. 2 indicates that the molecular aspect ratios of exemplified compounds AA1, AB1, and BC1 according to the embodiment are 1.7, 2.7, and 2.4, respectively, whereas the molecular aspect ratios of comparative compounds 1-a and 1-b are as high as 7.2 and 6.2, respectively. This is because each of exemplified compounds AA1, AB1, and BC1 has an amino group. As described above, since the compound according to the embodiment has a low molecular aspect ratio, molecular stacking is less likely to occur, and thus molecular association is less likely to occur.

[0057] The above feature is also effective in improving the amorphous nature of the organic compound. In the case where the compound according to the embodiment is used in the organic layer of an organic light-emitting device, a stable amorphous film that is less likely to crystallize is formed, and the organic light-emitting device has high durability without the occurrence of crystallization even in the case of long-term operation.



[0058] The above feature is also effective in improving sublimability. The improvement of


sublimability enables the purification of the material by sublimation and the production of an organic light-emitting device by vapor deposition. This can reduce the amount of impurities contained in the organic light-emitting device and can inhibit deteriorations in luminous efficiency and driving durability due to impurities.

[0059] The characteristics of the position of the amino group of the organic compound according to the embodiment will be described below in comparison with comparative compound 2-a with reference to Table 1. Table 1 presents S1 and T1 energy levels, the energy differences between S1 and T1 levels, and the LUMO levels calculated by the molecular orbital calculations of exemplified compounds AA1, AB1, AC1, AD1, BA1, BB1, BC1, and BD1, and comparative compound 2-a.


TABLE-US-00001 TABLE 1 Energy difference S1 T1 between LUMO calc. calc. S1 and calc.


Compound Structure (eV) (eV) T1 (eV) (eV) Exemplified compound AA1 [00014]


 2.45 2.37 0.08 -2.59 Exemplified compound AB1 [00015] 


2.71 2.52 0.19 -2.56 Exemplified compound AC1 [00016] 


Exemplified compound AD1 [00017] 

2.24 2.15 0.09 -2.57 Exemplified compound BA1 [00018] 

2.83 2.73 0.10 -2.28 Exemplified compound BB1 [00019] 

3.01 2.74 0.27 -2.25 Exemplified compound BC1 [00020] 

2.72 2.57 0.15 -2.30 Exemplified compound BD1 [00021] 

2.47 2.35 0.12 -2.26 Comparative compound 2-a [00022] 

2.00 1.43 0.57 -2.42

[0060] Comparative compound 2-a has an S1 energy level of 2.00 eV and emits light with a significantly longer wavelength; thus, the compound cannot be used as a light-emitting material that emits light with a shorter wavelength than red, for example, as a green light-emitting material.

In the case of using comparative compound 2-a as a host or an assist in a light-emitting device, the low S1 energy level also limits the energy transfer to the red light-emitting material. In other

words, the efficiency is reduced. When comparative compound 2-a is used especially in the light-emitting layer of a light-emitting device, the compound easily acts as a quencher because the N—H

group easily releases a proton. In contrast, exemplified compounds AA1, AB1, AC1, AD1, BA1, BB1, BC1, and BD1 contain no N—H group in their molecules and thus allow the devices to have

excellent durability characteristics. As described above, the introduction of an amino group into the compound represented by formula [1-1] or [1-2] at the position of R.sub.5, R.sub.10, R.sub.15, or

R.sub.20 deteriorates both the efficiency and the device durability. [0061] (3) The inventors have

found that the compound represented by formula [2-1] or [2-2], where R.sub.1, R.sub.6, R.sub.11, or R.sub.19 is an amino group, has a smaller energy difference between S1 and T1, as presented in

Table 1. When R.sub.1, R.sub.6, R.sub.11, or R.sub.19 is an amino group, a smaller energy

difference between S1 and T1 is obtained. Accordingly, among the organic compounds according

to the embodiment, the use of this compound in an organic light-emitting device can result in high

luminous efficiency. [0062] (4) The inventors have found that the compound represented by

formula [3-1] or [3-2], where R.sub.2, R.sub.7, R.sub.12, or R.sub.18 is an amino group, has a

higher S1 level as presented in Table 1. Accordingly, the compound can be suitably used for blue to

green organic light-emitting devices. [0063] (5) The inventors have found that the compound

represented by formula [4-1] or [4-2], where R.sub.4, R.sub.9, R.sub.14, or R.sub.16 is an amino

group, has an even higher S1 level as presented in Table 1. Accordingly, the compound can be

suitably used for green to red organic light-emitting devices. [0064] (6) The compound represented

by formula [5-1] or [5-2], where R.sub.3, R.sub.8, R.sub.13, or R.sub.17 is an amino group, can

have a lower LUMO level as presented in Table 1. For example, when this compound is used as a

light-emitting material in an organic light-emitting device, this compound has a low LUMO level

(far from the vacuum level) and thus can trap more electrons to confine charges in the light-

emitting layer, thus improving the luminous efficiency and the device durability lifetime. The

reason for this is that the position of the electron-withdrawing carbonyl group is located at the

meta-position with respect to the position of the electron-donating amino group and thus the

carbonyl group responsible for the LUMO is less affected by the electron-donating amino group.

[0065] Furthermore, the compound according to the embodiment can be used in the light-emitting layer of an organic light-emitting device. In this case, the compound has the following features. [0066] (7) The compound according to the embodiment is mixed with a host material in the light-emitting layer to facilitate exciton recombination of the compound according to the embodiment, thereby providing the light-emitting device with high efficiency. [0067] (8) The mixture of the compound according to the embodiment and the host material in the light-emitting layer and the presence of a light-emitting material provide the light-emitting device with high efficiency and high color purity. [0068] (9) The use of a hydrocarbon compound as the light-emitting material provides the light-emitting device with high efficiency and good durability characteristics. Features (7) to (9) above will be described below. (7) The compound according to the embodiment is mixed with a host material in the light-emitting layer to facilitate exciton recombination of the compound according to the embodiment, thereby providing the light-emitting device with high efficiency. [0069] The compound according to the embodiment is a compound containing an electron-withdrawing carbonyl group and an electron-donating amino group. When the compound according to the embodiment is mixed with the host material in the light-emitting layer of the organic light-emitting device, the light-emitting layer is an electron-trapping light-emitting layer due to the contribution of the electron-withdrawing properties or a hole-trapping light-emitting layer due to the contribution of the electron-donating properties.

[0070] Accordingly, in the light-emitting layer, electrons or holes fed from a transport layer are trapped by the compound according to the embodiment, and exciton recombination occurs. As described in feature (1) above, the compound according to the embodiment has a small energy difference between S1 and T1, can efficiently produce delayed fluorescence in the light-emitting layer, and can use a larger number of triplet excitons for light emission.

[0071] In particular, when the host material is a hydrocarbon compound, the LUMO level of the compound according to the embodiment tends to be lower (farther from the vacuum level) than that of the host material, or the HOMO level of the compound according to the embodiment tends to be higher (closer to the vacuum level) than that of the host material. For this reason, electrons or holes are more easily trapped, resulting in higher efficiency. The hydrocarbon compound is a compound that consists of only carbon and hydrogen in its molecule.

[0072] As described in feature (2) above, the compound according to the embodiment is less likely to undergo molecular association, and thus is less likely to undergo concentration quenching in the host material. This effect leads to the prevention of quenching due to exciton interaction when the compound according to the embodiment is in the excited state, and is effective in efficiently producing delayed fluorescence in the light-emitting layer. [0073] (8) The mixture of the compound according to the embodiment and the host material in the light-emitting layer and the presence of a light-emitting material provide the light-emitting device with high efficiency and high color purity. [0074] The use of the light-emitting layer that contains the compound according to the embodiment and that is doped with a light-emitting material having a high emission quantum yield or doped with a light-emitting material whose emission spectrum has a spectrum suitable for exhibiting high color purity provides a light-emitting device having even higher efficiency and high color purity. In this case, the compound according to the embodiment needs to be contained in a concentration sufficient to preferentially trap electrons and holes in the light-emitting layer in order to facilitate exciton recombination. The concentration of the organic compound according to the embodiment in the light-emitting layer is preferably 0.1% or more and 45% or less, more preferably 1% or more and 30% or less, based on the entire light-emitting layer.

