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(54) **ARRANGEMENT FOR AN ORGANIC PIN-TYPE LIGHT-EMITTING DIODE AND METHOD FOR MANUFACTURING**

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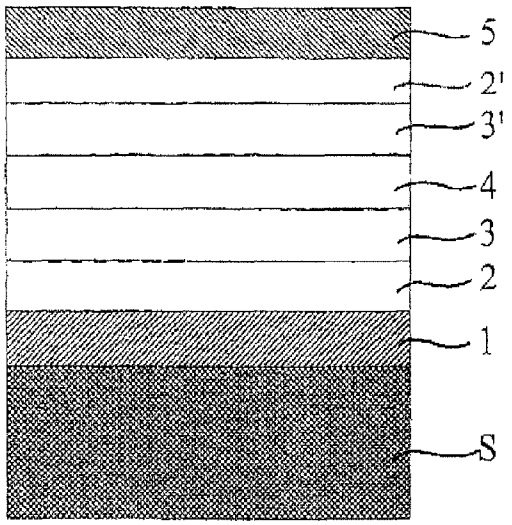
(57) **ABSTRACT**

The invention relates to an arrangement for an organic pin-type light-emitting diode with an electrode and a counter-electrode and a stack with organic layers between the electrode and the counter-electrode, where the stack with the organic layers comprises an emission layer comprising a k (k=1, 2, 3, . . .) organic matrix materials, a doped charge carrier transport layer, which is arranged between the electrode and the emission layer, a further doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer, and one block layer, which is arranged between one of the doped charge carrier transport layers and the emission layer. The organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, where the n organic matrix materials comprise the k organic matrix materials of the emission layer. The stack with the organic layers can also be executed in a block-layer-free manner, where then the emission layer and the doped charge carrier transport layer are formed from an organic matrix material. Furthermore, a method for manufacturing such arrangements is stated.

21 Claims, 7 Drawing Sheets



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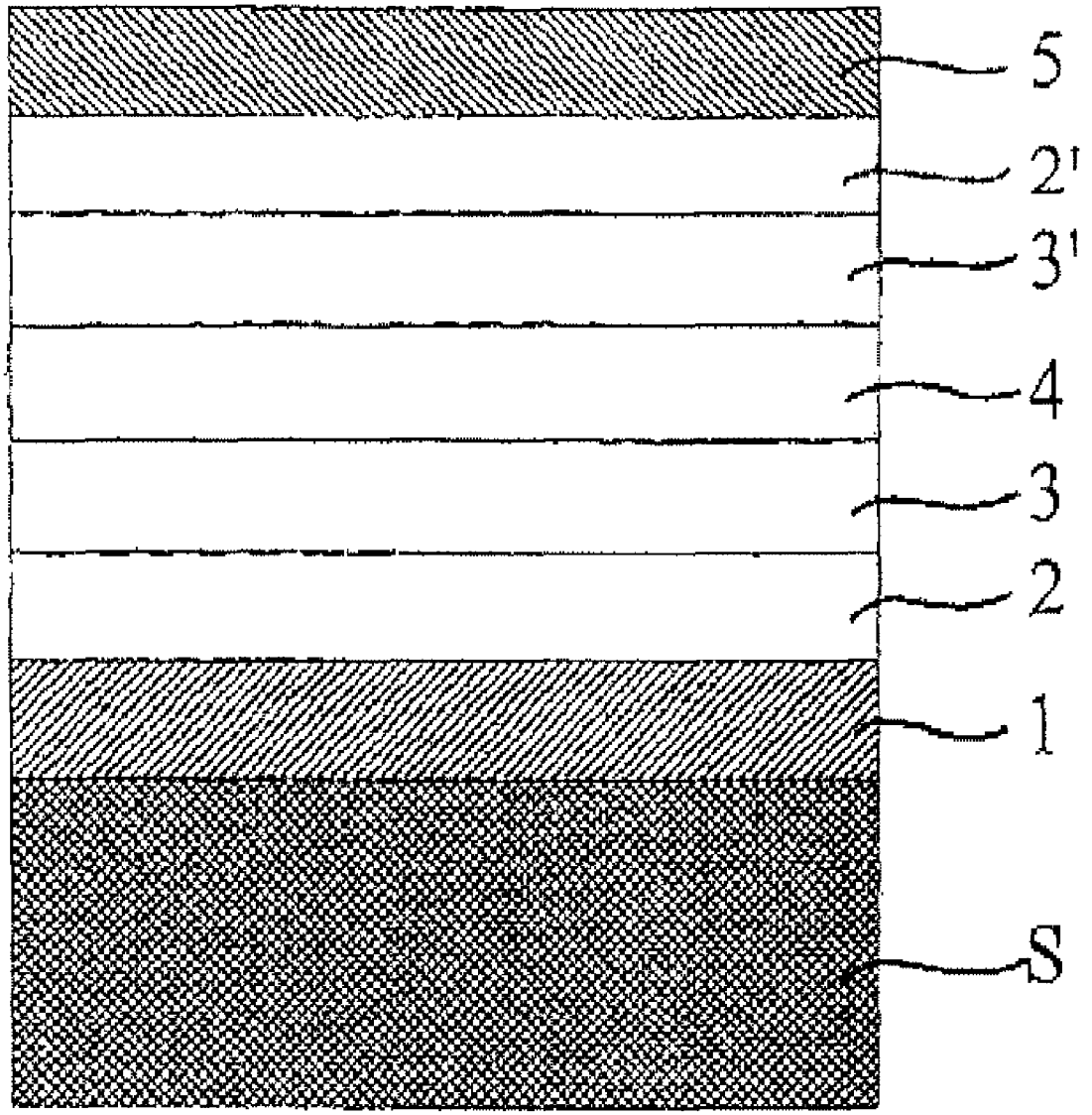


Fig. 1

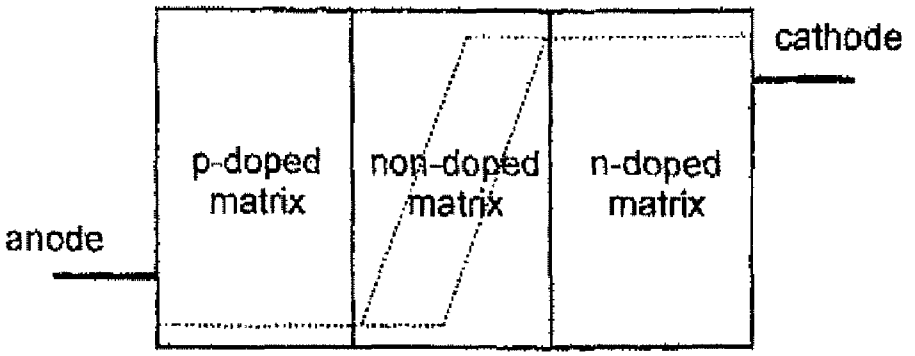
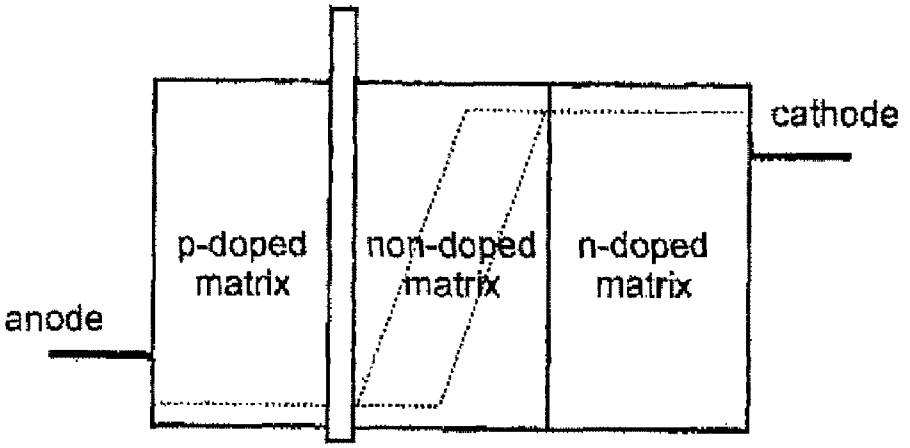


Fig. 2A



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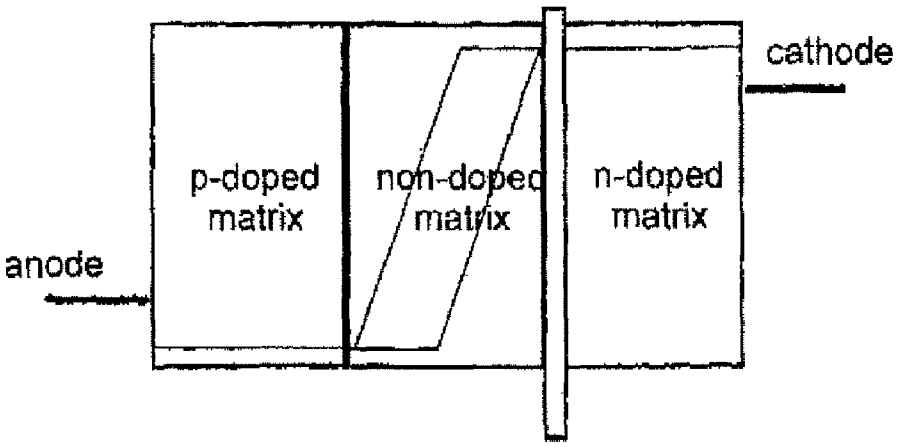

