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(54) **Organic light-emitting diode comprising electron transport layers with different matrix compounds**

(57) The present invention relates to an organic light-emitting diode comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound, wherein
- the matrix compound or compounds of the first electron

transport layer is/are different to the matrix compound or compounds of the second electron transport layer; and in addition,

- the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and
- the second electron transport layer is free of a dopant.

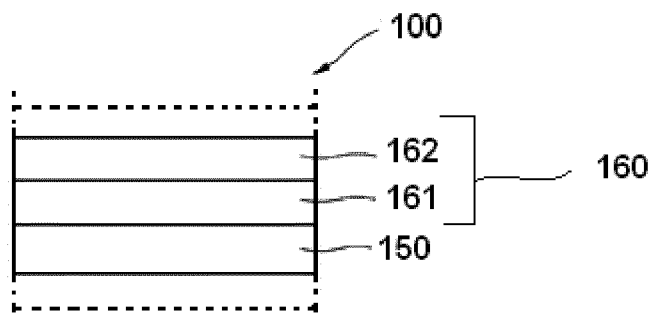


FIG. 1

Description

[0001] The present invention relates to an organic light-emitting diode containing electron transport layers with different matrix compounds and a method of manufacturing the same.

DESCRIPTION OF THE RELATED ART

[0002] Organic light-emitting diodes (OLEDs), which are self-emitting devices, have a wide viewing angle, excellent contrast, quick response, high brightness, excellent driving voltage characteristics, and color reproduction. A typical OLED includes an anode, a hole transport layer (HTL), an emission layer (EML), an electron transport layer (ETL), and a cathode, which are sequentially stacked on a substrate. In this regard, the HTL, the EML, and the ETL are thin films formed from organic and / or organometallic compounds.

[0003] When a voltage is applied to the anode and the cathode, holes injected from the anode move to the EML, via the HTL, and electrons injected from the cathode move to the EML, via the ETL. The holes and electrons recombine in the EML to generate excitons. When the excitons drop from an excited state to a ground state, light is emitted. The injection and flow of holes and electrons should be balanced, so that an OLED having the above-described structure has excellent efficiency. However, there is a continuously need to improve the conductivity and to reduce the voltage to operate an OLED more efficiently.

SUMMARY

[0004] It is one object to provide an organic light-emitting diode with a reduced low voltage to efficiently operate an OLED, especially for blue emitting OLEDs but also, for example, for red, green or white emitting OLEDs, in particular for top and/or bottom emission organic light-emitting diodes (OLED).

[0005] According to one aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound, wherein the matrix compound or matrix compounds of the first electron transport layer is/are different to the matrix compound or matrix compounds of the second electron transport layer; and in addition, the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and the second electron transport layer is free of a dopant.

[0006] According to one aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises each one matrix compound, wherein the matrix compound of the first electron transport layer is different to the matrix compound of the second electron transport layer; and in addition, the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and the second electron transport layer is free of a dopant.

[0007] According to various aspects the organic light-emitting diode as mentioned before may comprise an electron transport layer stack having preferably two to four electron transport layers and more preferred two electron transport layers or three electron transport layers.

[0008] According to various aspects the organic light-emitting diode as mentioned before may comprise an electron transport layer stack having three electron transport layers.

[0009] According to various aspects the organic light-emitting diode as mentioned before may comprise an electron injection layer; preferably the electron injection layer is arranged between the electron transport layer and the cathode electrode.

[0010] More preferred the OLED with two electron transport layers may comprise an electron injection layer.

[0011] According to various aspects the organic light-emitting diode as described above with three electron transport layers may be free of an electron injection layer.

[0012] According to one aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound, wherein the matrix compound or matrix compounds of the first electron transport layer is/are different to the matrix compound or matrix compounds of the second electron transport layer; and in addition, the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and the second electron transport layer is free of a dopant; and wherein the organic light-emitting diode comprises in addition an electron injection layer, preferably the electron injection layer is arranged between the electron transport layer and the cathode electrode, wherein the electron injection layer may:

- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with a lithium halide or

doped with a lithium organic complex, preferably lithium tetra(1H-pyrazol-1-yl)borate; or

- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with an elemental metal selected from a group comprising alkali, alkaline earth or rare earth metals, preferably Li, Cs, Mg, Ca, Yb, or Sm; or
- consist of a metal halide or of an organic complex, preferably LiQ, AlQ₃, ZrQ₄, KF or LiF, wherein Q is a 8-hydroxyquinolate;
- consist of an alkali, alkaline earth or of a rare earth metal, preferably Li, Cs, Mg, Ca, Yb, or Sm.

[0013] According to one aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound, wherein the matrix compound or matrix compounds of the first electron transport layer is/are different to the matrix compound or matrix compounds of the second electron transport layer; and in addition, the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and the second electron transport layer is free of a dopant; and wherein the organic light-emitting diode comprises in addition an electron injection layer, preferably the electron injection layer is arranged between the electron transport layer and the cathode electrode, wherein the electron injection layer has a layer thickness of about ≥ 0.5 nm to about ≤ 5 nm and may:

- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with a lithium halide or doped with a lithium organic complex, preferably lithium tetra(1H-pyrazol-1-yl)borate; or
- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with an elemental metal selected from a group comprising alkali, alkaline earth or rare earth metals, preferably Li, Cs, Mg, Ca, Yb, or Sm; or
- consist of a metal halide or of an organic complex, preferably LiQ, AlQ₃, ZrQ₄, KF or LiF, wherein Q is a 8-hydroxyquinolate;
- consist of an alkali, alkaline earth or rare earth metal, preferably Li, Cs, Mg, Ca, Yb, or Sm.

[0014] According to various embodiments of the OLED the electron transport layer and/or electron transport layer stack may comprise a lithium organic complex only.

[0015] According to various aspects, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound, wherein

- the matrix compound or compounds of the first electron transport layer is/are different to the matrix compound or compounds of the second electron transport layer; and in addition,
- the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0016] According to various aspects the organic light-emitting diode (OLED) may contain two or more electron transport layers, for example two or three electron transport layers.

[0017] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least three electron transport layers, preferably three electron transport layers, wherein a first electron transport layer, a second electron transport layer and a third electron transport layer comprises at least one matrix compound, wherein

- the matrix compound or matrix compounds of the first electron transport layer is/are different to the matrix compound or matrix compounds of the second electron transport layer; and in addition,
- the first and third electron transport layers comprise a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0018] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least three electron transport layers, preferably three electron transport layers, wherein a first electron transport layer, a second electron transport layer and a third electron transport layer comprises at least one matrix compound, wherein

- the matrix compound or matrix compounds of the first electron transport layer is/are different to the matrix compound or matrix compounds of the second electron transport layer;
- the matrix compound or matrix compounds of the first electron transport layer is identical to the matrix compound or matrix compounds of the third electron transport layer; and in addition,
- the first and third electron transport layers comprise a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0019] According to various embodiments of the organic light-emitting diode the electron transport layer stack may have three electron transport layers, wherein

- the first electron transport layer and the third electron transport layer comprise the same or different matrix compound and the same or different dopant; and
- the second electron transport layer contains a matrix compound that differs from the matrix compound of the first and third transport layers and is free of a dopant.

[0020] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, preferably two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound of a phosphine oxide, wherein

- the phosphine oxide matrix compound or phosphine oxide matrix compounds of the first electron transport layer is/are different to the phosphine oxide matrix compound or phosphine oxide matrix compounds of the second electron transport layer; and in addition,
- the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0021] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least three electron transport layers, preferably three electron transport layers, wherein a first electron transport layer, a second electron transport layer and a third electron transport layer comprises at least one matrix compound of a phosphine oxide, wherein

- the phosphine oxide matrix compound or phosphine oxide matrix compounds of the first electron transport layer is/are different to the phosphine oxide matrix compound or phosphine oxide matrix compounds of the second electron transport layer; and in addition,
- the first and third electron transport layers comprise a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0022] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least three electron transport layers, preferably three electron transport layers, wherein a first electron transport layer, a second electron transport layer and a third electron transport layer comprises at least one matrix compound of a phosphine oxide, wherein

- the phosphine oxide matrix compound or phosphine oxide matrix compounds of the first electron transport layer is/are different to the phosphine oxide matrix compound or phosphine oxide matrix compounds of the second electron transport layer;
- the phosphine oxide matrix compound or phosphine oxide matrix compounds of the first electron transport layer is identical to the phosphine oxide matrix compound or phosphine oxide matrix compounds of the third electron transport layer; and in addition,
- the first and third electron transport layers comprise a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant.

[0023] According to various aspects of the OLED the electron transport layer stack of three electron transport layers may contain a first electron transport layer comprising a matrix compound and at least one lithium compound and a third electron transport layer comprising a matrix compound and as a dopant at least one lithium compound, wherein the lithium compound of the first electron transport layer and third electron transport layer is same or different, preferably

same, and the second electron transport layer contains a matrix material that is different from the first electron transport layer or preferably different from the first and third electron transport layer; and wherein the second electron transport layer is free of a dopant.

[0024] According to various aspects of the OLED the electron transport layers of the electron transport layer stack, preferably the first electron transport layer and the second electron transport layer; or further preferred the first electron transport layer, the second electron transport layer and the third electron transport layer; may have similar or identical energy levels, more preferred the off-set in LUMO level is about ≤ 0.3 eV, and further more preferred the off-set in LUMO level is about ≤ 0.2 eV.

[0025] According to another aspect, there is provided an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, preferably two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound of a phosphine oxide, wherein

- the phosphine oxide matrix compound or phosphine oxide matrix compounds of the first electron transport layer is/are different to the phosphine oxide matrix compound or phosphine oxide matrix compounds of the second electron transport layer; and in addition,
- the first electron transport layer comprises a dopant of a lithium halide and/or lithium organic complex; and wherein
- the second electron transport layer is free of a dopant; and

wherein the first electron transport layer, the second electron transport layer and optional a third electron transport layer, may have similar or identical energy levels, more preferred the off-set in LUMO level is about ≤ 0.3 eV, and further more preferred the off-set in LUMO level is about ≤ 0.2 eV.

[0026] For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

[0027] In the context of the present specification the term "different" or "differs" in connection with the matrix material means that the matrix material differs in their structural formula.

[0028] In the context of the present specification the term "different" or "differs" in connection with the lithium compound means that the lithium compound differs in their structural formula.

[0029] The external quantum efficiency, also named EQE, is measured in percent (%).

[0030] The lifetime, also named LT, between starting brightness and 97 % of the original brightness is measured in hours (h).

[0031] The voltage, also named V, is measured in Volt (V) at 10 milliAmpere per square centimeter (mA/cm²) in bottom emission devices and at 15 mA/cm² for top emission devices.

[0032] The color space is described by coordinates CIE-x and CIE-y (International Commission on Illumination 1931). For blue emission the CIE-y is of particular importance. A smaller CIE-y denotes a deeper blue color.

[0033] The highest occupied molecular orbital, also named HOMO, and lowest unoccupied molecular orbital, also named LUMO, are measured in electron volt (eV).

[0034] The term "OLED" and "organic light-emitting diode" is simultaneously used and having the same meaning.

[0035] The term "electron transport layer stack" as used in the specification comprises at least two electron transport layers or at least three electron transport layers.

[0036] The term "different compound" as used in connection with the matrix compound means that the matrix compound differs from the other matrix compound in its chemical formula.

[0037] As used herein, "weight percent", "wt.-%", "percent by weight", "% by weight", and variations thereof refer to a composition, component, substance or agent as the weight of that component, substance or agent of the respective electron transport layer divided by the total weight of the respective electron transport layer thereof and multiplied by 100. It is understood that the total weight percent amount of all components, substances and agents of the respective electron transport layer are selected such that it does not exceed 100 wt.-%.

[0038] All numeric values are herein assumed to be modified by the term "about", whether or not explicitly indicated. As used herein, the term "about" refers to variation in the numerical quantity that can occur. Whether or not modified by the term "about" the claims include equivalents to the quantities.

[0039] It should be noted that, as used in this specification and the appended claims, the singular forms "a", "an", and "the" include plural referents unless the content clearly dictates otherwise.

[0040] The term "free of", "does not contain", "does not comprise" does not exclude impurities. Impurities have no technical effect with respect to the object achieved by the present invention.

[0041] The term "alkyl" refers to straight-chain or branched alkyl groups. The term "1 to 20 carbon atoms" as used herein refers to straight-chain or branched alkyl groups having 1 to 20 carbon atoms. The alkyl groups can be selected from the group comprising methyl, ethyl and the isomers of propyl, butyl or pentyl, such as isopropyl, isobutyl, tert.-butyl, sec.-butyl and/or isopentyl. The term "aryl" refers to aromatic groups for example phenyl or naphthyl.

[0042] Herein, when a first element is referred to as being formed or disposed "on" a second element, the first element can be disposed directly on the second element or one or more other elements may be disposed there between. When a first element is referred to as being formed or disposed "directly on" a second element, no other elements are disposed there between.

[0043] According to various aspects of the OLED the electron transport layer and/or electron transport layer stack is free of elemental metal.

[0044] According to various aspects of the OLED the electron transport layer stack may contain at least one electron transport layer, preferably the second electron transport layer, which is free of a metal salt and/or a metal organic complex.

[0045] According to various aspects of the OLED the electron transport layer stack contains at least one electron transport layer, preferably the second electron transport layer, which is free of a lithium compound selected from the group lithium halide and/or lithium organic complex.

[0046] In the context that the electron transport layer or layers are free of a dopant, metal salt, and/or metal organic complex, the term "free of" means that the so called "free off" electron transport layer or layers may comprise of about 5 wt.-% or less of a dopant, metal salt and/or a metal organic complex, preferably about 0.5 wt.-% or less, and more preferably about 0.05 wt.-% or less, and even more preferably about 0.005 wt.-% or less of a dopant, a metal salt and/or metal organic complex and most preferred is free of a dopant, metal salt and/or a metal organic complex.

[0047] According to various aspects, there is provided an organic light-emitting diode, whereby the organic light-emitting diode may not contain a charge generation layer (CGL).

[0048] According to various aspects, wherein for an OLED comprising two electron transport layer or three electron transport layers the OLED may contain at least one electron injection layer.

[0049] According to various aspects, wherein for an electron transport layer stack of at least two electron transport layers the first electron transport layer is arranged closest to an emission layer and the second electron transport layer is arranged closest to a cathode.

[0050] According to various aspects, wherein for an electron transport layer stack of three electron transport layers the first electron transport layer is arranged closest to an emission layer, the second electron layer is sandwiched between the first and the third electron transport layer and the third electron transport layer is arranged closest to a cathode.

[0051] The organic light-emitting diode can be a bottom emission OLED or a top emission OLED.

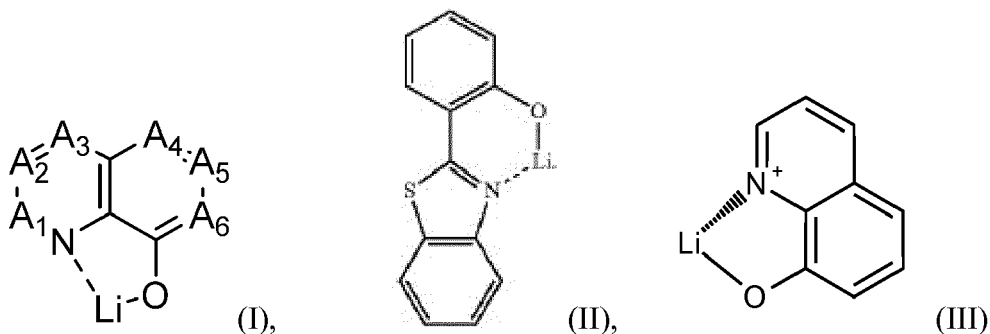
Dopant

[0052] According to various aspects the lithium halide dopant can be selected from the group comprising LiF, LiCl, LiBr or LiI, and preferably LiF.

[0053] According to various aspects the dopant of a lithium compound can be a lithium organic complex and preferably the dopant of the lithium compound can be selected from the group comprising a lithium quinolate, a lithium borate, a lithium phenolate, a lithium pyridinolate or a lithium Schiff base and lithium fluoride, preferably a lithium 2-(diphenylphosphoryl)-phenolate, lithium tetra(1H-pyrazol-1-yl)borate, a lithium quinolate of formula (III), a lithium 2-(pyridin-2-yl)phenolate and LiF, and more preferred selected from the group comprising a lithium 2-(diphenylphosphoryl)-phenolate, lithium tetra(1H-pyrazol-1-yl)borate, a lithium quinolate of formula (III) and a lithium 2-(pyridin-2-yl)phenolate.

[0054] More preferably the lithium organic complex can be selected from the group comprising a lithium quinolate, a lithium borate, a lithium phenolate, a lithium pyridinolate or a lithium Schiff base; preferably

- the lithium organic complex, is selected from the group comprising a lithium quinolate, a lithium borate, a lithium phenolate, a lithium pyridinolate or a lithium Schiff base;
- preferably the lithium quinolate has the formula I, II or III:

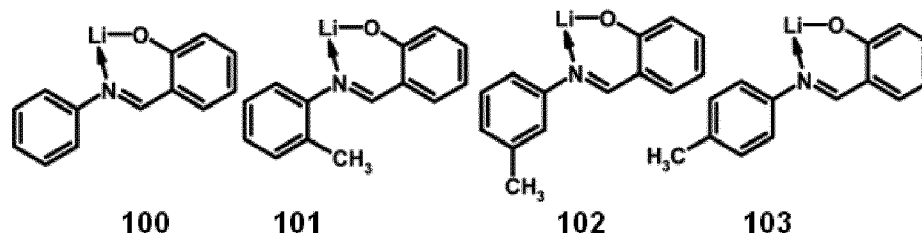


wherein

A1 to A6 are same or independently selected from CH, CR, N, O;

R is same or independently selected from hydrogen, halogen, alkyl or aryl or heteroaryl with 1 to 20 carbon atoms; and more preferred A1 to A6 are CH;

- preferably the lithium borate is a lithium tetra(1H-pyrazol-1-yl)borate;
- preferably the lithium phenolate is a lithium 2-(pyridin-2-yl)phenolate, a lithium 2-(diphenylphosphoryl)phenolate, a lithium imidazol phenolates, or a lithium 2-(pyridin-2-yl)phenolate and more preferred a lithium 2-(1-phenyl-1H-benzo[d]imidazol-2-yl)phenolate, or a lithium 2-(benzo[d]oxazol-2-yl)phenolate;
- preferably the lithium pyridinolate is a lithium 2-(diphenylphosphoryl)pyridin-3-olate,
- preferably the lithium Schiff base has the structure 100, 101, 102 or 103:



[0055] Quinolates that can be suitable used are disclosed in WO 2013079217 A1 and incorporated by reference.

