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(54) ORGANIC LIGHT-EMITTING DIODE, DISPLAY PANEL AND DISPLAY DEVICE

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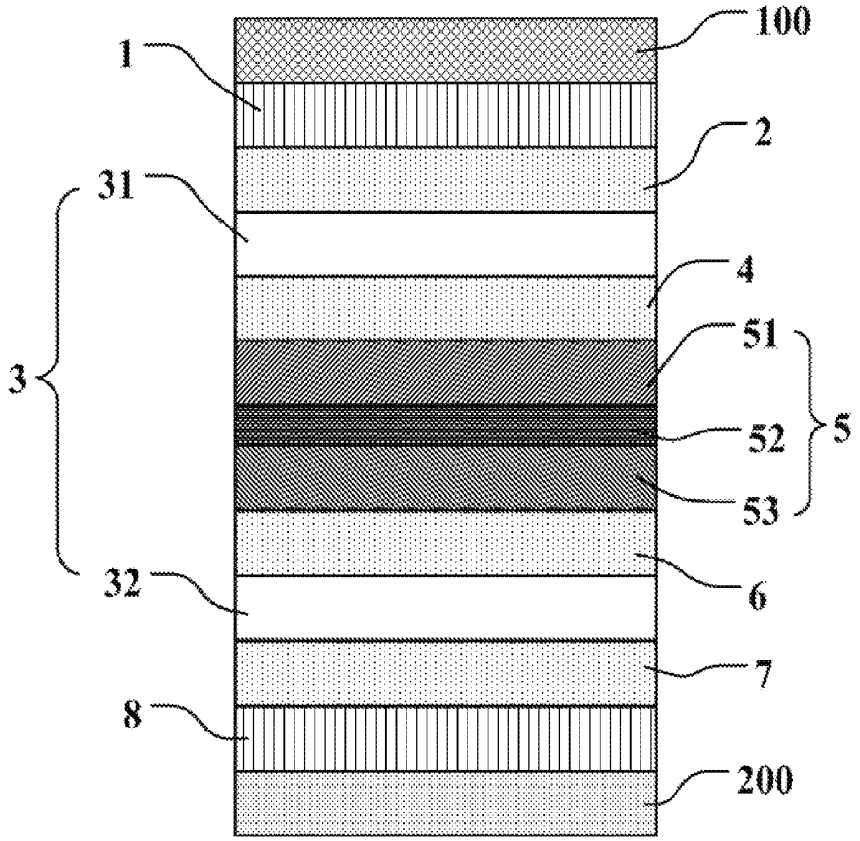
(57) **ABSTRACT**

The disclosure discloses an organic light-emitting diode, a display panel and a display device. The organic light-emitting diode includes an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, where the charge generation layer includes a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, where the first doping layer includes a P-type semiconductor material, and the second doping layer includes a N-type semiconductor material; the P-type semiconductor material includes a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material includes a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material.



