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White microcavity organic light-emitting diode based on one emitting material

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Abstract

A microcavity organic light-emitting diode (MOLED) was developed to emit white light. The MOLED was fabricated with a simple structure of glass/dielectric mirror/ITO/NPB/Alq/MgAg. White light was observed due to the emission of two cavity modes despite only one emitter layer. By well adjusting the resonance wavelength (488 and 612 nm) and intensity, the two cavity modes give rise to a bright, white electroluminescene emission with a maximum luminance of 16435 cd/m^2, maximum luminous efficiency of 11.1 cd/A. The MOLED has a CIE chromaticity coordinate of (0.32 and 0.34), which is very stable under the different applied voltage.

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Keywords: Microcavity; White light; Organic; LED; Cavity mode

1. Introduction

Recently, white organic light-emitting diodes (OLEDs) are attracting much attention due to the potential applications in illumination light source and back light for liquid crystal display (LCD) as well as full color displays [1–3]. A general solution to realize white color in OLEDs is to use a multiple emitter layers with separate layer to produce different colors. White light is achieved due to the color mixing. Unfortunately, the electroluminescent (EL) performance of this kind of devices such as color stability and efficiency are still need to be improved.

An optical microcavity is a structure with at least one dimension on the order of an optical wavelength [4–7]. In a microcavity device, only one or a few optical modes should be able to interact with the materials inside. Thus, the interaction between material and light within microcavity was changed greatly compared with the condition of free space.

In the past few years, a modification of emission properties of organic materials by microcavity effects have been shown as an effective way to enhance luminance and tune color [5–9]. Not only monochromatic light but also white lights [8,9] have been shown in microcavity OLEDs (MOLEDs). To obtain white light in MOLED, a multimode within the emission spectrum of a wide-band emitter is essential, and can be realized by increasing cavity length or structure design [9]. However, the reported white MOLED in Ref. [9] employed multiple emitting materials, and the EL performance was not fully reported. In this paper, we report the realization of a bright white MOLED with a simple two-layer structure and only one emitting material.

2. Design and experiment

The MOLED has a structure of glass/DBR/ITO/NPB/Alq/MgAg. ITO is the anode. MgAg mirror serves as cathode. 4-4′-bis[N-(1-naphthyl)-N-phenyl-amino]biphenyl (NPB) was used as the hole transport layer (HTL). Tris(8-hydroxyquinoline)aluminum (Alq) was used as the emitter layer (EML) and the electron transport layer (ETL). Distributed Bragg reflector (DBR) and MgAg are the two mirrors of the microcavity. The DBR consists of $2\frac{1}{2}$ pairs of quarter-wavelength thickness Ta_2O_5 and SiO_2 dielectric layers.

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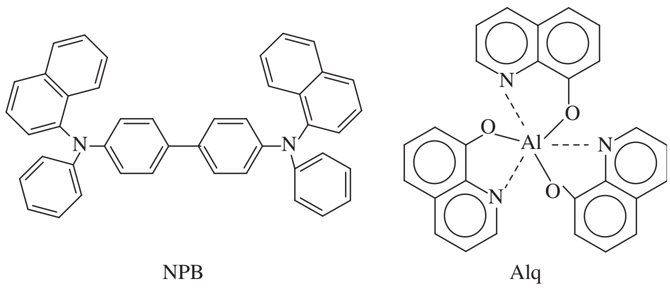

Fig. 1. The molecular structures of the organic materials used.

Fig. 1 shows the molecular structures of NPB and Alq materials. Alq is a frequently used green–yellow light-emitting material. Alq was selected as the EML due to its wideband photoluminescence (PL) spectrum, which shows an emission peak at about 515 nm. In order to realize white MOLED, at least two cavity modes with emission at blue and red color spectral region of Alq are required, at the same time most green light emission from Alq should be inhibited. Therefore, DBR is designed to have a maximum reflectance at the Bragg wavelength of 530 nm.

The EL spectrum of MOLED was modeled by the following equation [10]:

$$\left|E_{\mathrm{cav}}(\lambda)\right|^2=\frac{(1-R_{\mathrm{d}})\left[1+R_{\mathrm{m}}+2\sqrt{R_{\mathrm{m}}}\,\cos\left(\frac{4\pi z}{\lambda}\right)\right]}{1+R_{\mathrm{m}}R_{\mathrm{d}}-2\sqrt{R_{\mathrm{m}}R_{\mathrm{d}}}\,\cos\left(\frac{4\pi L}{\lambda}\right)}\left|E_{\mathrm{n}}(\lambda)\right|^2, \quad (1)$$

where z is the effective distance between exciton-forming area and the metal mirror, R_{d} and $\underline{R}_{\mathrm{m}}$ are the reflectances of DBR and metal mirrors, respectively. L is the total optical thickness of microcavity, and $\left|E_{\mathrm{n}}(\lambda)\right|^2$ is the free space intensity at λ. By the simulation, we have determined the structure of the MOLED is as follows:

Glass/DBR/ITO(194 nm)/NPB(93 nm)/Alq(49 nm)/MgAg (150 nm).