[0056] According to various embodiments of the organic light-emitting diode (OLED) of the present invention the organic ligand of the lithium organic complex can be a borate based organic ligand, Preferably the lithium organic complex is a lithium tetra(1H-pyrazol-1-yl)borate. Borate based organic ligands that can be suitable used are disclosed in WO 2013079676 A1 and incorporated by reference.

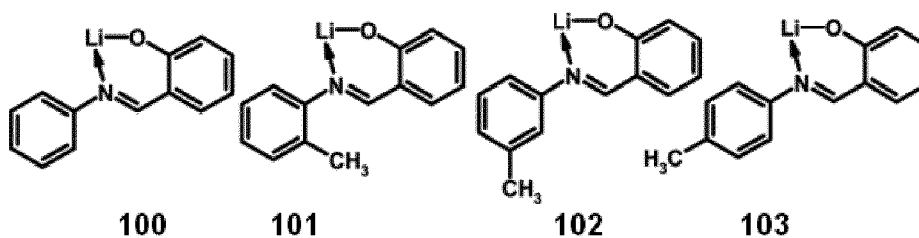
[0057] According to various embodiments of the organic light-emitting diode (OLED) of the present invention the organic ligand of the lithium organic complex can be a phenolate ligand, Preferably the lithium organic complex is a lithium 2-(diphenylphosphoryl)phenolate. Phenolate ligands that can be suitable used are disclosed in WO 2013079678 A1 and incorporated by reference.

[0058] Further, phenolate ligands can be selected from the group comprising pyridinolate, preferably 2-(diphenylphosphoryl)pyridin-3-olate. Pyridine phenolate ligands that can be suitable used are disclosed in JP 2008195623 and incorporated by reference.

[0059] In addition, phenolate ligands can be selected from the group comprising imidazol phenolates, preferably 2-(1-phenyl-1H-benzo[d]imidazol-2-yl)phenolate. Imidazol phenolate ligands that can be suitable used are disclosed in JP 2001291593 and incorporated by reference.

[0060] Also, phenolate ligands can be selected from the group comprising oxazol phenolates, preferably 2-(benzo[d]oxazol-2-yl)phenolate. Oxazol phenolate ligands that can be suitable used are disclosed in US 20030165711 and incorporated by reference.

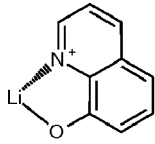
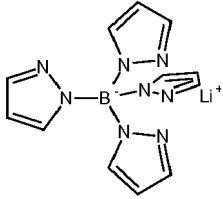
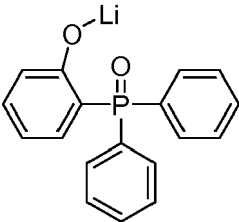
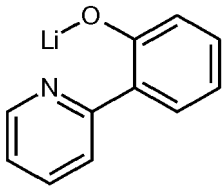
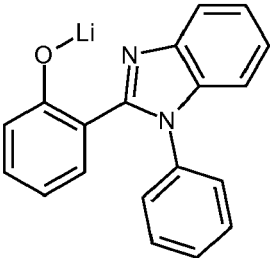
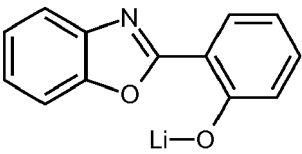
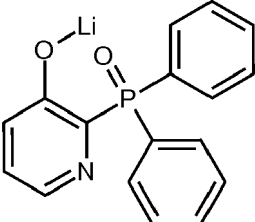
[0061] Lithium Schiff base organic complexes can be use. Lithium Schiff base organic complexes that can be suitable used having the structure 100, 101, 102 or 103:



[0062] Suitable organic ligands to form a lithium organic complex that can be used for the first electron transport layer and/or the second electron transport layer are disclosed, and incorporated by reference, for example in US 2014/0048792 and Kathirgamanathan, Poopathy; Arkley, Vincent; Surendrakumar, Sivagnanasundram; Chan, Yun F.; Ravichandran, Seenivasagam; Ganeshamurugan, Subramaniam; Kumaravel, Muttulingam; Antipan-Lara, Juan; Paramaswara, Gnanamolly; Reddy, Vanga R., Digest of Technical Papers - Society for Information Display International Symposium (2010), 41(Bk. 1), 465-468.

[0063] Suitable lithium organic complexes that can be most preferably used for the electron transport layer are summarized in Table 1 below.

Table 1

Lithium organic complex that can be suitable used			
	IUPAC name	Structure	Reference
Li-Q	lithium 8-hydroxyquinolate		WO 2013079217 A1
Li-1	lithium tetra(1H-pyrazol-1-yl)borate		WO 2013079676 A1
Li-2	lithium 2-(diphenylphosphoryl)phenolate		WO 2013079678A1
Li-3	lithium 2-(pyridin-2-yl)phenolate		JP2 008195623
Li-4	lithium 2-(1-phenyl-1H-benzo[d]imidazol-2-yl)phenolate		JP 2001291593
Li-5	lithium 2-(benzo[d]oxazol-2-yl)phenolate		US 20030165711
Li-6	lithium 2-(diphenyl-phosphoryl)pyridin-3-olate		EP 2724388

[0064] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-%, and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-% of a lithium halide or a lithium organic complex; or
- the first electron transport layer and the third electron transport layer may comprise each about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-% and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-% of a lithium halide or a lithium organic complex;

wherein the weight percent of the lithium halide and the lithium organic complex is based on the total weight of the corresponding electron transport layer.

Matrix compounds

[0065] According to various embodiments of the organic light-emitting diode (OLED) of the present invention the electron transport layer or the electron transport layers of an electron transport layer stack, may comprise at least one matrix compound each.

[0066] According to various embodiments of the organic light-emitting diode, wherein the first electron transport layer and/or the third electron transport layer may comprise of at least one matrix compound.

[0067] According to various embodiments of the organic light-emitting diode, wherein the first electron transport layer and/or the third electron transport layer may comprise independent of each other one, two, three or more matrix compounds, preferably one matrix compound; whereby the matrix compound or matrix compounds selected same or different.

[0068] According to various embodiments of the organic light-emitting diode, wherein the second electron transport layer may consist of at least one matrix compound.

[0069] According to various embodiments the organic light-emitting diode (OLED) may comprise an electron transport layer stack of at least two electron transport layers or at least three electron transport layers, wherein each electron transport layer comprises at least one matrix compound, whereby the matrix compound of the first and third electron transport layers are selected same or different; and whereby the matrix compound of the second electron transport layer is different to the first electron transport layer, or is different to the first and third electron transport layer or is different to all other electron transport layer/s.

[0070] According to various embodiments of the organic light-emitting diode (OLED) the matrix compound can be selected from:

- an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline;
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;
- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyl-di(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide;
- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline;
- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazoliny)-3,3'-bi-9H-carbazole;
- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline;
- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline;
- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine and / or
- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine.

[0071] According to various embodiments of the organic light-emitting diode (OLED) the at least two electron transport

layers or the at least three electron transport layers of an electron transport layer stack comprise at least one matrix compound, whereby the matrix compound of the first electron transport layer and third electron transport layer are selected same or different; and wherein the matrix compound of the second electron transport layer differs from the first electron transport layer or differs from the first electron transport layer and third electron transport layer; whereby the

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- an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline;
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;
- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphopine-3-oxide, phenyl-di(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide;
- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline;
- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole;
- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline;
- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline;
- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)bi-phenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine and / or
- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine.

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[0072] According to various embodiments of the organic light-emitting diode (OLED) a matrix compound for the electron transport layer can be more preferred; whereby the matrix compound of the second electron transport layer that differs from the first electron transport layer or first and third electron transport layer or all other electron transport layers can be selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphopine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide.

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[0073] According to one aspect the matrix compound for the electron transport layers of the electron layer stack can be selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphopine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenyl phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide.

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[0074] According to another aspect the matrix compound for the electron transport layers of the first, second and third electron transport layers can be selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphopine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenyl phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide.

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[0075] According to another aspect the matrix compound for the electron transport layers of the first and third electron transport layers can be selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups,

preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenyl phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide.

[0076] According to another aspect the OLED may comprises

- a first electron transport layer comprising a matrix material selected from the group of:

- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide and/or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide; and/or
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;

- a second electron transport layer comprising a matrix material selected from the group of:

- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline; and/or
- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole; and/or
- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline; and/or
- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline; and/or
- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]-quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine; and/or
- an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole, 9,10-di(2-naphthyl)anthracene, 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole; and/or
- a pyren phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide; and/or
- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine; and/or

- an optional third electron transport layer comprising a matrix material selected from the group of:

- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide and/or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide; and/or
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;

yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;

whereby the matrix material of the second electron transport layer is selected different to the matrix material of the first electron transport layer and the optional third electron transport layer.

[0077] According to another aspect the OLED may comprises

- a first electron transport layer comprising a matrix material selected from the group of 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole;
- a second electron transport layer comprising a matrix material selected from the group of 9,10-di(2-naphthyl)anthracene, 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole, 3-[3'-(10-phenyl-9-anthracenyl)-[1,1'-biphenyl]-4-yl]-quinolone, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline, 9-phenyl-9'-(4-phenyl-2-quinazolinyl) - 3,3'-bi-9H-carbazole, 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline, 4,4'-bis(4,6-diphenyl-1,3,5-triazine-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]-quinolone, and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine, and/or 7-(naphthalen-2-yl)dibenzo[c,h]acridine;
- an optional third electron transport layer comprising a matrix material selected from the group comprising 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole, 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide;

whereby the matrix material of the second electron transport layer is selected different to the matrix material of the first electron transport layer and the optional third electron transport layer.

[0078] According to another aspect the matrix compound of the first electron transport layer or of the first and third electron transport layer can be (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and the matrix compound of the second electron transport layer can be 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline and/or 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline and/or 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl and/or 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide.

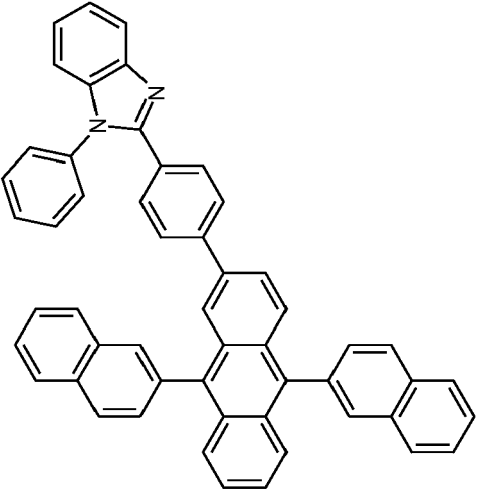
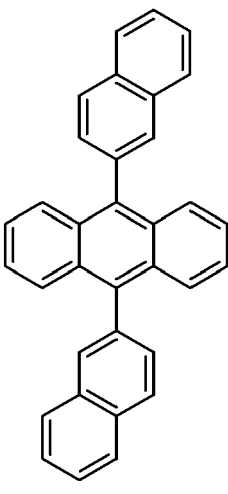
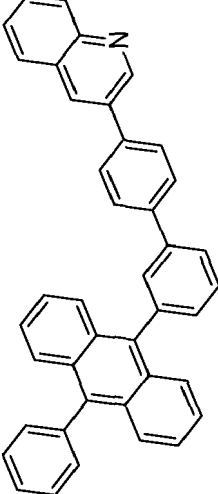
[0079] According to another aspect the first and third electron transport layer may consist of one matrix compound and one dopant and the second electron transport layer may consist of one matrix compound.

[0080] According to another aspect the first electron transport layer may consist of one matrix compound and one dopant and the second electron transport layer may consist of one matrix compound.

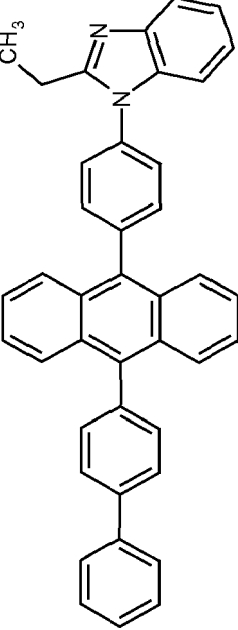
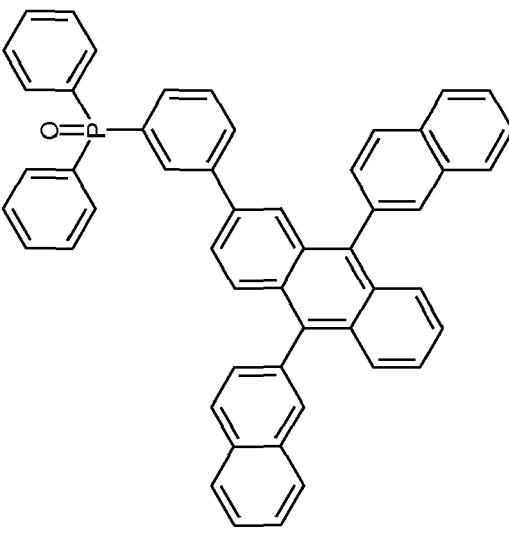
[0081] According to another aspect the second electron transport layer may consist of one matrix compound.

[0082] Suitable matrix compounds that can be suitable used for the electron transport layer are summarized in Table 2 below.

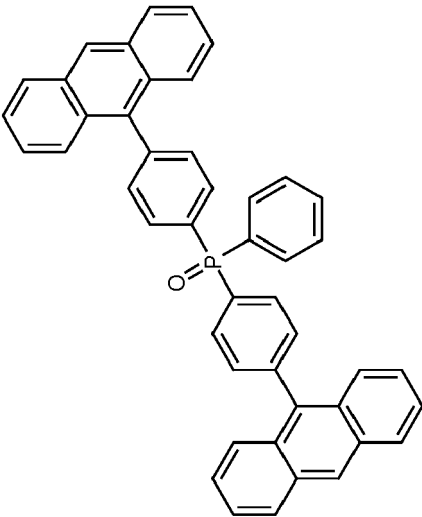
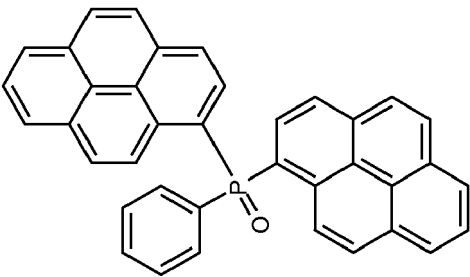
Table 2

Compound	Name	Chemical structures of matrix compounds that can be suitable used	Reference
MX1	2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1H-benzo[d]imidazole		US 6878469
MX 2	9,10-di(2-naphthyl)anthracene		US5935721
MX 3	3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline		KR2011018195

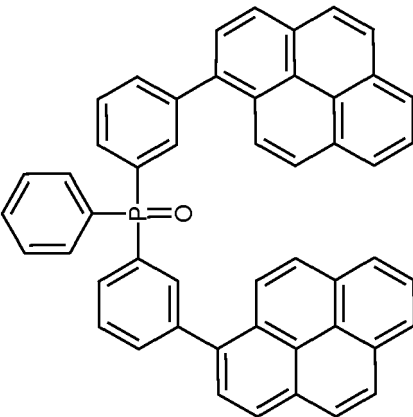
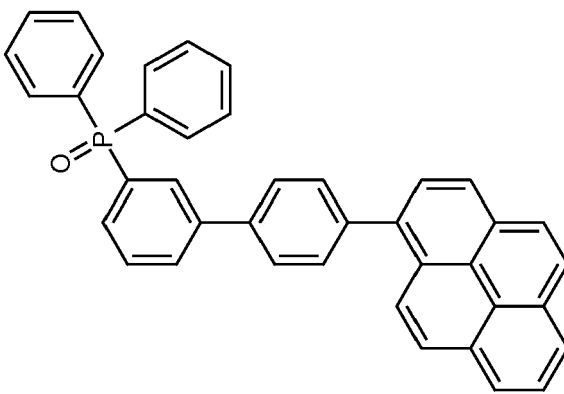
(continued)

Compound		Name	Structure	Reference
MX 4		1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole		WO2010134352
MX 5		(3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide		EP13187905.8

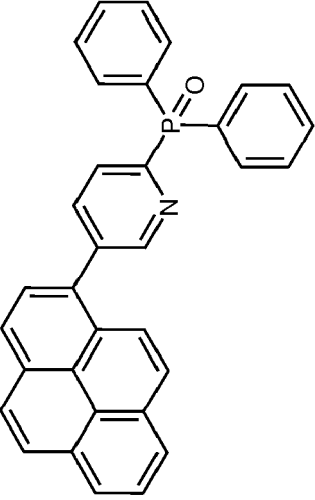
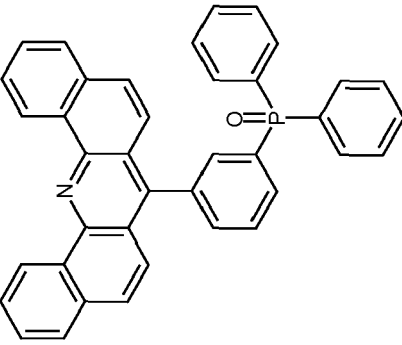
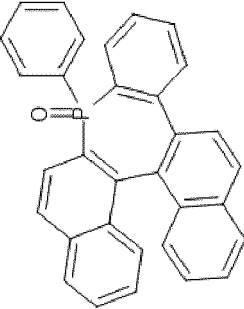
(continued)

5	Reference	EP13187905.8	JP4876333
10	Structure		
15	Name	bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide	Phenylidi(pyren-1-yl)phosphine oxide
20	Compound	MX 6	MX 7

