

CERTIFICATE OF TRANSLATION ACCURACY

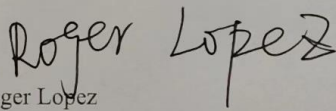
I, Roger Lopez, declare:

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2. The following translation of the corresponding source text from Chinese into English is accurate and complete to the best of my knowledge:
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I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and may jeopardize the validity of the application or any patent issuing thereon.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed on May 31, 2024 in United States of America


Roger Lopez



[12] **Invention Patent Publication Description**
[21] **Application No.:** 200410069263.4

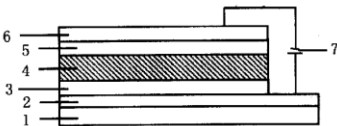
H05B 33/20 H05B 33/12
H05B 33/10 C09K 11/06

[43] Publication date: February 16, 2005 [22] Application Date: July 16, 2004 [21] Application No.: 200410069263.4 [30] Priority [32] February 27, 2004 [33] CN [31] 200410004468.4 [71] Applicant: Tsinghua University Address: Room 209A, Tsinghua University Engineering Museum, Tsinghua Garden, Haidian District, Beijing 100084 China Co-applicant: Beijing Visionox Technology Co., Ltd. [72] Inventors: Qiu Yong, Lei Gang-tie, Wang Li-duo	[11] Publication No.: CN 1582073A 5 pages of claims, 22 pages of description, and 4 pages of figures
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[54] **Invention Name:** A phosphorescent organic light emitting device and the preparation method thereof

[57] **Abstract**

The present invention relates to a phosphorescent organic light emitting device and the preparation method thereof. The device comprises a transparent substrate, an anode layer, an organic functional layer, and a cathode layer, wherein the organic functional layer comprises an organic light emitting layer, selective of one or more layers of hole injection layer, hole transporting layer, electron transporting layer, and electron injection layer; the organic light emitting layer comprises a host material and a phosphorescent dye, and the doping concentration of the phosphorescent dye gradually increases or decreases along the direction from the anode layer to the cathode layer with the increase of the thickness of the organic light emitting layer, forming a construction with gradient doping. In the organic light emitting layer of the device, phosphorescent dyes are doped into the host material in a gradient doping manner, expanding the luminescent region of the device, improving the utilization rate of the phosphorescent dyes, and facilitating the combination of electrons and holes to form excitons, thereby improving the device's luminescence efficiency and brightness, improving its stability, and overcoming the disadvantages of low luminescence efficiency and poor stability under high current.



I S S N 1 0 0 8 - 4 2 7 4

1. A phosphorescent organic light emitting device comprising a transparent substrate, an anode layer, a hole transporting layer, an organic light emitting layer, an electron transporting layer, and a cathode layer, wherein the organic light emitting layer comprises a host material and a phosphorescent dye, characterized in that: the doping concentration of the phosphorescent dye gradually increases or decreases along the direction from the hole transporting layer to the electron transporting layer with the increase of the thickness of the organic light emitting layer, forming a construction with gradient doping.
2. The phosphorescent organic light emitting device as claimed in claim 1, characterized in that the average doping concentration of the phosphorescent dye is 0.1-50 wt%.
3. The phosphorescent organic light emitting device as claimed in claim 2, characterized in that the average doping concentration of the phosphorescent dye is 1-30 wt%.
4. The phosphorescent organic light emitting device as claimed in claim 1, characterized in that the host material is one of the biphenyl and carbazole or benzene and carbazole compounds.
5. The phosphorescent organic light emitting device as claimed in claim 4, characterized in that the biphenyl and carbazole compound comprises 4,4'-N,N'-dicarbazole-biphenyl, and the biphenyl and carbazole compound comprises N,N'-dicarbazol-1,4-dimethylbenzene or 9,9-bis-(4-dicarbazole-phenyl) fluorene.
6. The phosphorescent organic light emitting device as claimed in claim 1, characterized in that the phosphorescent dye is a metal-organic complex.
7. The phosphorescent organic light emitting device as claimed in claim 6, characterized in that the metal-organic complex comprises Bis[2-(4,6-difluorophenyl)pyridinato-N,C^{2'}] iridium picolinate (III), Bis(1-phenyl-isoquinoline) (acetylacetonate) iridium (III), platinum octaethylporphine, Tris-(2-phenylpyridine) iridium (III) or Bis(2-phenylpyridine) (acetylacetonate) iridium (III).
8. The phosphorescent organic light emitting device as claimed in claim 1, characterized in that the hole transporting layer is made of one of the materials in triphenylamine compounds.
9. The phosphorescent organic light emitting device as claimed in claim 8, characterized in that the triphenylamine compound comprises N,N'-di-(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N, N'-bis(m-methylphenyl)-1,1'-biphenyl-4,4'-diamine, or 4,4',4''-tris(3-methylphenyl-phenyl-amino)triphenylamine.
10. The phosphorescent organic light emitting device as claimed in claim 1, characterized in that the electron transporting layer is made of one of the materials of metal-organic complexes, polycyclic aromatic compounds, ortho-phenanthroline compounds, or oxadiazole compounds.

11. The phosphorescent organic light emitting device as claimed in claim 10, characterized in that the metal-organic complex comprises Tris-(8-hydroxyquinoline)aluminum, Bis(2-methyl-8-quinolinolato)-4-phenylphenolato aluminum (III), Tris(8-hydroxyquinoline) gallium, (Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) aluminum complex (III) or (Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) gallium complex (III), the polycyclic aromatic compound comprises pentacene or perylene, the ortho-phenanthroline compounds comprise 4,7-diphenyl-1,10-phenanthroline or 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline, and the oxadiazole compound comprises 2-(4-di-tert-butylphenol)-5-(4-biphenyl)-1,3,4-oxadiazole.
12. A method for preparing a phosphorescent organic light emitting device as claimed in claim 1, comprising the following steps:
- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
 - ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit a hole transporting layer on the above conductive film;
 - ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an organic light emitting layer doped with phosphorescent dyes on the above hole transporting layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of the phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;
 - ④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an electron transporting layer on the above organic light emitting layer;
 - ⑤ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above electron transporting layer as the cathode layer of the device.
13. A phosphorescent organic light emitting device comprising a transparent substrate, an anode layer, an organic functional layer, and a cathode layer, wherein the organic functional layer comprises an organic light emitting layer, wherein the organic light emitting layer comprises a host material and a phosphorescent dye, characterized in that: the doping concentration of the phosphorescent dye gradually increases or decreases along the direction from the anode layer to the cathode layer with the increase of the thickness of the organic light emitting layer, forming a construction with gradient doping.
14. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the organic functional layer comprises a hole transporting layer and a light emitting layer.
15. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the organic functional layer comprises a light emitting layer and an electron transporting layer.
16. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the organic functional layer comprises a light emitting layer.
17. The phosphorescent organic light emitting device as claimed in claims 14, 15, or 16,

- characterized in that the organic functional layer comprises a hole injection layer.
18. The phosphorescent organic light emitting device as claimed in claims 14, 15, or 16, characterized in that the organic functional layer comprises an electron injection layer.
19. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the average doping concentration of the phosphorescent dye is 0.1-50 wt%.
20. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the average doping concentration of the phosphorescent dye is 1-30 wt%.
21. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the host material is one of the biphenyl and carbazole or benzo and carbazole compounds.
22. The phosphorescent organic light emitting device as claimed in claim 16, characterized in that the biphenyl and carbazole compound comprises 4,4'-N,N'-dicarbazole-biphenyl, and the biphenyl and carbazole compound comprises N,N'-dicarbazol-1,4-dimethylbenzene or 9,9-bis-(4-dicarbazole-phenyl) fluorene.
23. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the phosphorescent dye is a metal-organic complex.
24. The phosphorescent organic light emitting device as claimed in claim 18, characterized in that the metal-organic complex comprises Bis[2-(4,6-difluorophenyl)pyridinato-N, C2'] iridium picolinate (III), Bis(1-phenyl-isoquinoline) (acetylacetonate) iridium (III), platinum octaethylporphine, Tris-(2-phenylpyridine) iridium (III), or Bis(2-phenylpyridine) (acetylacetonate) iridium (III).
25. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the hole transporting layer is made of one of the materials in triphenylamine compounds.
26. The phosphorescent organic light emitting device as claimed in claim 20, characterized in that the triphenylamine compound comprises N,N'-di-(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine, N,N'-diphenyl-N,N'-bis(m-methylphenyl)-1,1'-biphenyl-4,4'-diamine, or 4,4',4''-tris(3-methylphenyl-phenyl-amino)triphenylamine.
27. The phosphorescent organic light emitting device as claimed in claim 13, characterized in that the electron transporting layer is made of one of the materials of metal-organic complexes, polycyclic aromatic compounds, ortho-phenanthroline compounds, or oxadiazole compounds.
28. The phosphorescent organic light emitting device as claimed in claim 22, characterized in that the metal-organic complex comprises Tris-(8-hydroxyquinoline)aluminum, Bis(2-methyl-8-quinolinolato)-4-phenylphenolato aluminum (III), Tris(8-hydroxyquinoline) gallium, (Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) aluminum complex (III), or (Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) gallium complex (III), the polycyclic

aromatic compound comprises pentacene or perylene, the ortho-phenanthroline compounds comprise 4,7-diphenyl-1,10-phenanthroline or 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline, and the oxadiazole compound comprises 2-(4-di-tert-butylphenol)-5-(4-biphenyl)-1,3,4-oxadiazole.