[0075] The light-emitting material having a smaller doping concentration is less susceptible to the influence of concentration quenching and a change in emission spectrum due to the intermolecular interaction. Thus, the light-emitting layer can be doped with the light-emitting material other than the compound according to the embodiment. The concentration of the light-emitting material is preferably 0.01% or more and 20% or less, more preferably 1% or more and 15% or less based on

the entire light-emitting layer. Accordingly, it is possible to provide the light-emitting device with high efficiency and high color purity. [0076] (9) The use of a hydrocarbon compound as the light-emitting material provides the light-emitting device with high efficiency and good durability characteristics.

[0077] The compound according to the embodiment contains a strong electron-withdrawing carbonyl group. Because of this, as a light-emitting material serving as a dopant described in feature (8) above, a light-emitting material that does not contain an electron-donating amino group can be used, and a hydrocarbon compound can be used. The reason for this is that an amino group-containing light-emitting material may interact with the carbonyl group of the compound according to the embodiment in the light-emitting layer to cause a decrease in luminous efficiency due to exciplex formation and a change in the emission spectrum of the light-emitting material, thereby deteriorating the color purity of the light-emitting device.

[0078] An amino group-containing light-emitting material is easily oxidized due to its low ionization potential and thus has poor device durability. For this reason, a hydrocarbon compound can be used as a light-emitting material, and a five-membered ring-containing fused polycyclic compound can be used. This is because the structure is less susceptible to oxidation due to its higher ionization potential. The hydrocarbon compound is a compound consisting of only carbon and hydrogen in its molecule.

[0079] As described above, the high-efficiency organic light-emitting device can be provided by mixing the compound according to the embodiment with the host material in the light-emitting layer. Here, the light-emitting material may be the compound according to the embodiment. In addition, a light-emitting material may be mixed, and the compound according to the embodiment may function as an assist material. The use of a light-emitting material with good color purity makes it possible to provide an organic light-emitting device with high efficiency and high color purity. When the host material is a hydrocarbon compound, the compound according to the embodiment can easily trap electrons and holes to contribute to higher efficiency.

[0080] Specific examples of the organic compound according to the embodiment are illustrated below. However, the present disclosure is not limited thereto.

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

[0081] Compounds belonging to group AA, and CA1 and CA2 are each a compound represented by formula [2-1]. Compounds belonging to group BA, and DA1 and DA2 are each a compound represented by formula [2-2]. As described above, these compounds have small energy differences between S1 and T1 among the compounds according to the embodiment. Thus, for example, when these compounds are used for organic light-emitting devices, these devices can each have high luminous efficiency.

[0082] Compounds belonging to group AB (excluding AB19 or AB21) are each a compound represented by formula [3-1]. Compounds belonging to group BB (excluding BB19) are each a compound represented by formula [3-2]. As described above, these compounds have high S1 energy levels among the compounds according to the embodiment. Thus, for example, when these compounds are used for organic light-emitting devices, these devices can emit blue to green light.

[0083] Compounds belonging to group AD are each a compound represented by formula [4-1]. Compounds belonging to group BD are each a compound represented by formula [4-2]. As described above, these compounds have low S1 energy levels among the compounds according to the embodiment. Thus, for example, when these compounds are used for organic light-emitting

devices, these devices can emit green to red light.

[0084] Compounds belonging to group AC, and CCI are each a compound represented by formula [5-1]. Compounds belonging to group BC, and DC1 are each a compound represented by formula [5-2]. As described above, these compounds have low LUMO levels among the compounds according to the embodiment. Thus, for example, when these compounds are used for organic light-emitting devices, these devices can good durability characteristics.

[0085] AA1 to AA8, AA10 to AA24, AA32, AB1 to AB12, AB19, AB20, AC1 to AC12, AC20, AD1 to AD10, BA1 to BA8, BA10 to BA24, BA32, BB1 to BB12, BB19, BB20, BC1 to BC12, and BD1 to BD10 are each a compound represented by formula [1-1] or [1-2] where X is oxygen. Since X is oxygen, a chemical reaction, such as oxidation, does not easily occur; thus, these chemically stable compounds are provided.

[0086] AA25, AA28 to AA31, AB13, AB16 to AB18, AC13, AC16, AC17, AC19, AD11, AD12, BA25, BA28 to BA30, BB13, BB16 to BB18, BC13, BC16, BC17, BC19, BD11, and BD12 are each a compound represented by formula [1-1] or [1-2] where at least one X is sulfur. Since the at least one X is sulfur, the six-membered ring formed has a distorted structure because the elemental radius of sulfur is larger than that of oxygen, leading to a low degree of flatness of the molecule. Thus, the concentration quenching is even less likely to occur.

[0087] AA26, AA27, AB14, AB15, AC14, AC15, AC18, BA26, BA27, BB14, BB15, BC14, BC15, and BC18 are each a compound represented by formula [1-1] or [1-2] where at least one X is selenium or tellurium. When X is selenium or tellurium, each of the elements has a d-orbital and metallic properties. Thus, these compounds have high electron mobility.

Organic Light-Emitting Device

[0088] The organic light-emitting device according to the embodiment will be described below.

[0089] The organic light-emitting device according to the embodiment at least includes an anode and a cathode, which are a pair of electrodes, and an organic compound layer disposed between these electrodes. In the organic light-emitting device according to the embodiment, the organic compound layer may be formed of a single layer or a multilayer stack including multiple layers, as long as it includes a light-emitting layer. In the case where the organic compound layer is formed of a multilayer stack including multiple layers, the organic compound layer may include, in addition to the light-emitting layer, a hole injection layer, a hole transport layer, an electron-blocking layer, a hole/exciton-blocking layer, an electron transport layer, an electron injection layer, and so forth. The light-emitting layer may be formed of a single layer or a multilayer stack including multiple layers.

[0090] In the organic light-emitting device according to the embodiment, at least one organic compound layer contains the organic compound according to the embodiment. Specifically, the organic compound according to the embodiment is contained in any of the light-emitting layer, the hole injection layer, the hole transport layer, the electron-blocking layer, the hole/exciton-blocking layer, the electron transport layer, the electron injection layer, and so forth described above. The organic compound according to the embodiment can be contained in the light-emitting layer. The light-emitting layer can emit green light or red light. The emission color is not limited thereto.

[0091] In the organic light-emitting device according to the embodiment, in the case where the organic compound according to the embodiment is contained in the light-emitting layer, the light-emitting layer may consist of only the organic compound according to the embodiment or may be composed of the organic compound according to the embodiment and another compound. In the case where the light-emitting layer is composed of the organic compound according to the embodiment and another compound, the organic compound according to the embodiment may be used as a host or a guest in the light-emitting layer. The organic compound may be used as an assist material that can be contained in the light-emitting layer. The term “host” used here refers to a compound having the highest proportion by mass in compounds constituting the light-emitting layer. The term “guest” refers to a compound that has a lower proportion by mass than the host in

the compounds constituting the light-emitting layer and that is responsible for main light emission. The term “assist material” refers to a compound that has a lower proportion by mass than the host in the compounds constituting the light-emitting layer and that assists the light emission of the guest.

[0092] In the case where the organic compound according to the embodiment is used as a guest in the light-emitting layer, the concentration of the guest is preferably 0.01% or more and 20% or less, more preferably 1% or more and 15% or less, based on the entire light-emitting layer. In the case where the organic compound according to the embodiment is used as an assist material in the light-emitting layer, the concentration of the assist material is preferably 0.1% or more and 45% or less, more preferably 1% or more and 30% or less, based on the entire light-emitting layer.

[0093] In the case where the organic compound according to the embodiment is used as a guest in the light-emitting layer, a material having a higher LUMO level than the organic compound according to the embodiment (a material having a LUMO level closer to the vacuum level) can be used as a host. The reason for this is as follows: The organic compound according to the embodiment tends to have a low LUMO level. Thus, when a material having a higher LUMO level than the organic compound according to the embodiment is used as a host, the organic compound according to the embodiment can receive more electrons supplied to the host of the light-emitting layer.

[0094] In the case where the organic compound according to the embodiment is used as an assist material in the light-emitting layer, a material having a higher LUMO level than the organic compound according to the embodiment (a material having a LUMO level closer to the vacuum level) can be used as a guest. The reason for this is as follows: The organic compound according to the embodiment tends to have a low LUMO level. Thus, when a material having a higher LUMO level than the organic compound according to the embodiment is used as a light-emitting material (guest), the organic compound according to the embodiment receives more electrons supplied to the host of the light-emitting layer, and the assist material is responsible for exciton recombination. This enables efficient energy transfer to the light-emitting material (guest).