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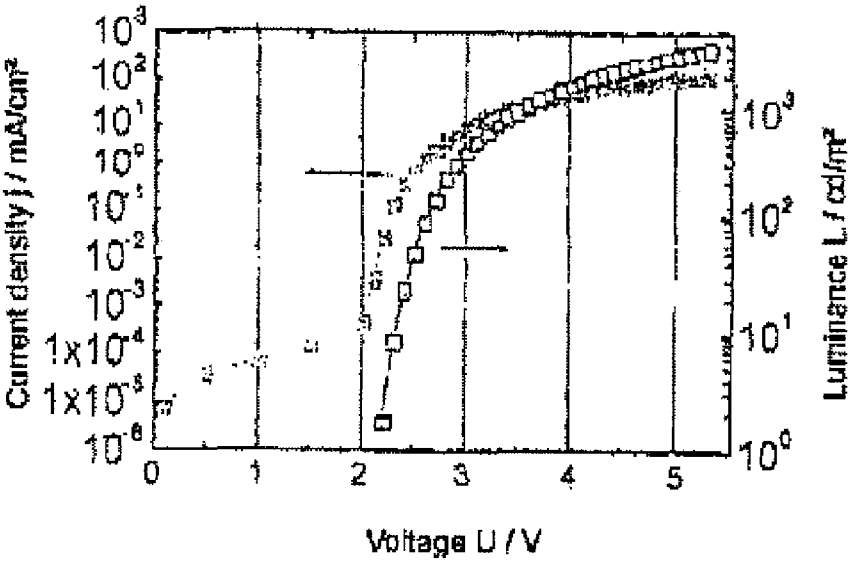
Current density j / mA/cm²
Luminance L / cd/m²
Voltage U / V

Fig. 3A

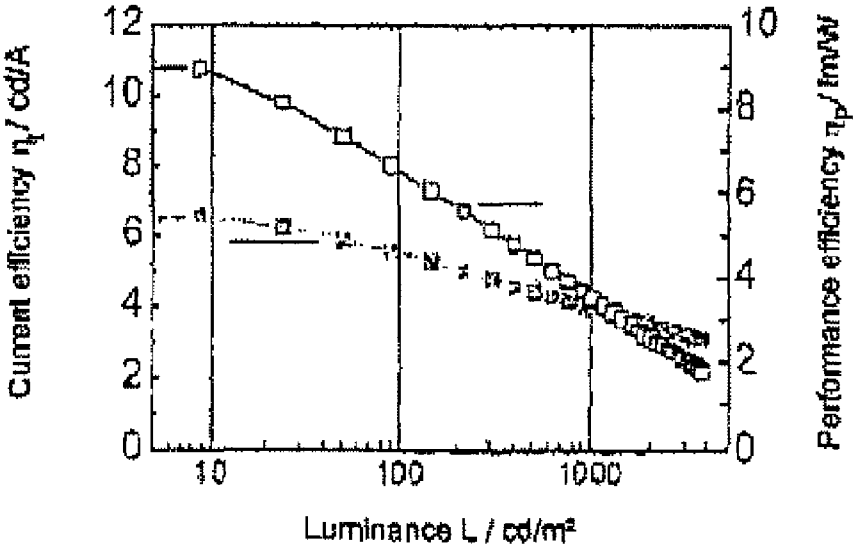
Current efficiency η_I / cd/A
Performance efficiency η_P / lm/W
Luminance L / cd/m²

Fig. 3B

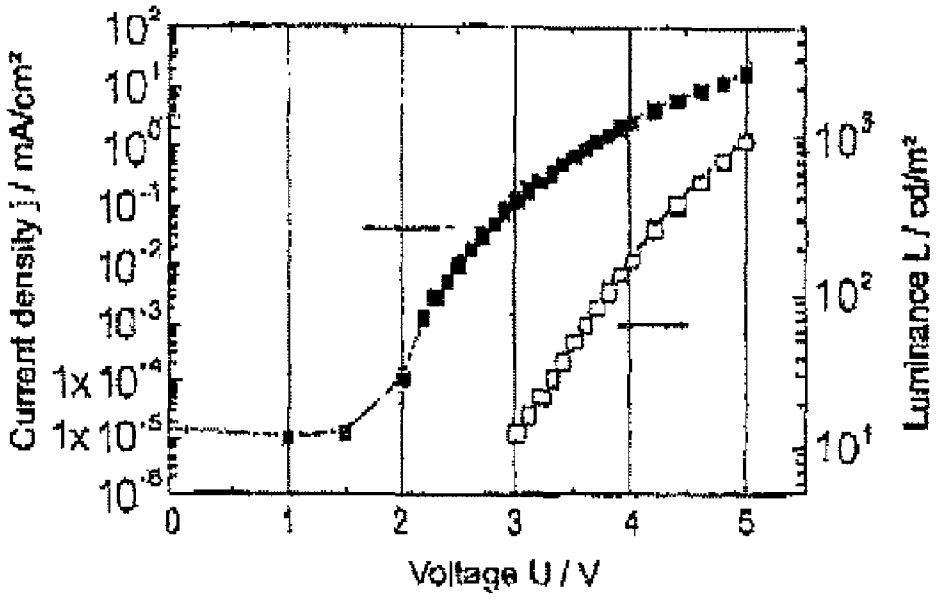
Current density j / mA/cm²
Luminance L / cd/m²
Voltage U / V

Fig. 4A

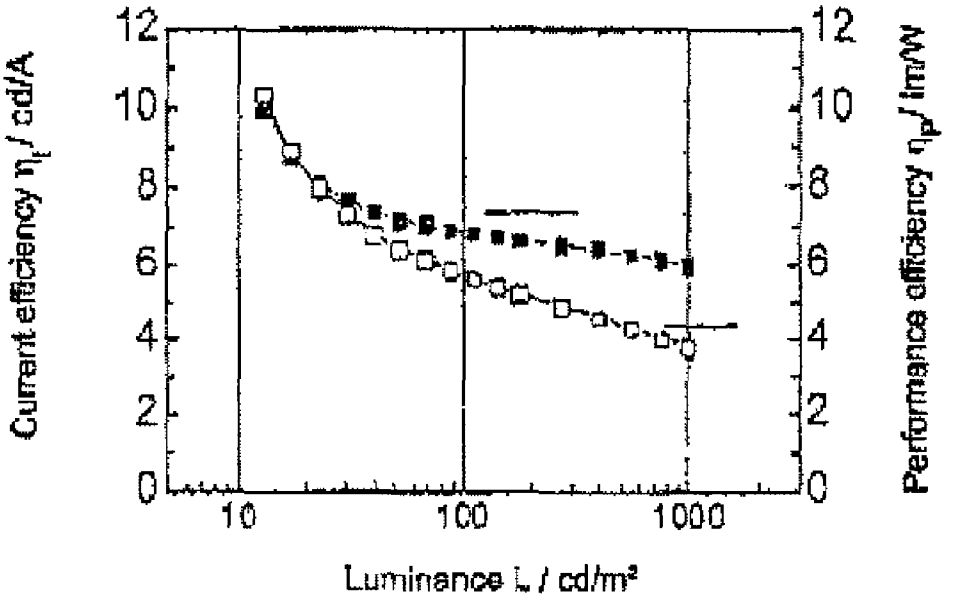
Current efficiency η_I / cd/A
Performance efficiency η_P / lm/W
Luminance L / cd/m²

Fig. 4B

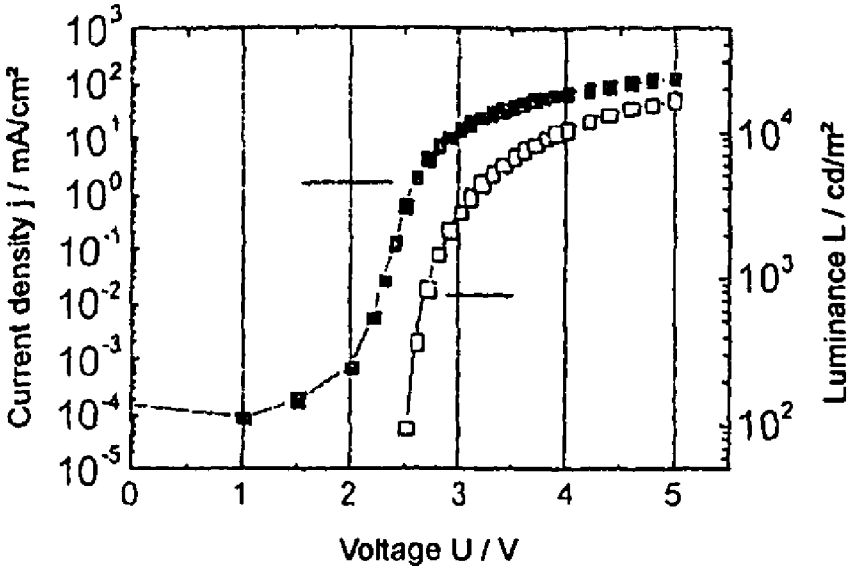
Current density j / mA/cm²
Luminance L / cd/m²
Voltage U / V

Fig. 5A

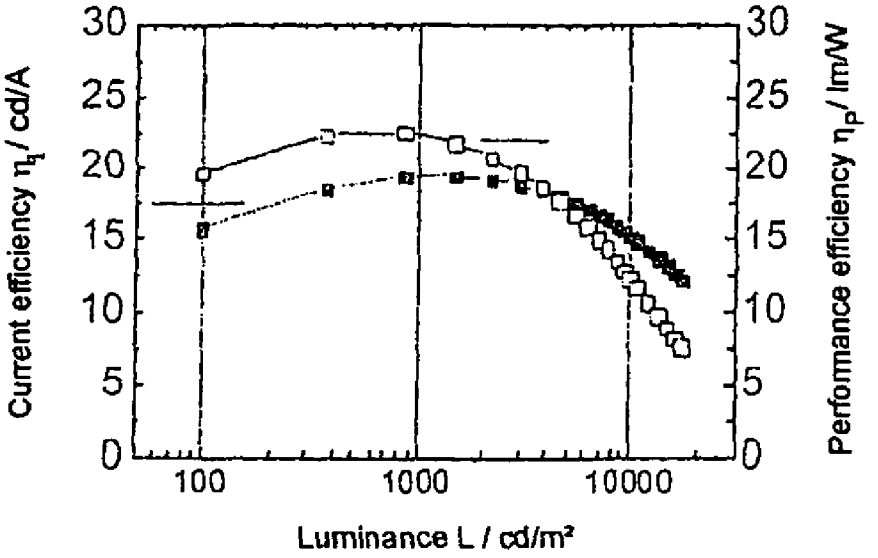
Current efficiency η_I / cd/A
Performance efficiency η_P / lm/W
Luminance L / cd/m²