29. A method for preparing a phosphorescent organic light emitting device as claimed in claim 13, comprising the following steps:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit an organic light emitting layer doped with phosphorescent dyes on the above anode layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;
- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an electron transporting layer on the above organic light emitting layer;
- ④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above electron transporting layer as the cathode layer of the device.

30. A method for preparing a phosphorescent organic light emitting device as claimed in claim 13, comprising the following steps:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit a hole transporting layer on the above conductive film;
- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an organic light emitting layer doped with phosphorescent dyes on the above hole transporting layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;
- ④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above organic light emitting layer as the cathode layer of the device.

31. A method for preparing a phosphorescent organic light emitting device as claimed in claim 13, comprising the following steps:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit an organic light emitting layer doped with

phosphorescent dyes on the anode layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;

- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above organic light emitting layer as the cathode layer of the device.

A phosphorescent organic light emitting device and the preparation method thereof

Field of the invention

The present invention relates to a phosphorescent organic light emitting device, and also relates to a preparation method for the device, belonging to the field of organic electroluminescence technology.

Background of the invention

Nowadays, with the development of multimedia technology and the advent of the information society, the requirements for the performance of flat panel displays are becoming increasingly high. In recent years, three new display technologies have emerged: plasma displays, field emission displays, and organic electroluminescent displays, all of which have to some extent made up for the disadvantages of cathode ray tubes and liquid crystal displays. Among them, organic electroluminescent displays have a series of advantages such as autonomous emission, low voltage DC drive, full curing, wide viewing angle, and rich colors. Compared with liquid crystal displays, organic electroluminescent displays do not require a backlight, have a large viewing angle and a low power, and have a response rate up to 1,000 times faster than that of liquid crystal displays. However, their manufacturing cost is lower than that of liquid crystal displays with the same resolution. Therefore, organic electroluminescent displays have a wide range of application prospects.

In 1987, C. W. Tang et al. in the US Kodak (C. W. Tang, S. A. Vanslyke, Appl. Phys. Lett., 1987, 51, 913) selected triphenylamine derivatives with good film-forming properties and Alq_3 as the hole transporting layer as well as the light emitting layer and electron transporting layer, respectively, to prepare Organic Electroluminescent Devices (OLEDs) with a high quantum efficiency (1%), a high luminescence efficiency ($> 1.5\text{ l m/W}$), a high brightness ($> 1,000\text{ cd/m}^2$), and a low driving voltage ($< 10\text{ V}$). This breakthrough has put new impetus into the development of organic electroluminescent devices, and organic electroluminescent technology has shown its potential practical value. In 1989, C. W. Tang et al. (C. W. Tang, S. A. Vanslyke, J. Appl. Phys., 1989, 65, 913) doped fluorescent dyes in light emitting layer to improve the efficiency of OLEDs. Due to the low doping concentration of fluorescent dyes, they could directly capture charge carriers and prevent quenching caused by self-absorption of fluorescent dyes at high doping concentrations. The construction of this type of device doped with fluorescent dyes is generally a double heterostructure construction, which has an independent hole transporting layer and an electron transporting layer, and the electron and hole recombination can be effectively carried out in the light emitting layer, making the efficiency of the device reach the theoretical limit of phosphorescent organic light emitting devices (internal quantum efficiency of 25%, and external quantum efficiency of 5%).

In 1990, R. H. Friend et al. in Cavendish Laboratory of Cambridge University in the United Kingdom (Burroughes JH, Bradley DDC, Brown AR, R. H. Friend. Nature (London), 1990, 347, 539) developed polymer OLEDs using poly(p-phenylene vinylene) (PPV) as the luminescent material, opening up another new field of luminescent devices - polymer thin film electroluminescent devices. Polymer luminescent materials have the characteristics of good thermal stability, easy adjustment of molecular construction, good film-forming ability, and simple film-forming process. The researchers have made significant progress in improving the solubility of polymer

luminescent materials, increasing glass transition temperature, enhancing photochemical stability, matching carrier injection and transporting equilibrium, improving quantum efficiency, and adjusting luminous color. Although they started relatively late, the performance of polymer light emitting diodes has also approached the practical levels.

Another breakthrough in OLEDs research is the doping of phosphorescent dyes in the light emitting layer of the device. The introduction of phosphorescent dyes enables the device to effectively utilize singlet and triplet excitons, bringing the internal quantum efficiency of the device close to the theoretical upper limit of 100%. The idea of using phosphorescent dyes as dopants to prepare high-efficiency OLEDs was first proposed in US patent US6,303,238 (publication date: October 16, 2001; patentee: Princeton University, and University of Southern California). This patent, as well as the subsequent literature reports by the Forrest Team at Princeton University (M. A. Baldo, D. F. O' Brien, Y. You et al. *Nature*, 1998, 395, 151), disclosed device research using phosphorescent dye PtOEP as the guest luminescent material doped in the light emitting layer host material Alq₃. Due to the spin forbidding of excitons, their utilization efficiency in fluorescent small molecule OLEDs is low (theoretical maximum being 25%), which limits the external quantum efficiency of the device (< 5%). By doping phosphorescent dyes into the light emitting layer of OLEDs, the theoretical utilization rate of excitons can reach 100%, which will greatly improve the efficiency of the device.

Gradient doped constructions have been widely used in traditional III-V semiconductor devices. R. H. Friend et al. also adopted the concept of gradient construction in polymer OLEDs (R. H. Friend, et al. *Nature*, 2000, 404, 481), and in the device, a hole transporting layer with a concentration gradient is deposited on the indium tin oxide (ITO) anode, achieving a balanced charge carrier injection for the device and improving the device's luminescence efficiency.

Gradient constructions are also used in small molecule fluorescent OLEDs. Anna B. Chwang et al. reported an OLED with a gradiently mixed light emitting layer (A. B. Chwang, R. C. Kwong, and J. J. Brown, *Appl. Phys. Lett.* 2002, 80, 725). In the device, the hole transporting material NPB and the electron transporting/light emitting material Alq₃ are mixed together at different concentrations in different regions. The concentration of NPB gradually decreases from the anode buffer layer to the cathode, while the concentration of Alq₃ gradually increases from the anode buffer layer to the cathode, forming a concentration gradient construction. In the light emitting layer of this device, the mass concentration ratio of NPB and Alq₃ is 1:1, and 1 wt% of fluorescent dye C545T is uniformly doped, and the construction of the device is: ITO/CuPc (375Å)/NPB: Alq₃ (300Å, 5 wt%)/NPB: Alq₃ (75Å, 20 wt%)/NPB: Alq₃ (75Å, 35 wt%)/NPB: Alq₃: C545T (500Å, [1:1]: 1 wt%)/NPB: Alq₃ (150Å, 90 wt%)/LiF (12Å)/Al (700Å). Although the device efficiency with this construction is lower than that of traditional heterostructure devices doped with the same concentration of C545T, the stability of the device is greatly improved. Dongge Ma et al. also reported a bipolar light emitting layer device with a gradient construction (Dongge Ma, C. S. Lee, S. T. Lee, and L. S. Hung, *Appl. Phys. Lett.* 2002, 80, 3641). The construction of this device is as follows: ITO/NPB/bipolar light emitting layer with a gradient construction Alq₃/Mg:Ag, wherein the NPB layer serves as the hole transporting layer and the Alq₃ layer serves as the electron transporting layer, and the bipolar light emitting layer is prepared using NPB and Alq₃ in different regions at different mass concentration ratios. In the bipolar light emitting layer of the device, the concentration of NPB gradually decreases from the hole transporting layer to the electron transporting layer, while the concentration of Alq₃ gradually increases from the hole transporting layer to the electron transporting layer, and this construction can better control the transporting and recombination of the charge carriers.