[0095] The inventors have conducted various studies and have found that when the organic compound according to the embodiment is used as a host, guest, or assist material of a light-emitting layer, especially as a guest of a light-emitting layer, a device that emits light with high efficiency and high luminance and that is extremely durable can be provided. The inventors have further found that when the organic compound according to the embodiment is used as an assist material in the light-emitting layer, a device that emits light with high efficiency and high luminance and that is extremely durable can be provided. The light-emitting layer may be formed of a single layer or multiple layers, and can contain multiple light-emitting materials. The term “multiple layers” may include a state in which the light-emitting layer and another light-emitting layer are stacked, or a state in which an intermediate layer is stacked between multiple light-emitting layers. Fluorescence and phosphorescence may be used. Tandem devices or stacked devices are also acceptable. In these cases, the emission color of the organic light-emitting device is not limited to a single color. More specifically, the emission color may be white or an intermediate color. A film-forming method is vapor deposition or coating. Details will be described in examples below.

[0096] The organic compound according to the embodiment can be used as a constituent material of an organic compound layer other than the light-emitting layer included in the organic light-emitting device according to the embodiment. Specifically, the organic compound may be used as a constituent material of the electron transport layer, the electron injection layer, the hole transport layer, the hole injection layer, the hole blocking layer, and so forth.

[0097] For example, a hole injection compound, a hole transport compound, a compound to be used as a host, a light-emitting compound, an electron injection compound, or an electron transport compound, which is known and has a low or high molecular weight, can be used together with the

organic compound according to the embodiment, as needed. Examples of these compounds will be described below.

[0098] As a hole injection-transport material, a material having a high hole mobility can be used so as to facilitate the injection of holes from the anode and to transport the injected holes to the light-emitting layer. To reduce a deterioration in film quality, such as crystallization, in the organic light-emitting device, a material having a high glass transition temperature can be used. Examples of a low- or high-molecular-weight material having the ability to inject and transport holes include triarylamine derivatives, aryl carbazole derivatives, phenylenediamine derivatives, stilbene derivatives, phthalocyanine derivatives, porphyrin derivatives, poly(vinyl carbazole), polythiophene, and other conductive polymers. Moreover, the hole injection-transport material can be used for the electron-blocking layer. Non-limiting specific examples of a compound used as the hole injection-transport material will be illustrated below.

##STR00058## ##STR00059## ##STR00060## ##STR00061## ##STR00062##

[0099] Among the hole transport materials illustrated above, HT16 to HT18 can be used in the layer in contact with the anode to reduce the driving voltage. HT16 is widely used in organic light-emitting devices. HT2, HT3, HT4, HT5, HT6, HT10, and HT12 may be used in an organic compound layer adjacent to HT16. Multiple materials may be used in a single organic compound layer.

[0100] Examples of a light-emitting material mainly associated with a light-emitting function include, in addition to the organic compounds represented by formulae [1] and [2], fused-ring compounds, such as fluorene derivatives, naphthalene derivatives, pyrene derivatives, perylene derivatives, tetracene derivatives, anthracene compounds, and rubrene, quinacridone derivatives, coumarin derivatives, stilbene derivatives, organoaluminum complexes, such as tris(8-quinolinolato)aluminum, iridium complexes, platinum complexes, rhenium complexes, copper complexes, europium complexes, ruthenium complexes, and polymer derivatives, such as poly(phenylene vinylene)derivatives, polyfluorene derivatives, and polyphenylene derivatives. Non-limiting specific examples of a compound used as a light-emitting material are illustrated below.

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

[0101] When the light-emitting material is a hydrocarbon compound, the material can prevent a decrease in luminous efficiency due to exciplex formation and a deterioration in color purity due to a change in the emission spectrum of the light-emitting material. The term “hydrocarbon compound” refers to a compound consisting of only carbon and hydrogen, and BD7, BD8, GD5 to GD9, and RD1 are hydrocarbon compounds. When the light-emitting material is a five-membered ring-containing fused polycyclic compound, the material has a high ionization potential and high resistance to oxidation. This can provide a highly durable device with a long lifetime. BD7, BD8, GD5 to GD9, and RD1 are five-membered ring-containing fused polycyclic compounds.

[0102] Examples of a host or an assist material in the light-emitting layer include aromatic hydrocarbon compounds and derivatives thereof, carbazole derivatives, dibenzofuran derivatives, dibenzothiophene derivatives, organoaluminum complexes, such as tris(8-quinolinolato)aluminum, and organoberyllium complexes. Non-limiting specific examples of a compound used as a host or an assist material in the light-emitting layer will be illustrated below.

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

[0103] When the host material is a hydrocarbon compound, the compound according to the embodiment can easily trap electrons and holes to contribute to higher efficiency. The term “hydrocarbon compound” refers to a compound consisting of only carbon and hydrogen, and EM1 to EM12 and EM16 to EM27 are hydrocarbon compounds.

[0104] The electron transport material can be freely-selected from materials capable of transporting

electrons injected from the cathode to the light-emitting layer and is selected in consideration of, for example, the balance with the hole mobility of the hole transport material. Examples of a material having the ability to transport electrons include oxadiazole derivatives, oxazole derivatives, pyrazine derivatives, triazole derivatives, triazine derivatives, quinoline derivatives, quinoxaline derivatives, phenanthroline derivatives, organoaluminum complexes, and condensed-ring compounds, such as fluorene derivatives, naphthalene derivatives, chrysene derivatives, and anthracene derivatives. The electron transport materials can be used for the hole-blocking layer. Non-limiting specific examples of a compound used as the electron transport material will be illustrated below.

##STR00081## ##STR00082## ##STR00083## ##STR00084## ##STR00085## ##STR00086## ##STR00087##

[0105] An electron injection material can be freely-selected from materials capable of easily injecting electrons from the cathode and is selected in consideration of, for example, the balance with the hole-injecting properties. As the organic compound, n-type dopants and reducing dopants are also included. Examples thereof include alkali metal-containing compounds, such as lithium fluoride, lithium complexes, such as lithium quinolinolate, benzimidazolidene derivatives, imidazolidene derivatives, fulvalene derivatives, and acridine derivatives.

Configuration of Organic Light-Emitting Device

[0106] The organic light-emitting device is provided by disposing an anode, the organic compound layer, and a cathode on a substrate. A protective layer, a color filter, and so forth may be disposed on the cathode. In the case of disposing the color filter, a planarization layer may be disposed between the protective layer and the color filter. The planarization layer can be composed of, for example, an acrylic resin.

Substrate

[0107] Examples of the substrate include silicon wafers, quartz substrates, glass substrates, resin substrates, and metal substrates. The substrate may include switching devices such as a transistor, a line, and an insulating layer thereon. As the insulating layer, any material can be used as long as a contact hole can be formed to establish the electrical connection between the anode and the line and as long as insulation with a non-connected line can be ensured. For example, a resin such as polyimide, silicon oxide, or silicon nitride can be used.

Electrode

[0108] A pair of electrodes can be used. The pair of electrodes may be an anode and a cathode. In the case where an electric field is applied in the direction in which the organic light-emitting device emits light, an electrode having a higher potential is the anode, and the other is the cathode. It can also be said that the electrode that supplies holes to the light-emitting layer is the anode and that the electrode that supplies electrons is the cathode.

[0109] As the constituent material of the anode, a material having a work function as high as possible can be used. Examples of the material that can be used include elemental metals, such as gold, platinum, silver, copper, nickel, palladium, cobalt, selenium, vanadium, and tungsten, mixtures thereof, alloys of combinations thereof, and metal oxides, such as tin oxide, zinc oxide, indium oxide, indium-tin oxide (ITO), and indium-zinc oxide. Additionally, conductive polymers, such as polyaniline, polypyrrole, and polythiophene, may be used.

[0110] These electrode materials may be used alone or in combination of two or more. The anode may be formed of a single layer or multiple layers.

[0111] In the case where the anode is used as a reflective electrode, for example, chromium, aluminum, silver, titanium, tungsten, molybdenum, an alloy thereof, or a stack thereof may be used. In the case where the anode is used as a transparent electrode, a transparent conductive oxide layer composed of, for example, indium-tin oxide (ITO) or indium-zinc oxide may be used; however, the anode is not limited thereto. The electrode may be formed by photolithography.

[0112] As the constituent material of the cathode, a material having a lower work function can be

used. Examples thereof include elemental metals such as alkali metals, e.g., lithium, alkaline-earth metals, e.g., calcium, aluminum, titanium, manganese, silver, lead, and chromium, and mixtures thereof. Alloys of combinations of these elemental metals may also be used. For example, magnesium-silver, aluminum-lithium, aluminum-magnesium, silver-copper, and zinc-silver may be used. Metal oxides such as indium-tin oxide (ITO) may also be used. These electrode materials may be used alone or in combination of two or more. The cathode may have a single-layer structure or a multilayer structure. In particular, silver can be used. To reduce the aggregation of silver, a silver alloy can be used. Any alloy ratio may be used as long as the aggregation of silver can be reduced. For example, 1:1 may be used.