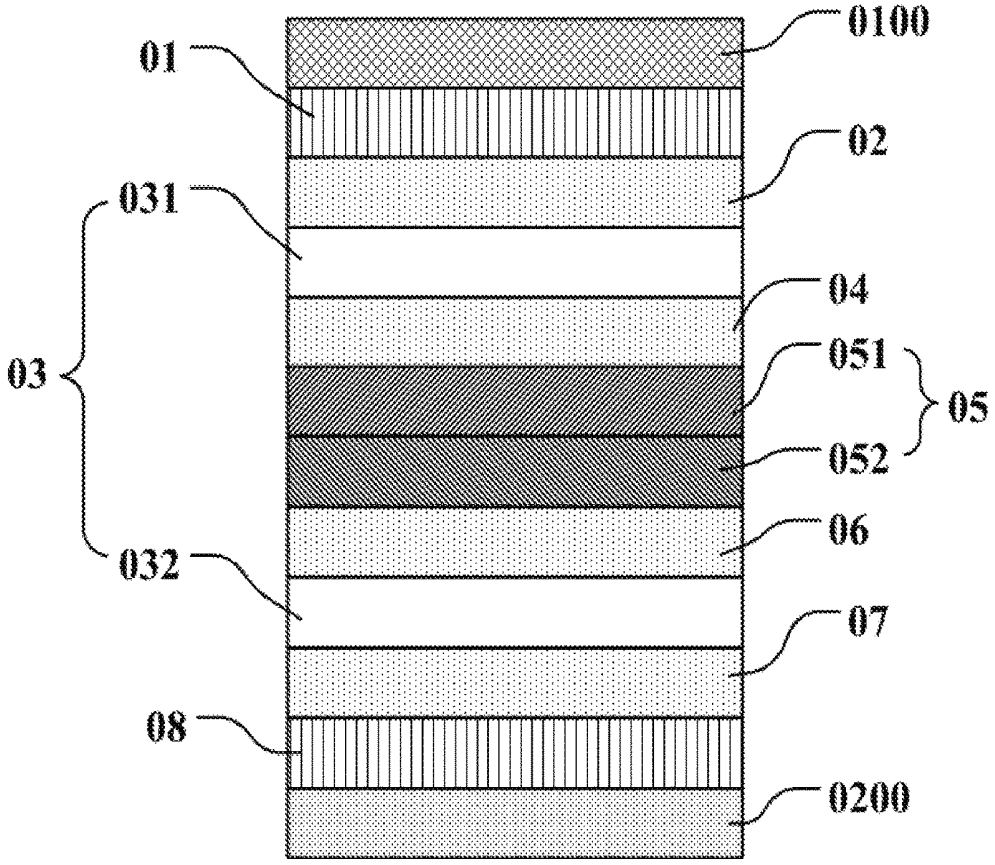


Fig.1

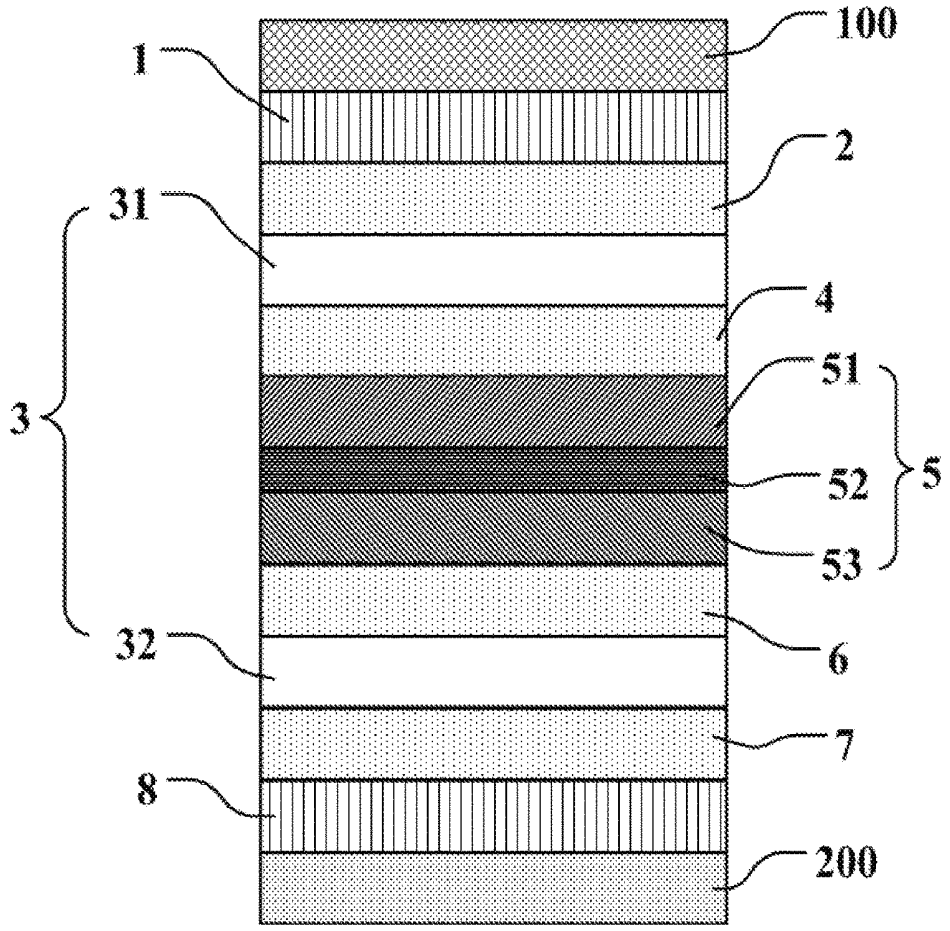


Fig.2

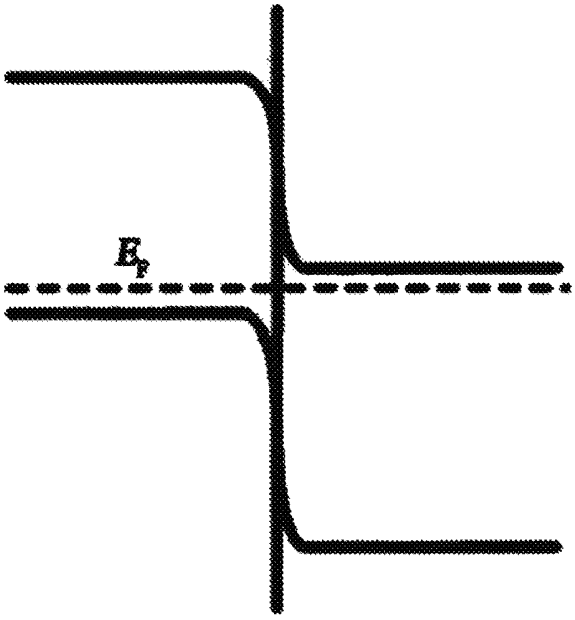


Fig.3

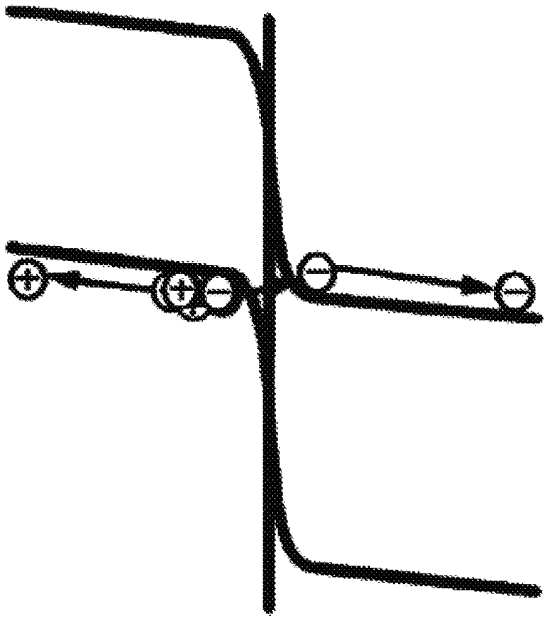


Fig.4

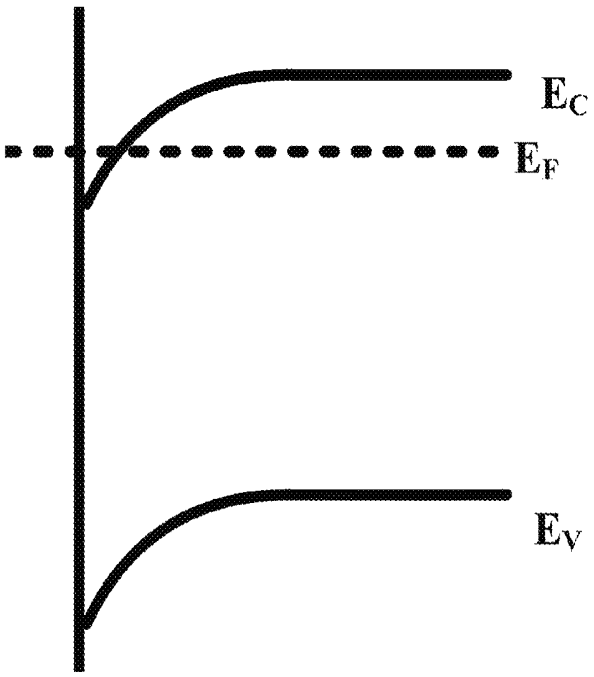


Fig.5

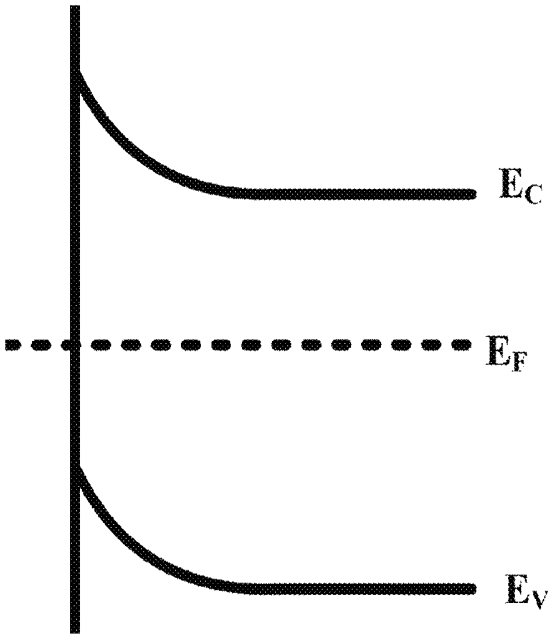


Fig.6

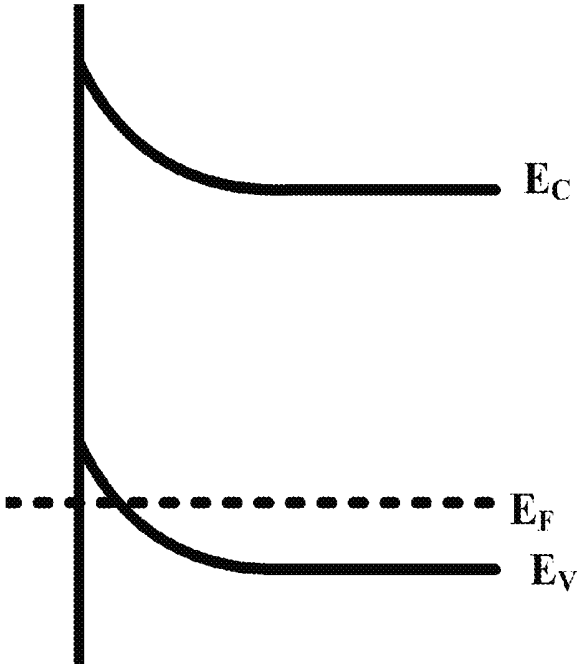


Fig.7

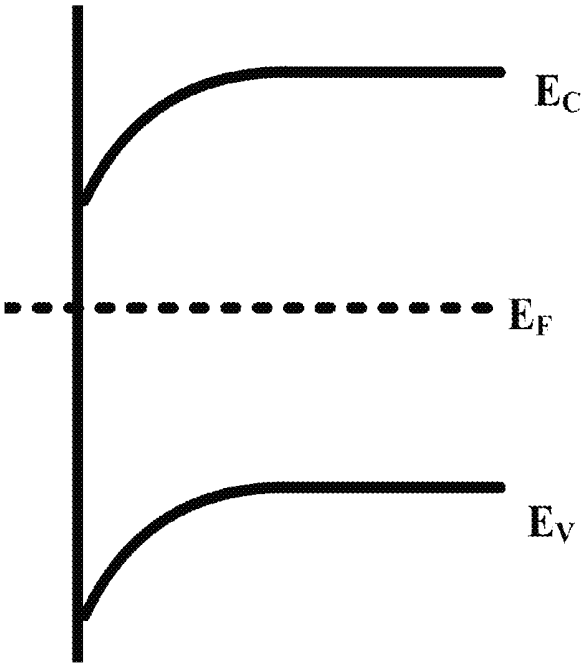


Fig.8

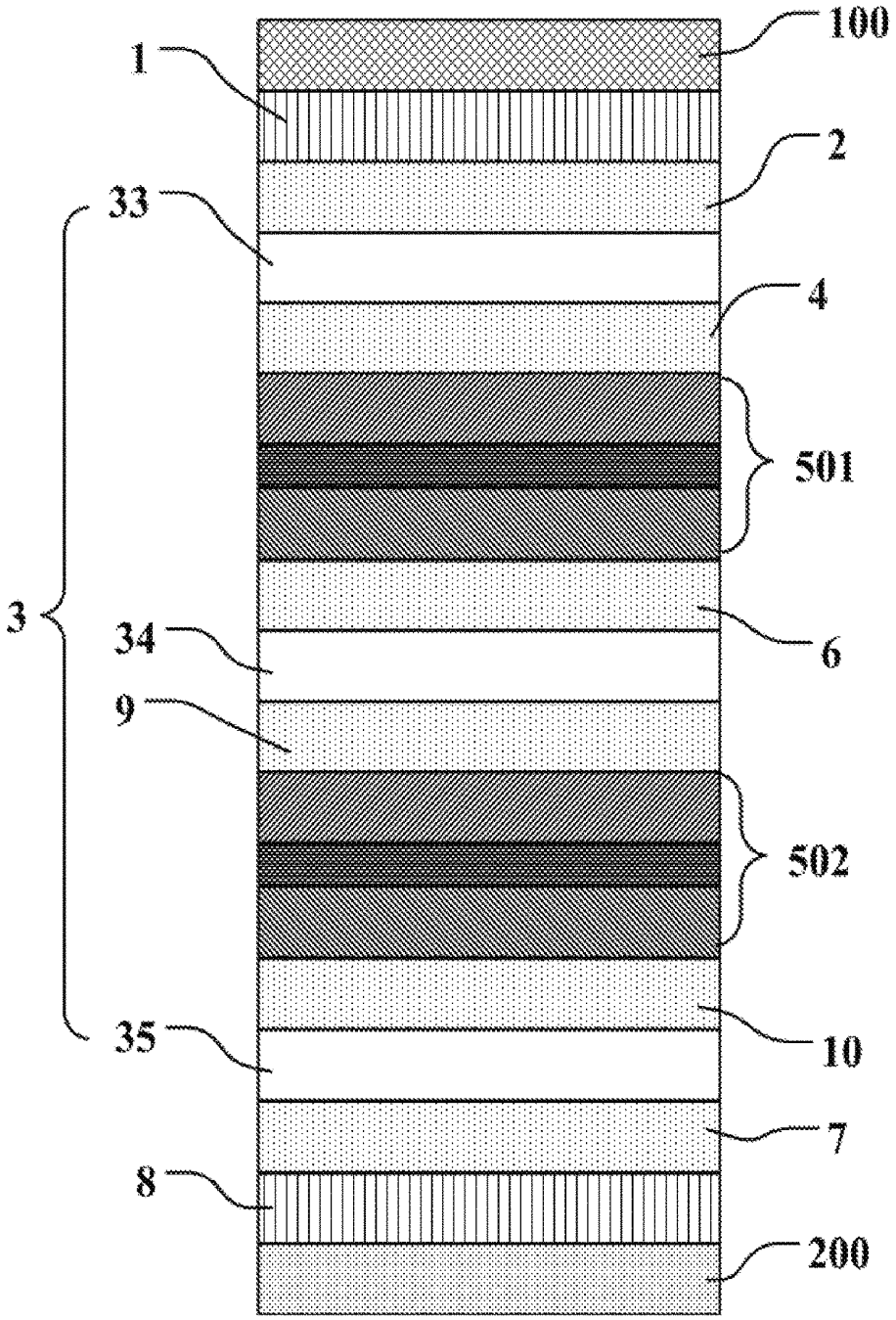


Fig.9

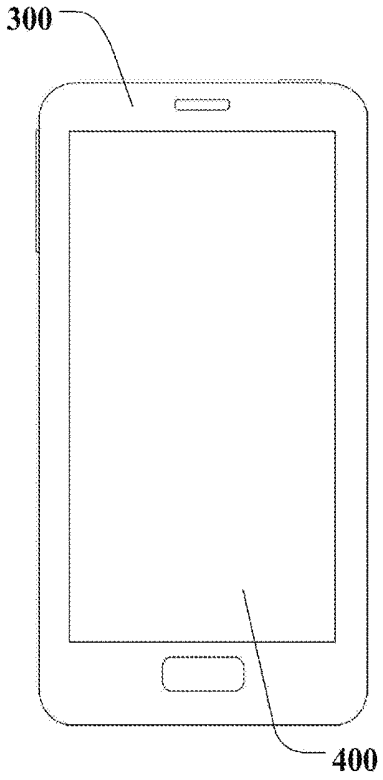

300
400

Fig.10

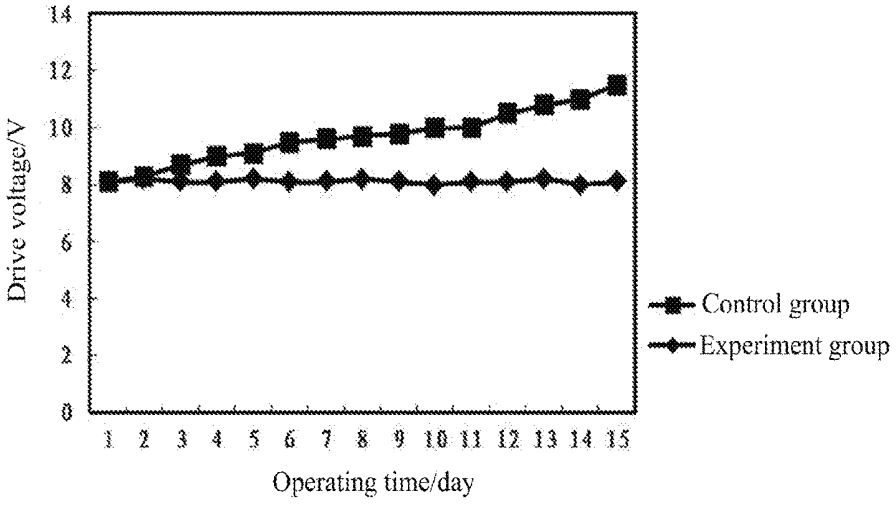

Drive voltage/V
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Operating time/day
Control group
Experiment group

Fig.11

ORGANIC LIGHT-EMITTING DIODE, DISPLAY PANEL AND DISPLAY DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese Patent Application No. 201710682462.X, filed on Aug. 10, 2017, the entire content of which is incorporated herein by reference.

FIELD

[0002] This application relates to the technical field of display, and in particular to an organic light-emitting diode, a display panel and a display device.

BACKGROUND

[0003] The organic electroluminescence is a phenomenon in which organic material are excited by an electric energy for light emitting. With advantages of low drive voltage, high luminous brightness, high luminous efficiency, wide luminous viewing angle, high response speed, ultrathin shape, light weight and compatible flexible substrate, the organic light-emitting devices occupy a position in the field of display.

[0004] As a representative product of organic light-emitting devices, the Organic Light-Emitting Diode (OLED) has been extensively studied.

[0005] Please refer to FIG. **1**, a common organic light-emitting diode in the prior art includes a cathode **0100**, an electron injection layer **01**, a first electron transport layer **02**, a first emitting layer **031**, a second hole transport layer **04**, a charge generation layer **05**, a second electron transport layer **06**, a second emitting layer **032**, a first hole transport layer **07**, a hole injection layer **08** and an anode **0200** which are arranged in sequence in an overlaying manner. The charge generation layer **05** arranged