The efficiency of devices with this construction is 1.5 times higher than that of traditional heterostructure constructions, while the lighting voltage remains unchanged.

Nowadays, phosphorescent dyes in light emitting layer of phosphorescent organic light emitting devices are uniformly doped in the host material. The research results of E. Tutis et al. (E. Tutis, D. Berner, and L. Zuppiroli, Appl. Phys. Lett. 2003, 93, 4594) show that the distribution of charge carriers (electrons and holes) in OLEDs is uneven. In general devices, holes are majority carriers, while electrons are minority carriers. In the light emitting layer of phosphorescent devices, the concentration distribution of electrons shows a non-linear decreasing trend along the direction from the electron transporting layer to the hole transporting layer. Therefore, uniformly doped phosphorescent devices can only emit light from dyes located in the emitting region, and their luminescence efficiency and brightness are limited to a certain extent.

Contents of the invention

The purpose of the present invention is to provide a phosphorescent organic light emitting device with a high luminescence efficiency, high brightness, and good stability.

The other purpose of the present invention is to provide a method for preparing a phosphorescent organic light emitting device.

To achieve the above objectives, a technical solution of the present invention provides a phosphorescent organic light emitting device, which comprises a transparent substrate, an anode layer, an organic functional layer, and a cathode layer, wherein the organic functional layer comprises an organic light emitting layer, selective of one or more layers of hole injection layer, hole transporting layer, electron transporting layer, and electron injection layer, the organic light emitting layer comprises a host material and a phosphorescent dye, and the doping concentration of the phosphorescent dye gradually increases or decreases along the direction from the anode layer to the cathode layer with the increase of the thickness of the organic light emitting layer, forming a construction with gradient doping.

The average doping concentration of the phosphorescent dyes in the technical solution of the present invention is 0.1-50 wt%.

In OLEDs, the concentration distribution of electrons generally decreases nonlinearly from the electron transporting layer to the hole transporting layer. The gradient distribution of the doping concentration of phosphorescent dyes in the organic light emitting layer in the host material in the above technical solution is to make the distribution trend of phosphorescent dyes in the host material conform to the distribution trend of electrons in the host material, and such concentration distribution expands the luminescent region of the device, improves the utilization rate of phosphorescent dyes, and is also conducive to the combination of electrons and holes to form excitons.

The doping concentration of phosphorescent dyes in the above technical solution gradually increases or decreases along the direction from the anode layer to the cathode layer with the increase of the thickness of the organic light emitting layer, which is determined by the properties of the phosphorescent dyes themselves. The ability of phosphorescent dyes to transport electrons or holes themselves is the main determining factor. For phosphorescent dyes with a strong electron transporting ability, the doping concentration distribution gradually increases along the direction from the anode layer to the cathode layer with the increase of the thickness of the light emitting layer, while phosphorescent dyes with a strong hole transporting ability have the opposite effect.

The phosphorescent organic light emitting device proposed in the present invention has the following advantages: phosphorescent dyes are doped in the host material in a gradient doping manner in the organic light emitting layer, expanding the luminescent region of the device, improving the utilization rate of the phosphorescent dyes, and facilitating the combination of excitons between electrons and holes, thereby improving the luminescent efficiency and brightness of the device, improving its stability, and overcoming the disadvantages of low luminescent efficiency and poor stability of the device under high current.

Another technical solution of the present invention provides a preparation method for a

phosphorescent organic light emitting device, which comprises the following four process steps to manufacture phosphorescent organic light emitting devices with different constructions:

Process steps for the first construction:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit a hole transporting layer on the above conductive film;
- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an organic light emitting layer doped with phosphorescent dyes on the above hole transporting layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;
- ④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an electron transporting layer on the above organic light emitting layer;
- ⑤ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above electron transporting layer as the cathode layer of the device.

Process steps for the second construction:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit an organic light emitting layer doped with phosphorescent dyes on the above anode layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;
- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an electron transporting layer on the above organic light emitting layer;
- ④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above electron transporting layer as the cathode layer of the device.

Process steps for the third construction:

- ① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;
- ② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit a hole transporting layer on the above conductive film;
- ③ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit an

organic light emitting layer doped with phosphorescent dyes on the above hole transporting layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;

④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above organic light emitting layer as the cathode layer of the device.

Process steps for the fourth construction:

① Carry out ultrasonic cleaning, drying, and pretreatment for the transparent conductive substrate in sequence, wherein the conductive film on the conductive substrate serves as the anode layer of the device;

② Place the above cleaned, dried, and pre-treated transparent conductive substrate in a vacuum chamber, vacuum it, and vapor deposit an organic light emitting layer doped with phosphorescent dyes on the anode layer, carry out gradient doping using a dual source vapor depositing method, place the host material and phosphorescent dyes in different evaporation sources respectively, and by controlling the vapor depositing rate of the two evaporation sources, the doping concentration of phosphorescent dyes in the host material gradually increases or decreases with the increase of the thickness of the organic light emitting layer;

④ Keeping the pressure inside the above vacuum chamber constant, further vapor deposit a metal layer on the above organic light emitting layer as the cathode layer of the device.

Description of figures

The present invention will become clearer on the basis of the specific implementation methods and embodiments, combined with the appended figures.

Figure 1 is a schematic diagram of the construction of the phosphorescent organic light emitting device proposed in the present invention, wherein 1 is the transparent substrate, 2 is the anode layer, 3 is the hole transporting layer, 4 is the organic light emitting layer, 5 is the electron transporting layer, 6 is the cathode layer, and 7 is the power supply.

Figure 2 shows the concentration distribution curve of phosphorescent dyes in OLED1 prepared in Embodiment 1 of the present invention.

Figure 3 shows the brightness vs voltage curves of OLED1 prepared in Embodiment 1 and Control OLED1 prepared in Control Embodiment 1 of the present invention.

Figure 4 shows the luminescence efficiency vs current density curves of OLED1 prepared in Embodiment 1 and Control OLED1 prepared in Control Embodiment 1 of the present invention.

Figure 5 shows the normalized lifetime curves (i.e. brightness vs luminescence time curves) of OLED1 prepared in Embodiment 1 and Control OLED1 prepared in Control Embodiment 1 of the present invention, wherein the initial brightness of OLED1 is 1,300 cd/m², and the initial brightness of Control OLED1 is 900 cd/m².

Figure 6 shows the EL spectrum of OLED1 prepared in Embodiment 1 and Control OLED1 prepared in Control Embodiment 1 of the present invention, wherein the CIE-1931 chromaticity diagram shows the color coordination of light emission of OLED1 and Control OLED1.

Figure 7 shows the concentration distribution curve of phosphorescent dyes in OLED4 prepared in Embodiment 4 of the present invention.

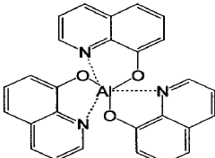
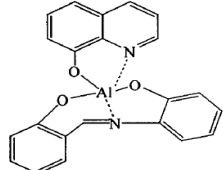
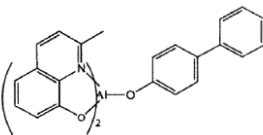
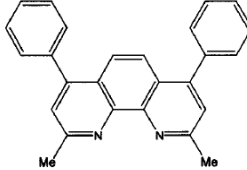
Figure 8 shows the concentration distribution curve of phosphorescent dyes in OLED5 prepared in Embodiment 5 of the present invention.

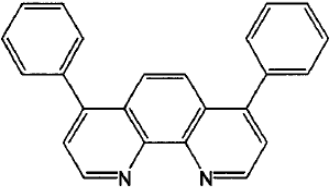
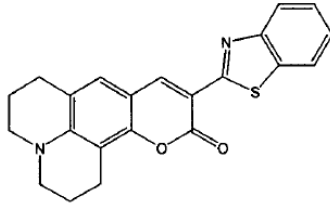
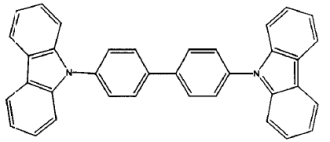
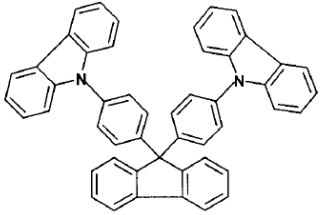
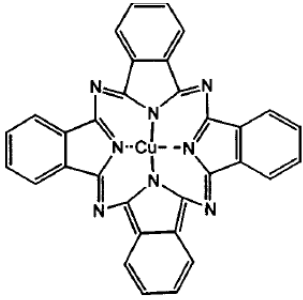
The following is a detailed explanation of the contents of the present invention in conjunction with the appended figures and specific embodiments. It should be understood that the present invention is not limited to the following preferred embodiments, which, however are only illustrative embodiments of the present invention.