[0113] A top emission device may be provided using the cathode formed of a conductive oxide layer composed of, for example, ITO. A bottom emission device may be provided using the cathode formed of a reflective electrode composed of, for example, aluminum (Al). The cathode is not particularly limited. Any method for forming the cathode may be used. For example, a direct-current or alternating-current sputtering technique can be employed because good film coverage is obtained and thus the resistance is easily reduced.

Protective Layer

[0114] A protective layer may be disposed on the cathode. For example, a glass member provided with a moisture absorbent can be bonded to the cathode to reduce the entry of, for example, water into the organic compound layer, thereby suppressing the occurrence of display defects. In another embodiment, a passivation film composed of, for example, silicon nitride may be disposed on the cathode to reduce the entry of, for example, water into the organic compound layer. For example, after the formation of the cathode, the substrate may be transported to another chamber without breaking the vacuum, and a silicon nitride film having a thickness of 2 μm may be formed by a chemical vapor deposition (CVD) method to provide a protective layer. After the film deposition by the CVD method, a protective layer may be formed by an atomic layer deposition (ALD) method.

Color Filter

[0115] A color filter may be disposed on the protective layer. For example, a color filter may be disposed on another substrate in consideration of the size of the organic light-emitting device and bonded to the substrate provided with the organic light-emitting device. A color filter may be formed by patterning on the protective layer using photolithography. The color filter may be composed of a polymer.

Planarization Layer

[0116] A planarization layer may be disposed between the color filter and the protective layer. The planarization layer may be composed of an organic compound. A low- or high-molecular-weight organic compound may be used. A high-molecular-weight organic compound can be used.

[0117] The planarization layers may be disposed above and below (or on) the color filter and may be composed of the same or different materials. Specific examples thereof include poly(vinyl carbazole) resins, polycarbonate resins, polyester resins, acrylonitrile butadiene styrene (ABS) resins, acrylic resins, polyimide resins, phenolic resins, epoxy resins, silicone resins, and urea resins.

Opposite Substrate

[0118] An opposite substrate may be disposed on the planarization layer. The opposite substrate is disposed at a position corresponding to the substrate described above and thus is called an opposite substrate. The opposite substrate may be composed of the same material as the substrate described above.

Organic Layer

[0119] The organic compound layer, such as the hole injection layer, the hole transport layer, the electron-blocking layer, the light-emitting layer, the hole-blocking layer, the electron transport layer, or the electron injection layer, included in the organic light-emitting device according to an embodiment of the present disclosure is formed by a method described below.

[0120] For the organic compound layer included in the organic light-emitting device according to an embodiment of the present disclosure, a dry process, such as a vacuum evaporation method, an ionized evaporation method, sputtering, or plasma, may be employed. Alternatively, instead of the dry process, it is also possible to employ a wet process in which a material is dissolved in an appropriate solvent and then a film is formed by a known coating method, such as spin coating, dipping, a casting method, a Langmuir-Blodgett (LB) technique, or an ink jet method.

[0121] In the case where the layer is formed by, for example, the vacuum evaporation method or the solution coating method, crystallization and so forth are less likely to occur, and good stability with time is obtained. In the case of forming a film by the coating method, the film may be formed in combination with an appropriate binder resin.

[0122] Non-limiting examples of the binder resin include poly(vinyl carbazole) resins, polycarbonate resins, polyester resins, acrylonitrile butadiene styrene (ABS) resins, acrylic resins, polyimide resins, phenolic resins, epoxy resins, silicone resins, and urea resins.

[0123] These binder resins may be used alone as a homopolymer or copolymer or in combination as a mixture of two or more. Furthermore, additives, such as a known plasticizer, antioxidant, and ultraviolet absorber, may be used, as needed.

Application of Organic Light-Emitting Device According to Embodiment of The Present Disclosure

[0124] The organic light-emitting device according to an embodiment of the present disclosure can be used as component member of a display apparatus or a lighting device. Other applications include exposure light sources for electrophotographic image-forming apparatuses, backlights for liquid crystal displays, and light-emitting devices including white light sources and color filters.

[0125] The display apparatus may be an image information-processing unit having an image input unit that receives image information from an area or linear CCD sensor, a memory card, or any other source, an information-processing unit that processes the input information, and a display unit that displays the input image. The display apparatus includes multiple pixels, and at least one of the multiple pixels may include the organic light-emitting device according to the embodiment and a transistor coupled to the organic light-emitting device.

[0126] The display unit of an image pickup apparatus or an inkjet printer may have a touch panel function. The driving mode of the touch panel function may be, but is not limited to, an infrared mode, an electrostatic capacitance mode, a resistive film mode, or an electromagnetic inductive mode. The display apparatus may also be used for a display unit of a multifunction printer.

[0127] The following describes a display apparatus according to the embodiment with reference to the attached drawings. FIG. 3 is a schematic cross-sectional view of an example of a display apparatus including organic light-emitting devices and thin-film transistor (TFT) devices coupled to the respective organic light-emitting devices. Each of the TFT devices is an example of active devices.

[0128] A display apparatus **10** illustrated in FIG. 3 includes a substrate **11** composed of, for example, glass and a moisture-proof film **12** disposed thereon, the moisture-proof film **12** being configured to protect the TFT devices or the organic compound layers. Reference numeral **13** denotes a gate electrode composed of a metal. Reference numeral **14** denotes a gate insulating film. Reference numeral **15** denotes a semiconductor layer.

[0129] TFT devices **18** each include the semiconductor layer **15**, a drain electrode **16**, and a source electrode **17**. An insulating film **19** is disposed on the TFT devices **18**. An anode **21** included in an organic light-emitting device **26** is coupled to the source electrode **17** through a contact hole **20**.

[0130] The way of electric coupling between the electrodes (the anode **21** and a cathode **23**) included in each of the organic light-emitting devices **26** and the electrodes (the source electrode **17** and the drain electrode **16**) included in a corresponding one of the TFT devices **18** is not limited to the configuration illustrated in FIG. 3. It is sufficient that one of the anode **21** and the cathode **23** is electrically coupled to one of the source electrode **17** and the drain electrode **16** of the TFT device

18.

[0131] In the display apparatus **10** illustrated in FIG. 3, each organic compound layer **22** is illustrated as a single layer; however, the organic compound layer **22** may be formed of multiple layers. A first protective layer **24** and a second protective layer **25** are disposed on the cathodes **23** in order to reduce the deterioration of the organic light-emitting devices **26**.

[0132] In the display apparatus **10** illustrated in FIG. 3, the transistors are used as switching devices; however, metal-insulator-metal (MIM) devices may be used as switching devices.

[0133] The transistors used in the display apparatus **10** illustrated in FIG. 3 are not limited to transistors formed using a single-crystal silicon wafer and may be thin-film transistors each having an active layer on the insulating surface of a substrate. Examples of the material of the active layer include single-crystal silicon, non-single-crystal silicon materials, such as amorphous silicon and microcrystalline silicon, and non-single-crystal oxide semiconductors, such as indium-zinc oxide and indium-gallium-zinc oxide. Thin-film transistors are also referred to as TFT devices.

[0134] The transistors in the display apparatus **10** illustrated in FIG. 3 may be formed in the substrate such as a Si substrate. The expression “formed in the substrate” indicates that the transistors are produced by processing the substrate such as a Si substrate. In the case where the transistors are formed in the substrate, the substrate and the transistors can be deemed to be integrally formed.

[0135] In the organic light-emitting device according to the embodiment, the luminance is controlled by the TFT devices, which are an example of switching devices; thus, an image can be displayed at respective luminance levels by arranging multiple organic light-emitting devices in the plane. The switching devices according to the embodiment are not limited to the TFT devices and may be low-temperature polysilicon transistors or active-matrix drivers formed on a substrate such as a Si substrate. The expression “on a substrate” can also be said to be “in the substrate”. Whether transistors are formed in the substrate or TFT devices are used is selected in accordance with the size of a display unit. For example, in the case where the display unit has a size of about 0.5 inches, organic light-emitting devices can be disposed on a Si substrate.