Fig. 5B

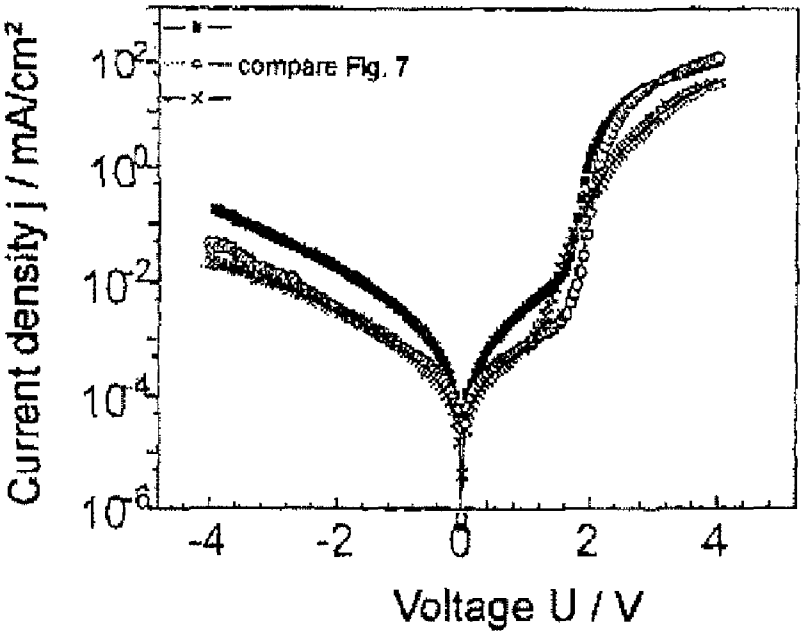
compare Fig. 7
Current density j / mA/cm²
Voltage U / V
-4
-2
0
2
4

Fig. 6

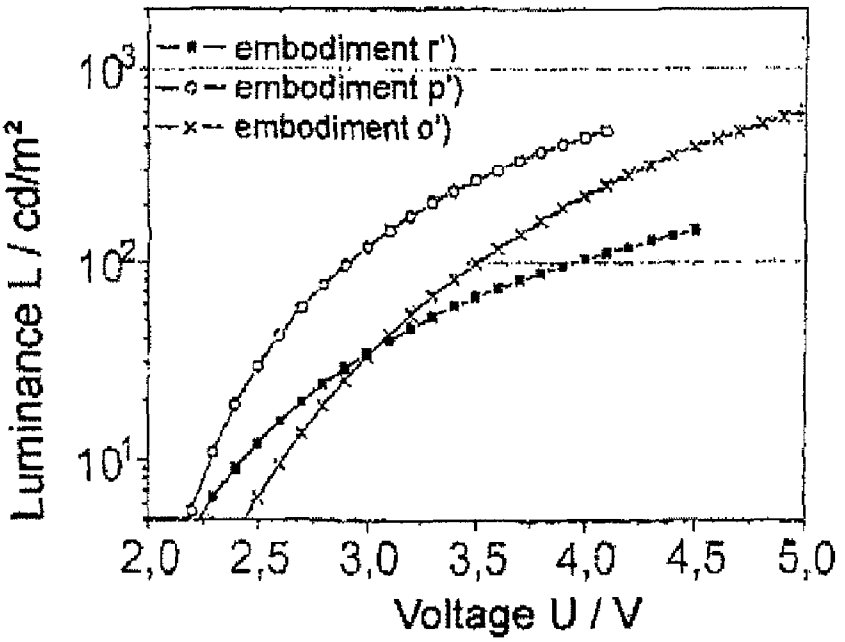
embodiment r')
embodiment p')
embodiment o')
Luminance L / cd/m²
Voltage U / V
2,0
2,5
3,0
3,5
4,0
4,5
5,0

Fig. 7

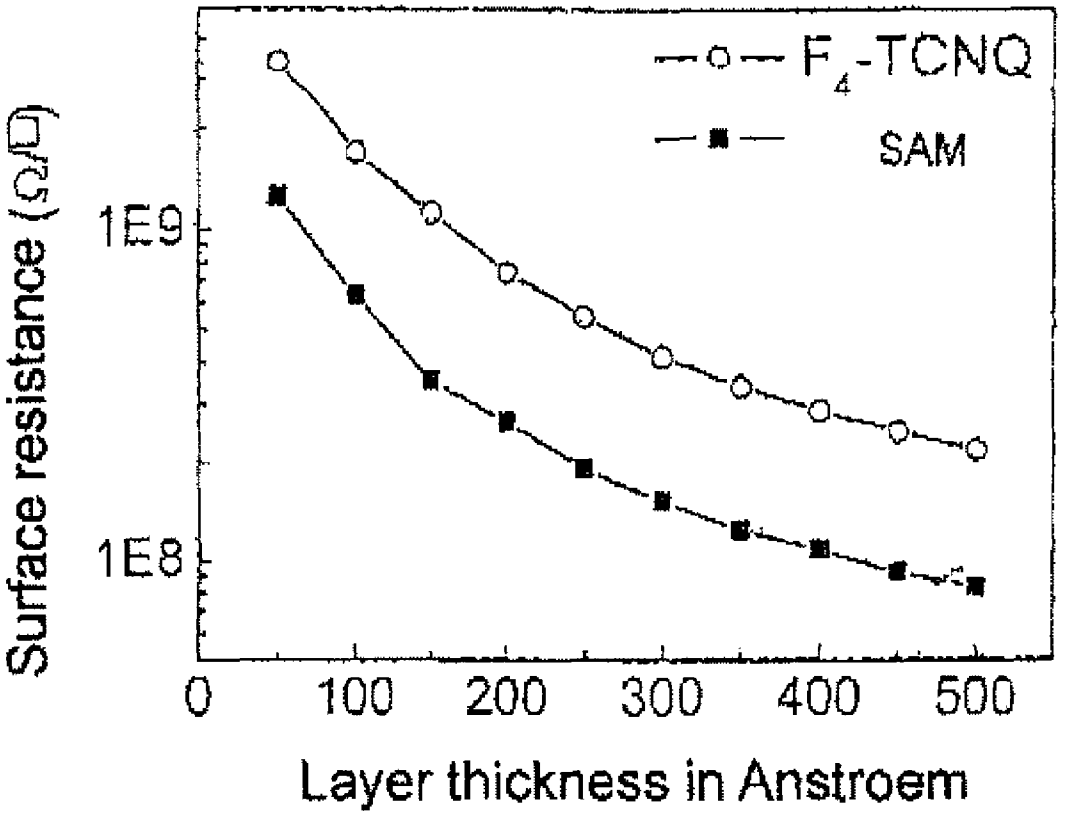
F4-TCNQ
SAM
Surface resistance (Ω/□)
1E9
1E8
0
100
200
300
400
500
Layer thickness in Anstroem

Fig. 8

ARRANGEMENT FOR AN ORGANIC PIN-TYPE LIGHT-EMITTING DIODE AND METHOD FOR MANUFACTURING

CROSS-REFERENCE TO RELATED APPLICATION

Applicants hereby claim priority under 35 U.S.C. 119(a) to European Patent Application No. 05008105.8, filed Oct. 7, 2004, the disclosure of which is expressly incorporated herein by reference in its entirety.

The invention relates to an arrangement for an organic pin-type light-emitting diode (OLED) and a method for manufacturing.

BACKGROUND OF THE INVENTION

Since the demonstration of low working voltages by Tang et al. (compare C. W. Tang et al.: Appl. Phys. Lett. 51 (12), 913 (1987)), organic light-emitting diodes have become promising candidates for the realisation of novel illuminating or display elements. They comprise a series of thin layers of organic materials which are preferably vapour-deposited in a vacuum or spin-coated in their polymer form. Following electric contacting by means of metal layers, they form a variety of electronic or optoelectric structural elements such as diodes, light-emitting diodes, photodiodes and transistors. With their respective properties, they provide for competition for the established structural elements on the basis of inorganic layers.

In the case of the organic light-emitting diodes, and by means of the injection of charge carriers, namely electrons from the one side and holes from the other, from the contacts into the adjoining organic layers as a result of an externally applied voltage, the following formation of excitons (electron-hole-pairs) in an active zone and the radiating recombination of these excitons, light is generated and emitted from the light-emitting diode.

The advantage of such structural elements on an organic basis compared with the conventional structural elements on an inorganic basis, for example semiconductors such as silicon, gallium arsenide, is that it is possible to manufacture very large-surface elements, meaning large display elements (monitors, screens). The organic basic materials are relatively inexpensive compared to inorganic materials. Moreover, these materials can be deposited onto flexible substrates because of their low process temperature compared with inorganic materials. This fact opens the way to a complete series of novel applications in the display and illuminating technique.

In the document U.S. Pat. No. 5,093,698 an organic pin-type light-emitting diode is described that involves an organic light-emitting diode with doped charge carrier transport layers. In particular, three organic layers are used, which are located between two electrodes. N-type and p-type doped layers improve here the charge carrier injection and the transport of holes and electrons in the corresponding doped layer. Consequently, the proposed structure consists of at least three layers with at least five materials.

The energy levels HOMO ("Highest Occupied Molecular Orbital") and LUMO ("Lowest Unoccupied Molecular Orbital") are preferably selected in such a way that both charge carriers are "captured" in the emission zone in order to ensure an efficient recombination of electrons and holes. The restriction of the charge carriers to the emission zone is realised by a suitable selection of the ionisation potentials and/or

electron affinities for the emission layer and/or the charge carrier transport layer, as will be explained later.