Specific embodiments

For reference purposes, the abbreviations and full names of some organic materials mentioned in the description are listed as follows:

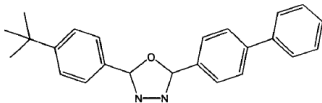
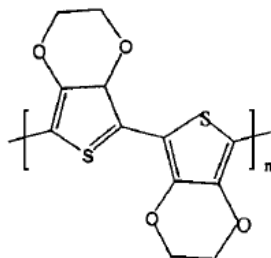
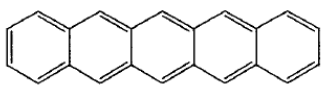
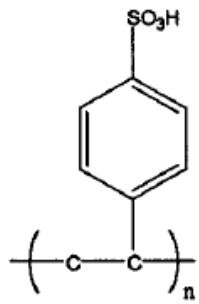
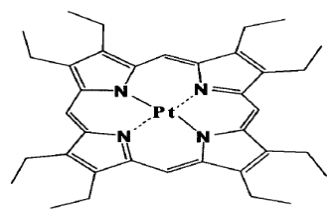
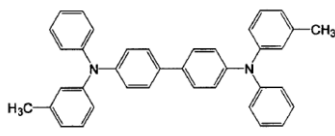
Table 1

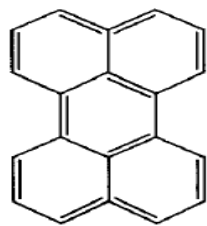
Abbreviation	Full name	Structural formula
Alq3	Tris-(8-hydroxyquinoline) aluminum	
Al (Saph-q)	(Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) aluminum complex (III)	
BAIq	Bis(2-methyl-8-quinolinolato)-4-phenylphenolato aluminum (III)	
BCP	2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline	

Abbreviation	Full name	Structural formula
Bphen	4,7-diphenyl-1,10-phenanthroline	
C545T	10-(2-benzothiazolyl)-1,1,7,7,-tetramethyl-2,3,6,7-tetrahydro-1H, 5H, 11H-benzo [1] pyranno [6,7,8-ij] quinoline	
CBP	4,4'-N,N'-dicarbazole-biphenyl	
CPF	9,9-bis-(4-dicarbazole-phenyl) fluorene	
CuPc	Copper phthalocyanine	

Abbreviation	Full name	Structural formula
DCB	N,N'-dicarbazol-1,4-dimethylbenzene	
FIrpic	Bis[2-(4,6-difluorophenyl)pyridinato-N,C ^{2'}] iridium picolate (III)	
Gaq ₃	Tris(8-hydroxyquinoline) gallium	
Ga(Saph-q)	(Salicylaldehyde o-aminophenol)-(8-hydroxyquinoline) gallium complex (III)	
Ir(piq) ₂ (acac)	Bis(1-phenyl-isoquinoline) (acetylacetonate) iridium (III)	

Abbreviation	Full name	Structural formula
Ir(ppy) ₃	Tris-(2-phenylpyridine) iridium (III)	
Ir(ppy) ₂ (acac)	Bis(2-phenylpyridine) (acetylacetonate) iridium (III)	
MTDATA	4,4',4''-tris(3-methylphenyl-phenyl-amino)triphenylamine	
NPB	N,N'-di-(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine	
PANI	Polyaniline	

Abbreviation	Full name	Structural formula
PBD	2-(4-di-tert-butylphenol)-5-(4-biphenyl)-1,3,4-oxadiazole	
PEDOT	Polythiophene	
Pentacene	Pentacene	
PSS	Polystyrene sulfonic acid	
PtOEP	Platinum octaethylporphine	
TPD	N,N'-diphenyl-N,N'-bis(m-methylphenyl)-1,1'-biphenyl-4,4'-diamine	

Abbreviation	Full name	Structural formula
Perylene	Perylene	

A construction of the phosphorescent organic light emitting device proposed in the present invention is shown in Figure 1, wherein: 1 is a transparent substrate, which can be glass or a flexible substrate, and the flexible substrate is made of one of polyester or polyimide compounds; 2 is an anode layer, which can be made of inorganic materials or organic conductive polymers, and the inorganic materials are generally metal oxides such as ITO, zinc oxide, tin zinc oxide, or metals with a high work function such as gold, copper, and silver, and the preferred choice is ITO, and the organic conductive polymer is preferably one of PEDOT:PSS and PANI materials; 3 is a hole transporting layer, which is made of p-type organic semiconductor materials with a strong hole transporting capability, and generally, it is a triphenylamine compound, such as one of NPB, TPD, MTDATA, and other materials, and NBP is preferred in the present invention; 4 is an organic light emitting layer, using small molecule materials as the host material, and the small molecule material has a high triplet state energy level, which can effectively transfer energy to the phosphorescent dye and make the phosphorescent dye emit light, and the small molecule host material is generally one of the biphenyl and carbazole compounds (such as CBP) or benzene and carbazole compounds (such as DCB, CPF), and the doping concentration of the phosphorescent dye doped in the host material gradually increases or decreases along the direction from the hole transporting layer to the electron transporting layer with the increase of the thickness of the organic light emitting layer, forming a construction with gradient doping, and it is generally a metal-organic complex, such as one of FIrpic (blue), Ir(piq)₂(acac) (red), PtOEP (red), Ir(ppy)₃ (green), Ir(ppy)₂(acac) (green), and other materials, with an average doping concentration of 0.1-50 wt%, and with a preferred average doping concentration of 1-30 wt%; 5 is an electron transporting layer, which is generally a material of metal-organic complexes (such as Alq₃, BALq, Gaq₃, Al (Saph-q) or Ga (Saph-q)), polycyclic aromatic compounds (such as pentacene, and perylene), ortho-phenanthroline compounds (such as Bphen and BCP), or oxadiazole compounds (such as PBD); 6 is an cathode layer (metal layer), which is generally made of metals with a low work function such as lithium, magnesium, calcium, strontium, aluminum, indium, or their alloys with copper, gold, and silver, and in the present invention, the preferred choices are Mg:Ag alloy layer and Ag layer in sequence, or LiF layer and Al layer in sequence.

The phosphorescent organic light emitting device proposed in the present invention may further comprise an anode buffer layer (not shown in Figure 1), which is located between the anode layer and the hole transporting layer, and generally, one material among phthalocyanines, polyacrylates, polyimides, fluorinated polymers, inorganic fluorides, inorganic oxides, or diamonds, such as CuPc, is used.

The preferred phosphorescent OLEDs with the above construction have the following structural formula (1):



The host material of the organic light emitting layer 1 in the above structural formula (1) is DCB, wherein phosphorescent dye FIrpic is doped in the layer in a gradient doping manner.

According to the above structural formula (1), combined with the preparation steps for the device, the detailed implementation method is described as follows:

- ① Clean the transparent conductive substrate ITO glass by ultrasonic cleaning using hot detergent and deionized water. After cleaning, place it under an infrared lamp to dry, and then perform UV ozone cleaning and low-energy oxygen ion beam bombardment pretreatment for the dried ITO glass. The ITO film on the conductive substrate serves as the anode layer of the device, and the square resistance of the ITO film is $5\ \Omega$ - $100\ \Omega$, and the film thickness is 80-280 nm;
- ② Place the above cleaned, dried, and pre-treated ITO glass in a vacuum chamber, vacuum it to 1×10^{-5} to 9×10^{-3} Pa, and then vapor deposit a layer of NBP on the above ITO film as the hole transporting layer of the device. The vapor depositing rate of the NPB film is 0.01-0.5 nm/s, and the film thickness is 20-80 nm;
- ③ Keeping the pressure in the above vacuum chamber constant, further vapor deposit an organic light emitting layer doped with phosphorescent dye FIrpic on the NPB hole transporting layer in a gradient doping manner, carry out gradient doping using a dual source vapor depositing method, place the host materials DCB and FIrpic in different evaporation sources, monitor the vapor depositing rates of the two evaporation sources using two film thickness monitoring probes during vapor depositing, and by controlling the vapor depositing rates of the two evaporation sources, the doping concentration of FIrpic in DCB gradually increases with the increase of vapor depositing thickness of the organic light emitting layer, and the vapor depositing rate ratio of DCB and FIrpic is 1,000:1 to 1:1,000, and the average doping concentration of FIrpic in DCB is 1-30 wt%, the total vapor depositing rate is 0.02-0.6 nm/s, and the total film thickness is 20-100 nm;
- ④ Keeping the pressure in the above vacuum chamber constant, further vapor deposit a layer of Bphen on the above organic light emitting layer as the electron transporting layer of the device. The vapor depositing rate of the Bphen film is 0.01-0.5 nm/s, and the film thickness is 20-80 nm;
- ⑤ Keeping the pressure in the above vacuum chamber constant, vapor deposit an Mg:Ag alloy layer and an Ag layer on the above Bphen electron transporting layer in sequence as the cathode layer of the device, wherein the alloy layer is doped using a dual source vapor depositing method, the Mg:Ag vapor depositing rate ratio in the alloy layer is 10:1, the total vapor depositing rate is 0.6-2 nm/s, the total vapor depositing thickness is 50-200 nm, the vapor depositing rate of the Ag layer is 0.3-0.8 nm/s, and the thickness is 40-200 nm.