between two emitting layers **03** usually includes a P-type organic semiconductor layer **051** and an N-type organic semiconductor layer **052** which are arranged in an overlapping manner. The P-type organic semiconductor layer **051** and the N-type organic semiconductor layer **052** of the charge generation layer **05** contact with each other directly, and along with the extension of accumulating operating time of the organic light-emitting diode, the material of the P-type organic semiconductor layer **051** and the N-type organic semiconductor layer **052** are subjected to mutual diffusion, therefore, the drive voltage of the organic light-emitting diode adopting such a structure gradually rises, and the luminous efficiency of the organic light-emitting diode is reduced, and the service life is shortened.

SUMMARY

[0006] Embodiment of the present disclosure is to provide an organic light-emitting diode, a display panel and a display device, so as to improve the voltage stability of the organic light-emitting diode during long-term operation, reduce the use power consumption of the organic light-emitting diode, and prolong the service life and improve the luminous efficiency of the organic light-emitting diode.

[0007] The organic light-emitting diode according to an embodiment of the present disclosure includes an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, where the charge generation layer includes a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, where the first doping layer includes a P-type semiconductor material, and the second doping layer includes a N-type semiconductor material; the P-type semiconductor material includes a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material includes a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material; when the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material; when the P-type semiconductor material includes the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material; when the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and when the N-type semiconductor material includes the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

[0008] The embodiment of the present disclosure further provides a display panel, and the display panel includes an organic light-emitting diode. The organic light-emitting diode includes an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, where the charge generation layer includes a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, where the first doping layer includes a P-type semiconductor material, and the second doping layer includes a N-type semiconductor material; the P-type semiconductor material includes a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material includes a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material; when the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material; when the P-type semiconductor material includes the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material; when the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and when the N-type semiconductor material includes the N-type organic semiconductor material, the fermi level of the material of the

intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

[0009] The embodiment of the present disclosure further provides a display device, and the display device includes a display panel. The display panel includes an organic light-emitting diode. The organic light-emitting diode includes an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, where the charge generation layer includes a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, where the first doping layer includes a P-type semiconductor material, and the second doping layer includes a N-type semiconductor material; the P-type semiconductor material includes a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material includes a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material; when the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material; when the P-type semiconductor material includes the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material; when the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and when the N-type semiconductor material includes the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a structural schematic diagram of an organic light-emitting diode according to an embodiment in the prior art;

