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Magnetic field effects on electroluminescence in phosphorescence organic light emitting diodes

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ABSTRACT

In this letter, we presented a method to study the MFEs on the triplets in phosphorescent OLEDs. The magnetic electroluminescence (MEL) was obtained by doping a red phosphorescent guest with low concentration into a fluorescent host, where the guest and host can simultaneously emit. Experimentally two different MEL shapes of Lorentz and linear were observed, depending on the used host materials. We presented two different mechanisms to explain their difference. The diffusion process of triplets from host to guest and prolonged lifetime of triplet by magnetic field were attributed to the formation of the Lorentz shape, and it is considered that the linear shape was caused by magnetic field increased Dexter energy transfer rate and determined by the triplet energy difference between guest and host. It can be seen that the competition of two processes lead to the formation of the two different MEL shapes in the phosphorescent OLEDs.

1. Introduction

Organic light emitting diodes (OLEDs) made of non-ferromagnetic components have unique magnetic field effects (MFEs) [1]. A low magnetic field (<200 mT) can significantly change the electroluminescence (EL), photoluminescence, photocurrent, and current in nonmagnetic organic semiconducting materials [2–5]. Various possible mechanisms such as magnetic field on carrier mobility [6,7] or polaron pairs [8,9] responsible for the MFEs in fluorescent OLEDs have emerged. In mobility based theory, the applied magnetic field disturbs spin–spin interaction between charge carriers during transport, consequently, modifies the charge mobility, thus generating MFE [10,11]. The MFE of OLEDs based on fluorescent small molecules usually uses the polaron-pair model, [3,8,12–14] which suggests that the hyperfine interaction is the dominate mechanism. In the polaron-pair model, an applied magnetic field increases the singlet ratio in polaron-pair states via intersystem crossing [14–16], as a result, the electroluminescence (EL) intensity and current of the fluorescent OLEDs are increased, in which the MFEs on the singlet emission behavior get full demonstration. However, phosphorescent materials generally show weak MFEs due to their strong spin–orbital coupling (SOC) [15,16], and the involved processes such as MFE on triplet lifetime [5,17] and energy transfer between host and guest make the research complicated and intriguing. It is well-known that there is not yet an effective way to study the magnetic effects on triplets [18] in phosphorescent OLEDs up to now.

In this letter, we presented a method to study the MFEs on triplets in phosphorescent OLEDs. The magnetic electroluminescence (MEL), where the MEL is defined as $MEL = (EL(B) - EL(0))/EL(0)$, $EL(B)$ and $EL(0)$ are the EL intensity with and without external magnetic field (B), respectively, can be obtained by doping a red phosphorescent guest with low concentration into a fluorescent host. The guest and host can simultaneously emit due to the inefficient energy transfer from host to guest. Experimentally, two different MEL shapes of Lorentz and linear were observed, depending on the used host materials. We presented two mechanisms to explain their differences. The

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diffusion process of triplets from host to guest and prolonged lifetime of triplet by magnetic field [5,17] contribute to the formation of the Lorentz shape. The linear shape was caused by the increased Dexter energy transfer rate induced by magnetic field and determined by the triplet energy levels difference between guest and host. It can be seen that the competition of two processes lead to the formation of the two different MEL shapes in the phosphorescent OLEDs.

2. Experimental methods

The basic device structure is ITO/N,N′-di(naphthalene-1-yl)-N,N′-diphenyl-benzidine(NPB) or 4,4′,4″-tri(N-carbazolyl)triphenylamine(TCTA)(45 nm)/host:guest (5 nm)/2,2′,2″(1,3,5-benzenetriyl) tris-[1-phenyl-1H-benzimidazole] (TPBi) (50 nm)/LiF(1 nm)/Al. Here the guest is a red phosphorescent dye bis(2,4-diphenylquinolinato-N,C(2′))iridium (acetylacelonate)(Ir(PPQ)$_2$(acac)). The host is 8-hydroxyquinoline aluminum (Alq_3), NPB, and TCTA, respectively. All materials were thermally evaporated on glass substrate with ITO at a rate of 0.1–0.2 nm/s. To test the current and EL response under magnetic field, Keithley 236 source meter and Keithley 2000 were used to measure the current and EL, and monochromator and photomultiplier tube were combined to get EL value at specific wavelength. For the delay transient measurement, Agilent 8114A pulse generator was used to generate the pulse voltage (1 kHz, 10 μs width), the current was measured by digital oscilloscope with input resistance 50 Ω, and the EL was measured by photomultiplier connected with another channel of digital oscilloscope with input resistance 50 Ω. All the measurements were carried out at room temperature under ambient condition.