The other preferred phosphorescent OLEDs with the above construction have the following structural formula (2):



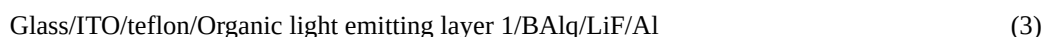
The host material of the organic light emitting layer 1 in the above structural formula (2) is DCB, wherein phosphorescent dye FIrpic is doped in the layer in a gradient doping manner.

According to the above structural formula (2), combined with the preparation steps for the device, the detailed implementation method is described as follows:

- ①-③ are the same as ①-③ in the preparation steps of the above structural formula (1);
- ④ Keeping the pressure in the above vacuum chamber constant, further vapor deposit a layer of BAlq on the above organic light emitting layer as the electron transporting layer of the device. The vapor depositing rate of the BAlq film is 0.01-0.5 nm/s, and the film thickness is 20-80 nm;
- ⑤ Keeping the pressure in the above vacuum chamber constant, vapor deposit an LiF layer and an Al layer on the BAlq electron transporting layer in sequence as the cathode layer of the device,

wherein the thickness of the LiF layer is 0.2-2 nm, the vapor depositing rate is 0.01-0.1 nm/s, the thickness of the Al layer is 40-200 nm, and the vapor depositing rate is 0.01-0.5 nm/s.

The device with a transparent substrate, anode, organic light emitting layer, and electron transporting layer construction proposed in the present invention is preferably prepared using the following structural formula (3):



The host material of the organic light emitting layer 1 in the above structural formula (3) is DCB, wherein phosphorescent dye FIrpic is doped in the layer in a gradient doping manner.

According to the above structural formula (3), combined with the preparation steps for the device, the detailed implementation method is described as follows:

- ① is the same as ① in the preparation steps of the above structural formula (1).
- ② Place the above cleaned, dried, and pre-treated ITO glass in a vacuum chamber, vacuum it to 1×10^{-5} to 9×10^{-3} Pa, and then vapor deposit a layer of Teflon on the above ITO film as the anode modification layer of the device. The vapor depositing rate of the Teflon film is 0.001-0.1 nm/s, and the film thickness is 2-20 nm;
- ③-⑤ are the same as ③-⑤ in the preparation steps of the above structural formula (2).

The device with a transparent substrate, anode, organic light emitting layer, and cathode construction proposed in the present invention is preferably prepared using the following structural formula (4):



According to the above structural formula (4), combined with the preparation steps for the device, the detailed implementation method is described as follows:

- ①-② are the same as ①-② in the preparation steps of the above structural formula (3).
- ③ is the same as ③ in the preparation steps of the above structural formula (3).
- ④ Keeping the pressure inside the above vacuum chamber constant, vapor deposit an Mg:Ag alloy layer and an Ag layer on the above light emitting layer in sequence as the cathode layer of the device, wherein the alloy layer is doped using a dual source vapor depositing method, the Mg:Ag vapor depositing rate ratio in the alloy layer is 10:1, the total vapor depositing rate is 0.6-2 nm/s, the total vapor depositing thickness is 50-200 nm, the vapor depositing rate of the Ag layer is 0.3-0.8 nm/s, and the thickness is 40-200 nm.

The device with a transparent substrate, anode, hole transporting layer, organic light emitting layer, and cathode construction proposed in the present invention is preferably prepared using the following structural formula:



According to the above structural formula (5), combined with the preparation steps for the device, the detailed implementation method is described as follows:

- ①-③ are the same as ①-③ in the preparation steps of the above structural formula (1).
- ④ Keeping the pressure in the above vacuum chamber constant, vapor deposit an Mg:Ag alloy layer and an Ag layer on the above light emitting layer in sequence as the cathode layer of the device, wherein the alloy layer is doped using a dual source vapor depositing method, the Mg:Ag vapor depositing rate ratio in the alloy layer is 10:1, the total vapor depositing rate is 0.6-2 nm/s, the total vapor depositing thickness is 50-200 nm, the vapor depositing rate of the Ag layer is 0.3-0.8 nm/s, and the thickness is 40-200 nm.

Embodiment 1 (Device No. OLED1)

Prepare OLED1 using the same method as that for the device shown in formula (1) above.

Control Embodiment 1 (Device No. Control OLED1)

Prepare Control OLED1 using the same method as that for Embodiment 1, wherein the vapor depositing rate ratio of the dual source vapor depositing remains unchanged when the organic light emitting layer is further vapor deposited on the NPB hole transporting layer of the device, i.e., FIrpic is uniformly doped in the DCB.

Embodiment 2 (Device No. OLED2)

Prepare OLED2 using the same method as that for the device shown in formula (1) above, wherein the host material of the organic light emitting layer of the device is CBP, and the phosphorescent dye is Ir(ppy)₃, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of Ir(ppy)₃ in CBP gradually decreases with the increase of the vapor depositing thickness of the organic light emitting layer.

Control Embodiment 2 (Device No. Control OLED2)

Prepare Control OLED2 using the same method as that for Embodiment 2, wherein the vapor depositing rate ratio of the dual source vapor depositing remains unchanged when the organic light emitting layer is further vapor deposited on the NPB hole transporting layer of the device, i.e., Ir(ppy)₃ is uniformly doped in CBP.

Embodiment 3 (Device No. OLED3)

Prepare OLED3 using the same method as that for the device shown in formula (1) above, wherein the host material of the organic light emitting layer of the device is CBP, and the phosphorescent dye is Ir(piq)₂(acac), and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of Ir(piq)₂(acac) in CBP gradually decreases with the increase of the vapor depositing thickness of the organic light emitting layer.

Control Embodiment 3 (Device No. Control OLED3)

Prepare Control OLED3 using the same method as that for Embodiment 3, wherein the vapor depositing rate ratio of the dual source vapor depositing remains unchanged when the organic light emitting layer is further vapor deposited on the NPB hole transporting layer of the device, i.e., Ir(piq)₂(acac) is uniformly doped in CBP.

The constructions of the devices prepared in the above Embodiments 1-3 and Control Embodiments 1-3 are shown in Table 2, the device parameters are shown in Table 3, and the brightness vs voltage curve, the luminescence efficiency vs current density curve, the normalized lifetime curve, the EL spectrum, and the color coordination of the OLED1 prepared in Embodiment 1 and the Control OLED1 prepared in the Control Embodiment 1 are shown in Figures 3-6, respectively.

Table 2

Embodiment No.	Device No.	Construction of OLEDs
Embodiment 1	OLED1	Glass/ITO/NPB/DCB:Flrpic (25 nm, 5 wt%)/DCB: Flrpic (3 nm, 20 wt%)/DCB:Flrpic (2 nm, 50 wt%)/Bphen/Mg:Ag/Ag The organic light emitting layer has a film thickness of 30 nm, and the Flrpic has an average doping concentration of 9.5 wt%, and its concentration distribution curve is shown in Figure 2. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Control Embodiment 1	Control OLED1	Glass/ITO/NPB/DCB:Flrpic (30 nm, 9.5 wt%)/Bphen/Mg:Ag/Ag The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Embodiment 2	OLED2	Glass/ITO/NPB/CBP:Ir(ppy)₃ (3 nm, 50 wt%)/CBP:Ir(ppy)₃ (5 nm, 20wt%)/CBP:Ir(ppy)₃ (27 nm, 5 wt%)/Bphen/Mg:Ag/Ag The organic light emitting layer has a film thickness of 35 nm, and the Ir(ppy)₃ has an average doping concentration of 11 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Control Embodiment 2	Control OLED2	Glass/ITO/NPB/CBP:Ir (ppy)₃ (35 nm, 11 wt%)/Bphen/Mg:Ag/Ag The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Embodiment 3	OLED3	Glass/ITO/NPB/CBP:Ir(piq)₂(acac) (4 nm, 40wt%)/CBP:Ir(piq)₂(acac)(6 nm, 20 wt%)/CBP:Ir (piq)₂(acac) (30 nm, 2.5 wt%)/Bphen/Mg:Ag/Ag The organic light emitting layer has a film thickness of 40 nm, and the Ir (piq)₂(acac) has an average doping concentration of 7 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Control Embodiment 3	Control OLED3	Glass/ITO/NPB/CBP:Ir(piq)₂(acac) (40 nm, 7 wt%)/Bphen/Mg:Ag/Ag The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.