The element structure as known from the document U.S. Pat. No. 5,093,698 leads to a greatly improved charge carter injection from the contacts into the organic layers. The high conductivity of the doped layers, moreover, reduces the voltage decline occurring at that location during the operation of the OLED. For this reason, doped structural elements should require significantly lower operating voltages for a desired luminance than comparable non-doped structures. Further examinations, related hereto, of such doped structural elements have shown, however, that this is not necessarily the case. In the original pin-structure, exciplex formation as well as the so-called luminescence quenching effects cannot be ruled out, and this has a negative effect on the quantum yield of the electroluminescence. Luminescence quenching occurs particularly in such a case when p- or n-dopants are in the immediate vicinity, meaning, in the organic layer adjoining the emission zone.

In the document DE 100 58 578 C2, block layers were inserted between the central emission layer and at least one charge carrier transport layer for these reasons. In this case, the charge carrier transport layers are also doped either with acceptors or donors. It is described as to how the energy levels of the block materials are to be selected in order to enrich electrons and holes in the light emitting zone. Thus, the known structure does in fact enable high efficiencies as the additional intermediate layers also act as a buffer zone to the formerly possible quenching effects at dopant disturbance locations.

A luminescence quenching can be caused by several effects. One possible mechanism is known as exciplex formation. In such a case, holes and electrons that should actually recombine with one another on an emitter molecule in the emission zone are located on two different molecules on one of the boundary surfaces to the emission layer. This so-called exciplex condition can be understood as a charge-transfer-exciton where the participating molecules are of a different natures. With an unsuitable selection of the materials for block and emission layer, respectively, this exciplex is the energetically lowest possible excitated condition, so that the energy of the actually desired exciton on an emitter molecule can be transferred into this exciplex condition. That leads to a reduction of the quantum yield of the electroluminescence and, consequently, of the OLED. In some cases the red-shifted electroluminescence of the exciplex is also observed. As a rule, however, this is then characterised by very small quantum yields.

Further mechanisms of the luminescence quenching occurring in OLEDs originate as a result of an alternating effect of excitons with charged and uncharged dopant molecules on the one hand and/or with charge carriers on the other hand. The first mechanism is effectively suppressed by means of the use of non-doped block layers based on the short range of the alternating effect. Charge carriers during the operation of the OLED must inevitably occur in and in the vicinity of the emission zone. For this reason there can only be an optimisation to that extent that an accumulation of charge carriers, for example in a band discontinuity, is avoided. This imposes, in particular, demands on the selection of the tape layers for block material and emitters in order to avoid barriers for the charge carrier injection and, subsequently, an accumulation of charge carriers.

A pin-structure according to the document DE 100 58 578 C2 already comprises at least five single layers with more than six different organic materials owing to the fact that the

functionality of each single layer is closely linked to the specific energy level, as is described in greater detail in the document DE 100 58 578 C2.

A first step for simplification is provided by BPhen/BPhen:Cs layer sequences (compare He et al.: Apply. Phys. Let., 85 (17), 3911 (2004)). This system uses the same matrix material, namely BPhen, both in the electron transport layer as well as for the directly adjacent hole block layer. With this known system, however, the possible exciplex formation is not prevented because of a decisive energy level difference between LUMO of BPhen and the HOMO of the matrix used for the emission zone. In actual fact, an improvement of the structural element by means of the selection of TAZ for the hole block layer is reported. Accordingly, the layer sequence BPhen/BPhen:Cs does not correspond to the simplification of layer structures while maintaining the efficiency of structural elements, which takes place with the help of a specific selection of the materials concerned. In particular, the known system is not compatible with the combination of emitter materials selected at that location. Furthermore, the structure as described by He et al. contains at least four matrix materials.

Furthermore, a structure is known in which the emission layer and a charge carrier transport layer consist of the same organic matrix material (compare J. Kido, Proc. 1st Int. Display Manufacturing Conference IDMC 2000, Seoul, 2000). Here, a structural element emitting organic light is explained that uses an Alq3 layer as emission layer, onto which again a Li-doped Alq3 electron transport layer is adjacent. This sequence is not embedded in a pin-OLED structure, where not only acceptors in the hole transport layer are present but also donors in the electron transport layer.

SUMMARY OF THE INVENTION

The task of the invention is to state and present an arrangement for an organic pin-type light-emitting diode and a method for manufacturing, where the structural configuration of the stack of organic layers is simplified.

This task is solved by an arrangement for an organic pin-type light-emitting diode according to Claim **1** and according to Claim **12**, as well as a method for manufacturing a stack with organic layers for an organic pin-type light-emitting diode wherein a first organic matrix material is processed with the help of a separating device, characterized in that the first organic matrix material is used for several organic layers of the stack.

Advantageous embodiments of the invention are subject-matter of dependent subclaims.

According to one aspect of the invention, an arrangement for an organic pin-type light-emitting diode with an electrode and a counter-electrode and a stack with organic layers between the electrode and the counter-electrode is created, where the stack with the organic layers comprises an emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials, a doped charge carrier transport layer, which is arranged between the electrode and the emission layer, a further doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer, and at least one block layer, which is arranged between one of the doped charge carrier transport layers and the emission layer. The organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, where the n organic matrix materials comprise the k organic matrix materials of the emission layer.

According to another aspect of the invention, an arrangement for an organic pin-type light-emitting diode with an electrode and a counter-electrode and a block-layer-free stack with organic layers between the electrode and the counter-electrode is created, where the block-layer-free stack comprises an emission layer, a doped charge carrier transport layer arranged between the electrode and the emission layer, and a further doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer. The emission layer and the doped charge carrier transport layer of the block-layer-free stack are formed from an organic matrix material.

With such an arrangement the overall number of adopted organic matrix materials and the number of layers are reduced by the fact that, in addition to the formation of several layers of the stack of organic layers, namely the emission layer, of the doped charge carrier transport layer and the further doped charge carrier transport layer from one and the same matrix material, block layers are saved.

According to a further aspect of the invention, a method for the manufacture of a stack with organic layers for an organic light-emitting diode of the simplified pin-type is created, where an organic matrix material is processed with the help of a separating device. This organic matrix material is used for several organic layers of the stack.

An organic matrix material in the sense of the invention is every organic host material to which further materials such as dopants or emitter substances, typically in the molar concentrations 1:100 000 to 5:1, can be admixed (doping). Furthermore, the sole constituent of a non-doped layer, for example block layers, is designated as a matrix. Fluorescent or phosphorescent emission materials are selectable as dopants for emission layers. Moreover, there are also emission layers, which emit light without doping—in this case the matrix is the emitter.

The simplified layer arrangements for pin-type OLEDs indicate no relevant disadvantages with regard to the usual characteristic data and in this respect are of equal standing with the known complex structures. Light-emitting diodes with the use of such layer arrangements have a high efficiency in the range of the required brightness.

The new layer arrangements for pin-type OLEDs are the result of comprehensive efforts in the field of research. Success was achieved in optimising various and partly antagonistically acting demands on the properties of the materials in the stack of organic layers to that extent that not only simple but also efficient pin-OLED structures can be realised. Compared to conventional organic light-emitting diodes with non-doped charge cater transport layers, the variety of the various requirements for the adopted matrix materials is substantially more complex with organic pin-type light-emitting diodes due to the envisaged doping of the charge carrier transport layers.

One advantage of the invention lies in the fact that the realisation of layer arrangements for pin-type OLEDs is enabled, which consist of less layers and/or less organic matrix materials than conventional layer arrangements. In a simplified structural element configuration the number of the adopted organic matrix materials and the adopted layers is limited where one and the same organic matrix material is used for several functional layers. This approach facilitates the quality assurance based on non-complicated processability and reliable manufacturing of OLED structural elements. In addition, investment and consumption costs for manufacturing plants can be minimised.

In addition to the substantially simplified processing, the limited number of required materials is also an advantage of the invention. Moreover, the manufacturing process is simplified be cause a reduction of the number of the sources

required for layer separation is possible. When several organic layers in series are formed by one and the same organic matrix material, the manufacturing process is simplified as a result. For example, in one preferred embodiment the evaporating source for this matrix material can be continually operated, where, in each case, the source shadowing of the sources for the additional substances has to be opened for a short period of time only.

If, in an embodiment for example in a layer structure, the emission layer as well as the block layer and the charge carrier transport layer consist of a stipulated matrix material, a source for the matrix material and a source for each of the emitter dopants and the electric dopants are required. The layer structure can then be manufactured in such a way that, with running operation of the source for the organic matrix material, at first the source of the emitter dopants is opened and again shadowed off for the formation of the block layer and finally, for the separation of the charge carder transport layer, the source of the electric dopant is opened. These advantages become effective, for example, during manufacturing with the use of conventional thermal evaporation in the high vacuum as well as during the separation of layers with the held of the method "Organic Vapour Phase Deposition" (OVPD) (compare M. Baldo et al., Adv. Mater. 10 (18), 1505 (1998).

With various and preferred embodiments of the invention, it can be achieved that the overall number n of the organic matrix materials used for the manufacture of the stack of organic layers can be reduced further, so that $n \leqq k+1$ or even $n=k$ applies if k (k=1, 2, 3 . . .) is the number of the organic matrix materials used in the emission layer.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

The invention is described as follows in greater detail on the basis of embodiment examples with reference to the Figures of the drawing. These Figures shows the following:

FIG. **1** a schematic illustration of a layer arrangement for a light-emitting structural element with multiple layers;

FIG. **2**A to **2**C schematic illustrations of energy levels for an arrangement of organic layers where at least two adjacent layers are made from the same organic matrix material;

FIGS. **3**A and **3**B a graphic illustration of characteristic data for the current density and the luminance as well as the current efficiency and the performance efficiency of a structural element on the basis of a structure according to an embodiment c');

FIGS. **4**A and **4**B a graphic illustration of characteristic data for the current density and the luminance as well as the current efficiency and the performance efficiency of a structural element on the basis of a structure according to an embodiment a');

FIGS. **5**A and **5**B a graphic illustration of characteristic data for the current density and the luminance as well as the current efficiency and the performance efficiency of a structural element on the basis of a structure according to an embodiment n);

FIG. **6** a graphic illustration of characteristic data for the current densities of structural elements according to the embodiments o'), p'), r');

FIG. **7** a graphic illustration of characteristic data for the luminance for the structural elements according to the embodiments o'), p'), r'); and

FIG. **8** a graphic illustration of the surface resistance over the layer thickness of two hole transport layers with the various dopants F4-TCNQ and 2-(6-dicyanomethylene-1,3,4,5,7,8-hexafluoro-6H-naphtalene-2-ylidene)-malononitrile, which are embedded in the same matrix with equal concentration.

