



# Magnetic field effects on electroluminescence emanated simultaneously from blue fluorescent and red phosphorescent emissive layers of an organic light-emitting diode

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## ABSTRACT

A simple method by employing white organic light-emitting diode (OLED) to simultaneously study the effects of magnetic fields (MFES) on the fluorescent and phosphorescent emission was presented. The white OLED consisting of the blue fluorescent and red phosphorescent materials was fabricated. The low-pass filter chopped at 500 nm and the high-pass filter chopped at 550 nm were used to separate the MFES on the blue fluorescence and red phosphorescence, separately. The magnetolectroluminescences (MELs) on the fluorescence sharply increased at low magnetic field then tended to saturation at high magnetic field. While the MELs on the phosphorescence sharply increased at low magnetic field then slowly monotonically increased as the magnetic field further increased. Our results indicated that the magnetic-field modulated singlet-to-triplet electron–hole pair conversion combining with the magnetic-field modulated triplet–triplet annihilation process are the origins of the MFES on the electroluminescence.

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## 1. Introduction

The effects of magnetic fields (MFES) on the electroluminescence (MEL) and current (MC) in organic light-emitting diodes (OLEDs) have been observed, and found to be the general phenomena in a range of both low-molecular weight materials and high-molecular weight polymers [1–24]. The phenomena have the following characteristics: first, the OLEDs do not consist of any magnetic materials. Second, a low magnetic field (10 mT) can induce a relative large change (several percent) of the signals [2]. Third, the signs of MEL and MC can be either positive or negative according to the used materials and structures of OLEDs [3]. During the past few years, a lot of works were done to understand the fundamental mechanisms of the MFES for two reasons. First, the MFES could be a tool to explore the device physics of the OLEDs and provide the theoretical

basis for improving the organic display technology. Second, they may lead to the development of the next optoelectronic devices and/or magnetic sensing devices [4]. Up to date, Several mechanisms to explain the phenomena have been proposed [1,5–8], but still deserve the debate. We noted that most reports of the MFES are based on the devices using the fluorescent materials, and generally have a “non-Lorentzian” shape:  $MFE \propto B^2/(B + B_0)^2$ , or “Lorentzian” shape:  $MFE \propto B^2/B^2 + B_0^2$ , where  $B_0$  is a fitting parameter whose value is close to the hyperfine field [3,6,8–13]. There are only a few reports based on the devices using the phosphorescent materials [20–22], and direct compare the MFES on the fluorescence and phosphorescence is lacking. In this work, we fabricated a type of white OLEDs in which the white emission is obtained by combining the blue emission from the fluorescent material with the red emission from the phosphorescent material. This type of white OLEDs offers the opportunity to study the MFES on fluorescent and phosphorescent emissions simultaneously, and eliminates the errors arising from the different processes

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of fabricating the fluorescence and phosphorescence devices separately.

## 2. Experimental methods

The OLEDs have the structure of indium tin oxide (ITO)/N,N'-di-1-naphthyl-N,N'-diphenylbenzidine (NPB) (40 nm)/4,4-Bis(carbazol-9-yl)biphenyl(CBP):bis(2,4-diphenylquinolinato-N,C2')iridium (acetylacetonate) (Ir(ppq)<sub>2</sub>(acac)) (w.t. 8%, 10 nm)/CBP (10 nm)/4,4'-Bis(2,2-diphenylvinyl)-1,1'-biphenyl (DPVBI) (40 nm)/1,3,5-tri(phenyl-2-benzimidazolyl)-benzene (TPBi) (40 nm)/Lithium fluoride (LiF) (0.5 nm)/Al (100 nm). The fluorescent material of DPVBI and phosphorescent material of Ir(ppq)<sub>2</sub>(acac) were used to emit blue and red light, respectively; NPB was used as the hole transporting layer and TPBi was used as both the electron transporting layer and the hole blocking layer; CBP was used as the host of the Ir(ppq)<sub>2</sub>(acac). Immediately after fabrication, the devices were placed on a Teflon stage between the poles of an electromagnet (perpendicular to the electrical current direction) for the MFEs measurements. A Keithley 2612 sourcemeter was used to provide a constant voltage from one channel which simultaneously recorded the current signals. The light output of the devices was collected by an optic fiber (2 m) connected to a Hamamatsu photomultiplier. The photomultiplier was placed far away from the electromagnet, and was connected to another channel of the Keithley 2612 to record the EL intensity. In order to measure the MELs of the blue fluorescence and the red phosphorescence separately, we used the low-pass filter chopped at 500 nm to permit the blue fluorescence pass and the high-pass filter chopped at 550 nm to permit the red phosphorescence pass, respectively. The EL spectra were recorded by an Ocean Optics spectrometer (Maya2000 Pro). All the measurements were carried out at room temperature under ambient condition.