Table 3

Embodiment No.		Embodiment 1	Control Embodiment 1	Embodiment 2	Control Embodiment 2	Embodiment 3	Control Embodiment 3
Device No.		OLED1	Control OLED1	OLED2	Control OLED2	OLED3	Control OLED3
Device parameters	Current density (A/m ²)	3,000					
	Brightness (cd/m ²)	35,000	17,000	83,000	56,000	18,000	12,000
	Max. luminescence efficiency (cd/A)	15.5	9.8	62.5	41.4	12.3	8.2
Device luminous color		Blue	Blue	Green	Green	Red	Red

From Table 3, it can be known that the brightness and luminescence efficiency of Devices OLED1-3 with gradient doping of phosphorescent dyes in the organic light emitting layer are better than those of Control Devices OLED1-3 with uniform doping of phosphorescent dye (compared with devices with the same luminous color), indicating that the gradient distribution of phosphorescent dyes in the host material conforms to the distribution trend of electrons in the device and greatly improves the performance of the device.

From Figure 5, it can be known that the lifetime of OLED1 is much longer than that of Control OLED 1. At the same time, Figure 6 shows that there are also differences in the EL spectrum of them. The reason is that the gradient doping of phosphorescent dye in the host material of the organic light emitting layer widens the carrier recombination region (light emitting region) of the device and transfers the light emitting center to the middle of the organic light emitting layer, and the light emitted by the device is reflected from the cathode layer, and the long reflection distance strengthens the intensity of light with a long wavelength.

Embodiment 4 (Device No. OLED4)

Prepare OLED4 using the same method as that for the device shown in formula (1) above, wherein the host material of the organic light emitting layer of the device is CPF, and the phosphorescent dye is FIrpic, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of FIrpic in CPF gradually increases with the increase of the vapor depositing thickness of the organic light emitting layer.

Embodiment 5 (Device No. OLED5)

Prepare OLED5 using the same method as that for the device shown in formula (1) above, wherein the host material of the organic light emitting layer of the device is CBP, and the phosphorescent dye is FIrpic, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of FIrpic in CBP gradually increases with the increase of the

vapor depositing thickness of the organic light emitting layer.

Embodiment 6 (Device No. OLED6)

Prepare OLED6 using the same method as that for the device shown in formula (2) above, wherein the host material of the organic light emitting layer of the device is CPF, and the phosphorescent dye is Ir(pyy)2(acac), and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of Ir(pyy)2(acac) in CPF gradually decreases with the increase of the vapor depositing thickness of the organic light emitting layer.

Embodiment 7 (Device No. OLED7)

Prepare OLED7 using the same method as that for the device shown in formula (2) above, wherein the host material of the organic light emitting layer of the device is CBP, and the phosphorescent dye is PtOEP, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of PtOEP in CBP gradually decreases with the increase of the vapor depositing thickness of the organic light emitting layer.

Embodiment 8 (Device No. OLED8)

Prepare OLED8 using the same method as that for the device shown in formula (2) above, wherein the host material of the organic light emitting layer of the device is CPF, and the phosphorescent dye is Ir(pig)2(acac), and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of Ir(pig)2(acac) in CPF gradually decreases with the increase of the vapor depositing thickness of the organic light emitting layer.

The construction of device prepared with the above embodiments 4-8 is shown in Table 4, and the device parameters are shown in Table 5.

Table 4

Embodiment No.	Device No.	Construction of OLEDs
Embodiment 4	OLED4	Glass/ITO/NPB/CPF:FIrpic/Bphen/Mg:Ag/Ag The organic light emitting layer has a film thickness of 35 nm, and the FIrpic has an average doping concentration of 24 wt%, and its concentration distribution curve is shown in Figure 7. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Embodiment 5	OLED5	Glass/ITO/NPB/CBP:FIrpic/Bphen/Mg:Ag/Ag The organic light emitting layer has a film thickness of 50 nm, and the FIrpic has an average doping concentration of 30 wt%, and its concentration distribution curve is shown in Figure 8. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Bphen layer has a film thickness of 30 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Embodiment 6	OLED6	Glass/ITO/NPB/CPF: Ir(ppy)₂(acac) (2 nm, 50 wt%)/CPF: Ir(ppy)₂(acac) (3 nm, 20 wt%)/CPF: Ir(ppy)₂(acac) (5 nm, 10wt%)/CPF: Ir(ppy)₂(acac) (20 nm, 5 wt%)/BALq/LiF/Al The organic light emitting layer has a film thickness of 30 nm, and the Ir(ppy)₂(acac) has an average doping concentration of 10 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the BALq layer has a film thickness of 30 nm, the LiF alloy layer has a film thickness of 1 nm, and the Al layer has a film thickness of 100 nm.
Embodiment 7	OLED7	Glass/ITO/NPB/CBP:PtOEP (15 nm, 18 wt%)/CBP:PtOEP (15 nm, 6wt%)/BALq/LiF/Al The organic light emitting layer has a film thickness of 30 nm, and the PtOEP has an average doping concentration of 12 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the BALq layer has a film thickness of 30 nm, the LiF alloy layer has a film thickness of 1 nm, and the Al layer has a film thickness of 100 nm.
Embodiment 8	OLED8	Glass/ITO/NPB/CPF:Ir(piq)₂(acac) (3 nm, 4wt%)/CPF: Ir(piq)₂(acac) (10 nm, 1 wt%)/CPF:Ir(piq)₂(acac) (17 nm, 0.5 wt%)/BALq /LiF/Al The organic light emitting layer has a film thickness of 30 nm, and the PtOEP has an average doping concentration of 1 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the BALq layer has a film thickness of 30 nm, the LiF alloy layer has a film thickness of 1 nm, and the Al layer has a film thickness of 100 nm.

Table 5

Embodiment No.		Embodiment 4	Embodiment 5	Embodiment 6	Embodiment 7	Embodiment 8
Device No.		OLED4	OLED5	OLED6	OLED7	OLED8
Device parameters	Current density (A/m ²)	3,000				
	Brightness (cd/m ²)	28,000	20,900	90,000	15,000	8,000
	Max. luminescence efficiency (cd/A)	13.1	12.4	70.2	9.6	6.5
Device luminous color		Blue	Blue	Green	Red	Red

Embodiment 9 (Device No. OLED9)

Prepare OLED9 using the same method as that for the device shown in formula (3) above, wherein the host material of the organic light emitting layer of the device is CBP, and the phosphorescent dye is FIrpic, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of FIrpic in CBP gradually increases with the increase of the vapor depositing thickness of the organic light emitting layer.

Embodiment 10 (Device No. OLED10)

Prepare OLED10 using the same method as that for the device shown in formula (4) above, wherein the host material of the organic light emitting layer of the device is DCB, and the phosphorescent dye is FIrpic, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of FIrpic in DCB gradually increases with the increase of the vapor depositing thickness of the organic light emitting layer.

Embodiment 11 (Device No. OLED11)

Prepare OLED11 using the same method as that for the device shown in formula (5) above, wherein the host material of the organic light emitting layer of the device is CPF, and the phosphorescent dye is FIrpic, and by controlling the vapor depositing rate ratio of the dual source vapor depositing, the doping concentration of FIrpic in CPF gradually increases with the increase of the vapor depositing thickness of the organic light emitting layer.