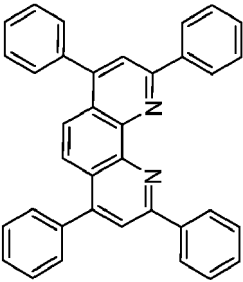
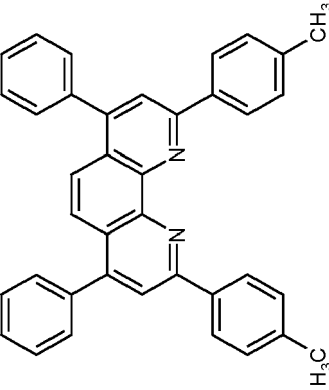
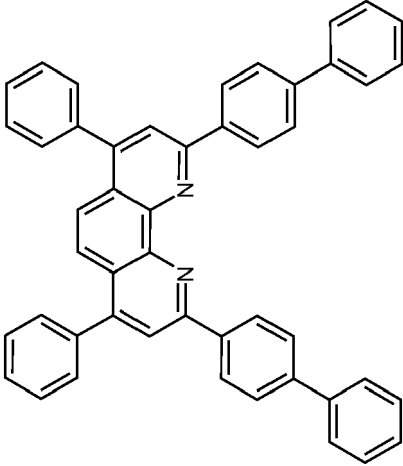
(continued)

5	Reference	EP13187905.8	
10 15 20 25 30	Structure		Phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide
35 40 45 50 55	Compound	MX 8	diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide
		MX 9	

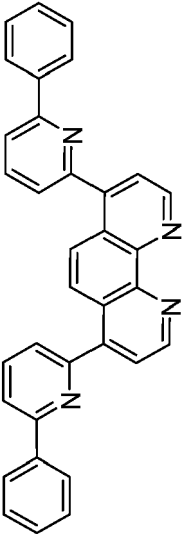
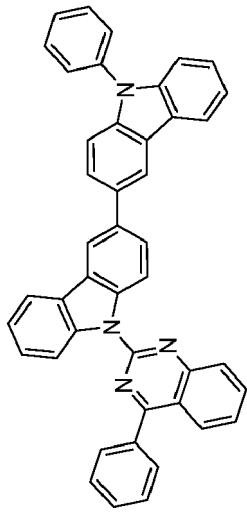
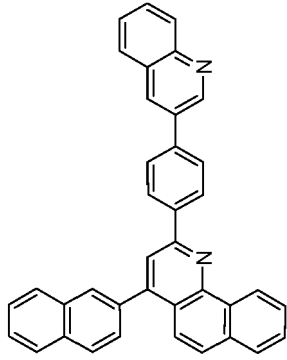
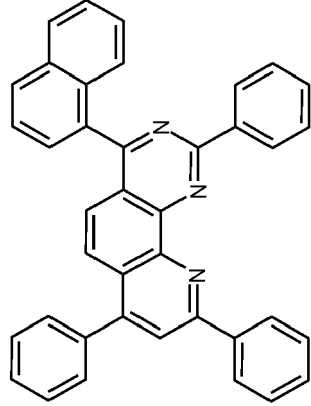
(continued)

Compound	Name	Structure	Reference
MX 10	diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide		WO2014167020
MX 11	(3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide		EP 2395571, WO2013079217
MX 12	3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide		EP13199361.0

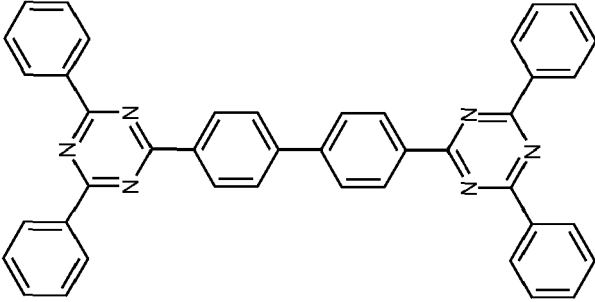
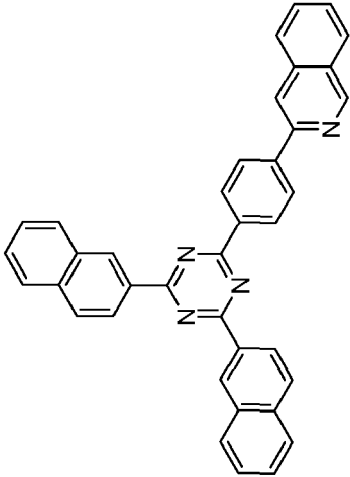
(continued)

Compound	Name	Structure	Reference
MX 13	2,4,7,9-tetraphenyl-1,10-phenanthroline		EP1786050
MX 14	4,7-di-phenyl-2,9-di-p-tolyl-1,10-phenanthroline		EP1786050
MX 15	2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline		EP1786050

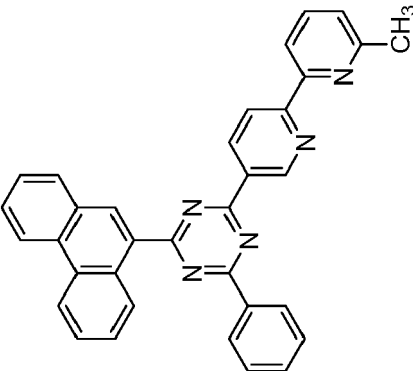
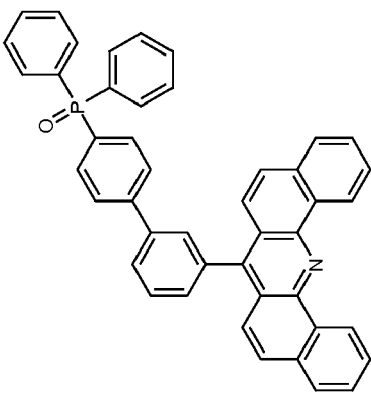
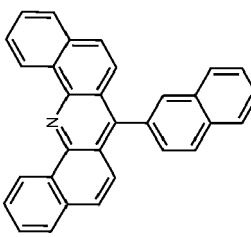
(continued)

Compound	Name	Structure	Reference
MX 16	3,8-bis(6-phenyl-2-pyridinyl)- 1,10-phenanthroline		CN102372708
MX 17	9-phenyl-9'-(4-phenyl-2-quinazolinyl)- 3, 3'-bi-9H-carbazole		KR2012102374
MX 18	4-(2-naphthalenyl)-2-[4-(3-quinolinyl) phenyl]- benzo[h]quinazoline		KR2014076522
MX 19	4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline		EP1970371

(continued)

Compound	Name	Structure	Reference
MX 20	4,4'-bis(4,6-diphenyl-1,3,5-triazine-2-yl)biphenyl		US6225467
MX 21	3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]-quinoline		US2011015601 3

(continued)

Compound	Name	Structure	Reference
MX 22	2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine		WO2014171541
MX 23	(3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide		EP 2395571, WO2013079217
MX 24	7-(naphthalen-2-yl)dibenzo[c,h]acridine		EP 2395571

[0083] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer comprises about ≤ 90 wt.-% to about ≥ 30 wt.-%, of a matrix compound; or
 - the first electron transport layer and the third electron transport layer comprises each about ≤ 90 wt.-% to about ≥ 30 wt.-%, of a matrix compound;
- wherein the weight percent of the matrix compound is based on the total weight of the corresponding transport layer

[0084] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≤ 80 wt.-% to about ≥ 35 wt.-% of a matrix compound; or
 - the first electron transport layer and the third electron transport layer comprises each about ≤ 80 wt.-% to about ≥ 35 wt.-% of a matrix compound;
- wherein the weight percent of the matrix compound is based on the total weight of the corresponding transport layer.

[0085] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≤ 50 wt.-% to about ≥ 40 wt.-% of a matrix compound; or
 - the first electron transport layer and the third electron transport layer comprises each about ≤ 50 wt.-% to about ≥ 40 wt.-% of a matrix compound;
- wherein the weight percent of the matrix compound is based on the total weight of the corresponding transport layer.

[0086] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≥ 10 wt.-% to about ≤ 70 wt.-%, of a lithium halide or a lithium organic complex; or
 - the first electron transport layer and the third electron transport layer may comprise each about ≥ 10 wt.-% to about ≤ 70 wt.-%, of a lithium halide or a lithium organic complex;
- wherein the weight percent of the lithium halide and the lithium organic complex is based on the total weight of the corresponding electron transport layer.

[0087] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≥ 20 wt.-% to about ≤ 65 wt.-%, of a lithium halide or a lithium organic complex; or
 - the first electron transport layer and the third electron transport layer may comprise each about ≥ 20 wt.-% to about ≤ 65 wt.-%, of a lithium halide or a lithium organic complex;
- wherein the weight percent of the lithium halide and the lithium organic complex is based on the total weight of the corresponding electron transport layer.

[0088] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer may comprise about ≥ 50 wt.-% to about ≤ 60 wt.-%, of a lithium halide or a lithium organic complex; or
 - the first electron transport layer and the third electron transport layer may comprise each about ≥ 50 wt.-% to about ≤ 60 wt.-%, of a lithium halide or a lithium organic complex;
- wherein the weight percent of the lithium halide and the lithium organic complex is based on the total weight of the corresponding electron transport layer.

[0089] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer or the first electron transport layer and third electron transport layer, comprises:
 - a) about ≥ 10 wt.-% to about ≤ 70 wt.-% of the dopant;
 - b) about ≤ 90 wt.-% to about ≥ 30 wt.-% of a matrix compound;
 - the second electron transport layer, which is free of a dopant, comprises a matrix compound that is selected different from the first electron transport layer and the optional third electron transport layer; and
- wherein the wt.-% of the components of each electron transport layer is selected such that the total wt.-% amount

does not exceed 100 wt.-% and the wt.-% of the components are based on the total weight of the corresponding transport layer.

[0090] According to various embodiments of the organic light-emitting diode, wherein

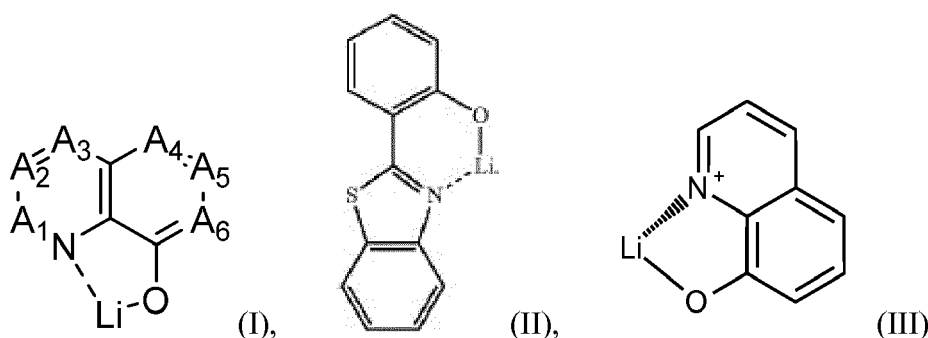
- the first electron transport layer or the first electron transport layer and third electron transport layer, comprises:
 - a) about ≥ 10 wt.-% to about ≤ 70 wt.-% of the dopant;
 - b) about ≤ 90 wt.-% to about ≥ 30 wt.-% of a matrix compound;
- the second electron transport layer, which is free of a dopant, comprises a matrix compound that is selected different from the first electron transport layer and the optional third electron transport layer; and wherein the wt.-% of the components of each electron transport layer is selected such that the total wt.-% amount does not exceed 100 wt.-% and the wt.-% of the components are based on the total weight of the corresponding transport layer.

[0091] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer or the first electron transport layer and third electron transport layer, comprises:
 - a) about ≥ 20 wt.-% to about ≤ 65 wt.-% of the dopant;
 - b) about ≤ 80 wt.-% to about ≥ 35 wt.-% of a matrix compound;
- the second electron transport layer, which is free of a dopant, comprises a matrix compound that is selected different from the first electron transport layer and the optional third electron transport layer; and wherein the wt.-% of the components of each electron transport layer is selected such that the total wt.-% amount does not exceed 100 wt.-% and the wt.-% of the components are based on the total weight of the corresponding transport layer.

[0092] According to various embodiments of the organic light-emitting diode, wherein

- the first electron transport layer, or the first electron transport layer and third electron transport layer, comprises:
 - a) about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-% and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-% of a lithium halide, selected from the group comprising a LiF, LiCl, LiBr or LiI, preferably LiF, or of a lithium organic complex of a lithium quinolate, a lithium borate, a lithium phenolate, a lithium pyridinolate or a lithium Schiff base; preferably of a lithium quinolate complex having the formula I, II or III:



wherein

- A1 to A6 are same or independently selected from CH, CR, N, O,
- R is same or independently selected from hydrogen, halogen, alkyl or aryl or heteroaryl with 1 to 20 carbon atoms, and more preferred of a lithium 8-hydroxyquinolate; and/or a lithium borate, more preferred the lithium borate is lithium tetra(1H-pyrazol-1-yl)borate;

b) about ≤ 90 wt.-% to about ≥ 30 wt.-%, preferably about ≤ 80 wt.-% to about ≥ 35 wt.-% and also preferred

about ≤ 50 wt.-% to about ≥ 40 wt.-% and also preferred about ≤ 50 wt.-% to about ≥ 40 wt.-% of a matrix compound of:

- an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline;
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;
- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide;
- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline;
- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazoliny)-3,3'-bi-9H-carbazole;
- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinoliny)phenyl]-benzo[h]quinazoline;
- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline;
- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine and / or
- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine;
- the second electron transport layer (162), which is free of a dopant, comprises a matrix compound of:
 - an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline;
 - a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;
 - a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide;
 - a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline;
 - a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazoliny)-3,3'-bi-9H-carbazole;
 - a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinoliny)phenyl]-benzo[h]quinazoline;
 - a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline;
 - a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine and / or
 - an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)diben-

zo[c,h]acridine;

whereby more preferred is a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group and most preferred is 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide;

whereby the matrix compound of the first electron transport layer, or the matrix compound of the first electron transport layer and third electron transport layer, is selected different from the second electron transport layer; and the wt.-% of the components of each electron transport layer is selected such that the total wt.-% amount does not exceed 100 wt.-% and the wt.-% of the components are based on the total weight of the corresponding transport layer.

[0093] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of about ≥ 1 nm to about ≤ 95 nm.

[0094] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of about ≥ 6 nm to about ≤ 80 nm.

[0095] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of, further preferred of about ≥ 8 nm to about ≤ 60 nm.

[0096] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of about ≥ 10 nm to about ≤ 40 nm.

[0097] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of about ≥ 8 nm to about ≤ 20 nm.

[0098] According to various embodiments of the organic light-emitting diode (OLED), the thicknesses of the first electron transport layer and/or the second electron transport layer and/or the third electron transport layer can be same or each independently in the range of about ≥ 10 nm to about ≤ 18 nm.

[0099] According to various embodiments of the organic light-emitting diode (OLED) the thicknesses of the electron transport layer stack can be in the range of about ≥ 25 nm to about ≤ 100 nm.

[0100] According to various embodiments of the organic light-emitting diode (OLED) the thicknesses of the electron transport layer stack can be in the range of about ≥ 30 nm to about ≤ 80 nm.

[0101] According to various embodiments of the organic light-emitting diode (OLED) the thicknesses of the electron transport layer stack can be in the range of about ≥ 35 nm to about ≤ 60 nm.

[0102] According to various embodiments of the organic light-emitting diode (OLED) the thicknesses of the electron transport layer stack can be in the range of about ≥ 36 nm to about ≤ 40 nm.

[0103] According to various embodiments of the organic light-emitting diode (OLED) of the present invention the electron transport layer stack has 2 to 4 electron transport layers and more preferred 2 to 3 electron transport layers.

[0104] According to various embodiments of the organic light-emitting diode (OLED) of the present invention the second electron transport layer can be arranged directly on the first electron transport layer and an optional third electron transport layer can be arranged directly on the second electron transport layer, so that the second electron transport layer is sandwiched between the first and third electron transport layers.

[0105] According to another aspect, there is provided an organic light-emitting diode comprising: a substrate; an anode electrode is formed on the substrate; an electron transport layer stack is formed on the anode electrode, whereby the electron transport layer stack comprises or consist of at least two electron transport layers; and finally a cathode electrode is formed, so that the electron transport layer stack is sandwiched between the anode electrode and the cathode electrode; and optional an electron injection layer is arranged between the electron transport layer and the cathode electrode.

[0106] According to various embodiments, the organic light-emitting diode (OLED) may further include at least one layer selected from the group consisting of a hole injection layer, a hole transport layer, an emission layer, and a hole blocking layer, arranged between the anode electrode and the electron transport layer.

[0107] According to another aspect, there is provided an organic light-emitting diode comprising in addition: at least one layer selected from the group consisting of a hole injection layer, a hole transport layer, an emission layer, and a hole blocking layer, arranged between the anode electrode and the electron transport layer stack.

[0108] According to various aspects, there is provided an organic light-emitting diode further comprising an electron injection layer arranged between the electron transport layer and the cathode electrode.

[0109] According to another aspect, there is provided an organic light-emitting diode comprising at least two electron transport layers and at least one electron injection layer.

[0110] Preferably the organic light-emitting diode may comprise an electron transport layer stack having two to four electron transport layers and more preferred two electron transport layers or three electron transport layers.

[0111] According to another aspect, there is provided an organic light-emitting diode comprising an electron transport

layer stack of at least three electron transport layers and at least one electron injection layer. More preferred can be an organic light-emitting diode comprising three electron transport layers and no electron injection layer.

[0112] According to another aspect the organic light-emitting diode comprising an electron transport layer stack can be free of an electron injection layer.

[0113] According to various embodiments of the OLED of the present invention, the OLED may not comprise an electron injection layer.

[0114] According to various embodiments of the OLED of the present invention, the OLED may not comprise a charge generation layer.

[0115] According to various embodiments of the OLED of the present invention, the OLED may not comprise an electron injection layer and a charge generation layer.

[0116] According to another aspect, there is provided a method of manufacturing an organic light-emitting diode (OLED), the method using:

- at least three deposition sources; and/or
- deposition via vacuum thermal evaporation; and/or
- deposition via solution processing, preferably the processing is selected from spin-coating, casting, printing and/or slot-die coating.

[0117] According to various aspects, there is provided a method using:

- a first deposition source to release the matrix compound, and
- a second deposition source to release lithium halide or lithium organic complex; the method comprising the steps of forming the electron transport layer stack; whereby the first electron transport layer is formed by releasing the matrix compound from the first deposition source and the lithium halide or lithium organic complex from the second deposition source;
- onto the first electron transport layer the second electron transport layer is formed by releasing the matrix compound from a third deposition source; wherein the matrix compound of the first electron transport layer is not the same as the matrix compound of the second electron transport layer.