[0136] FIG. 4 is a schematic view illustrating an example of a display apparatus according to the embodiment. A display apparatus **1000** may include a touch panel **1003**, a display panel **1005**, a frame **1006**, a circuit substrate **1007**, and a battery **1008** disposed between an upper cover **1001** and a lower cover **1009**. The touch panel **1003** and the display panel **1005** are coupled to flexible printed circuits FPCs **1002** and **1004**, respectively. The circuit substrate **1007** includes printed transistors. The battery **1008** need not be provided unless the display apparatus is a portable apparatus. The battery **1008** may be disposed at a different position even if the display apparatus is a portable apparatus.

[0137] The display apparatus according to the embodiment may be used for a display unit of a photoelectric conversion apparatus, such as an image pickup apparatus including an optical unit including multiple lenses and an image pickup device that receives light passing through the optical unit. The image pickup apparatus may include a display unit that displays information acquired by the image pickup device. The display unit may be a display unit exposed to the outside of the image pickup apparatus or a display unit disposed in a finder. The image pickup apparatus may be a digital camera or a digital camcorder.

[0138] FIG. 5A is a schematic view illustrating an example of an image pickup apparatus according to the embodiment. An image pickup apparatus **1100** may include a viewfinder **1101**, a rear display **1102**, an operation unit **1103**, and a housing **1104**. The viewfinder **1101** may include the display apparatus according to the embodiment. In this case, the display apparatus may display environmental information, imaging instructions, and so forth in addition to an image to be captured. The environmental information may include, for example, the intensity of external light, the direction of the external light, the moving speed of a subject, and the possibility that a subject is shielded by a shielding material.

[0139] The timing suitable for imaging is only for a short time; thus, the information may be displayed as soon as possible. Accordingly, the display apparatus including the organic light-emitting device according to the embodiment can be used because of its short response time. The display apparatus including the organic light-emitting device can be used more suitably than liquid crystal displays for these units required to have a high display speed.

[0140] The image pickup apparatus **1100** includes an optical unit (not illustrated). The optical unit includes multiple lenses and is configured to form an image on an image pickup device in the housing **1104**. The relative positions of the multiple lenses can be adjusted to adjust the focal point. This operation can also be performed automatically.

[0141] The display apparatus according to the embodiment may include a color filter having red, green, and blue portions. In the color filter, the red, green, and blue portions may be arranged in a delta arrangement.

[0142] A display apparatus according to the embodiment may be used for a display unit of an electronic apparatus, such as a portable terminal. In that case, the display apparatus may have both a display function and an operation function. Examples of the portable terminal include cellular phones, such as smartphones, tablets, and head-mounted displays.

[0143] FIG. 5B is a schematic view illustrating an example of an electronic apparatus according to the embodiment. An electronic apparatus **1200** includes a display unit **1201**, an operation unit **1202**, and a housing **1203**. The housing **1203** may accommodate a circuit, a printed circuit board including the circuit, a battery, and a communication unit. The operation unit **1202** may be a button or a touch-panel-type reactive unit. The operation unit may be a biometric recognition unit that recognizes a fingerprint to release the lock or the like. An electronic apparatus having a communication unit can also be referred to as a communication apparatus.

[0144] FIGS. 6A and 6B are schematic views illustrating examples of a display apparatus according to the embodiment. FIG. 6A illustrates a display apparatus, such as a television monitor or a personal computer monitor. A display apparatus **1300** includes a frame **1301** and a display unit **1302**. The display unit **1302** may include an organic electroluminescent element according to the embodiment. The display device **1300** also includes a base **1303** that supports the frame **1301** and the display unit **1302**. The base **1303** is not limited to a form illustrated in FIG. 6A. The lower side of the frame **1301** may also serve as a base. The frame **1301** and the display unit **1302** may be curved and may have a radius of curvature of 5,000 mm or more and 6,000 mm or less.

[0145] FIG. 6B is a schematic view illustrating another example of a display apparatus according to the embodiment. A display apparatus **1310** illustrated in FIG. 6B can be folded and is what is called a foldable display apparatus. The display apparatus **1310** includes a first display portion **1311**, a second display portion **1312**, a housing **1313**, and an inflection point **1314**. The first display portion **1311** and the second display portion **1312** may include a light-emitting device according to the embodiment. The first display portion **1311** and the second display portion **1312** may be a single, seamless display apparatus. The first display portion **1311** and the second display portion **1312** can be divided from each other at the inflection point. The first display portion **1311** and the second display portion **1312** may display different images from each other. Alternatively, a single image may be displayed in the first and second display portions.

[0146] FIG. 7A is a schematic view illustrating an example of a lighting device according to the embodiment. A lighting device **1400** may include a housing **1401**, a light source **1402**, a circuit board **1403**, an optical filter **1404** that transmits light emitted from the light source **1402**, and a light diffusion unit **1405**. The light source **1402** may include an organic light-emitting device according to the embodiment. The optical filter **1404** may be a filter that improves the color rendering properties of the light source. The light diffusion unit **1405** can effectively diffuse light from the light source to deliver the light to a wide range when used for illumination and so forth. The optical filter **1404** and the light diffusion unit **1405** may be disposed at the light emission side of the lighting device. A cover may be disposed at the outermost portion, as needed.

[0147] The lighting device is, for example, a device that lights a room. The lighting device may emit light of white, neutral white, or any color from blue to red. A light control circuit that controls the light may be provided. The lighting device may include the organic light-emitting device according to the embodiment and a power supply circuit coupled thereto. The power supply circuit is a circuit that converts an AC voltage into a DC voltage. The color temperature of white is 4,200 K, and the color temperature of neutral white is 5,000 K. The lighting device may include a color filter.

[0148] The lighting device according to the embodiment may include a heat dissipation unit. The heat dissipation unit is configured to release heat in the device to the outside of the device and is composed of, for example, a metal having a high specific heat and liquid silicone.

[0149] FIG. 7B is a schematic view illustrating an automobile as an example of a moving object. The automobile includes a tail lamp, which is an example of lighting units. An automobile **1500** includes a tail lamp **1501** and may be configured to light the tail lamp when a brake operation or the like is performed.

[0150] The tail lamp **1501** may include an organic light-emitting device according to the embodiment. The tail lamp **1501** may include a protective member that protects the organic light-emitting device. The protective member may be composed of any transparent material having high strength to some extent and can be composed of, for example, polycarbonate. The polycarbonate may be mixed with, for example, a furandicarboxylic acid derivative or an acrylonitrile derivative.

[0151] The automobile **1500** may include an automobile body **1503** and windows **1502** attached thereto. The windows **1502** may be transparent displays if the windows are not used to check the front and back of the automobile. The transparent displays may include an organic light-emitting device according to the embodiment. In this case, the components, such as the electrodes, of the organic light-emitting device are formed of transparent members.

[0152] The moving object according to the embodiment may be, for example, a ship, an aircraft, or a drone. The moving object may include a body and a lighting unit attached to the body. The lighting unit may emit light to indicate the position of the body. The lighting unit includes the organic light-emitting device according to the embodiment.

[0153] FIG. 8 is a schematic view of an example of an image-forming apparatus. An image-forming apparatus **40** is an electrophotographic image-forming apparatus and includes a photoconductor **27**, an exposure light source **28**, a charging unit **30**, a developing unit **31**, a transfer unit **32**, a transport roller **33**, and a fusing unit **35**. Light **29** is emitted from the exposure light source **28** and forms an electrostatic latent image on the surface of the photoconductor **27**. The exposure light source **28** includes the organic light-emitting device according to the embodiment. The developing unit **31** contains, for example, a toner. The charging unit **30** charges the photoconductor **27**. The transfer unit **32** transfers the developed image to a recording medium **34**. The transport roller **33** transports the recording medium **34**. The recording medium **34** is paper, for example. The fusing unit **35** fixes the image formed on the recording medium **34**.

[0154] FIGS. 9A and 9B each illustrate the exposure light source **28** and are each a schematic view illustrating multiple light-emitting portions **36** arranged on a long substrate. Arrows **37** each represent the row direction in which the organic light-emitting devices are arranged. The row direction is the same as the direction of the axis on which the photoconductor **27** rotates. This direction can also be referred to as the long-axis direction of the photoconductor **27**. FIG. 9A illustrates a configuration in which the light-emitting portions **36** are arranged in the long-axis direction of the photoconductor **27**. FIG. 9B is different from FIG. 9A in that the light-emitting portions **36** are arranged alternately in the row direction in a first row and a second row. The first row and the second row are located at different positions in the column direction. In the first row, the multiple light-emitting portions **36** are spaced apart. The second row has the light-emitting portions **36** at positions corresponding to the positions between the light-emitting portions **36** in the first row. In other words, the multiple light-emitting portions **36** are also spaced apart in the column

direction. The arrangement in FIG. **9B** can be rephrased as, for example, a lattice arrangement, a staggered arrangement, or a checkered pattern.