[0011] FIG. **2** is a structural schematic diagram of an organic light-emitting diode according to an embodiment of the present disclosure;

[0012] FIG. **3** is an energy band diagram of the PN junction in a balanced state;

[0013] FIG. **4** is an energy band diagram of the PN junction after an inverse voltage is applied;

[0014] FIG. **5** is an energy band diagram of the N-type semiconductor when the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material;

[0015] FIG. **6** is an energy band diagram of the N-type semiconductor when the fermi level of the material of the intermediate layer is greater than the fermi level of the N-type semiconductor material;

[0016] FIG. **7** is an energy band diagram of the P-type semiconductor when the fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material;

[0017] FIG. **8** is an energy band diagram of the P-type semiconductor when the fermi level of the material of the intermediate layer is less than the fermi level of the P-type semiconductor material;

[0018] FIG. **9** is a structural schematic diagram of an organic light-emitting diode according to another embodiment of the present disclosure;

[0019] FIG. **10** is a structural schematic diagram of a display device according to an embodiment of the present disclosure;

[0020] FIG. **11** is a diagram showing the change of the drive voltage of the organic light-emitting diode along with the extension of the operating time.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0021] In order to improve the voltage stability of the organic light-emitting diode during long-term operation, lower the use power consumption of the organic light-emitting diode, prolong the service life and improve the luminous efficiency of the organic light-emitting diode, embodiments of the present disclosure provide an organic light-emitting diode, a display panel and a display device.

[0022] As shown in FIG. **2** which is a structural schematic diagram of the organic light-emitting diode according to an embodiment of the present disclosure, the organic light-emitting diode according to the embodiment of the present disclosure includes an anode **200**, a cathode **100**, at least two emitting layers **3** arranged between the anode **200** and the cathode **100**, and a charge generation layer **5** arranged between every two adjacent emitting layers **3**.

[0023] The charge generation layer **5** includes a first doping layer **51**, an intermediate layer **52** and a second doping layer **53** which are arranged in sequence along the direction far away from the cathode **100**, where the first doping layer **51** includes a P-type semiconductor material, and the second doping layer **53** includes a N-type semiconductor material.

[0024] The P-type semiconductor material includes a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material. The N-type semiconductor material includes a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material.

[0025] When the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, the fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material.

[0026] When the P-type semiconductor material includes the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the HOMO level (energy level of the highest occupied molecular orbital of the P-type organic semiconductor material.

[0027] When the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material.

[0028] When the N-type semiconductor material includes the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the

LUMO level (energy level of the lowest unoccupied molecular orbital) of the N-type organic semiconductor material.

[0029] The luminous principle of the organic light-emitting diode is as follows: under the drive of an externally-applied electric field, the organic emitting layer leads to light emitting through the injection and recombination of charge carriers of the anode and the cathode, and the above charge carriers include electrons and holes. In one embodiment, under the effect of the drive voltage, the electrons and holes served as charge carriers are respectively injected into the electron injection layer and the hole injection layer from the cathode and the anode, the electrons and holes migrate to the organic emitting layer after penetrating through the electron transport layer and the hole transport layer, and the electrons and holes encounter in the organic emitting layer for recombination to form excitons, and the excitons exit from activation to release energy; and the released energy excites the luminescent molecules in the organic emitting layer, and the excited luminescent molecules emit a visible light after radiative relaxation.

[0030] In the organic light-emitting diode in the embodiment of the present disclosure, the charge generation layer **5** includes a first doping layer **51**, an intermediate layer **52** and a second doping layer **53**, and the charge generation layer **5** constitutes a P-I-N semiconductor structure. In the organic light-emitting diode, besides the cathode **100** and the anode **200** which can generate electrons and holes, the charge generation layer **5** can also generate holes and electrons which are respectively injected into the emitting layers **3** on the two sides of the charge generation layer **5**, then the quantity of excitons which are formed by the recombination of the electrons and the holes of the emitting layers **3** can be increased, and further the luminous efficiency of the organic light-emitting diode can be improved.

[0031] In the organic light-emitting diode of the embodiment of the present disclosure, a charge generation layer **5** is arranged between two adjacent emitting layers **3**, and under the effect of an externally-applied inverse voltage, the electrons of the P-type semiconductor migrate to the N-type semiconductor, then more holes migrate to the adjacent emitting layer **3**; and the electrons of the N-type semiconductor migrate to the adjacent emitting layer **3**. The electrodes of the electron-hole pairs generated by the charge generation layer **5** are divided into holes and electrons, then the holes and electrons are injected into the emitting layers **3** on the two sides through a channel due to zener breakdown, and are respectively recombined with the electrons and holes in the emitting layers on the two sides to form excitons, then the emitting layers **3** are enabled to emit light.

[0032] Zener breakdown refers to a phenomenon that when an inverse voltage is applied to a PN junction to generate a stronger electric field, the electric field is so strong that valence electrons can be directly pulled out from the covalent bonds, thus a large number of free electrons and holes are generated, and then the inverse current increases greatly. Please refer to FIG. **3** and FIG. **4**. FIG. **3** is an energy band diagram of the PN junction in a balanced state, while FIG. **4** is an energy band diagram of the PN junction after an inverse voltage is applied. When an inverse voltage is applied to the PN junction, the energy band in the barrier region inclines, the greater the inverse voltage is, the higher the potential barrier is, then the stronger the built-in electric field in the barrier region is, and the more inclined the energy band in the barrier region is, and even the bottom conduction band of the N region can be lower than the top of valence band of the P region. When the inverse voltage reaches a preset value, the electrons in the P-region valence band may penetrate through a forbidden band via the tunnel effect to reach the N-region conduction band.

[0033] In the embodiment of the present disclosure, the charge generation layer **5** includes a first doping layer **51**, an intermediate layer **52** and a second doping layer **53** which are arranged in sequence along the direction far away from the cathode **100**, where the first doping layer **51** includes a P-type semiconductor material, and the second doping layer **53** includes a N-type semiconductor material. An intermediate layer **52** is arranged between the first doping layer **51** and the second doping layer **53**, so as to prevent the P-type semiconductor material in the first doping layer **51** and the N-type semiconductor material in the second doping layer **53** from being diffused mutually after long-term operation, and further prevent the drive voltage of the organic light-emitting diode from being gradually increased. By adopting the solution, the drive voltage of the organic light-emitting diode can be lowered, the voltage of the organic light-emitting diode during long-term operation can be maintained to be stable, the luminous efficiency of the organic light-emitting diode can be improved, and the service life can be prolonged.