[0118] According to various aspects, there is provided a method using:

- a first and a third deposition source to release different matrix compounds, and
- a second and a fourth deposition source to release lithium halide or lithium organic complex, which is different to the lithium halide or lithium organic complex used for the second deposition source, preferably a lithium organic complex, and the method comprising the steps of forming the electron transport layer or the electron transport layer stack; whereby
- a first electron transport layer is formed by releasing the matrix compound from a first deposition source, and lithium halide or lithium organic complex from a second deposition source;
- onto the first electron transport layer a second electron transport layer is formed by releasing a matrix compound, different from the first electron transport layer, via a third deposition source;
- optional onto the second electron transport layer a third electron transport layer is formed by releasing the matrix compound used for the first electron transport layer via the first deposition source, and the fourth deposition source is used for releasing the lithium halide

or lithium organic complex different to that used for the first electron transport layer; whereby the second electron transport layer is free of a dopant.

[0119] According to various aspects, the method may further include forming on the anode electrode an emission layer and at least one layer selected from the group consisting of forming a hole injection layer, forming a hole transport layer, or forming a hole blocking layer, between the anode electrode and the electron transport layer stack.

[0120] According to various aspects, the method may further include the steps for forming an organic light-emitting diode (OLED), wherein

- on a substrate an anode electrode is formed,
- on the anode electrode an emission layer is formed,
- on the emission layer at least two electron transport layers are formed, whereby the second electron transport layer is free of a dopant, optional a third electron transport layer is formed directly on the second electron transport layer, whereby the matrix material of the third electron transport layer is different to the matrix material of the second

electron transport layer and the matrix material, lithium halide and/or lithium organic complex of the third electron transport layer is different or same to that of the first electron transport layer,

- on the electron transport layer stack a cathode electrode is formed,
- optional a hole injection layer, a hole transport layer, an emission layer, and a hole blocking layer, are formed between the anode electrode and the electron transport layer stack,
- optional an electron injection layer is formed between the electron transport layer or electron transport layer stack, and the cathode electrode.

[0121] According to various aspects, the method may further include the steps for forming an organic light-emitting diode (OLED), wherein an electron injection layer is formed between electron transport layer stack, and the cathode electrode.

[0122] According to various aspects, the method may further include the steps for forming an organic light-emitting diode (OLED), wherein an electron injection layer is formed between the electron transport layer stack, and the cathode electrode.

[0123] According to various aspects, the method may further include the steps for forming an organic light-emitting diode (OLED), wherein

- on a substrate an anode electrode is formed,
- on the anode electrode an emission layer is formed,
- on the emission layer an electron transport layer stack of at least a first electron transport and a second electron transport layer is formed, whereby the second electron transport layer is formed directly on the first electron transport layer and optional a third electron transport layer is formed directly on the second electron transport layer,
- on the electron transport layer stack a cathode electrode is formed,
- an electron injection layer is formed between the electron transport layer stack, and the cathode electrode
- optional a hole injection layer, a hole transport layer, an emission layer, and a hole blocking layer, are formed between the anode electrode and the electron transport layer stack.

[0124] However, according to various embodiments of the OLED of the present invention, the OLED comprising two electron transport layers may not comprise a charge generation layer. However, according to various embodiments of the OLED of the present invention, the OLED comprising three or more electron transport layers may not comprise an electron injection layer and / or a charge generation layer.

[0125] Additional aspects and/or advantages of the invention will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0126] These and/or other aspects and advantages of the present invention will become apparent and more readily appreciated from the following description of the exemplary embodiments, taken in conjunction with the accompanying drawings, of which:

- FIG. 1 is a schematic sectional view of an organic light-emitting diode (OLED), according to an exemplary embodiment of the present invention with an emission layer and two electron transport layers;
- FIG. 2 is a schematic sectional view of an OLED, according to an exemplary embodiment of the present invention with an emission layer and three electron transport layers;
- FIG. 3 is a schematic sectional view of an organic light-emitting diode (OLED), according to an exemplary embodiment of the present invention with an emission layer, two electron transport layers and an electron injection layer
- FIG. 4 is a schematic sectional view of an organic light-emitting diode (OLED), according to an exemplary embodiment of the present invention with an emission layer, two electron transport layers and an electron injection layer;
- FIG. 5 is a schematic sectional view of an OLED, according to an exemplary embodiment of the present invention with an emission layer, three electron transport layers and an electron injection layer,
- FIG. 6 is a schematic sectional view of an OLED, according to an exemplary embodiment of the present invention with an emission layer and two electron transport layers and having no electron injection layer (EIL).
- FIG. 7 is a schematic sectional view of an OLED, according to an exemplary embodiment of the present invention with three electron transport layers and having no electron injection layer (EIL).

DETAILED DESCRIPTION

[0127] Reference will now be made in detail to the exemplary aspects, examples of which are illustrated in the ac-

companying drawings, wherein like reference numerals refer to the like elements throughout. The exemplary embodiments are described below, in order to explain the aspects, by referring to the figures.

[0128] Herein, when a first element is referred to as being formed or disposed "on" a second element, the first element can be disposed directly on the second element, or one or more other elements may be disposed there between. When a first element is referred to as being formed or disposed "directly on" a second element, no other elements are disposed there between.

[0129] FIG. 1 is a schematic sectional view of an organic light-emitting diode 100, according to an exemplary embodiment of the present invention. The OLED 100 includes an emission layer 150 and an electron transport layer stack (ETL) 160 comprising a first electron transport layer 161 and a second electron transport layer 162, whereby the second electron transport layer 162 is disposed directly on the first electron transport layer 161.

[0130] FIG. 2 is a schematic sectional view of an organic light-emitting diode 100, according to an exemplary embodiment of the present invention. The OLED 100 includes an emission layer 150 and an electron transport layer stack (ETL) 160 comprising a first electron transport layer 161, a second electron transport layer 162, and a third electron transport layer 163, whereby the second electron transport layer 162 is disposed directly on the first electron transport layer 161 and the third electron transport layer 163 is disposed directly on the first electron transport layer 162.

[0131] FIG. 3 is a schematic sectional view of an organic light-emitting diode 100, according to an exemplary embodiment of the present invention. The OLED 100 includes an emission layer 150, an electron injection layer (EIL) 180 and an electron transport layer stack (ETL) 160 comprising a first electron transport layer 161 and a second electron transport layer 162, whereby the second electron transport layer 162 is disposed directly on the first electron transport layer 161.

[0132] FIG. 4 is a schematic sectional view of an organic light-emitting diode 100, according to an exemplary embodiment of the present invention. The OLED 100 includes a substrate 110, a first electrode 120, a hole injection layer (HIL) 130, a hole transport layer (HTL) 140, an emission layer (EML) 150, an electron transport layer stack (ETL) 160, an electron injection layer (EIL) 180, and a second electrode 190. The electron transport layer stack (ETL) 160 includes a first electron transport layer 161 including a matrix compound and a dopant of a lithium organic complex and a second electron transport layer 162 including a matrix compound that differs from the matrix compound of the first electron transport layer 161 and is free of a dopant. The second electron transport layer 162 is directly formed on the first electron transport layer 161. The first layer 161 may be formed directly on the EML 150 and the electron injection layer (EIL) 180 may be formed directly on the second electron transport layer 162.

[0133] FIG. 5 is a schematic sectional view of an organic light-emitting diode 100, according to an exemplary embodiment of the present invention. The OLED 100 includes a substrate 110, a first electrode 120, a hole injection layer (HIL) 130, a hole transport layer (HTL) 140, an emission layer (EML) 150, an electron transport layer stack (ETL) 160, an electron injection layer (EIL) 180, and a second electrode 190. The electron transport layer stack (ETL) 160 includes a first electron transport layer 161 and a third electron transport layer 163 including the same matrix compounds and two different lithium organic complexes; and the second electron transport layer 162 includes a matrix compound that differs from the matrix compound of the first and second electron transport layer 161/162 and is free of a dopant. The second electron transport layer 162 is directly formed on the first electron transport layer 161 and the third electron layer 163 is directly formed on the second electron layer 162. The first layer 161 may be formed directly on the emission layer (EML) 150.

[0134] The substrate 110 may be any substrate that is commonly used in manufacturing of organic light-emitting diodes. If light is emitted through the substrate, the substrate 110 may be a transparent material, for example a glass substrate or a transparent plastic substrate, having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and waterproofness. If light is emitted through the top surface, the substrate 110 may be a transparent or non-transparent material, for example a glass substrate, a plastic substrate, a metal substrate or a silicon substrate.

[0135] The anode electrode 120 may be formed by depositing or sputtering a compound that is used to form the anode electrode 120. The compound used to form the anode electrode 120 may be a high work-function compound, so as to facilitate hole injection. If a p-doped HIL is used, the anode material may also be selected from a low work function material (i.e. aluminum). The anode electrode 120 may be a transparent or reflective electrode. Transparent conductive compounds, such as indium tin oxide (ITO), indium zinc oxide (IZO), tin-dioxide (SnO_2), and zinc oxide (ZnO), may be used to form the anode electrode 120. The anode electrode 120 may also be formed using magnesium (Mg), aluminum (Al), aluminum-lithium (Al-Li), calcium (Ca), magnesium-indium (Mg-In), magnesium-silver (Mg-Ag), silver (Ag), gold (Au), or the like.

[0136] The HIL 130 may be formed on the anode electrode 120 by vacuum deposition, spin coating, printing, casting, slot-die coating, Langmuir-Blodgett (LB) deposition, or the like. When the HIL 130 is formed using vacuum deposition, the deposition conditions may vary according to the compound that is used to form the HIL 130, and the desired structure and thermal properties of the HIL 130. In general, however, conditions for vacuum deposition may include a deposition temperature of 100°C to 500°C , a pressure of 10^{-8} to 10^{-3} Torr (1 Torr equals 133.322 Pa), and a deposition rate of 0.1 to 10 nm/sec.

[0137] When the HIL 130 is formed using spin coating, printing, coating conditions may vary according to a compound that is used to form the HIL 130, and the desired structure and thermal properties of the HIL 130. For example, the coating conditions may include a coating speed of about 2000 rpm to about 5000 rpm, and a thermal treatment temperature of about 80° C to about 200° C. Thermal treatment removes a solvent after the coating is performed.

[0138] The HIL 130 may be formed of any compound that is commonly used to form an HIL. Examples of compounds that may be used to form the HIL 130 include a phthalocyanine compound, such as copper phthalocyanine (CuPc), 4,4',4"-tris (3-methylphenylphenylamino) triphenylamine (m-MTDATA), TDATA, 2T-NATA, polyaniline/dodecylbenzenesulfonic acid (Pani/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (Pani/CSA), and polyaniline)/poly(4-styrenesulfonate) (PANI/PSS).

[0139] The HIL 130 may be a pure layer of p-dopant or may be selected from a hole-transporting matrix compound doped with a p-dopant. Typical examples of known redox doped hole transport materials are: copper phthalocyanine (CuPc), which HOMO level is approximately -5.2 eV, doped with tetrafluoro-tetracyanoquinonodimethane (F4TCNQ), which LUMO level is about -5.2 eV; zinc phthalocyanine (ZnPc) (HOMO = -5.2 eV) doped with F4TCNQ; α -NPD (N,N'-Bis(naphthalen-1-yl)-N,N'-bis(phenyl)-benzidine) doped with F4TCNQ. α -NPD doped with 2,2'-(perfluoronaphthalene-2,6-diylidene) dimalononitrile (PD1). α -NPD doped with 2,2',2"-(cyclopropane-1,2,3-triylidene)tris(2-(p-cyanotetrafluorophenyl)acetonitrile) (PD2). Dopant concentrations can be selected from 1 to 20 wt.-%, more preferably from 3 wt.-% to 10 wt.-%.

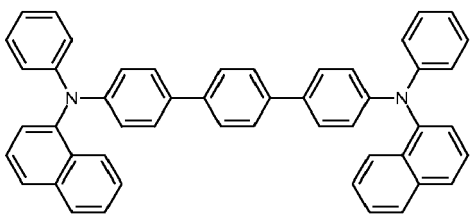
[0140] The thickness of the HIL 130 may be in the range of about 1 nm to about 100 nm, and for example, about 1 nm to about 25 nm. When the thickness of the HIL 130 is within this range, the HIL 130 may have excellent hole injecting characteristics, without a substantial increase in driving voltage.

[0141] The hole transport layer (HTL) 140 may be formed on the HIL 130 by vacuum deposition, spin coating, slot-die coating, printing, casting, Langmuir-Blodgett (LB) deposition, or the like. When the HTL 140 is formed by vacuum deposition or spin coating, the conditions for deposition and coating may be similar to those for the formation of the HIL 130. However, the conditions for the vacuum or solution deposition may vary, according to the compound that is used to form the HTL 140.

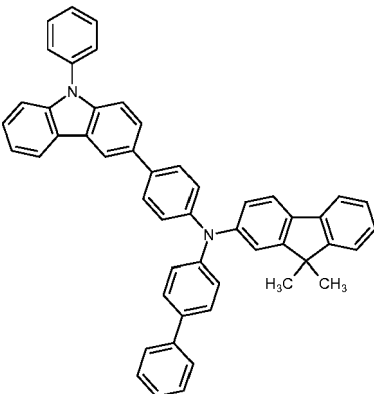
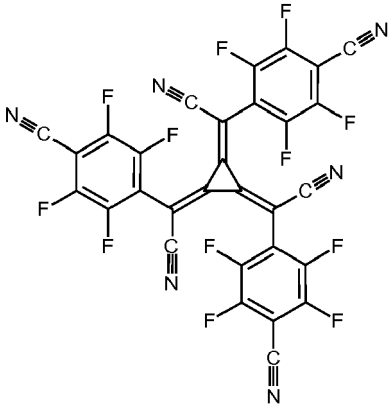
[0142] The HTL 140 may be formed of any compound that is commonly used to form a HTL. Compound that can be suitably used is disclosed for example in Yasuhiko Shirota and Hiroshi Kageyama, Chem. Rev. 2007, 107, 953-1010 and incorporated by reference. Examples of the compound that may be used to form the HTL 140 are: a carbazole derivative, such as N-phenylcarbazole or polyvinylcarbazole; an amine derivative having an aromatic condensation ring, such as N,N'-bis(3-methylphenyl)-N,N'-diphenyl-[1,1'-biphenyl]-4,4'-diamine (TPD), or N,N'-di(naphthalene-1-yl)-N,N'-diphenyl benzydine (α -NPD); and a triphenylamine-based compound, such as 4,4',4"-tris(N-carbazolyl)triphenylamine (TCTA). Among these compounds, TCTA can transport holes and inhibit excitons from being diffused into the EML.

[0143] Compounds that can be preferably used are summarized in Table 3.

Table 3

Name	Structure	Reference
N4,N4"-di(naphthalen-1-yl)-N4,N4"-diphenyl-[1,1':4',1"-terphenyl]-4,4"-diamine		DE102012101652 A1

(continued)

Name	Structure	Reference
Biphenyl-4-yl(9,9-diphenyl-9H-fluoren-2-yl)-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-amine		commercial material, CAS 1242056-42-3
2,2',2''-(cyclopropane-1,2,3-triylidene)tris(2-(p-cyanotetrafluorophenyl)acetonitrile)		EP 1988587 A1, EP 2180029 A1

[0144] The thickness of the HTL 140 may be in the range of about 5 nm to about 250 nm, preferably, about 10 nm to about 200 nm, further about 20 nm to about 190 nm, further about 40 nm to about 180 nm, further about 60 nm to about 170 nm, further about 80 nm to about 160 nm, further about 100 nm to about 160 nm, further about 120 nm to about 140 nm. A preferred thickness of the HTL 140 may be 170 nm to 200 nm.

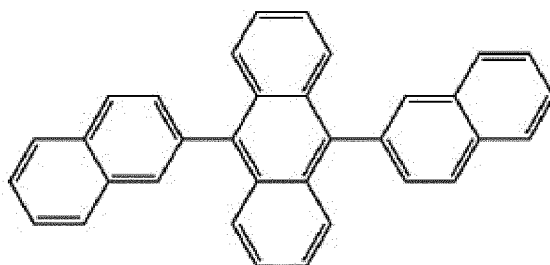
[0145] When the thickness of the HTL 140 is within this range, the HTL 140 may have excellent hole transporting characteristics, without a substantial increase in driving voltage.

[0146] The EML 150 may be formed on the HTL 140 by vacuum deposition, spin coating, slot-die coating, printing, casting, LB, or the like. When the EML 150 is formed using vacuum deposition or spin coating, the conditions for deposition and coating may be similar to those for the formation of the HIL 130. However, the conditions for deposition and coating may vary, according to the compound that is used to form the EML 150.

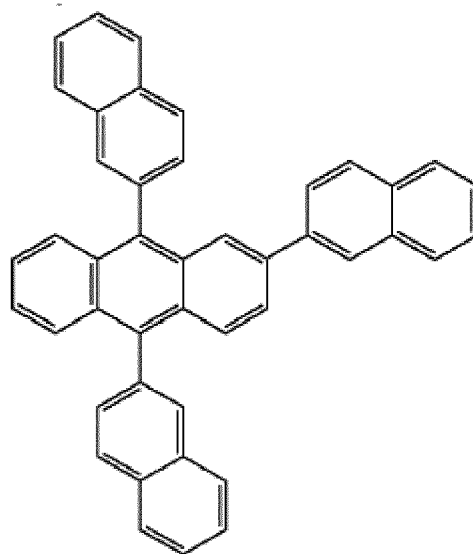
[0147] The emission layer (EML) 150 may be formed of a combination of a host and a dopant. Example of the host are Alq3, 4,4'-N,N'-dicarbazole-biphenyl (CBP), poly(n-vinylcarbazole) (PVK), 9,10-di(naphthalene-2-yl)anthracene (ADN), TCTA, 1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene (TPBI), 3-tert-butyl-9,10-di-2-naphthylanthracene (TBADN), distyrylarylene (DSA), Bis(2-(2-hydroxyphenyl)benzothiazole)zinc (Zn(BTZ) 2), E3 below, ADN and referred to as Formula 1, Compound 1 below, and Compound 2 below.