[0155] An example of applications of the display apparatuses of the above embodiments will be described with reference to FIGS. **10A** and **10B**. The display apparatuses can be used for systems that can be worn as wearable devices, such as smart glasses, head-mounted displays (HMDs), and smart contacts. An image pickup and display apparatus used in such an example of the applications has an image pickup apparatus that can photoelectrically convert visible light and a display apparatus that can emit visible light.

[0156] FIG. **10A** illustrates glasses **1600** (smart glasses) according to an example of applications. An image pickup apparatus **1602**, such as a complementary metal-oxide semiconductor (CMOS) sensor or a single-photon avalanche diode (SPAD), is provided on a front side of a lens **1601** of the glasses **1600**. The display apparatus according to any of the above-mentioned embodiments is provided on the back side of the lens **1601**.

[0157] The glasses **1600** further include a control unit **1603**. The control unit **1603** functions as a power source that supplies electric power to the image pickup apparatus **1602** and the display apparatus according to any of the embodiments. The control unit **1603** controls the operation of the image pickup apparatus **1602** and the display apparatus. The lens **1601** has an optical system for focusing light on the image pickup apparatus **1602**.

[0158] FIG. **10B** illustrates glasses **1610** (smart glasses) according to an example of applications. The glasses **1610** include a control unit **1612**. The control unit **1612** includes an image pickup apparatus corresponding to the image pickup apparatus **1602** and a display apparatus. A lens **1611** is provided with the image pickup apparatus in the control unit **1612** and an optical system that projects light emitted from the display apparatus. An image is projected onto the lens **1611**. The control unit **1612** functions as a power source that supplies electric power to the image pickup apparatus and the display apparatus and controls the operation of the image pickup apparatus and the display apparatus. The control unit may include a gaze detection unit that detects the gaze of a wearer. Infrared light may be used for gaze detection. An infrared light-emitting unit emits infrared light to an eyeball of a user who is gazing at a displayed image. An image of the eyeball is captured by detecting the reflected infrared light from the eyeball with an image pickup unit having light-receiving elements. The deterioration of image quality is reduced by providing a reduction unit that reduces light from the infrared light-emitting unit to the display unit when viewed in plan.

[0159] The user's gaze at the displayed image is detected from the image of the eyeball captured with the infrared light. Any known method can be employed to the gaze detection using the captured image of the eyeball. As an example, a gaze detection method based on a Purkinje image of the reflection of irradiation light on a cornea can be employed.

[0160] More specifically, the gaze detection process is based on a pupil-corneal reflection method. Using the pupil-corneal reflection method, the user's gaze is detected by calculating a gaze vector representing the direction (rotation angle) of the eyeball based on the image of the pupil and the Purkinje image contained in the captured image of the eyeball.

[0161] A display apparatus according to an embodiment of the present disclosure may include an image pickup apparatus including light-receiving elements, and may control an image displayed on the display apparatus based on the gaze information of the user from the image pickup apparatus.

[0162] Specifically, in the display apparatus, a first field of view at which the user gazes and a second field of view other than the first field of view are determined on the basis of the gaze information. The first field of view and the second field of view may be determined by the control unit of the display apparatus or may be determined by receiving those determined by an external control unit. In the display area of the display apparatus, the display resolution of the first field of view may be controlled to be higher than the display resolution of the second field of view. That is, the resolution of the second field of view may be lower than that of the first field of view.

[0163] The display area includes a first display area and a second display area different from the

first display area. Based on the gaze information, an area of higher priority is determined from the first display area and the second display area. The first display area and the second display area may be determined by the control unit of the display apparatus or may be determined by receiving those determined by an external control unit. The resolution of an area of higher priority may be controlled to be higher than the resolution of an area other than the area of higher priority. In other words, the resolution of an area of a relatively low priority may be low.

[0164] Artificial intelligence (AI) may be used to determine the first field of view or the high-priority area. The AI may be a model configured to estimate the angle of gaze from the image of the eyeball and the distance to a target object located in the gaze direction, using the image of the eyeball and the actual direction of gaze of the eyeball in the image as teaching data. The AI program may be stored in the display apparatus, the image pickup apparatus, or an external apparatus. When the AI program is stored in the external apparatus, the AI program is transmitted to the display apparatus via communications.

[0165] In the case of controlling the display based on visual detection, smart glasses that further include an image pickup apparatus that captures an external image can be used. The smart glasses can display the captured external information in real time.

[0166] As described above, the use of an apparatus including the organic light-emitting device according to the embodiment enables a stable display with good image quality even for a long time.

EXAMPLES

[0167] While the present disclosure will be described below by examples, the present disclosure is not limited these examples.

Example 1: Synthesis of Exemplified Compound AA1

[0168] Exemplified compound AA1 was synthesized according to the following scheme.

##STR00088##

(1) Synthesis of Compound E3

[0169] The following reagents and solvent were placed in a 500-mL recovery flask. [0170]

Compound E1: 5.0 g (18.2 mmol) [0171] Compound E2: 3.4 g (18.2 mmol) [0172] Potassium carbonate: 5.0 g (36.4 mmol) [0173] Dimethyl sulfoxide (DMSO): 200 mL

[0174] The reaction solution was heated and stirred at 120° C. for 12 hours under a stream of nitrogen. Extraction was performed with ethyl acetate. The organic layer was concentrated to dryness to give a solid. The resulting solid was purified by silica gel column chromatography (toluene-ethyl acetate mixture) to give 3.1 g (yield: 45%) of E3.

(2) Synthesis of Compound E4

[0175] The following reagent and solvent were placed in a 300-mL recovery flask. [0176]

Compound E3: 3.0 g (7.9 mmol) [0177] Methylene chloride: 150 mL

[0178] Under a stream of nitrogen, 15 mL of boron tribromide (1 M, solution in dichloromethane) was added dropwise to the reaction solution at 0° C. After the dropwise addition, the reaction solution was stirred at room temperature for 8 hours. The reaction solution was poured into ice water and extracted with toluene. The organic layer was concentrated to dryness to give a solid. The resulting solid was purified by silica gel column chromatography (toluene-ethyl acetate mixture) to give 2.4 g (yield: 82%) of E4.

(3) Synthesis of Compound E5

[0179] The following reagent and solvent were placed in a 100-mL recovery flask. [0180]

Compound E4: 2.3 g (6.30 mmol) [0181] Sulfuric acid: 30 mL

[0182] The reaction solution was stirred at 100° C. for 7 hours under a stream of nitrogen. After the completion of the reaction, the reaction mixture was poured into ice water and then filtered. The resulting solid was purified by silica gel column chromatography (chlorobenzene-ethyl acetate mixture) to give 0.8 g (yield: 38%) of E5.

(4) Synthesis of Compound AA1

[0183] The following reagents and solvent were placed in a 500-mL recovery flask. [0184]

Compound E5: 0.8 g (2.29 mmol) [0185] Compound E6: 0.5 g (2.75 mmol) [0186] Sodium tert-butoxide: 0.4 g (4.58 mmol) [0187] Pd (dba) 2:132 mg (0.23 mmol) [0188] Xphos: 329 mg (0.69 mmol) [0189] o-Xylene: 40 mL

[0190] The reaction solution was heated and stirred at 140° C. for 5 hours under a stream of nitrogen. After the completion of the reaction, filtration was performed through Celite, and then the filtrate was concentrated to dryness. The resulting solid was purified by silica gel column chromatography (chlorobenzene-ethyl acetate mixture) to give 0.78 g (yield: 71%) of AA1 as a pale yellow solid.

[0191] Exemplified compound AA1 was subjected to mass spectrometry with MALDI-TOF-MS (Bruker Autoflex LRF). [0192] MALDI-TOF-MS [0193] Measured value: m/z=479 [0194] Calculated value: C.sub.32H.sub.17NO.sub.4=479

Examples 2 to 31: Syntheses of Exemplified Compounds

[0195] As presented in Tables 2 to 4, exemplified compounds of Examples 2 to 31 were synthesized as in Example 1, except that raw material E1 was changed to raw material 1, raw material E2 was changed to raw material 2, and raw material E6 was changed to raw material 3. The resulting exemplified compounds were subjected to mass spectrometry as in Example 1. The resulting measured values (m/z) were described below.