DBR and ITO were deposited by electron-beam evaporations. All organic and metal MgAg (rate ratio 10:1) layers were prepared by vacuum deposition. The refractive indices were measured with a UVISEL Spectroscopic Phase Modulated Ellipsometer. PL emission spectrum was measured with a Hitachi spectrophotometer F-4500. Luminance and EL spectrum were taken with an Optikon CCD spectrometer. The transmittance spectrum was measured with a Shimadzu spectrophotometer UV-3000.

3. Results

The transmittance spectrum of the DBR is shown in Fig. 2 together with PL spectrum of Alq film and modeled EL spectrum of the MOLED. The PL spectrum of Alq film shows a peak at 515 nm, and a full-width at half-maximum (FWHM) of 90 nm.The transmittance spectrum of the DBR shows that the maximum reflectance of DBR is about 66% at Bragg wavelength of 530 nm. The modeled EL

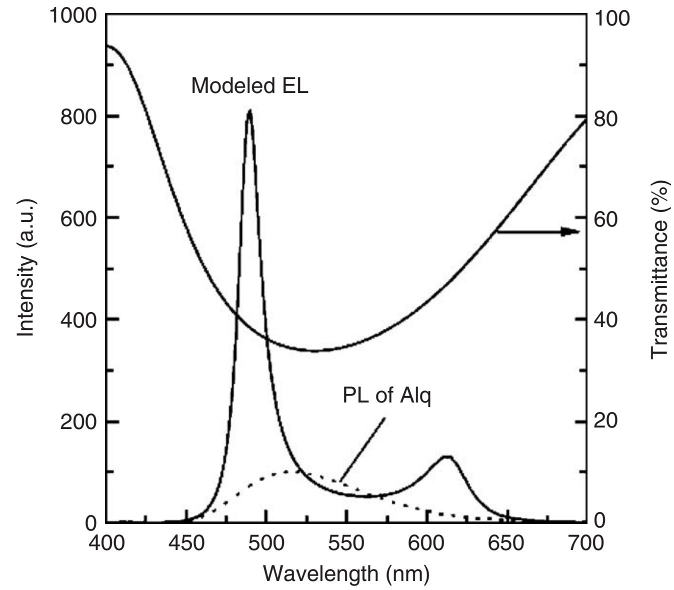

Fig. 2. Modeled EL spectrum of the MOLED (line) and PL spectrum of Alq film (scatter), the transmittance spectrum of the DBR.

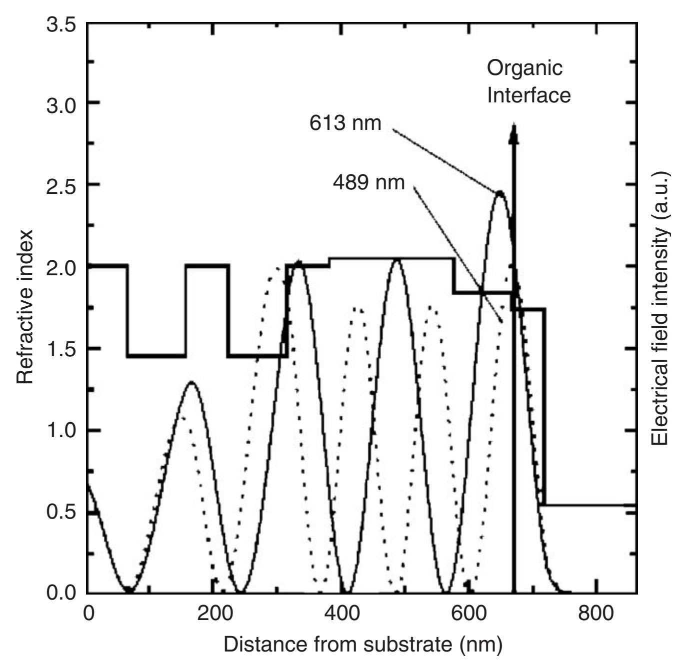

Fig. 3. Refractive index and electrical field distribution in MOLED.

spectrum shows that there are two cavity modes located at 489 nm (FWHM 18 nm) and 613 nm (FWHM 42 nm), respectively. The 1931 CIE chromaticity coordinate of the modeled EL emission is (0.27 and 0.4), which is within that of white color. Refractive index and electrical field distribution in MOLED are shown in Fig. 3. The refractive indices of Ta_2O_5, SiO_2, ITO, NPB, Alq and MgAg films were measured to be 2.0, 1.46, 2.05, 1.84 and 1.74, respectively. In order to optimize the luminance in the design, the antinodes of the confined cavity field at 489 and