3. Results and discussion

The MELs of Ir(PPQ)$_2$(acac) doped in 8-hydroxyquinoline aluminum(Alq_3), NPB, and TCTA, respectively, were measured by using monochromator filter fixed at 605 nm (corresponding to the EL peak of Ir(PPQ)$_2$acac). As shown in the inset of Fig. 1, the spectrum overlap between fluorescent host and phosphorescent guest emission was very small, so the MEL could easily be separated. It should be mentioned that the total phosphorescent emission (no fluorescent emission) showed negligible MEL due to the strong SOC of phosphorescent materials, which will be shown in the following experiments. The MEL was emerged only when both fluorescent and phosphorescent emission were simultaneously observed. So we kept the Ir(PPQ)$_2$acac concentration at ~1% to make sure the simultaneous EL of the fluorescence from host and the phosphorescence from Ir(PPQ)$_2$acac (Fig. 1 inset).

The MEL of Ir(PPQ)$_2$(acac) doped in three different hosts showed three different shapes, as shown in Fig. 1a, indicating different dynamic processes under magnetic field. In the phosphorescence doped systems, the MEL comes from MFEs on host or interaction between host and guest [19]. For the low doping of Ir(PPQ)$_2$(acac)-based devices, the magnetic field could affect the excitons formed on hosts

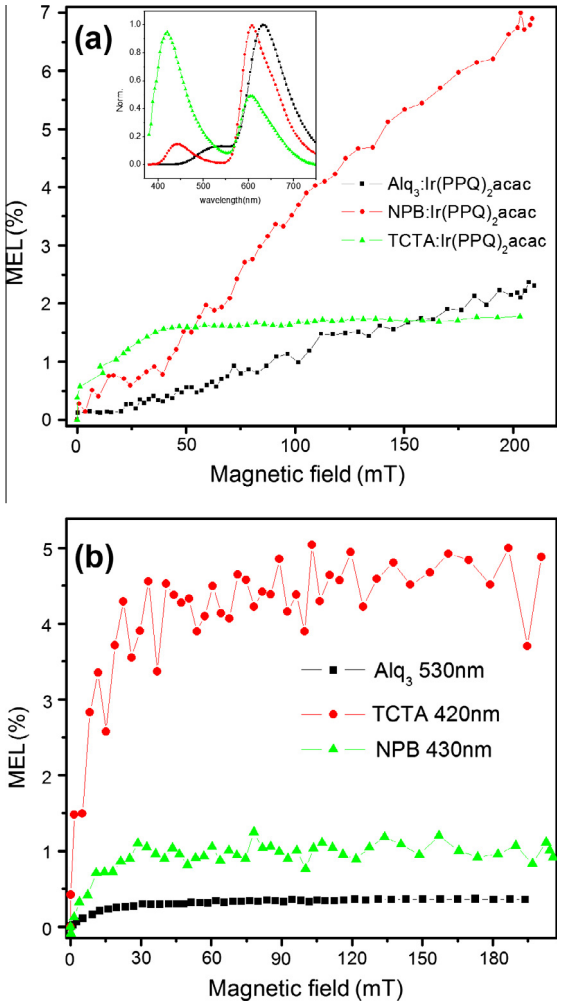

Fig. 1. (a) Phosphorescent-MEL (605 nm) of three different host doping red phosphorescent Ir(PPQ)$_2$acac. The inset shows their emission spectra, respectively, where both host and guest emission can be observed. (b) The MEL of singlet emission measured at their emission peak. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

by changing the triplet/singlet ratio through intersystem crossing (ISC) [20]. In fact, there are two ways of energy transfer from host to guest in this system, i.e. the singlet to singlet energy transfer and the triplet to triplet energy transfer. At low concentration, the singlet exciton formed on host could not be efficiently transferred to the guest because of its short lifetime. Even if this is the dominate process in phosphorescent emission, the MEL should have a Lorentz shape [21] due to the MEL of fluorescence emission (Fig. 1b), which was not happened in NPB and Alq_3 as host based devices. However, in the TCTA as host based device, the MEL of Lorentz shape was realized (Fig. 1a). To elucidate the mechanism, we fabricated another device with structure of ITO/TCTA (45 nm)/TCTA: Ir(PPQ)$_2$(acac) (5 nm)/TCTA (10 nm)/TPBi (50 nm)/LiF (1 nm)/Al, where the emissive layer was at 10 nm away from the TCTA/TPBi interface to avoid the transfer of singlet excitons to