## 3. Results and discussion

Fig. 1a–e shows the chemical structures of NPB, TPBi, CBP, DPVBI and Ir(ppq)<sub>2</sub>(acac), respectively. Fig. 1f shows the structure of the OLEDs together with the energy levels of lowest unoccupied molecular orbital (LUMO) and highest occupied molecular orbital (HOMO) of the materials used in this work. The LUMO and HOMO levels were obtained from the literatures [25,26]. As can be seen in Fig. 1f, a CBP layer of 10 nm was inserted between the fluorescence layer and the phosphorescence layer to prevent the excitons in DPVBI layer from diffusing into the phosphorescence layer. Fig. 1g shows the EL spectrum of the OLEDs. By using the low-pass and high-pass filters, we separated the fluorescence and phosphorescence, as showed in insets (i) and (ii) in Fig. 1g, respectively. It should be mentioned that one can see the small shoulder in the phosphorescence EL spectrum (inset (ii) in Fig. 1g). The shoulder contains a portion of fluorescence from the DPVBI. However, it is so tiny compared to the phosphorescence emission and was neglected in the phosphorescence's MEL measurement. The MELs of the red phosphorescence from Ir(ppq)<sub>2</sub>(acac) and the blue fluorescence from DPVBI

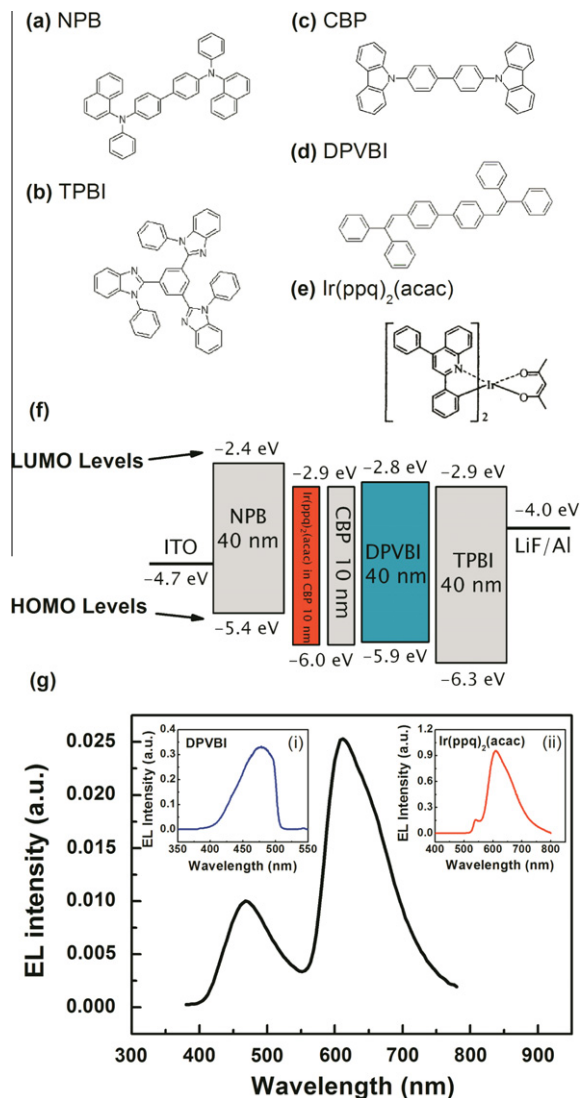


Fig. 1. (a–e) The molecular structures of the NPB, TPBi, CBP, DPVBI, and Ir(ppq)<sub>2</sub>(acac), respectively. (f) The schematic of the structure of the OLEDs together with the energy levels of the HOMO and LUMO of the materials used in the experiment. (g) The EL spectrum of the OLEDs, insets (i) and (ii) the EL spectrum of the fluorescence from DPVBI and the phosphorescence from Ir(ppq)<sub>2</sub>(acac) separated by the filter lenses.

were shown in Fig. 2a and b, respectively. Clearly, there are three differences between the MELs of the phosphorescence (MELs<sub>(Phos)</sub>) and the MELs of the fluorescence (MELs<sub>(Fluo)</sub>). First, the magnitude of the MELs<sub>(Fluo)</sub> is larger than that of the MELs<sub>(Phos)</sub>. Second, the MELs<sub>(Fluo)</sub> have a sharp increasing at low magnetic field then tend to saturation at high magnetic field, while the MELs<sub>(Phos)</sub> increase sharply at low magnetic field and then rise slowly as the magnetic field continually increases. Third, the MELs<sub>(Fluo)</sub> first increase and then decrease as the driving voltage increases, while the MELs<sub>(Phos)</sub> increase monotonically with increasing the driving voltage.

Fig. 3a shows the MELs (at the magnetic field of 300 mT) as the function of voltage, which is extracted from Fig. 2

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