FIG. **1** shows the usual structure of an organic light-emitting diode (OLED). A base electrode **1** is deposited in a structured manner onto a carrier substrate S, for example glass or poly-Si. In the next step, the layer-wise thermal evaporation and separation of a stack of organic layers is effected whose properties are specified more precisely further below. Finally, a cover electrode **5** is deposited, which covers the upper organic layer of the stack processed beforehand.

At least one of the electrodes is transparent in any case in order to allow the light emission. In the case of an organic "bottom-emission" diode where the generated light is radiated through the substrate, both the substrate S as well as the base electrode **1** must be transparent. It is however necessary that, with an organic "top-emission" diode, the cover electrode **5** and an encapsulation of the structural element are adequately transparent. It is also conceivable that both sides of the structural element are transparent so that the diode appears transparent.

It is to be emphasised at this point that both electrodes **1** and **5** can inject either electrons or holes, but that no restriction is to be effected with regard to the actual polarity of the presented structural element. For this reason, the invention can be implemented in conjunction, with inverted (base electrode as cathode) as well as with non-inverted (base electrode as anode) structural elements including time-saving and cost-favourable manufacturing processes.

The non-inverted stack of organic layers comprises five basic components: a p-type doped hole transport layer **2**, a non-doped intermediate layer on the hole side, namely an electron block layer **3**, a light-elementing emission layer with k (k=1, 2, 3 . . .) layers, a non-doped intermediate layer on the electron side namely a hole block layer **3'**, and an n-type doped electron transport layer **2'**.

However, if an inverted structure is selected, then the n-type doped electron transport layer **2** is followed by a non-doped intermediate layer on the electron side, namely a hole block layer **3**, then the light-emitting emission layer **4** with k (k=1, 2, 3 . . .) layers, the non-doped intermediate layer on the hole side, namely an electron block layer **3'**, and the p-type doped hole transport layer **2'**.

With regard to the dopants, it is to be noted that acceptor molecules for p-type doping are selected preferably from the group of the quinones (compare also for this purpose DE 103 57 044.6). A well known example is F4-TCNQ that is frequently used in order to dope organic hole transport layers. This has been elaborately described by Pfeiffer for example (compare Appl. Phys. Lett., 73, 22 (1998)). As an alternative, other oxidising substances are also applied for p-doping, for example FeCl3 (compare J. Endo et al. Jpn. J. Appl. Phys. Pt. 2, 41, L358 (2002)). For n-doping it is standard practice to select elements from the group of the alkaline metals (for example Li, Cs) or alkaline earth metals (for example Mg). However, molecular donors can also be used.

The stack of organic layers is described as follows in greater details. In this case, O**1** to O**4** designate in general different organic matrix materials. The organic matrix materials O**1** to O**4** are partially dopable, selectively by means of n-doping and/or p-doping. At first, the same organic matrix material O**1** is used for the layers **2** and **3** of the stack. At the same time, another organic matrix material O**2** is used as a matrix for the two layers **2'** and **3'**:

p-doped O1/O1/4/O2/n-doped O2

This layer arrangement corresponds to a stack of organic layers with a p-doped hole transport layer from the organic matrix material O**1**, an electron block layer from the organic matrix material. O**1**, the emission layer **4**, a hole block layer from the organic matrix material O**2** and an n-doped electron transport layer from the organic matrix material O**2**. These embodiment examples have in common that, for the p-doped hole transport layer and the adjacent electron block layer, the same organic matrix material O**1** is used and for the n-doped electron transport layer and the adjacent hole block layer the same organic matrix material O**2** is used. The p-doped hole transport layer and the relevant and adjacent electron block layer as also the n-doped electron transport layer and the relevant and adjacent hole block layer are each made from the same organic matrix material, where the transport layers have a doping but the block layers do not. For this reason, a doping gradient is formed in each case within the two matrixes consisting of transport layer and block layer.

In principle, a pin-structure is envisaged where the overall number of the organic matrix materials used in the stack of the organic layers exceeds by not more than two the number of the organic matrix materials used for the emission layer. The organic material(s) used for the emission layer **4** can be fluorescent as well as phosphorescent. The emission layer can then be designed as a plain emission layer (k=1), where the emission layer consisting of:

a) O**1** or
b) O**2** or
c) O**3** or
a') a system consisting of matrix O**1**:emitter or
b') a system consisting of matrix O**2**:emitter or
c') a system consisting of matrix O**3**:emitter.

The designation "matrix Ox:emitter" means that the emission layer is formed from an organic matrix material Ox (x=1, 2, . . .) and an added emitter material. However, the emission layer **4** can also be configured as a double emission layer (k=2), where

d) O**1** on the hole side and O**3** on the electron side or
e) O**3** on the hole side and O**2** on the electron side or
f) O**1** on the hole side and O**2** on the electron side or
g) O**3** on the hole side and O**4** on the electron side are arranged.

The emission layer **4** can be furthermore designed as a double emission layer, where as organic matrix material for one or several added emitters the following selections are made:

d') O**1** on the hole side and O**3** on the electron side or
e') O**3** on the hole side and O**2** on the electron side or
f') O**1** on the hole side and O**2** on the electron side or
g') O**3** on the hole side and O**4** on the electron side.

Therefore, the organic matrix materials of the transport layers are in each case identical with the adjacent block layers or even a component of the emission layer. A prerequisite for this is, however, that the organic matrix material O**1** (and/or O**2**) can be doped with acceptors (donors) and functions at the same time as a barrier for electrons (holes) in the organic stack, during which it also allows that holes (electrons) access the emission zone. An exception are the embodiment examples c), c'), g) and g') where the organic matrix material of the emission layer differs from that of the block layers.

The stated structures are the result of comprehensive examinations and are substantially simplified compared to the known complex structures as stated, for example, in the document DE 100 58 578 C2. In addition to this, critical parameters were determined, which preferably have the individual materials for a certain function, namely in particular as doped charge carrier transport layer, block layer or emission layer. These parameters are, in particular, the energetic positions of the charged and/or excited conditions of this molecule. The description of these parameters is given below.

These examinations were combined with comprehensive test series for the identification of materials whose properties enable their application for a plurality of the required functions. For the purpose of gaining a more indepth understanding, simulations of OLEDs were carried out with a specially developed program. The procedure is described in an exemplary manner as follows and the knowledge as well as the design rules derived therefrom are stated.

The procedure is explained with the example of the hole transport layers adjacent to the anode. A pin-OLED with MeO-TPD as a hole transport layer, Spiro-TAD as electron block layer and TAZ as anode-side emitter matrix are deployed as this is known (compare He et al.: Appl. Phys. Lett., 85 (17), 3911 (2004)). An observation of the ionisation potentials of the participating substances shows that the barrier for holes during transport of hole transport layer to the electron block layer is 0.3 eV. The hole injection from the electron block layer into the emission layer is effected barrier-free (compare Pfeiffer et al.: Adv. Mat., 14 (22), 1633 (2002)). The barrier for the injection of holes from the anode into the hole transport layer is approximately 0.5 eV. It is known that the anode made of ITO with hole transport materials with similar ionisation potential such as MeO-TPD forms ohmic contacts. With regard to the potential layers of the participating substances, the anode-side OLED structure as stated by He et al. corresponds essentially to the structures, which were reported for pin-OLEDs with block layers up to now, in the first instance by Huang et al. (Appl. Phys. Lett. 80 (1), 139 (2002)).

In order to realise a plain OLED structure, the number of applied matrix materials was reduced. All known realisations of efficient pin-OLEDs use different matrix materials for the hole transport layer and the electron block layer. The cause for this is that the doping capability of the hole transport layer on the one band, and the good function of the electron block layer on the other, impose very different demands on the properties on these layers.

At first, the p-doped hole transport layer was made from Spiro-TAD. It was evident here that Spiro-TAD can not be adequately doped with the normally used acceptor molecule F4-TCNQ. The result is that the contact to ITO is no longer ohmic and light emission can only be observed with comparably high operating voltages. Furthermore, the electron block layer was manufactured from non-doped Spiro-TTB (2,2',7,7'-Tetrakis-N,N-ditolylamino)-9,9'spirobifluorene), whereas the hole transport layer consists of p-doped Spiro-TTB. With reference to the ionisation potential and the doping capability with F4-TCNQ, this material is to be regarded as being equivalent to MeO-TPD. It was discovered here that an ohmic contact to the ITO is however formed but that, an the other hand, minor efficiencies for light emission occur due to the high barrier for hole injection into the emission layer used here. The cause is quenching effects resulting from exciplex formation and luminescence quenching at the accumulated holes at the boundary surface between block layer and emission layer. Furthermore, other hole transporting materials with a higher ionisation potential than MeO-TPD, but with a lesser ionisation potential than Spiro-TAD, were used as p-doped hole transport layer and as electron block layer. It was discovered here that none of the materials, in the doped case on the one hand, forms ohmic contacts with ITO and at the same time, on the other hand, does not produce any quenching effects in the emission layer. Electrical simulations showed that a barrier of approximately 200 meV

between two organic layers does not yet substantially influence the current transport, but that at about 400 meV considerable accumulation build-up already occurs.