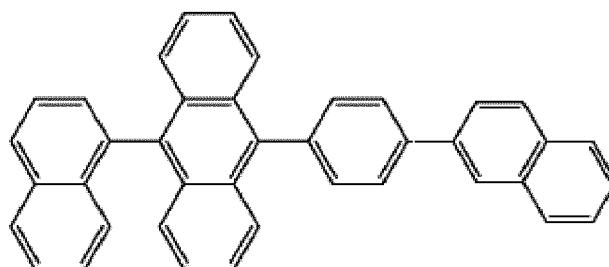
E3



Formula 1 (ADN)



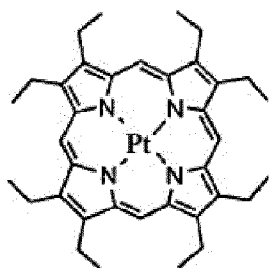
Compound 1



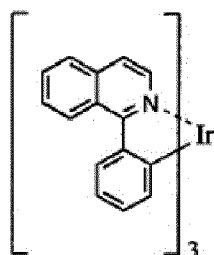
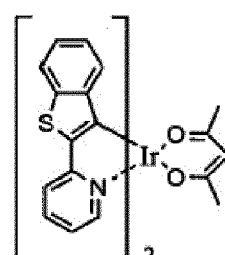
Compound 2

[0148] The dopant may be a phosphorescent or fluorescent emitter. Phosphorescent emitters are preferred due to their higher efficiency

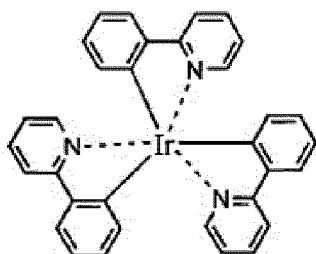
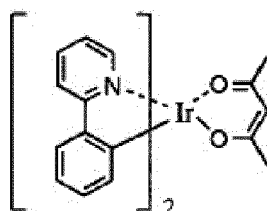
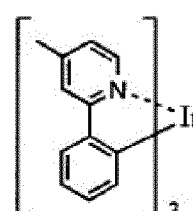
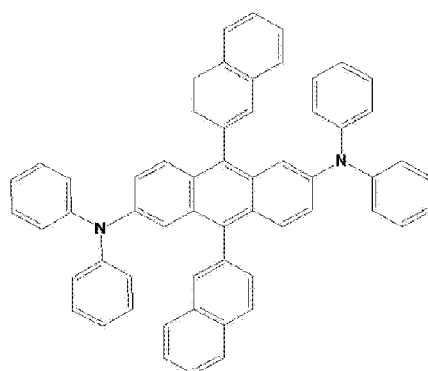
[0149] Examples of a red dopant are PtOEP, Ir(piq) 3, and Btp 2Ir(acac), but are not limited thereto. These compounds are phosphorescent emitters, however, fluorescent red dopants could also be used.



PtOEP

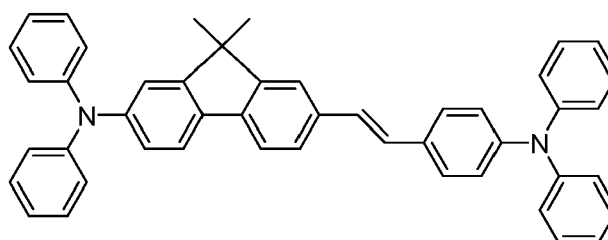
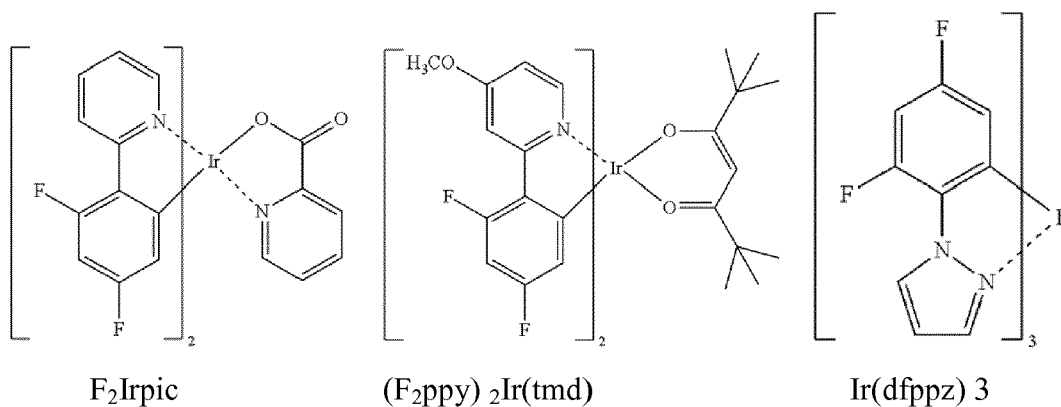
Ir(piq)₃Btp₂Ir(acac)

[0150] Examples of a phosphorescent green dopant are Ir(ppy) 3 (ppy = phenylpyridine), Ir(ppy) 2(acac), Ir(mpyp) 3 are shown below. Compound 3 is an example of a fluorescent green emitter and the structure is shown below.

Ir(ppy)₃Ir(ppy)₂(acac)Ir(mpyp)₃

Compound 3

[0151] Examples of a phosphorescent blue dopant are F₂Irpic, (F₂ppy)₂Ir(tmd) and Ir(dfppz) 3, ter-fluorene, the structures are shown below. 4,4'-bis(4-diphenyl amino styryl)biphenyl (DPAVB), 2,5,8,11-tetra-tert-butyl perylene (TBPe), and Compound 4 below are examples of fluorescent blue dopants.



Compound 4

[0152] The amount of the dopant may be in the range of about 0.01 to about 50 parts by weight, based on 100 parts by weight of the host. The EML 150 may have a thickness of about 10 nm to about 100 nm, for example, about 20 nm to about 60 nm. When the thickness of the EML 150 is within this range, the EML 150 may have excellent light emission, without a substantial increase in driving voltage.

[0153] When the EML 150 comprises a phosphorescent dopant, a hole blocking layer (HBL) (not shown) may be formed on the EML 150, by using vacuum deposition, spin coating, slot-die coating, printing, casting, LB deposition, or the like, in order to prevent the diffusion of triplet excitons or holes into the ETL 160. When the HBL is formed using vacuum deposition or spin coating, the conditions for deposition and coating may be similar to those for the formation of the HIL 130. However, the conditions for deposition and coating may vary, according to the compound that is used to form the HBL. Any compound that is commonly used to form a HBL may be used. Examples of compounds for forming the HBL include an oxadiazole derivative, a triazole derivative, and a phenanthroline derivative.

[0154] The HBL may have a thickness of about 5 nm to about 100 nm, for example, about 10 nm to about 30 nm. When the thickness of the HBL is within this range, the HBL may have excellent hole-blocking properties, without a substantial increase in driving voltage.

[0155] The ETL 160 may be formed on the EML 150 or on the HBL if the HBL is formed.

[0156] The ETL 160 has a stacked structure, preferably of two ETL-layers (161/162), so that injection and transport of electrons may be balanced and holes may be efficiently blocked. In a conventional OLED, since the amounts of electrons and holes vary with time, after driving is initiated, the number of excitons generated in an emission area may be reduced. As a result, a carrier balance may not be maintained, so as to reduce the lifetime of the OLED.

[0157] However, in the ETL 160, the first layer 161 and the second layer 162 may have similar or identical energy levels. In general the matrix compound for the first electron layer (161) and second electron layer (162) are different.

[0158] The matrix compound for the first electron layer 161 and second electron layer 162 that can be suitably used are selected for example from the group comprising anthracene compounds, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole; whereby the matrix material of the second electron transport layer 162 is selected different to the matrix material of the first electron transport layer 161 and the optional third electron transport layer 163.

[0159] The matrix compound for the electron transport layers of the electron layer stack for the first and the optional third electron transport layers can be selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenyl phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide and/or phenyl bis(3-(pyren-

1-yl)phenyl)phosphine oxide; whereby the matrix material of the second electron transport layer is not a phosphine oxide compound.

[0160] Anthracene compounds that can be used as matrix compounds are disclosed in US 6878469 B and incorporated by reference.

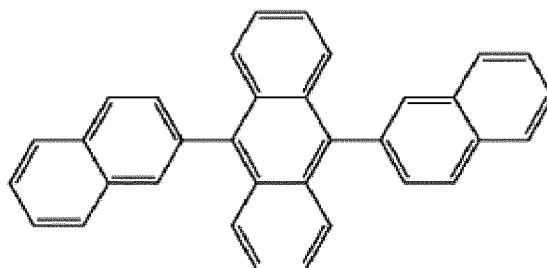
[0161] Other matrix compounds that can be used are diphenylphosphine oxide, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, phenyldi(pyren-1-yl)phosphine oxide.

[0162] Diphenylphosphine oxide compounds that can be used as matrix compounds are disclosed in EP 2395571 A1, WO2013079217 A1, EP 13187905, EP13199361 and JP2002063989 A1, incorporated by reference. Other suitable matrix compounds that can be used are phenanthroline compounds, preferably selected from the group comprising 2,4,7,9-tetraphenyl-1,10-phenanthroline and 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline. Phenanthroline compounds that can be used as matrix compounds are disclosed in EP 1786050 A1 and incorporated by reference.

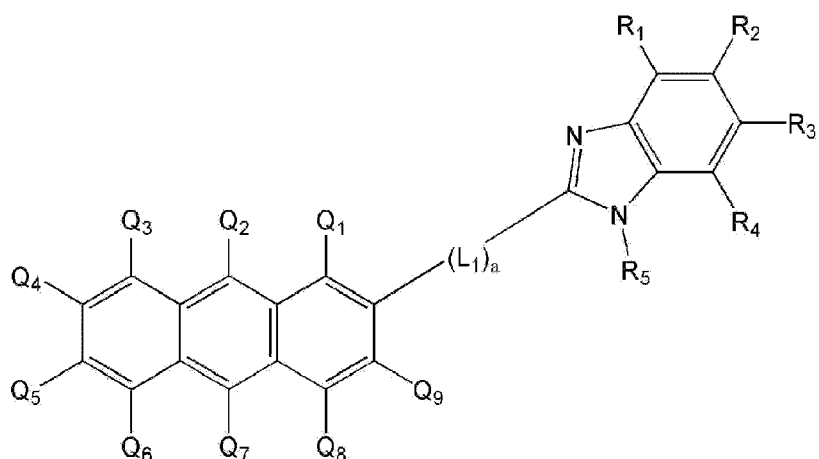
[0163] Other suitable matrix compounds that can be used are pyrido[3,2-h]quinazoline compounds, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline. Pyrido[3,2-h]quinazoline compounds that can be used as matrix compounds are disclosed in EP1970371 and incorporated by reference. Other suitable matrix compounds that can be used are triazine compounds, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazine-2-yl)biphenyl. Triazine compounds that can be used as matrix compounds are disclosed in US6225467 and incorporated by reference. Other suitable matrix compounds that can be used are acridine compounds, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine. Acridine compounds that can be used as matrix compounds are disclosed in EP 2395571 and incorporated by reference.

[0164] The matrix compound of the first electron layer (161) and/or second electron transport layer (162) may be a compound that efficiently transports electrons, such as an anthracene-based compound, diphenylphosphine oxide compound, triazine compound, quinazoline compound or a phenanthroline based compound, and preferably a matrix compound mentioned in Table 2; whereby the matrix material of the second electron transport layer 162 is selected different to the matrix material of the first electron transport layer 161 and the optional third electron transport layer 163.

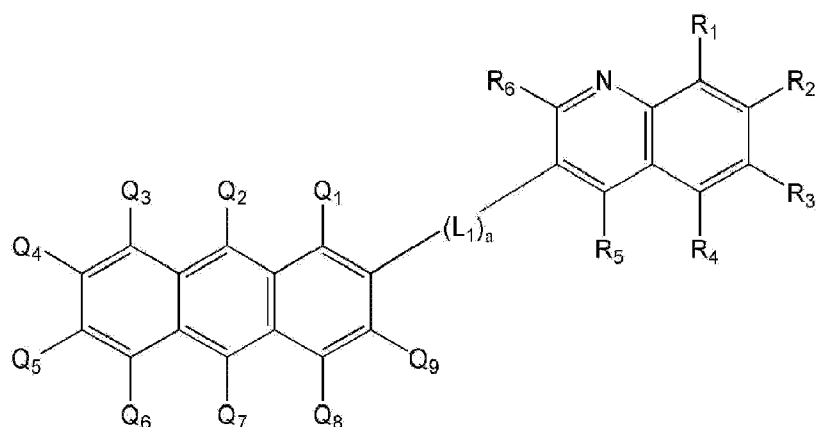
[0165] For example, the matrix compound of the first electron layer and/or second electron transport layer may be selected from the group consisting of ADN and referred to as Formula 1, a compound represented by Formula 2, and a compound represented by Formula 3 below; whereby the matrix material of the second electron transport layer is selected different to the matrix material of the first electron transport layer and the optional third electron transport layer:



Formula 1 (ADN)



Formula 2



Formula 3

[0166] In Formulae 2 and 3, R_1 to R_6 are each independently a hydrogen atom, a halogen atom, a hydroxy group, a cyano group, a substituted or unsubstituted C_1 - C_{30} alkyl group, a substituted or unsubstituted C_1 - C_{30} alkoxy group, a substituted or unsubstituted C_1 - C_{30} acyl group, a substituted or unsubstituted C_2 - C_{30} alkenyl group, a substituted or unsubstituted C_2 - C_{30} alkynyl group, a substituted or unsubstituted C_6 - C_{30} aryl group, or a substituted or unsubstituted C_3 - C_{30} heteroaryl group. At least two adjacent R_1 to R_6 groups are optionally bonded to each other, to form a saturated or unsaturated ring. L_1 is a bond, a substituted or unsubstituted C_1 - C_{30} alkylene group, a substituted or unsubstituted C_6 - C_{30} arylene group, or a substituted or unsubstituted C_3 - C_{30} hetero arylene group. Q_1 through Q_9 are each independently a hydrogen atom, a substituted or unsubstituted C_6 - C_{30} aryl group, or a substituted or unsubstituted C_3 - C_{30} hetero aryl group, and "a" is an integer from 1 to 10.

[0167] For example, R_1 to R_6 may be each independently selected from the group consisting of a hydrogen atom, a halogen atom, a hydroxy group, a cyano group, a methyl group, an ethyl group, a propyl group, a butyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a phenyl group, a naphthyl group, an anthryl group, a pyridinyl group, and a pyrazinyl group.

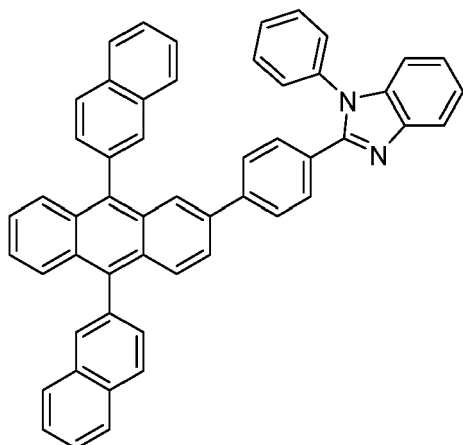
[0168] In particular, in Formula 2 and/or 3, R_1 to R_4 may each be a hydrogen atom, R_5 may be selected from the group consisting of a halogen atom, a hydroxy group, a cyano group, a methyl group, an ethyl group, a propyl group, a butyl group, a methoxy group, an ethoxy group, a propoxy group, a butoxy group, a phenyl group, a naphthyl group, an anthryl group, a pyridinyl group, and a pyrazinyl group. In addition, in Formula 3, R_1 to R_6 may each be a hydrogen atom.

[0169] For example, in Formula 2 and/or 3, Q_1 to Q_9 are each independently a hydrogen atom, a phenyl group, a naphthyl group, an anthryl group, a pyridinyl group, and a pyrazinyl group. In particular, in Formulae 2 and/or 3, Q_1 , Q_3 - Q_6 , Q_8 and Q_9 are hydrogen atoms, and Q_2 and Q_7 may be each independently selected from the group consisting of a phenyl group, a naphthyl group, an anthryl group, a pyridinyl group, and a pyrazinyl group.

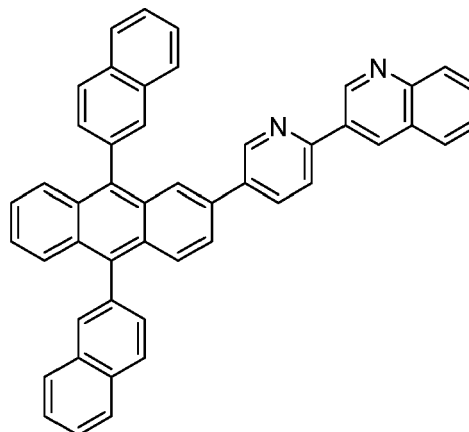
[0170] For example, L_1 , in Formula 2 and/or 3, may be selected from the group consisting of a phenylene group, a naphthylene group, an anthrylene group, a pyridinylene group, and a pyrazinylene group. In particular, L_1 may be a

phenylene group or a pyridinylene group. For example, "a" maybe 1, 2, or, 3.

[0171] The matrix compound may be further selected from Compound 6 or 7 below:



Compound 6



Compound 7

[0172] The first electron transport layer 161 comprises a dopant of a lithium halide or a lithium organic complex; and the second electron transport layer 162 is free of a dopant.

[0173] According to another aspect the first electron transport layer 161 comprises a lithium halide or a lithium organic complex; and the second electron transport layer 162 comprises no dopant; and the third electron transport layer 163 comprises a lithium halide or a lithium organic complex that is the same or differs from the lithium halide or lithium organic complex of the first electron transport layer 161.

[0174] The ETL layer stack thickness can be adjusted such that the light out coupling is maximized. Further ETL layer stack thickness can be adjusted for the desired color tuning, for example to achieve a deeper shade of blue, i.e. smaller CIE-y.

[0175] The thicknesses of the first electron transport layer 161, second electron transport layer 162 and/or third electron transport layer 163 may be the same or each independently in the range of about ≥ 1 nm to about ≤ 95 nm, preferably of about ≥ 3 nm to about ≤ 80 nm, further preferred of about ≥ 5 nm to about ≤ 60 nm, also preferred of about ≥ 6 nm to about ≤ 40 nm, in addition preferred about ≥ 8 nm to about ≤ 20 nm and more preferred of about ≥ 10 nm to about ≤ 18 nm.

[0176] When the thicknesses of the first electron transport layer 161, second electron transport layer 162 and/or third electron transport layer 163 within this range, preferably of about ≥ 10 nm to about ≤ 18 nm, the electron transport layer stack 160 may effectively inject and transport electrons, without a substantial increase in driving voltage.