[0034] In one embodiment, the P-type semiconductor material can be P-type inorganic semiconductor material, P-type metal dopant or P-type organic semiconductor material, and the N-type semiconductor material can be N-type inorganic semiconductor material. N-type metal dopant or N-type organic semiconductor material. In actual application, the selection of the dopant of the first doping layer and the second doping layer is not limited, the P-type semiconductor material and the N-type semiconductor material can be the same type of material, and can also be different types of materials. For example, the selection of materials can be as follows: the P-type semiconductor material of the first doping layer can be P-type inorganic semiconductor material, and the N-type semiconductor material of the second doping layer can also be N-type inorganic semiconductor material; or the P-type semiconductor material of the first doping layer can be P-type metal dopant, while the N-type semiconductor material of the second doping layer can be N-type organic semiconductor material.

[0035] When the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material. Such a structure may be used for the electrons to flow to the N-type semiconductor layer from the intermediate layer, and a negative space charge layer is formed on the surface of the N-type semiconductor layer. Please refer to FIG. **5** which is an energy band diagram showing that the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material. The energy band nearby the surface in the space charge region bends downwards, the electron concentration on the surface of the N-type semiconductor is greater than the equilibrium concentration inside the N-type semiconductor, and the electrons can migrate to the N-type semiconductor material with potentially no need of crossing a potential barrier, then an anti-barrier layer can be formed. In contrary, please refer to FIG. **6** which is an energy band

diagram showing that the fermi level of the material of the intermediate layer is greater than the fermi level of the N-type semiconductor material. The energy band nearby the surface in the potential barrier region bends upwards, the electron concentration on the surface of the N-type semiconductor is less than the equilibrium concentration inside the N-type semiconductor, and the electrons can only migrate to the N-type semiconductor material after crossing a potential barrier, then a barrier layer can be formed. Therefore, the structure in the embodiment of the present disclosure may be used for the charge generation layer to generate electrons and also may be used for electron injection and transport.

[0036] When the N-type semiconductor material includes the N-type organic semiconductor material, the fermi level of the material in the intermediate layer is less than the LUMO level of the N-type organic semiconductor material. The reasons for adopting such a structure are the same as the above reasons, and will not be repeatedly described herein.

[0037] Similarly, when the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, the fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material. Please refer to FIG. **7** which is an energy band diagram of the P-type semiconductor when the fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material. The electrons can migrate to the intermediate layer from the P-type semiconductor material with potentially no need of crossing a potential barrier, then more holes are generated, and an anti-barrier layer is formed. In contrary, please refer to FIG. **8** which is an energy band diagram of the P-type semiconductor when the fermi level of the material of the intermediate layer is less than the fermi level of the P-type semiconductor material. The electrons can only migrate to the intermediate layer from the P-type semiconductor material after crossing a potential barrier, then holes are difficult to form, and a barrier layer is formed. Therefore, the structure in the embodiment of the present disclosure may be used for the charge generation layer to generate holes and also may be used for hole injection and transport.

[0038] When the P-type semiconductor material includes the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the HOMO level of the P-type organic semiconductor material. The reasons for adopting such a structure are the same as the above reasons, and will not be repeatedly described herein.

[0039] In an embodiment, the material of the intermediate layer is not specifically limited, and can be metal, metal alloy or metal oxide. The material of the intermediate layer includes silver element, ytterbium element, europium element or zinc element. In one embodiment, when the P-type semiconductor material includes the P-type inorganic semiconductor material or the P-type metal dopant, the fermi level of the P-type semiconductor material ranges from 1.8 eV to 5.5 eV. For example, the fermi level of the P-type semiconductor material can be 2 eV, 2.2 eV, 2.5 eV, 3 eV, 3.4 eV, 3.8 eV, 4 eV, 4.3 eV, 4.8 eV, 5 eV, 5.2 eV or 5.4 eV, etc.

[0040] When the P-type semiconductor material includes the P-type organic semiconductor material, the HOMO level of the P-type organic semiconductor material ranges from −6.5 eV to −5 eV. For example, the HOMO level of the P-type organic semiconductor material can be −5.2 eV, −5.5 eV, −5.8 eV, −6 eV, −6.1 eV or −6.4 eV, etc.

[0041] When the N-type semiconductor material includes the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the N-type semiconductor material ranges from 1.8 eV to 5.5 eV. For example, the fermi level of the N-type semiconductor material can be 2 eV, 2.2 eV, 2.5 eV, 2.7 eV, 3 eV, 3.2 eV, 3.5 eV, 3.8 eV, 4 eV, 4.2 eV, 4.5 eV, 4.8 eV, 5 eV or 5.2 eV, etc.

[0042] When the N-type semiconductor material includes N-type organic semiconductor material, the LUMO level of the N-type organic semiconductor material ranges from −3.5 eV to −1.8 eV. For example, the LUMO level of the N-type organic semiconductor material can be −2 eV, −2.2 eV, −2.5 eV, −2.7 eV, −3 eV, −3.1 eV or −3.4 eV, etc.

[0043] In an embodiment, the thickness of the intermediate layer ranges from 0.5 nm to 10 nm. The first doping layer and the second doping layer can be isolated when the thickness of the intermediate layer is greater than 0.5 nm, and when the thickness of the intermediate layer is less than 10 nm, the first doping layer, the intermediate layer and the second doping layer can form a PIN structure, such that the organic light-emitting diode emits light normally. For example, the thickness of the intermediate layer can be 0.8 nm, 1 nm, 1.5 nm, 2 nm, 2.7 nm, 3 nm, 3.4 nm, 3.8 nm, 4 nm, 4.3 nm, 4.5 nm, 4.9 nm, 5 nm, 5.5 nm, 5.9 nm, 6 nm, 6.5 nm, 7 nm, 7.1 nm, 7.5 nm, 8 nm, 8.4 nm, 8.6 nm, 9 nm, 9.3 nm or 9.7 nm, etc.