It was recognised that the problem can be solved if acceptor molecules stronger than F4-TCNQ are used. In this way, materials with a higher ionisation potential than MeO-TPD or Spiro-TTB could also be doped, and even Spiro-TAD under certain circumstances. However, acceptor molecules stronger than F4-TCNQ were unknown in the state of the art up to the present. An acceptor molecule stronger than F4-TCNQ was used, which is 2-(6-dicyanomethylene-1,3,4,5,7,8-hexafluoro-6H-naphtalene-2-ylidene)-malononitrile and which is designated in the following as SAM (compare FIG. **8**). It was discovered that a doping of Spiro-TAD was actually successful in that way. It was possible in that way to form the doped hole transport layer and the electron block layer from the same material (Spiro-TAD) and at the same time to ensure a good injection from the anode formed with ITO and minor quenching effects at the boundary surface to the emission layer.

Finally, Spiro-TAD was used also as a matrix material for red triplet emitters, and this made possible a further simplification of the OLED (compare application example a' above).

In a next step, it was examined to what extent one or several block layers are necessary at all with the novel layer structures. Block layers can be deployed in order to avoid negative quenching effects. Up to now, all efficient OLEDs with pin-structure have two block layers, in each case one on the cathode side and one of the anode side.

An important factor for the understanding of the quenching effects is the knowledge of the location of the recombination zone of the pin-OLEDs. As excitons in organic layers have as a rule limited diffusion length in the magnitude of 10 nm, there is only an appreciable exciton density in the structural element also only within the diffusion range. As a rule, quenching effects are attributable to short-range alternating effects with excitons. For this reason, the source of these effects must be within the diffusion zone around the recombination area in order to noticeably worsen the efficiency. Little is known about the location of the emission zone in pin-OLEDs. Experiments with the so-called "doped-slab" technique were carried out for conventional OLEDs. In this case, various OLEDs were manufactured with the same structure for which, in each case, a very thin exciton sensor layer was introduced at various positions in the emission layer. The luminescence signal of the exciton sensor layer is assumed as being proportional to the exciton density locally. In conventional OLEDs, a difference was made between so-called electron-rich and/or electron-poor structures. In the first case, the recombination zone is primarily on the anode side of the emission layer, whereas in the second case it is on the cathode side. The cause for electron surplus and/or electron shortage is, in addition to the differently large mobility for electrons and holes, the barriers for the charge carrier injection in particular.

Furthermore, another method was selected for the examination of pin-diodes, namely the comparison of OLEDs with a variation of the thicknesses of the transport layers with an optical model. This variation leads to a variation of the distance of the emission layer from the reflecting electrode, which is frequently a cathode. Displacements in the emission spectrum and a variation of the decoupling efficiency and the emission characteristics result because of interference in the originating thin layer system.

The comparison of experiment and optical simulation for various locations of the emission zone in the stack enables the determination of their actual location in the structural element. In the result of these experiments it was discovered that, for pin-OLEDs, the location of the emission zone is established not by barriers for load carrier injection but rather primarily because of the relation of movements for electrons and holes in the emission layer. The differentiation between electron-poor and electron-rich OLEDs therefore loses its original significance. If the electron mobility is prevailing in relation to the hole mobility in a concrete emitting layer, the recombination takes place in the vicinity of the electron block layer. This means that, in this case and with sufficient thickness of the emission layer, the exciton density at the hole block layer is very small. Quenching effects at this boundary surface are thus insignificant, and the hole block layer is not required. By way of analogy, the electron block layer is not required with a dominating hole mobility. For examination purposes, OLEDs were manufactured (see below) where no non-doped intermediate layer is inserted between the hole transport layer and the emission layer with a dominating hole mobility. Strong quenching effects are normally expected for such OLEDs as the requirements for practically all types of luminescence quenching at the boundary surface are established, namely the presence of the charged dopant anions, the accumulation of a high hole density due to a high barrier to the emission layer and the energetic acceptance of exciplex formation. In fact, it was observed that the efficiency of these structures is very high. A surprising result that can, however, be explained with the help of the reasons stated above.

Properties with regard to the energy levels of the participating materials are compiled as follows for the manufacture of efficient but uncomplicated structured OLEDs.

As the available acceptors (donors) have a limited doping strength (according to electron affinities and/or ionisation potentials), maximum values for the ionisation potential (minimal values for the electron affinity) result therefrom for the organic matrix materials O**1** to O**4**. In order to additionally serve as an electron (hole) barrier, there are additionally maximum values for the electron affinity (minimal values for the ionisation potential) of the organic matrix materials.

The commercially available acceptor molecule F4-TCNQ can be used as a p-dopant in a hole transport material. It has an electron affinity EA(A) of approximately 5.3 eV (estimation from cyclovoltammetry). For a matrix O**1** doped with F4-TCNQ, there is therefore the requirement that the ionisation potential IP(O**1**) (estimated from cyclovoltammetry) is 0.5 eV larger as a maximum. Caesium atoms are frequently used as donors. Atomic caesium has an ionisation potential of 3.9 eV. Based on a strong alternating effect between matrix and dopant (complex formation) it is however possible to dope matrix materials with a far smaller electron affinity. The well known matrix material BPhen has, for example, an electron affinity between 3.0 eV (estimation from ionisation potential and optical band gap) and 2.4 eV (estimation from cyclovoltammetry). However, it can be expected that, for materials with an electron affinity smaller by 0.5 eV, a doping effect with caesium cannot be achieved. For a molecular n-dopant, and based on the details for p-dopants, in the result the electron affinity of the matrix EA(O**2**) shall not drop below the value, reduced by 0.5 eV, of the ionisation potential of the donor IP(D).

Consequently, the following relationships result from the requirement of the doping capability: IP(O**1**)<EA(A)+0.5 eV and/or EA(O**2**)>IP(D)−0.5 eV. The following applies in the case of doping with caesium: EA(O**2**)>1.9 eV.

For the fulfillment of the barrier characteristics, the requirement on the EA(O**1**) and/or IP(O**2**) results from the potential levels of the emission layer. Electrons that move

energetically it the level of the electron affinity of the emission layer EA(E) shall only access the layer O1 at a low rate. The result is subsequently: EA(O1)<(E)−0.2 eV. At the same time, holes that move energetically in the level of the ionisation potential of the emission layer IP(E) shall only access the layer O2 at a low rate: IP(O2)>IP(E)+0.2 eV. Attention is drawn again here to the fact that the conditions for barrier characteristics do not have to be fulfilled in every OLED stack. If the emission zone is near to the hole transport layer, there is frequently no necessity that the layer adjacent to the emission stack on the cathode side represents a barrier for holes. The same applies for an OLED with an emission zone near the electron transport layer, in that there is frequently no necessity that the layer adjacent to the emission stack on the anode side represents a barrier for electrons.

In order to obtain an efficient injection of charge carriers from the individual charge carrier transport layers and/or the block layers into the emission layer, it is to be demanded that the barriers to be overcome by the charge carriers it this case are not too large, meaning, smaller than 0.5 eV. It is emphasised here that, where higher barriers are concerned, an increase of the operating voltage is to be expected on the one hand. On the other hand, a reduction of the efficiency of the emission can also occur if the accumulated charge carrier density at the boundary surface to the emission layer leads to an increase of the non-radiating recombination of excitons in the emission layer. On the whole, these criteria result: IP(O1)>IP(E)−0.5 eV and EA(O2)<EA(E)+0.5 eV.

It is at first surprising that, on the one hand, an efficient charge carrier injection into the emission layer can take place if the barrier is up to 0.5 eV, but on the other hand the performance of the diode is not detrimentally affected if the barrier for the injection from the emission layer into the block layer is only 0.2 eV. This is attributable to the fact that the desired recombination of electrons and holes occurs within the emission layer as a competing process to the charge carrier loss into the block layers. For this reason, the residence time of the charge carriers in the vicinity of the barrier in the emission layer is significantly shorter than in the case of a unipolar charge transport layer. This leads to a limitation of the charge carrier losses also for comparably small barriers. Material examples are: BPhen can be doped with caesium, but at the same time can also be used as a hole block layer and matrix for the green emitting molecule Ir(ppy)3.

On the hole side, Spiro-TAD offers the possibility at the same time for p-doping and as electron block layer and functions additionally as a matrix for red emitters also, for example.

In the following, further embodiment examples for layer arrangements in the stack of organic layers are explained in greater detail for an organic pin-type light-emitting diode. O1 to O4 again designate generally different organic matrix materials.

m) p-doped O1/O1/O1:emitter/O3/n-doped O2

n) p-doped O1/O3/O2:emitter/O2/n-doped O2

As previously explained in an exemplary manner, such an arrangement leads to the formation of a kind of uniform transition on only one side of the emission layer in each case which is shown in the embodiments blow as an underlined text. A uniform transition in the sense of the invention is a layer sequence that is formed from a charge carrier transport layer up to the emission layer by means of a uniform matrix. If the emission zone is in the middle of the emission layer, the block layers can be deleted. This leads to the structures m*) and n*):

m*) p-doped O1/O1:emitter/n-doped O2

n*) p-doped O1/O2:emitter/n-doped O2

After the stepwise adaptation of the layer materials (compare embodiment examples o), o*), p), p*), q) below), the structures of the embodiment examples r), s), t) can be realised where the HOMO-levels and the LUMO-levels perfectly assimilate because the same matrix material is used all the way through in all layers.

o) p-doped O1/O1/O1:emitter/O2/n-doped O1

o*) p-doped O1/O1:emitter/O2/n-doped O1

p) p-doped O1/O2/O1:emitter/n-doped O1

p*) p-doped O1/O2/O1:emitter/O1/n-doped O1

q) p-doped O1/O2/O1:emitter/O3/n-doped O1

r) p-doped O1/O1/O1:emitter/n-doped O1

s) p-doped O1/O1:emitter/O1/n-doped O1

t) p-doped O1/O1:emitter/n-doped O1

Furthermore, the emission layer can exist in the structures of the embodiment examples m) to t) even out of only one of the materials O1, O2 or O3:

m') p-doped O1/O1/O3/n-doped O2

m") p-doped O1/O1/n-doped O2

n') p-doped O1/O3/O2/n-doped O2

n") p-doped O1/O2/n-doped O2

o') p-doped O1/O1/O2/n-doped O1

p') p-doped O1/O2/O1/n-doped O1

q') p-doped O1/O2/O1/O3/n-doped O1

r'=s'=t') p-doped O1/O1/n-doped O1

All layer combinations listed above can be used in inverted and in non-inverted OLEDs, depending on the polarity of the base and cover electrode. The structures in the embodiment examples m) to t') all comprise only one emission layer from one single matrix material, therefore k=1 applies. By way of analogue, the simplifications named apply however also for the structures in the embodiment examples m) to q) and m') to q') for k=1, 2, 3 . . . . Particularly where white OLEDs are concerned, k is frequently larger than 1 as the white spectrum is made up of constituents of different colours.