[0177] For blue emitting OLEDs, the thickness of the ETL layer stack is 10 nm to 50 nm, preferably 30 nm to 40 nm. For red and green emitting OLEDs, the thickness of ETLs is 20 nm to 100 nm, preferably 20 nm to 100 nm and more preferably 30 nm to 80 nm. The thickness is selected so as to maximize efficiency of light emission.

[0178] The amount of the total lithium organic complex in the first electron transport layer 161 may be in the range of about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-%, and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-%, by weight of the first electron transport layer 161.

[0179] The amount of the total lithium organic complex in the first electron transport layer 161 that is free of a metal salt may be in the range of about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-%, and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-%, by weight of the first electron transport layer 161.

[0180] The amount of the total lithium organic complex in the third electron transport layer 163 may be in the range of about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-%, and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-%, by weight of the third electron transport layer 163.

[0181] The amount of the total lithium organic complex in the third electron transport layer 163 that is free of a metal salt may be in the range of about ≥ 10 wt.-% to about ≤ 70 wt.-%, preferably about ≥ 20 wt.-% to about ≤ 65 wt.-%, and also preferred about ≥ 50 wt.-% to about ≤ 60 wt.-%, by weight of the third electron transport layer 163.

[0182] The ETL-stack 160 may be formed on the EML 150 by vacuum deposition, spin coating, slot-die coating, printing, casting, or the like. When the ETL 160 is formed by vacuum deposition or spin coating, the deposition and coating conditions may be similar to those for formation of the HIL 130. However, the deposition and coating conditions may vary, according to a compound that is used to form the ETL-stack 160.

[0183] Using vacuum deposition, the first electron transport layer 161 of the ETL 160 may be formed using a first deposition source to deposit a matrix compound and a second deposition source to deposit a lithium halide or lithium

organic complex. The first deposition source and second deposition source are positioned relative to one another, such that a mixed deposition region of the first electron transport layer 161 is formed directly on the EML 150.

[0184] The second electron transport layer 162 of the ETL 160 may be formed using a third deposition source, since the matrix compound is different to the first electron transport layer ETL 161 and optional third electron transport layer ETL 163.

[0185] If compounds used to form the first ETL 161 and third ETL 163 are identical, then the same deposition sources can be used.

[0186] If compounds used to form the first ETL 161 and third ETL 163 are not identical, then the additional deposition sources can be used for the third ETL 163.

[0187] The deposition sources are positioned relative to one another, such that the second electron transport layer 162 is formed directly on the first electron transport layer 161.

[0188] The stacking process is more simply and quickly performed, as compared to prior methods. In particular, since a plurality of ETL layers may be almost simultaneously deposited in a single chamber, the chamber may not be required to be exhausted after the formation of each layer.

[0189] The EIL 180, which facilitates injection of electrons from the cathode, may be formed on the ETL 160, preferably directly on the second electron transport layer 162. Examples of materials for forming the EIL 180 include KF, LiF, NaCl, CsF, Li₂O, BaO, Ca, Ba, Yb, Mg which are known in the art. Deposition and coating conditions for forming the EIL 180 are similar to those for formation of the HIL 130, although the deposition and coating conditions may vary, according to a material that is used to form the EIL 180.

[0190] According to one aspect the electron injection layer may comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with a lithium halide or doped with a lithium organic complex, preferably lithium tetra(1H-pyrazol-1-yl)borate.

[0191] According to one aspect the electron injection layer may comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with an elemental metal selected from a group comprising an alkali, alkaline earth or rare earth metals, preferably Li, Cs, Mg, Ca, Yb, or Sm.

[0192] According to one aspect the electron injection layer may consist of a metal halide or organic complex, preferably LiQ, AlQ₃, ZrQ₄, KF or LiF, wherein Q is a 8-hydroxyquinolate.

[0193] According to one aspect the electron injection layer may consist of an alkali, alkaline earth or rare earth metal, preferably Li, Cs, Mg, Ca, Yb, or Sm.

[0194] According to a preferred embodiment the electron transport layer stack of two electron transport layers 161/162 may contain an electron injection layer 180.

[0195] According to a preferred embodiment the electron transport layer stack of three electron transport layers 161/162/163 may not contain an electron injection layer 180.

[0196] The thickness of the EIL 180 may be in the range of about 0.1 nm to 10 nm, for example, in the range of 0.5 nm to 9 nm or about ≥ 0.5 nm to ≤ 5 nm. When the thickness of the EIL 180 is within this range, the EIL 180 may have satisfactory electron-injecting properties, without a substantial increase in driving voltage.

[0197] The cathode electrode 190 is formed on the EIL 180 if present. The cathode electrode 190 may be a cathode, which is an electron-injecting electrode. The second electrode 190 may be formed of a metal, an alloy, an electrically conductive compound, or a mixture thereof. The second electrode 190 may have a low work function. For example, the second electrode 190 may be formed of lithium (Li), magnesium (Mg), aluminum (Al), aluminum (Al)-lithium (Li), calcium (Ca), barium (Ba), ytterbium (Yb), magnesium (Mg)-indium (In), magnesium (Mg)-silver (Ag), or the like. In addition, the second electrode 190 may be formed of a transparent conductive material, such as ITO or IZO.

[0198] The thickness of the cathode electrode 190 may be in the range of about 5 nm to 1000 nm, for example, in the range of 10 nm to 100 nm. When the cathode electrode 190 is in the range of 5 nm to 50 nm, the electrode will transparent even if a metal or metal alloy is used.

[0199] Since the layers of the ETL 160 have similar or identical energy levels, the injection and transport of the electrons may be controlled, and the holes may be efficiently blocked. Thus, the OLED 100 may have long lifetime.

[0200] FIG. 6 and FIG. 7 is a schematic sectional view of an OLED 200, according to another exemplary embodiment of the present invention. The OLED 200 of Figs. 7 and 8 has no electron injection layer (EIL) 180.

[0201] Referring to Figs. 6 and 7 the OLED 200 includes a substrate 110, a first electrode 120, a HIL 130, a HTL 140, an EML 150, an ETL 160, and a second electrode 190. The ETL stack 160 of FIG. 6 includes a first ETL layer 161 and a second ETL layer 162. The ETL stack 160 of FIG. 7 includes a first ETL layer 161, a second ETL layer 162 and a third ETL layer 163.

[0202] The electron transport layer stack 160 of FIG. 6 comprises at least two electron transport layers 161 and 162, wherein a first electron transport layer 161 and a second electron transport layer 162 comprises at least one matrix compound, whereby the matrix compound of the second electron transport layer 162 differs from the matrix compound

of the first electron transport layer 161, and in addition,

- the first electron transport layer comprises as a dopant at least one lithium organic complexes, and
- the second electron transport layer comprises no dopant; wherein the first electron transport layer is arranged closest to an anode and the second electron transport layer is arranged closest to a cathode.

The electron transport layer stack 160 of FIG. 7 comprises at least three electron transport layers 161, 162 and 163, wherein a first electron transport layer 161, a second electron transport layer 162 and a third electron transport layer 163 comprises at least one matrix compound, whereby the matrix compound of the second electron transport layer 162 differs from the matrix compound of the first electron transport layer 161 and third electron transport layer 163, and in addition,

- the first electron transport layer 161 comprises as a dopant a lithium halide or lithium organic complex,
- the third electron transport layer 163 comprises as a dopant a lithium halide or lithium organic complex, and
- the second electron transport layer 162 is free of a dopant; wherein the first electron transport layer 161 is arranged closest to an anode and the third electron transport layer 163 is arranged closest to a cathode.

[0203] The layers of the ETL 161 and 162 or of the ETL 161 and 163 have similar or identical energy levels.

[0204] The OLED 200 have a significant reduced low voltage to efficiently operate an OLED. The substrate 110, the first electrode 120, the hole injection layer 130, the hole transport layer 140, the emission layer 150, and the electron transport layer 161 and 162 of the OLED 200 of FIG. 6 and FIG. 7 are similar to corresponding elements described with reference to Figs. 4 and 5, respectively. Even though the structure of the OLED 200 and the method of manufacturing the OLED 200 are described with reference to Figs. 4 and 5, other methods known in the art can be used. For example, the ETL stack 160 may include three or more ETL layers but two ETL layers of ETL 161 and 162 or three two ETL layers of ETL 161, 162 and 163 may be preferred.

[0205] In the description above the method of manufacture an OLED of the present invention is started with a substrate 110 onto which an anode electrode 120 is formed, on the anode electrode 120 an emission layer 150 is formed. An electron transport layer 161 or electron transport layer stack 160 is formed on the emission layer 150, wherein in case of an electron transport layer stack 160 the first electron transport layer 161 is formed on the emission layer 150 and the second electron transport layer 162 is formed directly on the first electron transport layer 161, on the electron transport layer stack 160, in this case on the second electron transport layer 162, a cathode electrode 190 is formed, optional a hole injection layer 130, and a hole transport layer 140, are formed between the anode electrode 120 and the electron transport layer stack 160, an optional hole blocking layer is formed between the emission layer and the ETL layer stack, and an electron injection layer 180 is formed between the electron transport layer 160 and the cathode electrode 190.

[0206] However, the OLED of the present invention can be manufactured also the other way around, starting with the cathode electrode 190 onto which optionally an electron injection layer 180 is formed. On the cathode electrode 190 or on the electron injection layer 180, if present, the electron transport layer stack 160 is formed, whereby directly on the second electron transport layer 162 the first electron transport layer 161 is formed, and so on.

[0207] In case of a three layer electron transport layer stack 160, the second electron layer 162 is formed on the first electron layer 161 and the third electron layer 163 is formed on the second electron layer 162. Then a cathode electrode 190 is formed, optional a hole injection layer 130, and a hole transport layer 140, are formed between the anode electrode 120 and the electron transport layer stack 160, an optional hole blocking layer is formed between the emission layer and the ETL layer stack, and optionally an electron injection layer 180 is formed between the electron transport layer 160 and the cathode electrode 190.

[0208] While not shown in Figs. 4 to 7, a sealing layer may further be formed on the second electrodes 190, in order to seal the OLEDs 100, 200. In addition, various other modifications may be applied thereto.

[0209] Hereinafter, one or more exemplary aspects will be described in detail with, reference to the following examples. However, these examples are not intended to limit the purpose and scope of the one or more exemplary aspects.

Examples

General procedure for comparative examples 1 to 2 and ETL stacks comprising two electron transport layers

[0210] For bottom emission devices, a 15Ω /cm² glass substrate (available from Corning Co.) with 100 nm ITO was cut to a size of 50 mm x 50 mm x 0.7 mm, ultrasonically cleaned with isopropyl alcohol for 5 minutes and then with pure water for 5 minutes, and cleaned again with UV ozone for 30 minutes, to prepare a first electrode.

[0211] For top emission devices, the anode electrode was formed from 100 nm silver on glass which was prepared by the same methods as described above.

[0212] Then, 92 wt.-% of N4,N4"-di(naphthalen-1-yl)-N4,N4"-diphenyl-[1,1':4',1"-terphenyl]-4,4"-diamine and 8 wt.-%

of 2,2',2''-(cyclopropane-1,2,3-triylidene)tris(2-(p-cyanotetrafluorophenyl)acetonitrile) was vacuum deposited on the ITO electrode, to form a HIL having a thickness of 10 nm. Then N4,N4''-di(naphthalen-1-yl)-N4,N4''-diphenyl-[1,1':4',1''-terphenyl]-4,4''-diamine was vacuum deposited on the HIL, to form a HTL having a thickness of 130 nm. 97 wt.-% of ABH113 (Sun Fine Chemicals) as a host and 3 wt.-% of NUBD370 (Sun Fine Chemicals) as a dopant were deposited

on the HTL, to form a blue-emitting EML with a thickness of 20 nm.
[0213] Then the ETL-layer stack is formed by depositing the first electron transport layer (ETL 1) including a matrix compound according to Example 1 to Example 3 and comparative examples 1 and 2 by depositing the matrix compound from a first deposition source and the lithium organic complex from a second deposition source directly on the EML.

[0214] The second electron transport layer (ETL 2) for examples 1 to 3 including a matrix compound is formed by depositing the matrix compound from a third deposition source, since the matrix material is different to the matrix material of the first electron transport layer (ETL 1). For the comparative examples 1 and 2 only one electron transport layer ETL 1 is formed. The wt.-% of the lithium organic complex for the ETL1 can be taken from Table 4, whereby the wt.-% amount of the matrix compound is added to 100 wt.-%, respectively. That means, that the matrix compound of ETL 1 are added in a wt.-% amount such that the given wt.-% of the lithium organic complex for the ETL1 and the matrix compound of the ETL 1 are in total 100 wt.-%, based on the weight of the ETL 1. Further, the thickness d (in nm) of the ETL 1 can be taken from Table 4. The cathode was evaporated at ultra-high vacuum of 10^{-7} bar. Therefore, a thermal single co-evaporation of one or several metals was performed with a rate of 0, 1 to 10 nm/s (0.01 to 1 Å/s) in order to generate a homogeneous cathode with a thickness of 5 to 1000 nm. For top emission devices, the cathode electrode was formed from 13 nm magnesium (90 vol.-%) and silver (10 vol.-%) alloy, followed by 60 nm N4,N4''-di(naphthalen-1-yl)-N4,N4''-diphenyl-[1,1':4',1''-terphenyl]-4,4''-diamine. For bottom emission devices, the cathode electrode was formed from 100 nm aluminum.

[0215] The OLED stack is protected from ambient conditions by encapsulation of the device with a glass slide. Thereby, a cavity is formed, which includes a getter material for further protection.

[0216] To assess the performance of the inventive examples compared to the prior art, the current efficiency is measured under ambient conditions (20°C). Current voltage measurements are performed using a Keithley 2400 sourcemeter, and recorded in V. At 15 mA/cm², a calibrated spectrometer CAS140 from Instrument Systems is used for measurement of CIE coordinates and brightness in Candela. Lifetime LT of the device is measured at ambient conditions (20°C) and 15 mA/cm², using a Keithley 2400 sourcemeter, and recorded in hours. The brightness of the device is measured using a calibrated photo diode. The lifetime LT is defined as the time till the brightness of the device is reduced to 97 % of its initial value.

[0217] In bottom emission devices, the emission is predominately Lambertian and quantified in percent external quantum efficiency (EQE). To determine the efficiency EQE in % the light output of the device is measured using a calibrated photodiode at 10 mA/cm².

[0218] In top emission devices, the emission is forward directed, non-Lambertian and also highly dependent on the micro-cavity. Therefore, the efficiency EQE will be higher compared to bottom emission devices. To determine the efficiency EQE in % the light output of the device is measured using a calibrated photodiode at 15 mA/cm².

[0219] In Table 4, comparative device stacks without a second ETL are compared with examples containing a second ETL. Comparative examples 1 and 2 contain a single ETL. The voltage of Comparative example 1 is comparable to Comparative example 2, which additionally contains an EIL. Table 4 shows that the voltage of Comparative example 2 is increased by 0.1 V compared to Comparative example 1. The EIL has practical no effect on the voltage.

[0220] Example 1 contains a first and second ETL and EIL. Compared to the Comparative example 2, the voltage according to Example 1 is decreased by 0.49 V. Insertion of a second ETL between the first ETL and EIL has a clear beneficial effect on conductivity.

Effect of LUMO level of ETL2 relative to ETL1

[0221] Reduction and oxidation potentials are determined via cyclic voltammetry, using the Ferrocene/Ferrocenium (Fc/Fc⁺) redox couple as internal reference. A simple rule is very often used for the conversion of redox potentials into electron affinities and ionization potential: IP (in eV) = 4.84 eV + e*Eox (wherein Eox is given in volts vs. ferrocene/ferrocenium (Fc/Fc⁺) and EA (in eV) = 4.84 eV + e*Ered (Ered is given in volts vs. Fc/Fc⁺) respectively (see B.W. D'Andrade, Org. Electron. 6, 11-20 (2005)), e* is the elemental charge. It is common practice, even if not exactly correct, to use the terms "energy of the HOMO" E(HOMO) and "energy of the LUMO" E(LUMO), respectively, as synonyms for the ionization energy and electron affinity (Koopmans Theorem).

[0222] In Example 1, the ETL2 is selected from a triazine matrix compound. The ETL2 has a LUMO level which is 0.17 eV deeper, that means further away from vacuum level than the LUMO level of ETL1.

[0223] In Example 2, the ETL2 is selected from a pyrido[3,2-h]quinazoline matrix compound. The ETL2 has a LUMO level which is 0.02 eV deeper than the LUMO level of ETL1. The voltage is reduced by 0.54 V compared to Example 1.

[0224] In Example 3, the ETL2 is selected from a phenanthroline matrix compound. The ETL2 has a LUMO level which

EP 3 035 400 A1

is 0.17 eV shallower, that means closer to vacuum level than the LUMO level of ETL1. The voltage is reduced by 0.52 V compared to Example 1.

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Table 4

Voltage, external quantum efficiency (EQE) and lifetime of bottom emission OLEDs											
	ETL1	wt.-% Li organic complex*1	d (ETL1) /nm	ETL2*2	d (ETL2) / nm	EIL	wt.-%Li organic complex*3	d (EIL) /nm	V at 10 mA/ cm ² / V	EQE*4 / %	LT/h
Comparative Example 1	MX 11: Li-2	50	36	-	-	-	-	-	4.77	6.8	98
Comparative Example 2	MX 11: Li-2	50	36	-	-	MX 12: Li-1	30	2.4	4.87	6.7	103
Example 1	MX 11: Li-2	50	10	MX 20	26	MX 12: Li-1	30	2.4	4.36	6.1	170
Example 2	MX 11: Li-2	50	10	MX 19	25	MX 12: Li-1	30	3.2	3.82	6.9	35
Example 3	MX 11: Li-2	50	10	MX 14	25	MX 12: Li-1	30	3.2	3.84	7.2	30
*1= the wt.-% of the matrix compound MX 11 and the wt.-% of the lithium organic complex Li-2 are in total 100 wt.-% based on the weight of the ETL1.											
*2 = the wt.-% of the matrix compound of the second electron transport layer ETL 2 is 100 wt.-% based on the weight of the ETL2.											
*3 = the wt.-% of the matrix compound MX 12 and the wt.-% of the lithium organic complex Li-1 are in total 100 wt.-% based on the weight of the EIL.											
*4 = detecting the light output efficiency with a calibrated photo diode.											