TABLE-US-00002 TABLE 2 Exemplified Example compound Raw material 1 Raw material 2








Raw material 3 m/z	2 AA2	[00089]	[embedded image]	[00090]	[embedded image]	[00091]
[embedded image] 482	3 AA8	[00092]	[embedded image]	[00093]	[embedded image]	[00094]
[embedded image] 592	4 AA12	[00095]	[embedded image]	[00096]	[embedded image]	[00097]
[embedded image] 522	5 AA14	[00098]	[embedded image]	[00099]	[embedded image]	[00100]
[embedded image] 495	6 AA16	[00101]	[embedded image]	[00102]	[embedded image]	[00103]
[embedded image] 570	7 AA22	[00104]	[embedded image]	[00105]	[embedded image]	[00106]
[embedded image] 505	8 AA23	[00107]	[embedded image]	[00108]	[embedded image]	[00109]
[embedded image] 536	9 AA25	[00110]	[embedded image]	[00111]	[embedded image]	[00112]
[embedded image] 496	10 AB1	[00113]	[embedded image]	[00114]	[embedded image]	[00115]
[embedded image] 479	11 AB6	[00116]	[embedded image]	[00117]	[embedded image]	[00118]
[embedded image] 522						

TABLE-US-00003 TABLE 3 Exemplified Example compound Raw material 1 Raw material 2

Raw material 3 m/z	12 AB13	[00119]	[embedded image]	[00120]	[embedded image]	[00121]
[embedded image] 496	13 AC1	[00122]	[embedded image]	[00123]	[embedded image]	[00124]
[embedded image] 479	14 AC2	[00125]	[embedded image]	[00126]	[embedded image]	[00127]
[embedded image] 482	15 AC5	[00128]	[embedded image]	[00129]	[embedded image]	[00130]
[embedded image] 522	16 AC6	[00131]	[embedded image]	[00132]	[embedded image]	[00133]
[embedded image] 512	17 AD1	[00134]	[embedded image]	[00135]	[embedded image]	[00136]
[embedded image] 479	18 BA1	[00137]	[embedded image]	[00138]	[embedded image]	[00139]
[embedded image] 479	19 BA2	[00140]	[embedded image]	[00141]	[embedded image]	[00142]
[embedded image] 482	20 BA6	[00143]	[embedded image]	[00144]	[embedded image]	[00145]
[embedded image] 634	21 BA12	[00146]	[embedded image]	[00147]	[embedded image]	[00148]
[embedded image] 522	22 BA14	[00149]	[embedded image]	[00150]	[embedded image]	[00151]
[embedded image] 495						

TABLE-US-00004 TABLE 4 Exemplified Example compound Raw material 1 Raw material 2

Raw material 3 m/z	23 BA25	[00152]	[embedded image]	[00153]	[embedded image]	[00154]
[embedded image] 496	24 BB1	[00155]	[embedded image]	[00156]	[embedded image]	[00157]
[embedded image] 479	25 BB6	[00158]	[embedded image]	[00159]	[embedded image]	[00160]
[embedded image] 522	26 BC1	[00161]	[embedded image]	[00162]	[embedded image]	[00163]
[embedded image] 479	27 BC5	[00164]	[embedded image]	[00165]	[embedded image]	[00166]
[embedded image] 522	28 BC6	[00167]	[embedded image]	[00168]	[embedded image]	[00169]
[embedded image] 495	29 BC13	[00170]	[embedded image]	[00171]	[embedded image]	[00172]

 496 30 BD1 [00173]  [00174]  [00175]
 479 31 DC1 [00176]  [00177]  [00178]
 645

Example 32

[0196] In this Example, an organic light-emitting device having a bottom-emission structure was produced in which an anode, a hole injection layer, a hole transport layer, an electron-blocking layer, a light-emitting layer, a hole-blocking layer, an electron transport layer, an electron injection layer, and a cathode were sequentially formed on a substrate.

[0197] An ITO film was formed on a glass substrate and subjected to desired patterning to form an ITO electrode (anode). The ITO electrode had a thickness of 100 nm. The substrate on which the ITO electrode had been formed in this way was used as an ITO substrate in the following steps. Next, vacuum evaporation was performed by resistance heating in a vacuum chamber to continuously form organic compound layers and an electrode layer presented in Table 5 on the ITO substrate. Here, the opposite electrode (metal electrode layer, cathode) had an electrode area of 3 mm.^{sup.2}

TABLE-US-00005 TABLE 5 Material Thickness (nm) Cathode Al 100 Electron injection layer LiF 1 (EIL) Electron transport layer ET2 15 (ETL) Hole-blocking layer ET11 15 (HBL) Light- host light- 20 emitting layer emitting material (EML) EM14 AA1 Light-emitting layer 88 12 percentage Electron-blocking layer HT12 15 (EBL) Hole transport layer HT3 30 (HTL) Hole injection layer HT16 5 (HIL)

[0198] The characteristics of the resulting device were measured and evaluated. As the initial characteristics associated with the light emission, green light emission with a maximum external quantum efficiency (E.Q.E.) of 6.1% was obtained. With regard to measurement instruments, specifically, the current-voltage characteristics were measured with a Hewlett-Packard 4140B microammeter, and the luminance was measured with a Topcon BM7. The device was subjected to a continuous operation test at a current density of 50 mA/cm.^{sup.2}. The time when the percentage of luminance degradation reached 5% (LT95) was measured to be 96 hours.

Examples 33 to 37

[0199] Organic light-emitting devices were produced in the same way as in Example 32, except that the compounds listed in Table 6 were used as appropriate. The characteristics of the resulting devices were measured and evaluated in the same way as in Example 32. Table 6 presents the measurement results.

TABLE-US-00006 TABLE 6 EML Light-emitting E.Q.E. LT95 Emission HTL EBL Host material HBL ETL [%] [h] color Example HT3 HT12 EM14 AA2 ET10 ET2 6.3 95 yellow 33 Example HT3 HT9 EM11 AB6 ET12 ET2 4.8 92 green 34 Example HT3 HT12 EM9 AC5 ET12 ET2 4.9 110 yellow 35 Example HT2 HT11 EM6 AD1 ET22 ET2 5.0 82 red 36 Example HT2 HT10 EM10 BA6 ET12 ET5 6.4 99 green 37

Example 38

[0200] An organic light-emitting device was produced in the same way as in Example 32, except that the organic compound layers and the electrode layer listed in Table 7 were continuously deposited.

TABLE-US-00007 TABLE 7 Thickness Material (nm) Cathode Al 100 Electron injection layer LiF 1 (EIL) Electron transport layer ET2 15 (ETL) Hole-blocking layer ET11 15 (HBL) Light- host assist light-emitting 20 emitting layer material material (EML) EM11 AA8 RD1 Light-emitting layer 82 15 3 percentage Electron-blocking layer HT12 15 (EBL) Hole transport layer HT3 30 (HTL) Hole injection layer HT16 5 (HIL)

[0201] The characteristics of the resulting device were measured and evaluated in the same way as in Example 32. As the initial characteristics associated with the light emission, a red light emission with a maximum external quantum efficiency (E.Q.E.) of 7.5% was obtained. The device was subjected to a continuous operation test at a current density of 50 mA/cm.^{sup.2}. The time when the

percentage of luminance degradation reached 5% (LT95) was measured to be 168 hours.

Examples 39 to 53 and Comparative Examples 1 to 3

[0202] Organic light-emitting devices were produced in the same way as in Example 38, except that the compounds listed in Table 8 were used as appropriate. The characteristics of the resulting devices were measured and evaluated in the same way as in Example 38. Table 8 presents the measurement results.