[0044] In an embodiment, the volume concentration of the P-type semiconductor material doped in the first doping layer ranges from 3% to 35%. When the volume concentration of the P-type semiconductor material is within the above range, it may be used for separating the electrons from the holes in the charge generation layer and improving the luminous efficiency of the organic light-emitting diode. For example, the volume concentration of the P-type semiconductor material is 3.5%, 4%, 6%, 7%, 7.8%, 8%, 9.5%, 10%, 10.6%, 11%, 11.5%, 12%, 14%, 15%, 16%, 18%, 19%, 20%, 22%, 24%, 25%, 26%, 26.5%, 27%, 27.5%, 28%, 28.4%, 29%, 30%, 30.5%, 31%, 32%, 33% or 33.8%, etc.

[0045] In an embodiment, the volume concentration of the N-type semiconductor material doped in the second doping layer ranges from 3% to 45%. When the volume concentration of the N-type semiconductor material is within the above range, it may be used for separating the electrons from the holes in the charge generation layer and improving the luminous efficiency of the organic light-emitting diode. For example, the volume concentration of the N-type semiconductor material is 3.5%, 4%, 5%, 7%, 7.5%, 8%, 9%, 10.5%, 10.6%, 11.5%, 12%, 13%, 15%, 17%, 19%, 20%, 22%, 23%, 25%, 26%, 26.8%, 27%, 27.5%, 28%, 29%, 29.5%, 30%, 32%, 33.8%, 35%, 38%, 39.8%, 40%, 42%, 43% or 44%, etc.

[0046] In one embodiment, material of the emitting layer is not limited. For example, the emitting layer can be a fluorescent emitting layer and can also be a phosphorescent emitting layer. The materials of at least two emitting layers in the organic light-emitting diode can be identical and can also be not identical. For example, the organic light-emitting diode includes two emitting layers, the two emitting layers can be respectively a fluorescent emitting layer and a phosphorescent emitting layer, and the two emitting layers can also be both fluorescent emitting layers or be both phosphorescent emitting layers.

[0047] In an embodiment of the present disclosure, the number of the emitting layers can be two and can also be

three. Please refer to FIG. **2**, according to an embodiment of the present disclosure, the number of the emitting layers **3** of the organic light-emitting diode is two, and the emitting layer **3** includes a cathode **100**, an electron injection layer **1**, a first electron transport layer **2**, a first emitting layer **31**, a first hole transport layer **4**, a charge generation layer **5**, a second electron transport layer **6**, a second emitting layer **32**, a second hole injection layer **7**, a hole injection layer **8** and an anode **200** which are arranged in sequence in an overlaying manner, where the charge generation layer **5** includes a first doping layer **51**, an intermediate layer **52** and a second doping layer **53** which are arranged in sequence along the direction far away from the cathode **100**. In one embodiment, the two emitting layers **3** can be respectively a blue emitting layer and a yellow emitting layer.

[0048] Please refer to FIG. **9** which is a structural schematic diagram of an organic light-emitting diode according to another embodiment of the present disclosure. The organic light-emitting diode in the present embodiment includes three emitting layers **3**. In one embodiment, the organic light-emitting diode includes a cathode **100**, an electron injection layer **1**, a first electron transport **2**, a third emitting layer **33**, a first hole transport layer **4**, a first charge generation layer **501**, a second electron transport layer **6**, a fourth emitting layer **34**, a second hole transport layer **9**, a second charge generation layer **502**, a third electron transport layer **10**, a fifth emitting layer **35**, a second hole transport layer **7**, a hole injection layer **8** and an anode **200** which are arranged in sequence in an overlaying manner, where the charge generation layer according to any of the above technical solution is arranged between every two adjacent emitting layers **3**.

[0049] In one embodiment, when the organic light-emitting diode includes three emitting layers, the three emitting layers usually include a red emitting layer, a green emitting layer and a blue emitting layer.

[0050] The embodiment of the present disclosure further provides a display panel, and the display panel includes the organic light-emitting diode according to any of the above technical solution.

[0051] The display panel can still maintain a stable drive voltage after long-term use, and the use power consumption of the display panel is lower, the service life is prolonged, and the luminous efficiency is higher.

[0052] Please refer to FIG. **10**. The embodiment of the present disclosure further provides a display device **300**, and the display device **300** includes the above display panel **400**.

[0053] In the embodiment of the present disclosure, the display device is not limited in specific types, and can be a mobile phone, a display, a tablet computer or a television. For example, the display device shown in FIG. **10** is a mobile phone.

[0054] In the present disclosure, the inventor selected two groups of organic light-emitting diodes for comparative experiment, which are respectively an experiment group and a control group, where the organic light-emitting diode in the embodiment of the present disclosure is in the experiment group, namely, the charge generation layer includes a first doping layer, an intermediate layer and a second doping layer; the existing organic light-emitting diode is in the control group, except that the charge generation layer does not include an intermediate layer, the other structures of the organic light-emitting diode in the control group are the same as those of the organic light-emitting diode in the experiment group. In one embodiment, the inventor enables the above two groups of organic light-emitting diodes to be in an operating state for a long time, and detects the change of the drive voltage of each organic light-emitting diode. The experimental results are as shown in FIG. **11** which shows the change of the drive voltage of each organic light-emitting diode during the fifteen-day operation.

[0055] It can be seen from FIG. **11** that, the drive voltage of the organic light-emitting diode in the embodiment of the present disclosure is in a stable state for a long time, and is nearly unchanged, while the drive voltage of the organic light-emitting diode in the control group is gradually increased with the extension of the operation time. Therefore, the solution can improve the voltage stability of the organic light-emitting diode during long-term operation, reduce the use power consumption, prolong the service life and improve the luminous efficiency of the organic light-emitting diode.

1. An organic light-emitting diode, comprising:

an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, wherein:

the charge generation layer comprises a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, wherein the first doping layer comprises a P-type semiconductor material, and the second doping layer comprises a N-type semiconductor material;

the P-type semiconductor material comprises a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material comprises a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material;

when the P-type semiconductor material comprises the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material;

when the P-type semiconductor material comprises the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material;

when the N-type semiconductor material comprises the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and

when the N-type semiconductor material comprises the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

2. The organic light-emitting diode according to claim **1**, wherein a material of the intermediate layer includes one or more of: metal, metal alloy, and metal oxide.

3. The organic light-emitting diode according to claim **2**, wherein the material of the intermediate layer includes one or more of: silver element, ytterbium element, europium element, and zinc element.