Technical Effect of the inventionBottom emission devices with two electron transport layers

[0225] In Table 4 results are shown for bottom emission devices with one electron transport layer (ETL1) containing a matrix compound MX 11 and an lithium organic complex Li-2; and for bottom emission devices with a first electron transport layer (ETL1) containing a matrix compound MX 11 and an lithium organic complex Li-2 and a second electron transport layer (ETL2) that is formed of a matrix compound MX 20 (example 1), MX 19 (example 2) or MX 14 (Example). For examples 1 to 3 a voltage reduction to operate the OLED is observed compared to the emission device with one electron transport layer (ETL1) only, containing a matrix compound MX 11 and an lithium organic complex Li-2 (comparative examples 1 and 2).

[0226] In comparison to devices without second ETL (comparative examples 1 and 2), a reduction in voltage has been achieved independent of the LUMO level of ETL2 relative to ETL1.

[0227] A voltage reduction has the benefit that the energy required to operate the OLED can be reduced. The OLEDs of the present invention shows a significant voltage reduction which is an improvement in saving electrical energy compared to the prior art.

[0228] Another aspect is directed to a device comprising at least one or a plurality of organic light-emitting diodes (OLED). A device comprising organic light-emitting diodes is for example a display.

Bottom emission devices with three electron transport layers

[0229] General procedure for comparative example 3 and ETL stacks comprising three electron transport layers 161, 162, and 163

[0230] For bottom emission devices, a $15\Omega/\text{cm}^2$ glass substrate (available from Corning Co.) with 100 nm ITO was cut to a size of 50 mm x 50 mm x 0.7 mm, ultrasonically cleaned with isopropyl alcohol for 5 minutes and then with pure water for 5 minutes, and cleaned again with UV ozone for 30 minutes, to prepare a first electrode.

[0231] Then, 92 wt.-% of biphenyl-4-yl(9,9-diphenyl-9H-fluoren-2-yl)-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-amine and 8 wt.-% of 2,2',2''-(cyclopropane-1,2,3-triylidene)tris(2-(p-cyanotetrafluorophenyl)acetonitrile) was vacuum deposited on the ITO electrode, to form a HIL having a thickness of 10 nm. Then biphenyl-4-yl(9,9-diphenyl-9H-fluoren-2-yl)-[4-(9-phenyl-9H-carbazol-3-yl)phenyl]-amine was vacuum deposited on the HIL, to form a HTL having a thickness of 130 nm. 97 wt.-% of ABH113 (Sun Fine Chemicals) as a host and 3 wt.-% of NUBD370 (Sun Fine Chemicals) as a dopant were deposited on the HTL, to form a blue-emitting EML with a thickness of 20 nm.

[0232] Then the ETL-layer stack is formed by depositing the first and third electron transport layer (ETL 1 and ETL 3) including a matrix compound according to example 4 to example 9 by depositing the matrix compound from a first deposition source and the lithium organic complex from a second deposition source directly on the EML.

[0233] The second electron transport layer (ETL 2) for examples 4 to 9 including a matrix compound is formed by depositing the matrix compound from a third deposition source, since the matrix material is different to the matrix material of the first and third electron transport layer (ETL 1 and ETL 3). For the comparative example 3 only one electron transport layer ETL 1 is formed. The wt.-% of the lithium organic complex for the ETL1 and ETL 3 can be taken from Table 5, whereby the wt.-% amount of the matrix compound is added to 100 wt.-%, respectively. That means, that the matrix compound of ETL 1 and ETL 3 are added in a wt.-% amount such that the given wt.-% of the lithium organic complex for the ETL1 and ETL 3 and the matrix compound of the ETL 1 and ETL 3 are in total 100 wt.-%, based on the weight of the ETL 1 and ETL 3. Further, the thickness d (in nm) of the ETL 1 and ETL 3 can be taken from Table 5. The cathode was evaporated at ultra-high vacuum of 10^{-7} bar. Therefore, a thermal single co-evaporation of one or several metals was performed with a rate of 0, 1 to 10 nm/s (0.01 to 1 Å/s) in order to generate a homogeneous cathode with a thickness of 5 to 1000 nm. For bottom emission devices, the cathode electrode was formed from 100 nm aluminum.

[0234] The OLED stack is protected from ambient conditions by encapsulation of the device with a glass slide. Thereby, a cavity is formed, which includes a getter material for further protection.

[0235] The performance of the inventive examples compared to the prior art was assessed as described in the General Process for ETL stacks comprising two electron transport layers above.

[0236] In Table 5, comparative device stacks without a second and third ETL are compared with examples containing a second and third ETL.

Table 5

Voltage, external quantum efficiency (EQE) and lifetime of bottom emission OLEDs											
	ETL1	wt.-% Li organic complex*1	d (ETL1) /nm	ETL2*2	d (ETL2) / nm	ETL 3	wt.-%Li organic complex*3	d (ETL3) / nm	V at 10 mA/cm ² / V	EQE*4 / %	LT/h
Comparative Example 3	MX 23 : LiQ	50	36	-	-	-	-	-	4.87	5.3	400
Example 4	MX 23 : LiQ	50	21	MX 24	13	MX 23 : LiQ	53	4	4.33	6.7	125
Example 5	MX 23 : LiQ	50	21	MX 19	13	MX 23 : LiQ	51	3	4.34	6.9	210
Example 6	MX 23 : LiQ	50	15	MX 19	19	MX 23 : LiQ	51	3	4.16	7.2	100
Example 7	MX 23 : LiQ	50	11	MX 19	23	MX 23 : LiQ	51	3	4.04	7.5	53
Example 8	MX 23 : LiQ	50	5	MX 19	29	MX 23 : LiQ	51	3	3.97	7.9	28
Example 9	MX 23 : Li-2	50	21	MX 19	13	MX 23 : Li-2	48	3	4.32	8.6	20

*1= the wt.-% of the matrix compound MX 23 and the wt.-% of the lithium organic complex LiQ or Li-2 are in total 100 wt.-% based on the weight of the ETL1.

*2 = the wt.-% of the matrix compound of the second electron transport layer ETL 2 is 100 wt.-% based on the weight of the ETL2.

*3 = the wt.-% of the matrix compound MX 23 and the wt.-% of the lithium organic complex LiQ or Li-2 are in total 100 wt.-% based on the weight of the EIL.

*4 = detecting the light output efficiency with a calibrated photo diode.

[0237] Comparative example 3 contains a single ETL. The voltage of comparative example 3 in Table 5 is comparable to comparative example 1 in Table 4. These results show that the performance is independent of the exact structure of the matrix compound and Li organic complex used.

[0238] Example 4 contains a first, second and third ETL. Compared to the comparative example 3, the voltage according to example 4 is decreased by 0.54 V. Insertion of a second and third ETL between the first ETL and cathode has a clear beneficial effect on conductivity.

[0239] Example 5 contains a different matrix compound in the second ETL compared to example 4. A benzo[h]quinazoline compound, 4-(2-naphthalenyl)-2-[4-(3-quinoliny)phenyl] - benzo[h]quinazoline (MX 19) was used in place of acridine compound, 7-(naphthalen-2-yl)dibenzo[c,h]acridine (MX 24). The LUMO level of MX 19 is 0.07 eV shallower (closer to vacuum level) compared to MX 24. As can be seen in Table 5, the voltage is very similar, even though the chemical structure of the matrix compound in the second ETL is very different.

[0240] In example 5 to example 8, different thicknesses of the first and second ETL are compared. The thickness of the first ETL was varied between 5 and 21 nm, the thickness of the second ETL was varied between 13 and 29 nm and the thickness of the third ETL was kept constant at 3 nm. The overall thickness of the ETL layer stack was kept constant at 37 nm. As can be seen in Table 5, independent of the thickness of the first and second ETL, the voltage is always lower compared to comparative example 3 with a single ETL. The best performance in terms of voltage is achieved for a very thin first ETL, see example 8 compared to example 5. The thickness of the first ETL has been reduced by 16 nm and the voltage is reduced by 0.37 V. Oppositely, the thickness of the second ETL has been increased from 13 nm in example 5 to 29 nm in example 8. The increase in thickness of the second ETL goes hand in hand with a reduction in voltage by 0.37 V.

[0241] In summary, the thickness of the first and second ETL can be varied between a wide range of thicknesses without loss in performance.

[0242] In example 9 Li-2 is used as dopant in the first and third ETL compared to example 5, where LiQ was used. As can be seen in Table 5, the voltage is very similar for example 5 and example 9. The improved performance compared to comparative example 3 can be achieved irrespective of the exact chemical structure of the Li organic complex.

[0243] The ETL layer stack according to this invention may also be employed for other emission colors, for example green, red, and white-light emitting devices.

[0244] Another aspect is directed to a device comprising at least one organic light-emitting diode (OLED). A device comprising organic light-emitting diodes (OLED) is for example a display.

[0245] From the foregoing detailed description and examples, it will be evident that modifications and variations can be made to the compositions and methods of the invention without departing from the spirit and scope of the invention. Therefore, it is intended that all modifications and/or combinations of embodiments made to the invention without departing from the spirit and scope of the invention come within the scope of the appended claims.

Claims

1. An organic light-emitting diode (OLED) (100) comprising an emission layer and an electron transport layer stack of at least two electron transport layers (160/161), wherein a first electron transport layer (161) and a second electron transport layer (162) comprises at least one matrix compound, wherein

- the matrix compound or compounds of the first electron transport layer (161) is/are different to the matrix compound or compounds of the second electron transport layer (162); and in addition,
- the first electron transport layer (161) comprises a dopant of a lithium halide and/or lithium organic complex; and
- the second electron transport layer (162) is free of a dopant.

2. The OLED (100) according to any one of the preceding claim 1, wherein the electron transport layer stack (160) has two to four electron transport layers and more preferred two electron transport layers (162/162) or three electron transport layers (162/162/163).

3. The OLED (100) according to claim 1 or 2, wherein the electron transport layer stack has three electron transport layers (161/162/163), wherein

- the first electron transport layer (161) and the third electron transport layer (163) comprise the same or different matrix compound and the same or different dopant; and
- the second electron transport layer (162) contains a matrix compound that differs from the matrix compound of the first and third transport layers and is free of a dopant.

4. The OLED (100) according to any one of the preceding claims 1 to 3, wherein the OLED (100) comprises an electron injection layer (180), which is arranged between the electron transport layer stack (160) and the cathode electrode (190).

5. The OLED (100) according to any one of the preceding claims 1 to 4, wherein the OLED (100) comprises an electron injection layer (180) which is arranged between the electron transport layer stack (160) and the cathode electrode (190), wherein the electron transport layer stack (160) is formed of two electron transport layers (162/162).

6. The OLED (100) according to any one of the preceding claims 1 to 5, wherein the matrix compound is selected from:

- an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline;
- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;
- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide;
- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline;
- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole;
- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline;
- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline;
- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine and / or
- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine.

7. The OLED (100) according to any one of the preceding claims 1 to 6, wherein the matrix compound for the electron transport layers of the electron layer stack (160); or for the first, second and third electron transport layers (161/162/163); or for the first and third electron transport layer (161/163); is selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenyl phosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide; whereby the matrix material of the second electron transport layer (162) is selected different to the matrix material of the first electron transport layer (161) and the optional third electron transport layer (163).

8. The OLED (100) according to any one of the preceding claims 1 to 7, wherein

- the first electron transport layer (161) comprises a matrix material selected from the group comprising:

- a phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, diphenyl(5-(pyren-1-

yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide and/or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide; and/or

- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole;

- the second electron transport layer (162) comprises a matrix material selected from the group comprising:

- a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)-1,10-phenanthroline; and/or

- a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole; and/or

- a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline; and/or

- a pyrido[3,2-h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline; and/or

- a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]-quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine; and/or

- an anthracene compound substituted with aryl or heteroaryl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole, 9,10-di(2-naphthyl)anthracene,

1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole and/or 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinoline, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole; and/or

- a pyren phosphine oxide compound substituted with aryl, heteroaryl or alkyl groups, preferably phenyl-di(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide; and/or

- an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo[c,h]acridine;

- the optional third electron transport layer (163) comprises a matrix material selected from the group comprising:

- a phosphine oxide compound substituted with aryl heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide and/or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide; and/or

- a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1 H-benzo [d] imidazole;

whereby the matrix material of the second electron transport layer (162) is selected different to the matrix material of the first electron transport layer (161) and the optional third electron transport layer (163).

9. The OLED (100) according to any one of the preceding claims 1 to 8, wherein

- the first electron transport layer (161) comprises a matrix material selected from the group comprising 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole;

- the second electron transport layer (162) comprises a matrix material selected from the group comprising

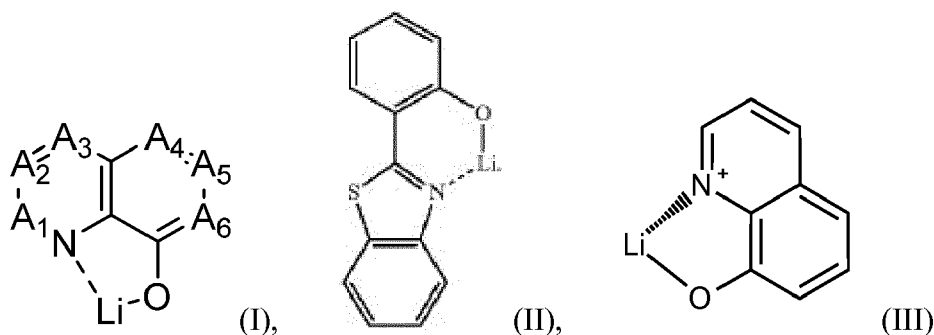
9,10-di(2-naphthyl)anthracene, 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole, 3-[3'-(10-phenyl-9-anthracenyl)[1,1'-biphenyl]-4-yl]-quinolone, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline, 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole, 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline, 4,4'-bis(4,6-diphenyl-1,3,5-triazine-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]-quinolone, 7-(naphthalen-2-yl)dibenzo[c,h]acridine, and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine;

- the optional third electron transport layer (163) comprises a matrix material selected from the group comprising 2-(4-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole, 3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, phenylbis(3-(pyren-1-yl)phenyl)phosphine oxide, (3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenylphosphine oxide and/or 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide;

whereby the matrix material of the second electron transport layer (162) is selected different to the matrix material of the first electron transport layer (161) and the optional third electron transport layer (163).

10. The OLED (100) according to any one of the preceding claims 1 to 9, wherein:

- the lithium halide is selected from the group comprising a LiF, LiCl, LiBr or LiI, and preferably LiF; and/or
- the lithium organic complex, is selected from the group comprising a lithium quinolate, a lithium borate, a lithium phenolate, a lithium pyridinolate or a lithium Schiff base;
- preferably the lithium quinolate has the formula I, II or III:

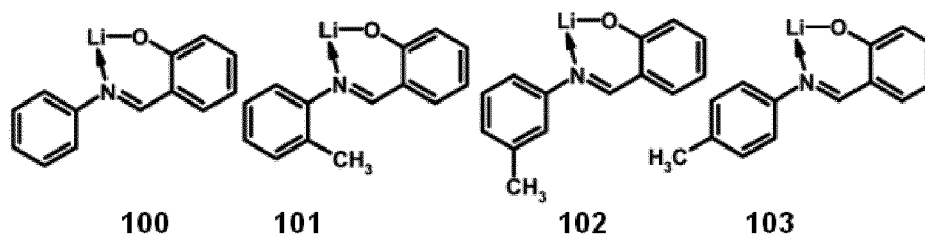


wherein

A1 to A6 are same or independently selected from CH, CR, N, O;

R is same or independently selected from hydrogen, halogen, alkyl or aryl or heteroaryl with 1 to 20 carbon atoms; and more preferred A1 to A6 are CH;

- preferably the lithium borate is a lithium tetra(1H-pyrazol-1-yl)borate;
- preferably the lithium phenolate is a lithium 2-(pyridin-2-yl)phenolate, a lithium 2-(diphenylphosphoryl)phenolate, a lithium imidazol phenolates, or a lithium 2-(pyridin-2-yl)phenolate and more preferred a lithium 2-(1-phenyl-1H-benzo[d]imidazol-2-yl)phenolate, or a lithium 2-(benzo[d]oxazol-2-yl)phenolate;
- preferably the lithium pyridinolate is a lithium 2-(diphenylphosphoryl)pyridin-3-olate,
- preferably the lithium Schiff base has the structure 100, 101, 102 or 103:



11. The OLED (100) according to any one of the preceding claims 1 to 10, wherein

- the first electron transport layer (161) comprises about ≤ 90 wt.-% to about ≥ 30 wt.-%, of a matrix compound; or
 - the first electron transport layer (161) and the third electron transport layer (163) comprises each about ≤ 90 wt.-% to about ≥ 30 wt.-%, of a matrix compound;
 wherein the weight percent of the matrix compound is based on the total weight of the corresponding transport layer.

12. The OLED (100) according to any one of the preceding claims 1 to 11, wherein the second electron transport layer (162) consist of at least one matrix compound.

13. The OLED (100) according to any one of the preceding claims 1 to 12, wherein

- the first electron transport layer (161) comprises about ≥ 10 wt.-% to about ≤ 70 wt.-%, of a lithium halide or a lithium organic complex; or
 - the first electron transport layer (161) and the third electron transport layer (163) comprises each about ≥ 10 wt.-% to about ≤ 70 wt.-%, of a lithium halide or a lithium organic complex;
 wherein the weight percent of the lithium halide and the lithium organic complex is based on the total weight of the corresponding electron transport layer.

14. The OLED (100) comprising the electron transport layer stack (160) according to any one of the preceding claims 1 to 13, wherein

- the first electron transport layer (161), or the first electron transport layer (161) and third electron transport layer (163), comprises:

- a) about ≥ 10 wt.-% to about ≤ 70 wt.-% of the dopant;
- b) about ≤ 90 wt.-% to about ≥ 30 wt.-% of a matrix compound;

- the second electron transport layer (162), which is free of a dopant, comprises a matrix compound that is selected different from the first electron transport layer (161) and the optional third electron transport layer (163); and the wt.-% of the components of each electron transport layer is selected such that the total wt.-% amount does not exceed 100 wt.-% and the wt.-% of the components are based on the total weight of the corresponding transport layer.