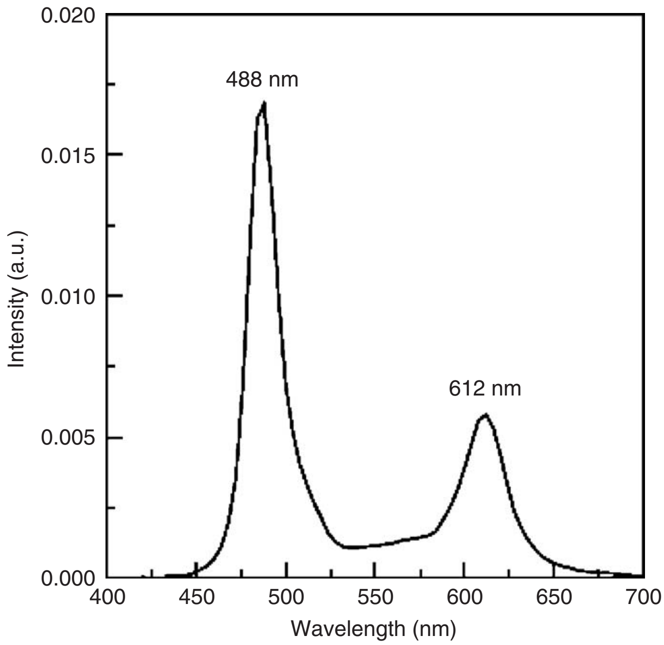

Fig. 4. EL spectrum of the MOLED at 12 V.

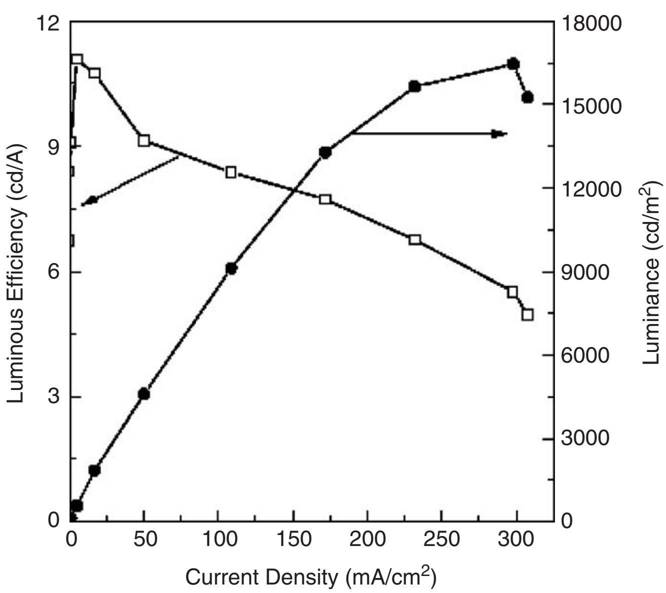

Fig. 5. Dependence of luminous efficiency (open square) and luminance (Solid square) of the MOLED on current density.

613 nm is positioned around the interface between NPB and Alq layers, near where the excitons are formed.

The MOLED has a turn-on voltage of 3 V. When applying voltage, white light from glass side can be observed in the normal direction. The EL spectrum at 12 V in the normal direction is shown in Fig. 4. The two resonant peaks are around 488 and 612 nm, in good agreement with the design. The FWHM are 20 and 32 nm, respectively. Fig. 5 shows the dependence of luminous efficiency and luminance on current density of the MOLED. The maximum luminance in the normal direction is 16435 cd/m^2, and the maximum efficiency is 11.1 cd/A. At the typical luminance of 100 cd/m^2 for the MOLED device, the luminous efficiency, voltage and current density are 9 cd/A, 6 V and 1.2 mA/cm^2, respectively. The emission color is white with a 1931CIE chromaticity coordinate of (0.32 and 0.34). The emission color is quite stable under different applied voltages, mainly resulting from the simple structure employed, and stable emitting material Alq as well.

4. Summary

We have developed a white light MOLED that has a simple structure with a wideband organic emitting material Alq. White light was realized by controlling the microcavity structure, resulting in two cavity modes emission located at blue (488 nm) and red (612 nm) region. The bright EL emission has been obtained with a maximum luminance of 16435cd/m^2, and maximum luminous efficiency of 11.1 cd/A. The 1931 CIE chromaticity coordinate of the white color is (0.32 and 0.34), which is very stable under different applied voltages. The result indicates that microcavity is an efficient structure to construct white OLED.

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