The greatest challenge during the construction of an OLED with the same matrix for p- and n-doping is finding a matrix material that can be doped with a p- as well as with an n-dopant, so that it can be used in the hole and the electron transport layer. For the case that this material is also to be used as emitter or emitter host, its energy gap between HOMO and LUMO must be in a range that enables electrons and holes to penetrate the emission zone and to recombine there is a radiating manner. The explained details for the orbital levels of the matrix result direct from the considerations stated above according to the identity of the organic matrix materials O1 and O2. Phthalocyanine, for example ZnPc and CuPc, phorphyrine, for example ZnOEP, PtOEP or iridium (III) tris(1-phenylisoquinoline) are materials that have been used.

In the following, reference is made to the FIG. 2A to 2C. The most uncomplicated structure can be realised by a three-layer system which is shown above, for example, as embodiment r'). In principle, HOMO and LUMO levels match perfectly at every boundary surface if the same matrix material is involved on both sides of the boundary surface. That means that there is absolutely no energy barrier in such an OLED within the organic, neither for the electrons on their route through the LUMO nor for the holes on their route through the HOMO.

In order to obtain low operating voltages of the OLED, both charge carder transport layers are doped. This presupposes that the matrix material can be p-doped as well as n-doped. The balance of the two charge carrier types which must be balanced out for a high current efficiency can be set by way of the degree of the p- and n-doping.

The greatest advantage of this structure is its uncomplicated processing. In this case, however, charge carrier balance

must be set. This can namely also depend on the applied voltage and, subsequently, on the brightness. A further parameter that has to be taken into account is the exciton diffusion length. If it is so large that the excitons can diffuse out of the emission zone, that will also reduce the efficiency.

As required, one (compare FIGS. **2**B and **2**C; embodiment examples o*), o'), p), p')) or even two (compare embodiment examples o), q), p*) and q')) block layers must be introduced, which restrict the holes and electrons in the emission layer. In this case, the energy difference of the LUMOs/HOMOs of the layer **3**/**3'** and the emission layer **4** (compare FIG. **1**) acts as a barrier for the electrons/holes with a non-inverted structure. This applies by analogy for an inverted structure. In this way, charge carriers are accumulated in the emission layer, a fact which again results in efficient light generation.

In OLED structures there are occasionally further layers that are introduced between the contacts and the layer structures described here. These layers can, for example, serve the improvement of the charge carrier injection or a better adhesion of the contact at the organic layers. It is understood that the described layer structures also concern such OLEDs, which include this type of layers additionally to the layer stack described here. This refers not only to coloured but also to white OLEDs.

Particularly attractive is the simplification according to the invention of the layer stack for the use in so-called "stacked" OLEDS. "Pin-stacked" OLEDs is normally understood to mean OLEDs with several pin-layer sequences on top of each other. These OLEDs enable high current efficiencies and the mixing of colours with the use of variously emitting emission stacks in the individual sub-pin-OLEDs. Particularly with these OLEDs which can consist of ten or more layers, the saving of each individual layer is a guarantee for higher production yield and more cost-favourable manufacture.

Full-colour displays with red, green and blue sub-pixels are a significant application for OLEDs. Pin-structures are used for this application also, where the attempt is made to deposit in a structured manner only the emission layer stack and/or the emission layer by means of a shadow mask in order to obtain the three differently coloured sub-pixels types. All other layers, meaning for example the transport and block layers, are to be jointly deposited for the three colours. However, this means for example that a block layer on the electron side can only then be dispensed with if the OLED simplified in this way functions equally well for all three colours. By means of the knowledge gained, the emitter matrixes can now be specifically selected in such a way that the same blocker can be dispensed with for all three colours. For example, one could select emitter matrixes for all three colours, which predominantly transport holes and subsequently, depending on the circumstances, dispense with the electron block layer.

In the following, and supplementary to the embodiments already described, other examples for the realisation of the simplified structures are described. Here, SAM was used as a p-dopant.

i) Example for a Structure According to the Embodiment c'

A red bottom-emitting OLED was processed on ITO with Spiro-TTB as organic matrix material for the hole transport layer and as electron block layer. On the electron side, a combination of non-doped and Cs-doped BPhen was implemented. A reflective aluminium cathode was deposited as a cover electrode. The emission layer consists of the emitter system NPD:Indium (III) to (2-methyldibenzo[f,h]-quinoxaline)(acetylacetonate). The characteristic data are shown in the FIGS. **3**A and **3**B. At only 2.6V, light with a brightness of 100 cd/m^2 and an efficiency of 6.6 lm/W is emitted.

ii) Example for a Structure According to the Embodiment a'

In contrast to the previous example, Spiro-TAD is applied here as a matrix for the hole transport layer, as intermediate layer **3** and as matrix for the emitter dye iridium (III) tris(1-phenylisoquinoline). All other layers were grown on by analogy with the previous example. The characteristic data are shown in the FIGS. **4**A and **4**B. The performance efficiency reaches 5.7 lm/W with a brightness of 100 cd/m^2 and an operating voltage of 3.7V.

iii) Example for a Structure According to the Embodiment n

A uniform transition on the electron side is realised with the help of a BPhen-matrix that is doped with Cs in order to ensure a high n-conductivity. BPhen is furthermore used as a hole block layer and as matrix material for the green-emitting emitter Ir(ppy)3. On the p-side and with SAM, p-doped Spiro-TTB was deposited on transparent ITO and onto this non-doped Spiro-TAD as electron block layer, restricting the electrons in the emission zone, was separated. The characteristic data were shown in the FIGS. **5**A and **5**B. Steep current-voltage characteristic curves were measured. 1000 cd/m^2 was obtained at an operating voltage of 2.75V and a performance efficiency of 22.2 lm/W.

iv) Example for an Individual Structure According to the Embodiments o'), p'), r'

The red-emitting material iridium (III) tris(1-phenylisoquinoline) is a suitable organic matrix material, which shows an increased conductivity with doping with acceptors as well as with donors. Three OLEDs based on this matrix material were built, namely a diode without block layers, a diode with MeT-TPD that was applied as an electron block layer (EB) and a diode in the 4,7-diphenyl-2,9-dicyano-1,10-phenanthroline(bathophenanthroline) as a hole block layer. Cs was used as an n-dopant. Characteristic data of these diodes are shown in the FIGS. **6** and **7**. All samples show a good diode characteristic. The diode with EB emitted red light of a brightness of 100 cd/m^2 at 2.9 V. It is clearly evident that the luminance of the diodes is increased with the use of the block layers.

On the whole and with the described arrangements of organic layers, new configuration options with reference to the interaction between block layer and charge carrier transport layer and emission layer are created. Proceeding on the basis of simplified OLED structure, a method was furthermore created as to how OLEDs could be significantly and more easily processed. The point of initiation is the use of the same organic matrix material for several layers, for example as matrix material for the p-dopant, as electron blocker and as matrix material for the emission layer. For the manufacture of such layer arrangements, one or several evaporation sources for further matrix materials can be saved, which have to be vapour-deposited in known processes. In addition, it is enabled that the source for the matrix material can be continually operated. At first, a co-evaporation of the matrix with the p-dopant takes place (vapour deposition of the hole transport layer). Then the closure of the source of the p-dopant is closed and only the matrix is evaporated further (vapour deposition of the electron block layer). Then the closure for

the emitter dye is opened and the emitter dye is co-evaporated together with the matrix material (vapour deposition of the emission layer). This procedure saves time for the heat-up and heat-down of the source for the matrix material and saves costs as well because only one source is used for the matrix material.

In summarising, the invention is based on the knowledge that the plurality of criteria that has to observed with the selection and the combination of organic matrix materials for the charge carrier transport, the charge carrier blockage and the light emission in organic pin-type light-emitting diodes does not necessarily lead to a situation where these matrix materials have to be different with regard to pairing. For example, one and the same organic matrix material, for example Spiro-TAD, can also be used as a matrix material for a hole transport layer in addition to its known use as block material, even though the criterion of doping capability and the criterion of the small barrier for the injection of holes into the omission layer are in opposition to one another. Here, new types of acceptors such as SAM, for example, are incorporated, which considerably expand the class of the p-dopable matrixes. In particular, materials, which were formerly used exclusively as block material can now also be used as p-doped hole transport material.

It was furthermore recognised that, in embodiments, the use of a block layer is dispensable for a charge carrier type, particularly if the mobility of this charge carrier type exceeds the mobility of the other charge carrier type in such a way that the emission zone is located far away on the opposite side of the emission layer. In this case it is also possible to select the same matrix material for the emission layer as for the transport layer of this highly mobile charge carrier type. For example, in the case of an emission layer comprising TCTA: Ir(ppy)3, an electron blocker consisting of Spiro-TAD for example can be dispensed with, even though in the state of the art such structures with Spiro-TAD or similar are stated at all times, for example in He et al.: Apply. Phys. Lett., 85 (17), 3911 (2004)). And in this case also, the emission layer and the hole transport layer can consist of the matrix material Spiro-TAD. This is surprising as the organic pin-type light-emitting diode as such has been known for more than ten years.