15. The OLED (100) comprising the electron transport layer stack (160) according to any one of the preceding claims 1 to 14, wherein the thicknesses of the first electron transport layer (161), the second electron transport layer (162) and/or the third electron transport layer (163) are same or each independently in the range of about ≥ 1 nm to about ≤ 95 nm.

16. The OLED (100) comprising the electron transport layer stack (160) according to any one of the preceding claims 1 to 15, wherein the thicknesses of the electron transport layer stack (160) is in the range of about ≥ 25 nm to about ≤ 100 nm.

17. The OLED (100) comprising the electron transport layer stack (160) according to any one of the preceding claims 1 to 16, wherein the second electron transport layer (162) is formed directly on the first electron transport layer (161) and optional the third electron transport layer (163) is formed directly on the second electron transport layer (162).

18. The OLED (100) according to any one of the preceding claims 1 to 17 comprising: a substrate (110); an anode electrode (120) is formed on the substrate (110); an electron transport layer stack (160) is formed on the anode electrode (120), whereby the electron transport layer stack (160) comprises or consist of at least two electron transport layers (160/161); and finally a cathode electrode (190) is formed, so that the electron transport layer stack (160) is sandwiched between the anode electrode (110) and the cathode electrode (190); and optional an electron injection layer (180) is arranged between the electron transport layer (160) and the cathode electrode (190).

19. The OLED (100) according to any one of the preceding claims 1 to 18, further comprising at least one layer selected from the group consisting of a hole injection layer (130), a hole transport layer (140) and a hole blocking layer, formed between the anode electrode (120) and the electron transport layer (160).

20. The OLED (100) according to any one of the preceding claims 1 to 19, wherein the electron injection layer:

- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with a lithium halide or doped with a lithium organic complex, preferably lithium tetra(1H-pyrazol-1-yl)borate; or
- comprises a matrix compound of a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide or 3-Phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, and doped with an elemental metal selected from a group comprising alkali, alkaline earth or rare earth metals, preferably Li, Cs, Mg, Ca, Yb, or Sm; or
- consist of a metal halide or organic complex, preferably LiQ, AlQ₃, ZrQ₄, KF or LiF, wherein Q is a 8-hydroxyquinolate; or
- consist of a alkali, alkaline earth or rare earth metal, preferably Li, Cs, Mg, Ca, Yb, or Sm.

21. A method of manufacturing an organic light-emitting diode (OLED) (100) according to any one of claims 1 to 20, the method using:

- at least three deposition sources; and/or
- deposition via vacuum thermal evaporation; and/or
- deposition via solution processing, preferably the processing is selected from spin-coating, casting, printing and/or slot-die coating.

22. A method of manufacturing an organic light-emitting diode (OLED) (100) according to claim 21, the method using:

- a first deposition source to release the matrix compound, and
- a second deposition source to release lithium halide or lithium organic complex; the method comprising the steps of forming the electron transport layer stack;
- whereby the first electron transport layer (161) is formed by releasing the matrix compound from the first deposition source and the lithium halide or lithium organic complex from the second deposition source;
- onto the first electron transport layer (161) the second electron transport layer (162) is formed by releasing the matrix compound from a third deposition source;
- wherein the matrix compound of the first electron transport layer (161) is not the same as the matrix compound of the second electron transport layer (162).

23. The method according to any one of the preceding claims 21 or 22, comprising the steps for an organic light-emitting diode (OLED), wherein

- on a substrate (110) an anode electrode (120) is formed,
- on the anode electrode (120) an electron transport layer stack (160) is formed, preferably the first electron transport layer (161) is formed on the anode electrode (120) and the second electron transport layer (162) is formed directly on the first electron transport layer (161),
- on the electron transport layer stack (160) a cathode electrode (190) is formed,
- optional a hole injection layer (130), a hole transport layer (140), an emission layer (150), and a hole blocking layer, formed in that order between the anode electrode (120) and the electron transport layer stack (160),
- optional an electron injection layer (180) is formed between the electron transport layer stack (160) and the cathode electrode (190).

24. A device comprising at least one organic light-emitting diode (OLED) to any one of the preceding claims 1 to 20.

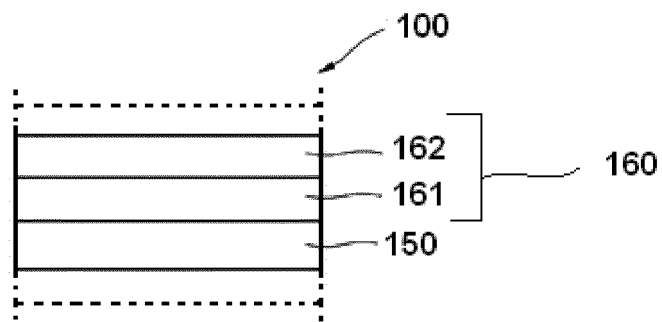


FIG. 1

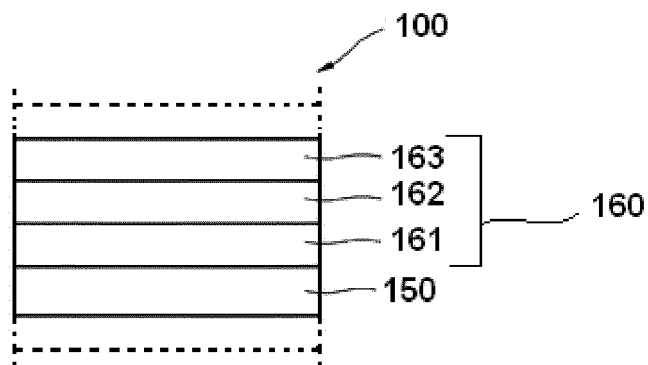


FIG. 2

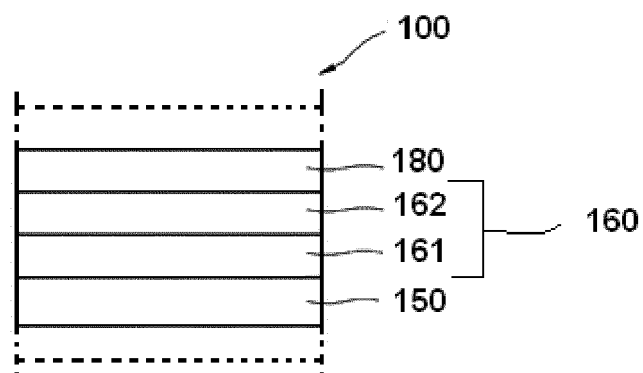


Fig. 3

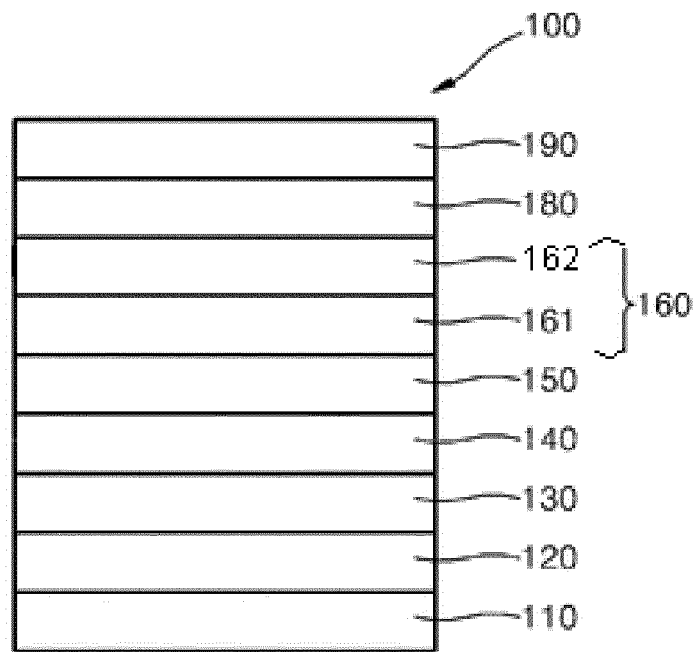


FIG. 4

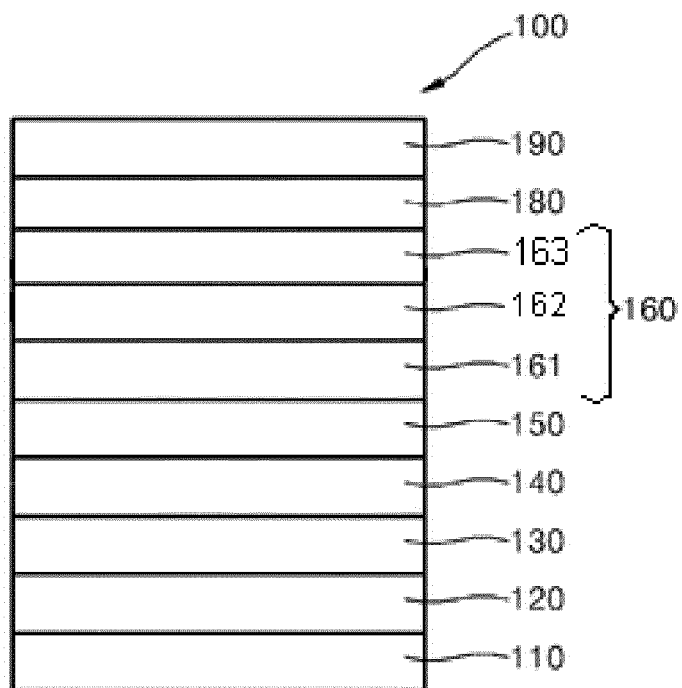


FIG. 5

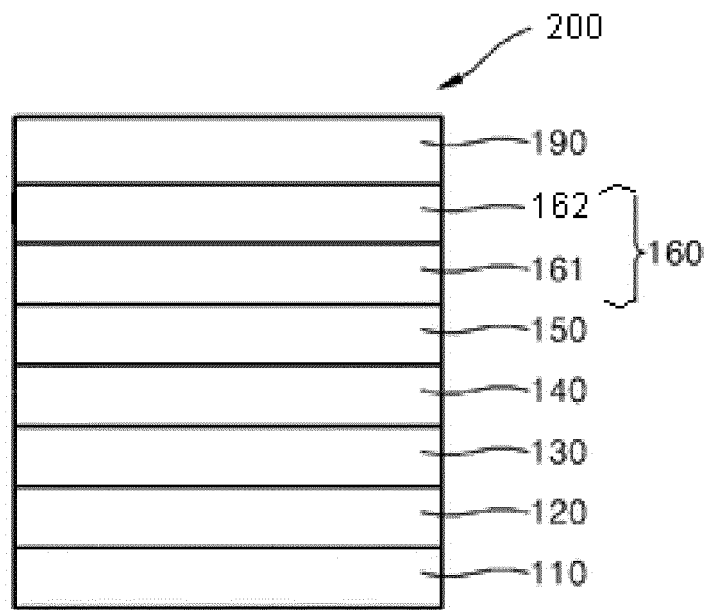


FIG. 6

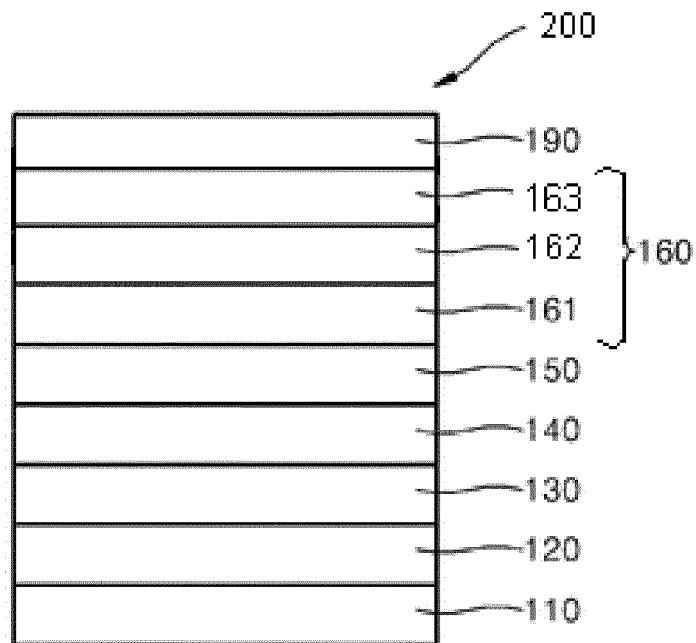


FIG. 7



EUROPEAN SEARCH REPORT

Application Number
EP 14 19 8655

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	TW 201 448 309 A (SAMSUNG DISPLAY CO LTD [KR]) 16 December 2014 (2014-12-16) * page 34, paragraph 120 - page 35, paragraph 128; example 1 *	1-6,8-24	INV. H01L51/50
X	WO 2007/050302 A1 (EASTMAN KODAK CO [US]; BEGLEY WILLIAM JAMES [US]; HATWAR TUKARAM KISAN) 3 May 2007 (2007-05-03) * page 99, line 11 - line 18; example 13 * * page 32; compounds Cpd-10 * * page 41; compounds MC-16 *	1-6,8-24	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01L C07C
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 26 May 2015	Examiner Parashkov, Radoslav
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03/02 (P04C01)



Application Number

EP 14 19 8655

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-6, 8-24(all partially)

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



LACK OF UNITY OF INVENTION
SHEET B

Application Number

EP 14 19 8655

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from an anthracene compound substituted with aryl, heteroaryl or alkyl groups, preferably, 9,10-di(2-naphthyl)anthracene and/or 3-[3'-(10-phenyl-9-anthracenyl)[I,I'-biphenyl]-4-yl]-quinoline; and the method for fabrication of the said device;

2. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a benzimidazole compound substituted with aryl, heteroaryl or alkyl groups, preferably 2-(4-(9,10-di(naphthalen-2-yl)anthracene-2-yl)phenyl)-1-phenyl-1H-benzo[d]imidazole and/or 1-(4-(10-([1,1'-biphenyl]-4-yl)anthracen-9-yl)phenyl)-2-ethyl-1H-benzo[d]imidazole; and the method for fabrication of the said device;

3. claims: 7(completely); 1-6, 8-24(partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a phosphine oxide compound substituted with aryl, heteroaryl or alkyl group substituted with aryl, heteroaryl or alkyl groups, preferably (3-(dibenzo[c,h]acridin-7-yl)phenyl)diphenylphosphine oxide, 3-phenyl-3H-benzo[b]dinaphtho[2,1-d:1',2'-f]phosphine-3-oxide, phenyldi(pyren-1-yl)phosphine oxide, bis(4-(anthracen-9-yl)phenyl)(phenyl)phosphine oxide, (3-(9,10-di(naphthalen-2-yl)anthracen-2-yl)phenyl)diphenylphosphine oxide, phenyldi(pyren-1-yl)phosphine oxide, diphenyl(5-(pyren-1-yl)pyridin-2-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[1,1'-biphenyl]-3-yl)phosphine oxide, diphenyl(4'-(pyren-1-yl)-[I,I'-biphenyl]-3-yl)phosphine oxide,



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SHEET B

Application Number

EP 14 19 8655

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

(3'-(dibenzo[c,h]acridin-7-yl)-[1,1'-biphenyl]-4-yl)diphenyl phosphine oxide and/or phenyl bis(3-(pyren-1-yl)phenyl)phosphine oxide; and the method for fabrication of the said device;

4. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a phenanthroline compound substituted with aryl or heteroaryl groups, preferably 2,4,7,9-tetraphenyl-1,10-phenanthroline, 4,7-diphenyl-2,9-di-p-tolyl-1,10-phenanthroline, 2,9-di(biphenyl-4-yl)-4,7-diphenyl-1,10-phenanthroline and/or 3,8-bis(6-phenyl-2-pyridinyl)- 1,10-phenanthroline; and the method for fabrication of the said device;

5. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a quinazoline compound substituted with aryl or heteroaryl groups, preferably 9-phenyl-9'-(4-phenyl-2-quinazolinyl)-3,3'-bi-9H-carbazole; and the method for fabrication of the said device;

6. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a benzo[h]quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(2-naphthalenyl)-2-[4-(3-quinolinyl)phenyl]-benzo[h]quinazoline; and the method for fabrication of the said device;

7. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an



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Application Number

EP 14 19 8655

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a pyrido[3,2-h] quinazoline compound substituted with aryl or heteroaryl groups, preferably 4-(naphthalen-1-yl)-2,7,9-triphenylpyrido[3,2-h]quinazoline; and the method for fabrication of the said device;

8. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from a triazine compound substituted with aryl or heteroaryl groups, preferably 4,4'-bis(4,6-diphenyl-1,3,5-triazin-2-yl)biphenyl, 3-[4-(4,6-di-2-naphthalenyl-1,3,5-triazin-2-yl)phenyl]quinoline and/or 2-[3-(6'-methyl[2,2'-bipyridin]-5-yl)-5-(9-phenanthrenyl)phenyl]-4,6-diphenyl-1,3,5-triazine; and the method for fabrication of the said device;

9. claims: 1-6, 8-24(all partially)

an organic light-emitting diode (OLED) comprising an emission layer and an electron transport layer stack of at least two electron transport layers, wherein a first electron transport layer and a second electron transport layer comprises at least one matrix compound selected from an acridine compound substituted with aryl or heteroaryl groups, preferably 7-(naphthalen-2-yl)dibenzo [c,h] acridine; and the method for fabrication of the said device;

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 14 19 8655

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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26-05-2015

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专利名称(译)	有机发光二极管，包括具有不同基质化合物的电子传输层		
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IPC分类号	H01L51/50		
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其他公开文献	EP3035400B1		
外部链接	Espacenet		

摘要(译)

本发明涉及一种有机发光二极管，包括发光层和至少两个电子传输层的电子传输层叠层，其中第一电子传输层和第二电子传输层包含至少一种基质化合物，其中 - 第一电子传输层的基质化合物或化合物与基质化合物或第二电子传输层的化合物不同;此外， - 第一电子传输层包含卤化锂和/或锂有机络合物的掺杂剂; - 第二电子传输层不含掺杂剂。

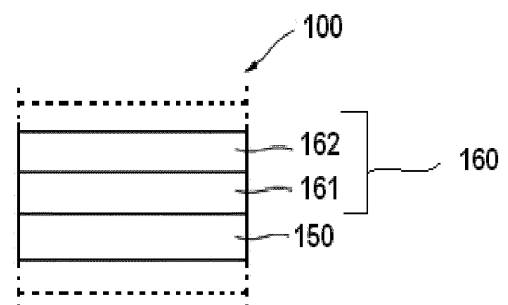


FIG. 1