TABLE-US-00008

TABLE 8	EML	Light-	emitting	E.Q.E	LT95	Emission	HTL	EBL	Host	Assist												
material	HBL	ETL	[%]	[h]	color	Example	39	HT3	HT12	EM11	AA12	RD1	ET12	ET2	7.4	160	red					
Example 40	HT3	HT11	EM11	AA14	RD1	ET12	ET2	7.1	165	red	Example 41	HT3	HT12	EM10	AA25	RD2	ET12	ET2	7.0	159	red	
Example 42	HT2	HT11	EM9	AB6	GD6	ET12	ET2	5.5	143	green	Example 43	HT2	HT10	EM10	AC5	RD1	ET16	ET5	6.2	189	red	
Example 44	HT3	HT11	EM14	AC6	RD1	ET12	ET2	6.0	192	red	Example 45	HT3	HT12	EM11	AD1	RD1	ET11	ET2	6.3	150	red	
Example 46	HT3	HT11	EM14	BA1	GD1	ET12	ET2	7.9	162	green	Example 47	HT3	HT12	EM14	BA6	GD6	ET11	ET2	8.0	170	green	
Example 48	HT2	HT11	EM11	BA12	GD9	ET16	ET	7.9	169	green	Example 49	HT2	HT12	EM11	BB1	GD6	ET12	ET2	5.4	145	green	
Example 50	HT3	HT10	EM9	BB6	GD6	ET12	ET2	5.6	141	green	Example 51	HT2	HT12	EM14	BC1	GD6	ET11	ET5	6.4	188	green	
Example 52	HT3	HT10	EM9	BC6	GD1	ET12	ET2	6.2	180	green	Example 53	HT2	HT12	EM14	BD1	GD6	ET11	ET5	6.1	151	green	
Comparative	HT3	HT11	EM14	GD9	ET12	ET2	1.9	30	green	example 1	compound 1-a	Comparative	HT3	HT11	EM14	GD9	ET12	ET2	2.1	35	green	
example 2	compound 1-b	Comparative	HT3	HT11	EM14	GD9	ET12	ET2	2.3	15	red	example 3	compound 2-a									

[0203] As described in Table 8, the maximum external quantum efficiency (E.Q.E.) in Comparative example 1 was as low as 1.9%, and the maximum external quantum efficiency (E.Q.E.) in Comparative example 2 was as low as 2.1%. The 5% degradation lifetime (LT95) in Comparative example 1 was 30 hours, and the 5% degradation lifetime (LT95) in Comparative example 2 was 35 hours, indicating poor durability characteristics. The reason for the low efficiencies is that the large differences between S1 and T1 levels results in the absence of an emission component based on delayed fluorescence. In addition, the reason for these is presumably due to concentration quenching caused by molecular association because of the high molecular aspect ratios. The reason for the poor durability is presumably that these compounds tend to undergo molecular association, have poor film properties, and crystallize, because of the high molecular aspect ratios.

[0204] The maximum external quantum efficiency (E.Q.E.) in Comparative example 3 was as low as 2.3%. The 5% degradation lifetime (LT95) was 15 hours, indicating poor durability characteristics. The reason for the low efficiency is that the large difference between S.sub.1 and T.sub.1 levels results in the absence of an emission component based on delayed fluorescence.

[0205] In contrast, the devices containing the compounds according to the embodiment exhibited high efficiencies and good durability characteristics. Each of the compounds according to the embodiment contains, as a basic skeleton, a fused ring containing two carbonyl groups, and contains an amino group attached thereto, thus resulting in a small energy gap between S1 and T1 and a low molecular aspect ratio. Accordingly, it is thought that concentration quenching could be reduced to result in high-efficiency light emission based on delayed fluorescence. In addition, the presence of an amino group that reduces the degree of molecular flatness in the basic skeleton having a high degree of flatness is thought to have resulted in a film having a low molecular aspect ratio and a high degree of amorphous nature, exhibiting good durability characteristics.

[0206] In an organic compound according to an embodiment of the present disclosure, the excited state level can be controlled by controlling the structure of its molecule, thereby reducing the molecular association. Thus, the use of the organic compound according to an embodiment of the present disclosure for an organic light-emitting device provides the organic light-emitting device excellent in luminous efficiency and driving durability characteristics.

[0207] While the present disclosure has been described with reference to exemplary embodiments,

it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

Claims

1. An organic compound represented by formula [1-1] or [1-2]: ##STR00179## where in formula [1-1] or [1-2], R.sub.1 to R.sub.20 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted alkoxy group, a substituted or unsubstituted amino group, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted heterocyclic group, a substituted or unsubstituted aryloxy group, a silyl group, and a cyano group, wherein at least one of R.sub.1 to R.sub.4 and R.sub.6 to R.sub.9 and at least one of R.sub.11 to R.sub.14 and R.sub.16 to R.sub.19 are substituted or unsubstituted amino groups, and groups bonded to nitrogen atoms of the substituted or unsubstituted amino groups are optionally taken together to form a ring structure, X.sub.1 to X.sub.4 are each oxygen, sulfur, selenium, or tellurium and are optionally the same or different, when, in formula [1-1], X.sub.1 and X.sub.2 are sulfur, and at least one of both R.sub.3 and R.sub.7 and both R.sub.2 and R.sub.8 are substituted amino groups, a substituent of the respective substituted amino groups forms a ring by bonding, when, in formula [1-1], X.sub.1 and X.sub.2 are sulfur, and one of both R.sub.2 and R.sub.7 and both R.sub.3 and R.sub.8 is an amino group, the amino group contains a substituent and the substituent is an aromatic hydrocarbon group or a heterocyclic group, and when, in formula [1-2], X.sub.3 and X.sub.4 are sulfur, and at least one of both R.sub.13 and R.sub.17 and both R.sub.12 and R.sub.18 are substituted amino groups, the amino groups do not include an N—H bond.

2. The organic compound according to claim 1, wherein the organic compound is represented by formula [2-1] or [2-2]: ##STR00180## where in formula [2-1] or [2-2], R.sub.21 to R.sub.24 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group, wherein R.sub.21 and R.sub.22, or R.sub.23 and R.sub.24 are optionally taken together to form a ring structure.

3. The organic compound according to claim 1, wherein the organic compound is represented by formula [3-1] or [3-2]: ##STR00181## where in formula [3-1] or [3-2], R.sub.25 to R.sub.28 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group, wherein R.sub.25 and R.sub.26, or R.sub.27 and R.sub.28 are optionally taken together to form a ring structure.

4. The organic compound according to claim 1, wherein the organic compound is represented by formula [4-1] or [4-2]: ##STR00182## where in formula [4-1] or [4-2], R.sub.29 to R.sub.32 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group, wherein R.sub.29 and R.sub.30, or R.sub.31 and R.sub.32 are optionally taken together to form a ring structure.

5. The organic compound according to claim 1, wherein the organic compound is represented by formula [5-1] or [5-2]: ##STR00183## where in formula [5-1] or [5-2], R.sub.33 to R.sub.36 are each independently selected from a hydrogen atom, a halogen atom, a substituted or unsubstituted alkyl group, a substituted or unsubstituted aromatic hydrocarbon group, and a substituted or unsubstituted heterocyclic group, wherein R.sub.33 and R.sub.34, or R.sub.35 and R.sub.36 are optionally taken together to form a ring structure.

6. The organic compound according to claim 1, wherein, in a case where the at least one of R.sub.1 to R.sub.4 and R.sub.6 to R.sub.9 and the at least one of R.sub.11 to R.sub.14 and R.sub.16 to

R.sub.19 are substituted amino groups, substituents of the substituted amino groups form rings by bonding.

7. The organic compound according to claim 6, wherein the substituted amino groups have any of structures represented by the following structural formulae, and in the following structural formulae, each * represents a binding position ##STR00184## ##STR00185## ##STR00186## ##STR00187##

8. An organic light-emitting device, comprising: an anode; a cathode; and at least one organic compound layer disposed between the anode and the cathode, wherein at least one layer of the at least one organic compound layer contains the organic compound according to claim 1.

9. The organic light-emitting device according to claim 8, wherein the at least one layer containing the organic compound is a light-emitting layer.

10. The organic light-emitting device according to claim 9, wherein the light-emitting layer further contains a host material.

11. The organic light-emitting device according to claim 10, wherein the host material is a hydrocarbon compound.

12. The organic light-emitting device according to claim 10, wherein the light-emitting layer further contains a light-emitting material.

13. The organic light-emitting device according to claim 12, wherein the light-emitting material is a hydrocarbon compound.

14. The organic light-emitting device according to claim 9, wherein the light-emitting layer emits green light or red light.

15. A display apparatus, comprising: multiple pixels, at least one of the multiple pixels including: the organic light-emitting device according to claim 8; and a transistor connected to the organic light-emitting device.

16. A photoelectric conversion apparatus, comprising: an optical unit including multiple lenses; an image pickup device that receives light passing through the optical unit; and a display unit that displays an image captured by the image pickup device, wherein the display unit includes the organic light-emitting device according to claim 8.

17. An electronic apparatus, comprising: a display unit including the organic light-emitting device according to claim 8; a housing provided with the display unit; and a communication unit being disposed in the housing and communicating with an outside.

18. A lighting device, comprising: a light source including the organic light-emitting device according to claim 8; and a light diffusion unit or an optical filter that transmits light emitted from the light source.

19. A moving object, comprising: a lighting unit including the organic light-emitting device according to claim 8; and a body provided with the lighting unit.

20. An exposure light source for an electrophotographic image-forming apparatus, comprising: the organic light-emitting device according to claim 8.