Furthermore, the knowledge was gained that it is possible in embodiments to use the one and the same material as matrix for the electron as well as the hole transport layer. Here, the conditions of doping capability for both charge carrier types, on the one hand, and the condition of the low barriers for charge carrier injection into the mission layer as welt as the condition of exclusion of the exciplex formation, on the other hand, are in opposition. It was recognised that acceptor and/or donor compounds can be selected, which are strong in order to ensure the charge carrier injection into a red radiating emission layer.

Despite the fact that with the described arrangements of organic layers, the entire structure of the OLED was significantly simplified, highly efficient structural elements are still being manufactured. The cause in this case is the uncomplicated injection of the charge carriers from the electrodes into the organic layer arrangement and the almost loss-free transport of the charge carriers through the transport layers based on the doping as well as the efficient recombination in the emission zone.

The features of the invention as disclose in the description given above, as well as in the drawing and the Claims can be of significance both individually as well as in random combination for the realisation of the invention is it various embodiments.

The invention claimed is:

1. Organic pin-type light-emitting diode comprising an electrode and a counter-electrode and a stack comprising organic layers between the electrode and the counter-electrode, wherein the stack comprising the organic layers comprises:

an emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials;

a doped charge carrier transport layer, which is arranged between the electrode and the emission layer;

an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer; and

a block layer, which is arranged between the doped charge carrier transport layer and the emission layer; wherein the organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, n is the overall number of the matrix materials, the n organic matrix materials also comprise the k organic matrix materials of the emission layer, k is the number of the organic matrix materials used in the emission layer, and wherein the doped charged carrier transport layer or the additional doped charged carrier transport layer comprises at least one acceptor molecule stronger than F4-TCNQ.

2. Organic pin-type light-emitting diode according to claim **1**, further comprising an additional block layer, which is arranged between the additional doped charge carrier transport layer and the emission layer.

3. Organic pin-type light-emitting diode according to claim **1**, wherein the doped charge carrier transport layer and the block layer are made from a first of the n organic matrix materials.

4. Organic pin-type light-emitting diode according to claim **3**, comprising an additional block layer, which is arranged between the additional doped charge carrier transport layer and the emission layer, wherein the additional block layer is made from the first of the n organic matrix materials, and wherein the organic pin-type light-emitting diode comprises at least one hole block layer and at least one electron block layer.

5. Organic pin-type light-emitting diode according to claim **4**, wherein the emission layer includes at least one layer formed from the first of the n organic matrix materials, the at least one layer being adjacent to the block layer and/or to the additional block layer.

6. Organic pin-type light-emitting diode according to claim **3**, wherein the additional doped charge carrier transport layer is made from a second of the n organic matrix materials.

7. Organic pin-type light-emitting diode according to claim **6**, comprising an additional block layer, which is arranged between the additional doped charge carrier transport layer and the emission layer, wherein the additional block layer is made from the second of the n organic matrix materials wherein the organic pin-type light-emitting diode comprises at least one hole block layer and at least one electron block layer.

8. Organic pin-type light-emitting diode according to claim **7**, wherein the emission layer includes at least one layer formed from the second of the n organic matrix materials, the at least one layer being adjacent to the additional block layer.

9. Organic pin-type light-emitting diode according to claim **1**, wherein the doped charge carrier transport layer, the emission layer and the additional doped charge carrier transport layer are made from a first of the n organic matrix materials, and wherein the block layer is made from a second of the n organic matrix materials.

10. Organic pin-type light-emitting diode according to claim 9, comprising an additional block layer, which is arranged between the additional doped charge carrier transport layer and the emission layer, wherein the additional block layer is made from a third of the n organic matrix materials.

11. Organic pin-type light-emitting diode according to claim 10, wherein the emission layer includes at least one layer formed from the third of the n organic matrix materials and/or at least one layer formed from a fourth of the n organic matrix materials.

12. An organic pin-type light-emitting diode comprising an electrode and a counter-electrode and a block-layer-free stack comprising organic layers between the electrode and the counter-electrode, wherein the block-layer free stack comprises an emission layer, a doped charge carrier transport layer, which is arranged between the electrode and the emission layer, and an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer, wherein the emission layer and the doped charge carrier transport layer of the block-layer-free stack are formed from one organic matrix material.

13. Organic pin-type light-emitting diode according to claim 12, wherein the additional doped charge carrier transport layer of the block-layer-free stack is formed from the one organic matrix material.

14. Organic pin-type light-emitting diode according to claim 13, wherein the block-layer free stack comprises an organic stack between electrode and counter-electrode, the organic stack being formed as a single organic matrix.

15. Organic pin-type light-emitting diode according to claim 1, wherein the doped charge carrier transport layer is formed from a first organic matrix material and comprises a p-dopant, and the additional doped charged carrier transport layer is formed from a second organic matrix material and comprises a n-dopant; wherein the doped charge carrier transport layer and the additional doped charged carrier transport layer are characterized by at least one of the following relations:

$$IP(O1)<EA(A)+0.5\text{ eV};$$

$$EA(O2)>IP(D)-0.5\text{ eV};$$

wherein IP(O1) is the ionization potential of the first organic matrix material; EA(A) is the electron affinity of the p-dopant; EA(O2) is the electron affinity of the second matrix material; and IP(D) is the ionization potential of the n-dopant.

16. Organic pin-type light-emitting diode according to claim 1, wherein the stack comprising organic layers comprises a molecule for doping selected from the group consisting of: quinones; oxidizing substances; $FeCl_3$; and 2-(6-dicyanomethylene-1,3,4,5,7,8-hexafluoro-6H-naphthalene-2-ylidene)-malononitrile.

17. Organic pin-type light-emitting diode according to claim 1, wherein the stack comprising organic layers comprises a dopant for n-type doping selected from the group consisting of: alkaline metals and alkaline earth metals.

18. Organic pin-type light-emitting diode with an electrode and a counter-electrode and a stack comprising organic layers between the electrode and the counter-electrode, wherein the stack comprising the organic layers comprises:

an emission layer, the emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials;

a doped charge carrier transport layer, which is arranged between the electrode and the emission layer;

an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer; and

a block layer, which is arranged between the doped charge carrier transport layer and the emission layer;

wherein the organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, wherein n is the overall number of the matrix materials, the n organic matrix materials also comprises the k organic matrix materials of the emission layer, k is the number of the organic matrix materials used in the emission layer and the doped charge carrier transport layer, the block layer, and the additional doped charge carrier transport layer are made from a first of the n organic matrix materials.

19. Organic pin-type light-emitting diode comprising an electrode and a counter-electrode and a stack comprising organic layers between the electrode and the counter-electrode, wherein the stack comprising the organic layers comprises:

an emission layer, the emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials;

a doped charge carrier transport layer, which is arranged between the electrode and the emission layer;

an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer; and

a block layer, which is arranged between the doped charge carrier transport layer and the emission layer;

wherein the organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, n is the overall number of the matrix materials, the n organic matrix materials also comprises the k organic matrix materials of the emission layer, k is the number of the organic matrix materials used in the emission layer, the doped charge carrier transport layer and the block layer are made from a first organic matrix material, and the additional doped charge carrier transport layer and the additional block layer are made from a second of the n organic matrix materials.

20. Organic pin-type light-emitting diode comprising an electrode and a counter-electrode and a stack comprising organic layers between the electrode and the counter electrode, wherein the stack comprising the organic layers comprises:

an emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials;

a doped charge carrier transport layer, which is arranged between the electrode and the emission layer;

an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer;

a block layer, which is arranged between the doped charge carrier transport layer and the emission layer; wherein the organic layers of the stack are formed by means of n ($n \leqq k+2$) organic matrix materials, n is the overall number of the matrix materials, the n organic matrix materials also comprise the k organic matrix materials of the emission layer, k is the number of the organic matrix materials used in the emission layer; and

wherein the doped charge carrier transport layer is formed from a first organic matrix material and comprises a p-dopant, and the additional doped charged carrier transport layer is formed from a second organic matrix material and comprises a n-dopant; wherein the doped charge carrier transport layer and the additional doped charged

carrier transport layer are characterized by at least one of the following relations:

$$IP(O1)<EA(A)+0.5\text{ eV};$$

$$EA(O2)>IP(D)-0.5\text{ eV; or}$$

when cesium is a dopant, EA(O**2**)>1.9 Ev;

wherein IP(O**1**) is the ionization potential of the first organic matrix material; EA(A) is the electron affinity of the p-dopant; EA(O**2**) is the electron affinity of the second matrix material; and IP(D) is the ionization potential of the n-dopant.

21. Organic pin-type light-emitting diode comprising an electrode and a counter-electrode and a stack comprising organic layers between the electrode and the counter-electrode, wherein the stack comprising the organic layers comprises:

an emission layer comprising k (k=1, 2, 3, . . .) organic matrix materials;

a doped charge carrier transport layer, which is arranged between the electrode and the emission layer;

an additional doped charge carrier transport layer, which is arranged between the counter-electrode and the emission layer;

a block layer, which is arranged between the doped charge carrier transport layer and the emission layer; wherein the organic layers of the stack are formed by means of n (n≦k+2) organic matrix materials, n is the overall number of the matrix materials, the n organic matrix materials also comprise the k organic matrix materials of the emission layer, k is the number of the organic matrix materials used in the emission layer; and

wherein the doped charge carrier transport layer is formed from a first organic matrix material and comprises a n-dopant, and the additional doped charged carrier transport layer is formed from a second organic matrix material and comprises a p-dopant; wherein the doped charge carrier transport layer and the additional doped charged carrier transport layer are characterized by at least one of the following relations:

$$IP(O2)<EA(A)+0.5\text{ eV};$$

$$EA(O1)>IP(D)-0.5\text{ eV; or}$$

when cesium is a dopant, EA(O**1**)>1.9 eV;

wherein IP(O**1**) is the ionization potential of the first organic matrix material; EA(A) is the electron affinity of the p-dopant; EA(O**2**) is the electron affinity of the second matrix material; and IP(D) is the ionization potential of the n-dopant.

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