4. The organic light-emitting diode according to claim **1**, wherein

when the P-type semiconductor material comprises the P-type inorganic semiconductor material or the P-type metal dopant, the fermi level of the P-type semiconductor material ranges from 1.8 eV to 5.5 eV,

when the P-type semiconductor material comprises the P-type organic semiconductor material, the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material ranges from −6.5 eV to −5 eV;

when the N-type semiconductor material comprises the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the N-type semiconductor material ranges from 1.8 eV to 5.5 eV; and

when the N-type semiconductor material comprises the N-type organic semiconductor material, the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material ranges from −3.5 eV to −1.8 eV.

5. The organic light-emitting diode according to claim **1**, wherein a thickness of the intermediate layer ranges from 0.5 nm to 10 nm.

6. The organic light-emitting diode according to claim **1**, wherein a volume concentration of the P-type semiconductor material doped in the first doping layer ranges from 3% to 35%.

7. The organic light-emitting diode according to claim **1**, wherein a volume concentration of the N-type semiconductor material doped in the second doping layer ranges from 3% to 45%.

8. The organic light-emitting diode according to claim **1**, wherein the emitting layer comprises a fluorescent emitting layer or a phosphorescent emitting layer.

9. The organic light-emitting diode according to claim **1**, wherein the number of the emitting layers is two or three.

10. A display panel, comprising an organic light-emitting diode, the organic light-emitting diode comprising an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, wherein:

the charge generation layer comprises a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, wherein the first doping layer comprises a P-type semiconductor material, and the second doping layer comprises a N-type semiconductor material;

the P-type semiconductor material comprises a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material comprises a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material;

when the P-type semiconductor material comprises the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material;

when the P-type semiconductor material comprises the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material;

when the N-type semiconductor material comprises the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and

when the N-type semiconductor material comprises the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

11. The display panel according to claim **10**, wherein a material of the intermediate layer includes one or more of: metal, metal alloy, and metal oxide.

12. The display panel according to claim **11**, wherein the material of the intermediate layer one or more of: silver element, ytterbium element, europium element, and zinc element.

13. The display panel according to claim **10**, wherein

when the P-type semiconductor material comprises the P-type inorganic semiconductor material or the P-type metal dopant, the fermi level of the P-type semiconductor material ranges from 1.8 eV to 5.5 eV;

when the P-type semiconductor material comprises the P-type organic semiconductor material, the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material ranges from −6.5 eV to −5 eV;

when the N-type semiconductor material comprises the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the N-type semiconductor material ranges from 1.8 eV to 5.5 eV; and

when the N-type semiconductor material comprises the N-type organic semiconductor material, the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material ranges from −3.5 eV to −1.8 eV.

14. The display panel according to claim **10**, wherein a thickness of the intermediate layer ranges from 0.5 nm to 10 nm.

15. The display panel according to claim **10**, wherein a volume concentration of the P-type semiconductor material doped in the first doping layer ranges from 3% to 35%.

16. The display panel according to claim **10**, wherein a volume concentration of the N-type semiconductor material doped in the second doping layer ranges from 3% to 45%.

17. The display panel according to claim **10**, wherein the emitting layer one or more of: a fluorescent emitting layer, and a phosphorescent emitting layer.

18. The display panel according to claim **10**, wherein the number of the emitting layers is two or three.

19. A display device, comprising:

a display panel, the display panel comprising an organic light-emitting diode, the organic light-emitting diode comprising an anode, a cathode, at least two emitting layers arranged between the anode and the cathode, and a charge generation layer arranged between every two adjacent emitting layers, wherein:

the charge generation layer comprises a first doping layer, an intermediate layer and a second doping layer which are arranged in sequence along the direction far away from the cathode, wherein the first doping layer com-

prises a P-type semiconductor material, and the second doping layer comprises a N-type semiconductor material;

the P-type semiconductor material comprises a P-type inorganic semiconductor material, a P-type metal dopant or a P-type organic semiconductor material, and the N-type semiconductor material comprises a N-type inorganic semiconductor material, a N-type metal dopant or a N-type organic semiconductor material;

when the P-type semiconductor material comprises the P-type inorganic semiconductor material or the P-type metal dopant, a fermi level of the material of the intermediate layer is greater than the fermi level of the P-type semiconductor material;

when the P-type semiconductor material comprises the P-type organic semiconductor material, the fermi level of the material of the intermediate material is greater than the energy level of the highest occupied molecular orbital of the P-type organic semiconductor material;

when the N-type semiconductor material comprises the N-type inorganic semiconductor material or the N-type metal dopant, the fermi level of the material of the intermediate layer is less than the fermi level of the N-type semiconductor material; and

when the N-type semiconductor material comprises the N-type organic semiconductor material, the fermi level of the material of the intermediate material is less than the energy level of the lowest unoccupied molecular orbital of the N-type organic semiconductor material.

* * * * *

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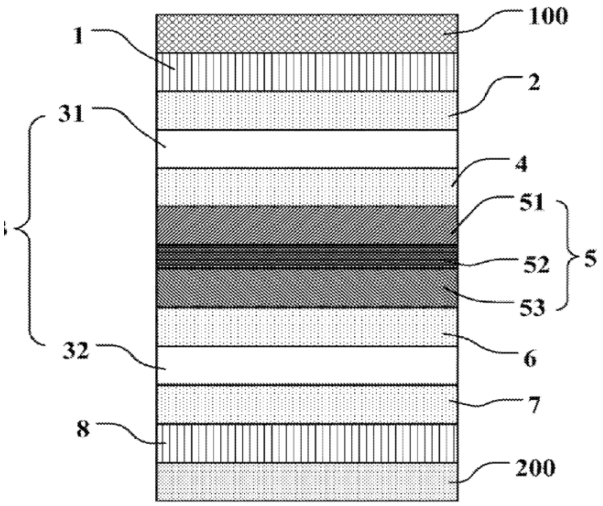
摘要(译)

本发明公开了一种有机发光二极管，显示面板和显示装置。有机发光二极管包括阳极，阴极，布置在阳极和阴极之间的至少两个发光层以及布置在每两个相邻发光层之间的电荷产生层，其中电荷产生层包括第一掺杂层，中间层和第二掺杂层，所述中间层和第二掺杂层沿远离所述阴极的方向依次排列，所述第一掺杂层包括P型半导体材料，所述第二掺杂层包括N型半导体材料;所述P型半导体材料包括P型无机半导体材料，P型金属掺杂剂或P型有机半导体材料，所述N型半导体材料包括N型无机半导体材料，N型金属掺杂剂或N型有机半导体材料。