Table 6

Embodiment No.	Device No.	Construction of OLEDs
Embodiment 9	OLED9	Glass/ITO/teflon/CBP:FIrpic/BAlq/LiF/Al The organic light emitting layer has a film thickness of 35 nm, and the FIrpic has an average doping concentration of 25 wt%. The ITO layer has a film thickness of 20 nm, the teflon layer has a film thickness of 6 nm, the Balq layer has a film thickness of 30 nm, the LiF alloy layer has a film thickness of 1 nm, and the Al layer has a film thickness of 100 nm.
Embodiment 10	OLED10	Glass/ITO/Teflon/DCB:FIrpic/Mg:Ag/Ag The organic light emitting layer has a film thickness of 50 nm, and the FIrpic has an average doping concentration of 30 wt%. The ITO layer has a film thickness of 200 nm, the teflon layer has a film thickness of 4 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.
Embodiment 11	OLED11	Glass/ITO/NPB/CPF:FIrpic/Mg:Ag/Ag The organic light emitting layer has a film thickness of 40 nm, and the FIrpic has an average doping concentration of 20 wt%. The ITO layer has a film thickness of 200 nm, the NPB layer has a film thickness of 40 nm, the Mg:Ag alloy layer has a film thickness of 100 nm, and the Ag layer has a film thickness of 50 nm.

Table 7

Embodiment No.		Embodiment 9	Embodiment 10	Embodiment 11
Device No.		OLED9	OLED10	OLED11
Device parameters	Current density (A/m ²)	3,000		
	Brightness (cd/m ²)	42,000	23,000	21,000
	Max. luminescence efficiency (cd/A)	17.1	13.3	12.5
Device luminous color		Blue	Blue	Blue

Although the present invention has been explained in conjunction with the preferred embodiments, it is not limited to the aforementioned embodiments and figures. It should be understood that under the guidance of the concept of the present invention, those skilled in the art can make various modifications and improvements, and the appended claims summarize the scope of the present invention.

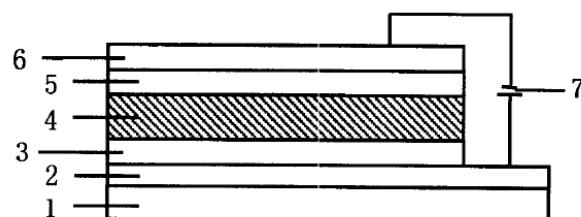


Figure 1

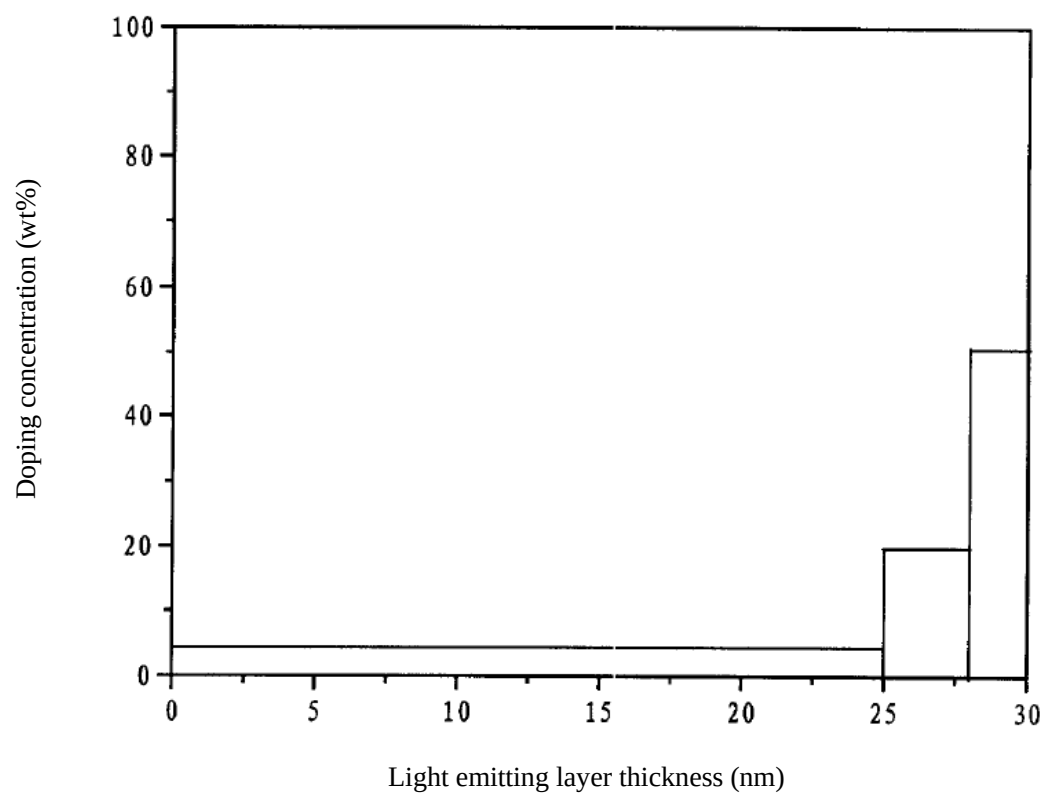


Figure 2

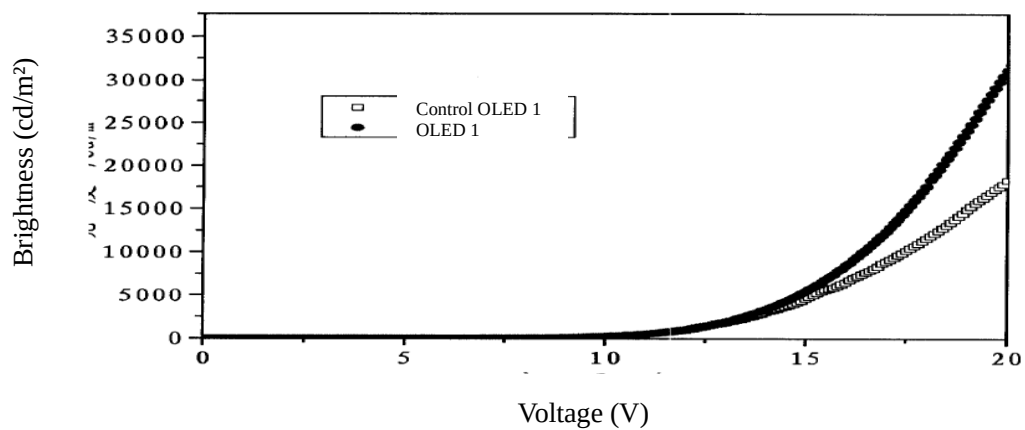


Figure 3

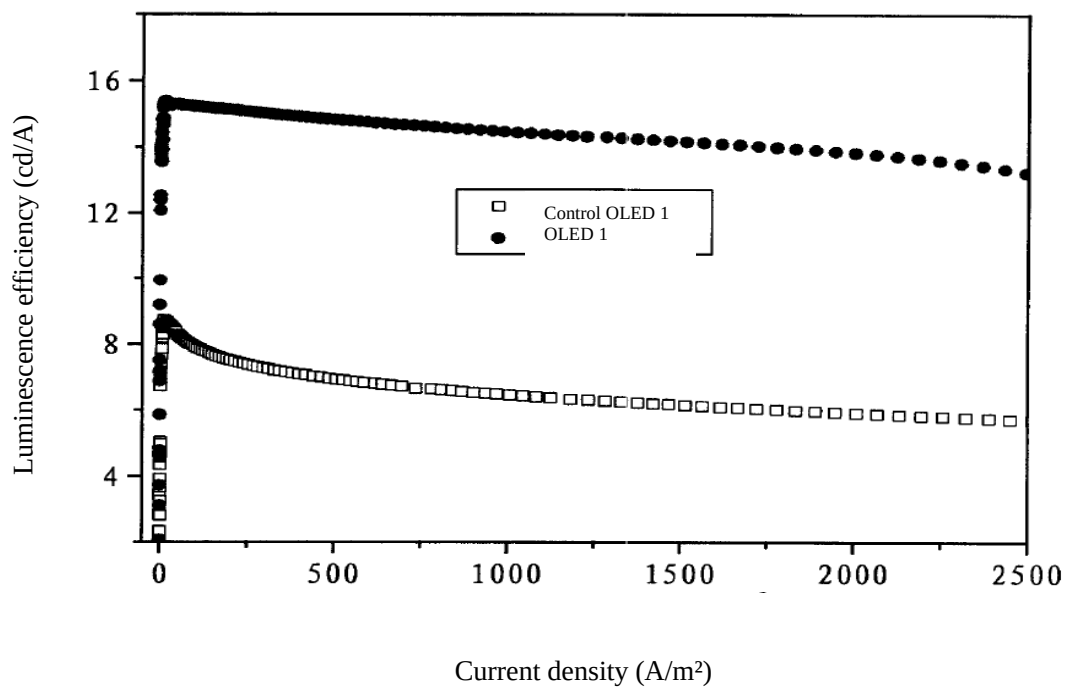


Figure 4

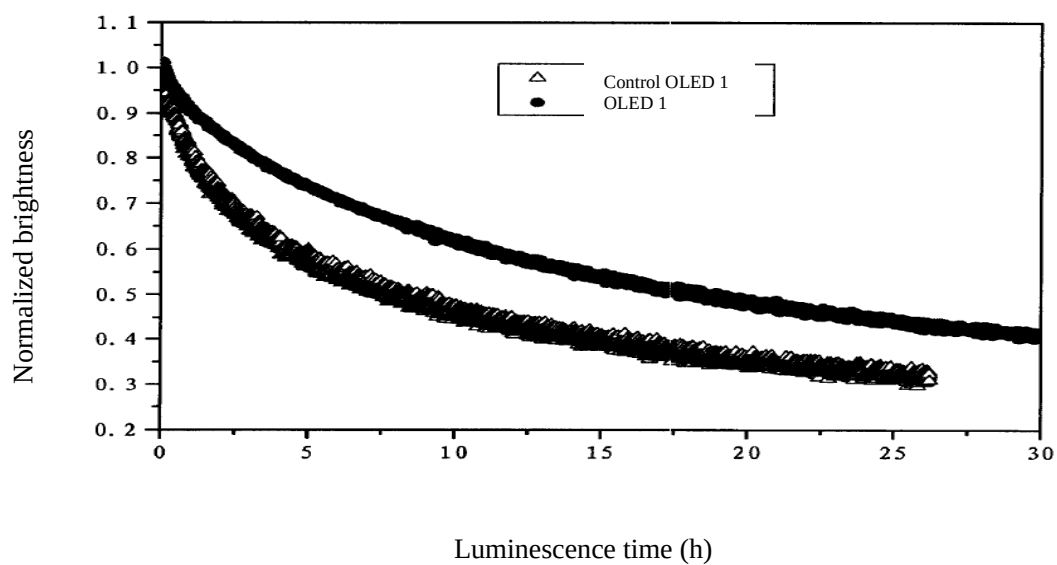


Figure 5

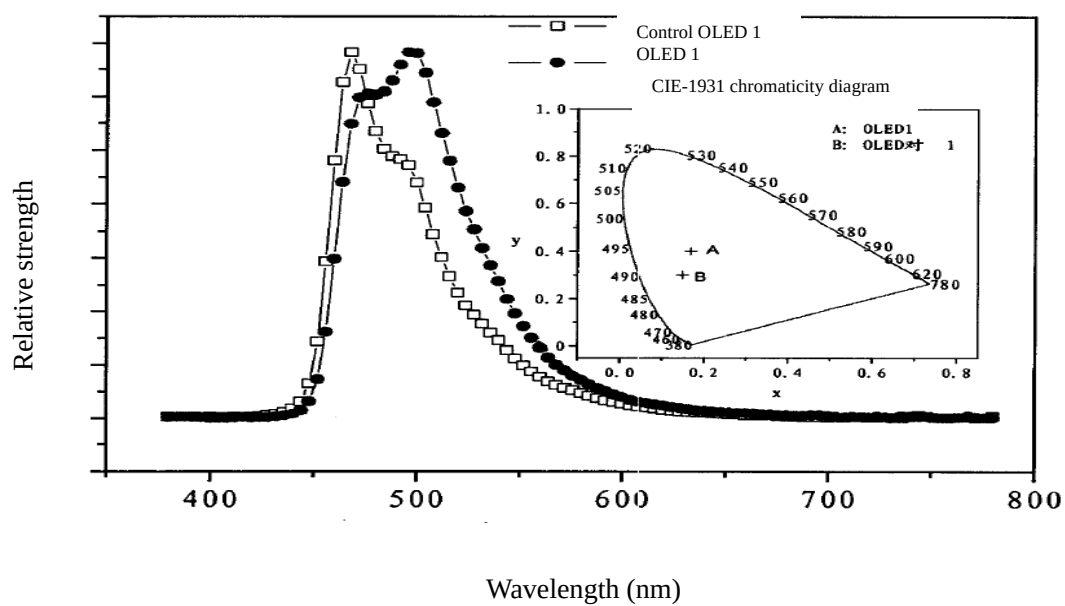


Figure 6

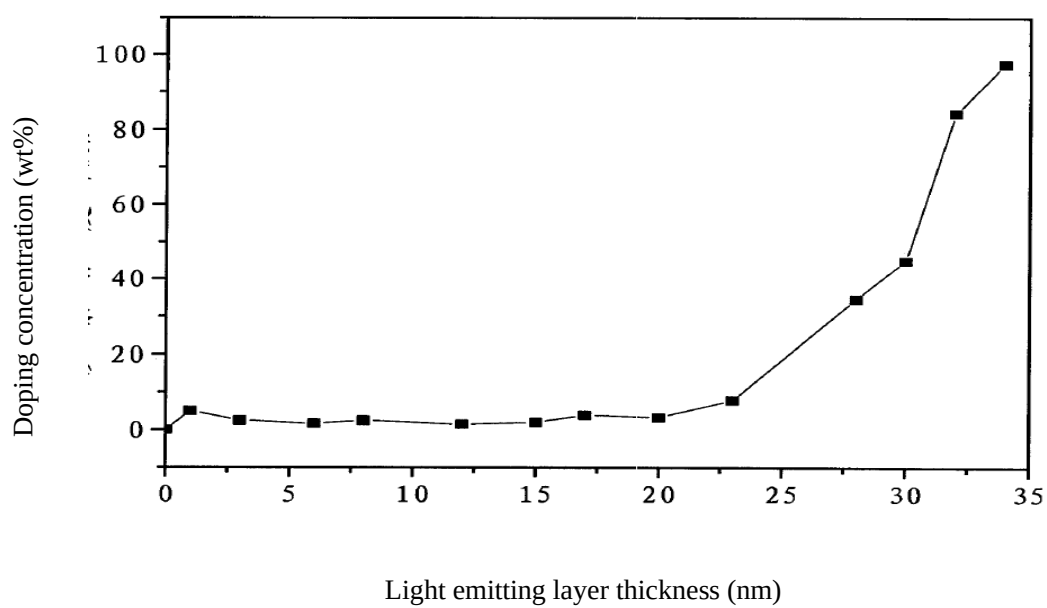


Figure 7

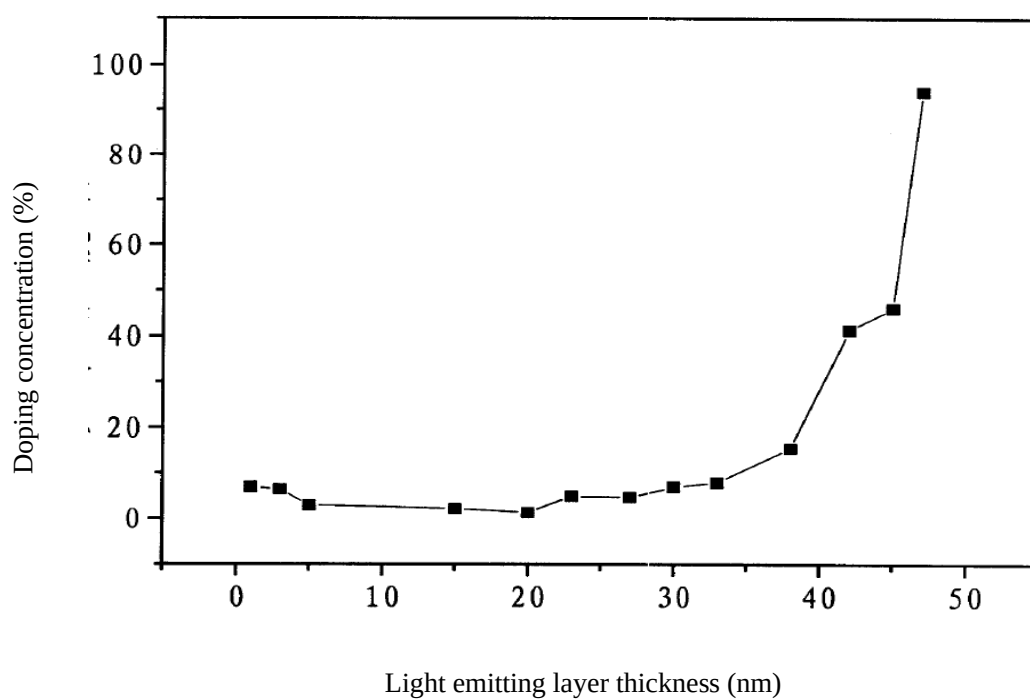


Figure 8