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The storage of charges and its optical application in organic light-emitting diodes measured by a transient electroluminescence method

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ABSTRACT

Organic light-emitting diodes (OLEDs) device capable of stored charges with poly (methyl methacrylate) (PMMA) layer is studied by transient electroluminescence measurements. The mechanism and optical application of stored carriers are elucidated. A spike after a driven pulse is found in the device with PMMA layer, which is attributed to the drifting back of accumulated electrons and trapped ones in shallow states, and the detrapping of latter may result in a long decay tail. A reversed post-pulse is applied to release the electrons in deep traps as they are immobile unless under a strong reversed field. Since the stored charges can lead to a great loss of carriers and weaken the performance of device, we find a way to use them in the form of light emitting with an enhanced intensity more than 3 times as against steady-state. So we have a good reason to believe if in a proper way, we can make full use of the stored charges in optical application.

1. Introduction

Since Tang et al. firstly developed the multilayer Organic light-emitting diodes (OLEDs) [1], much great progress has taken place during the past decades [2–5]. To perform well, the device should possess the characteristics such as low operating voltage, high efficiency and good stability. Efficient OLEDs are crucially dependent on the balanced injection of charge carriers, but the carriers in device are imbalanced commonly. As a result, it will lead to the increase of leak current and the quenching near the electrode, which can weaken the performance of device. To overcome these problems, enhancing either charge injecting ability or charge confinement for bipolar recombination will be achieved [6]. As to the former, it can be realized by inserting some buffer layers like carrier injection layers [7–9], SAM layers [10–12], insulator layers [13–16] etc. The charge confinement in the emission layer can be assisted by applying the carrier blocking layers [17,18] or quantum well structure [19–22]. However, any effort to enhance the charge balance of OLEDs will result in the storage of carriers in OLEDs [23–25].

The stored carriers, including accumulated carriers and trapped ones, can take place in many OLEDs structures more or less, which are inevitable and suspected to decrease the efficiency of device. First, excitons may be quenched by the extra polarons [26]. Second, it will lead to field-induced quenching because of the additional electric field created by these charges [27]. Third, the trap-assisted carriers will result in the nonradiative recombination to compete with the radiative one, and eventually decrease the external quantum efficiency [25,28]. Finally, the storage of charges in the interface may lead to the local overheating and even the degradation [29]. Now that these stored charges are not favorable to the performance of devices, to solve the problem may be a great challenge. However, there are few papers related to measure and use the stored charges in electroluminescence. In this paper, we prepared a structure capable of the stored charges. With the help of transient measurement, we not only analyzed the mechanism on them, but significantly made use of them in the form of light emitting, so as to realize the optical application of the stored charges.

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2. Experimental details

The device was fabricated on patterned indium tin oxide (ITO) with a sheet resistance 20 Ω/□. The device structure is ITO/poly (methyl methacrylate) (PMMA)/Tris-(8-hydroxyquinoline) aluminum (Alq_3) (60 nm)/LiF (0.6 nm)/Al (80 nm), as shown in Fig. 1(a). ITO was treated by UV-ozone for 10 min. PMMA was dissolved in chloroform and spin-coated on ITO, and other parts were thermally evaporated sequentially. In order to investigate the rule of PMMA in storing carriers, devices with different thickness of PMMA were prepared and measured. Among them, device with 10 nm PMMA showed the best performance in storing charges. Thus, we show the devices with PMMA thickness of 0(device A) and 10 nm (device B), respectively. The active area of the device was 0.09 cm^2.

The current density–voltage–luminance (*J–V–L*) characteristics were measured with a programmable Keithley Source Meter 2410 and Newport 1830 Optical Power Meter. The electroluminescence (EL) spectra were detected by a charge-coupled device (CCD) spectrometer. The transient EL was performed under a series of forward and reversed pulses. The forward pulse was generated by RIGOL DG1022 Function/Arbitrary Waveform Generator, and the reversed pulse was generated by Agilent 8114A High Power Pulse Generator. Both the generators were controlled by DG535 Digital Delay/Pulse generator. The characteristics of transient EL were detected by a Zolix Instruments Model PMTH-S1C1-CR131 Photomultiplier Tube and recorded with a Tektronix Model DPO 4104 digital phosphor oscilloscope. All measurements were carried out at room temperature under ambient atmosphere.

3. Results and discussion

3.1. EL characteristics and transient EL measurements

The EL spectra and *J–V–L* characteristics of both devices are shown in Fig. 2. The emission of devices is from the exciton recombination of Alq_3 without any change. Compared to device A, the current density of device B with 10 nm PMMA decreases sharply and the luminance enhances much, which may result from the blocking and storage of carriers to increase the carrier recombination.

In order to study whether there are stored charges, the transient electroluminescence measurements under a pulse bias with the period of 1ms were carried out and shown in Fig. 3. In Fig. 3(a), two devices were driven by a single pulse with the amplitude of 10 V and the width of 250 μs. The electroluminescence intensity of device A decayed directly when the pulse ended. However, there is a remarkable spike and a much longer emission tails, i.e., a much slower emission decay taking place in device B when the pulse bias was removed. The spike and the longer emission decay are resulted from the recombination emission of excitons formed by stored

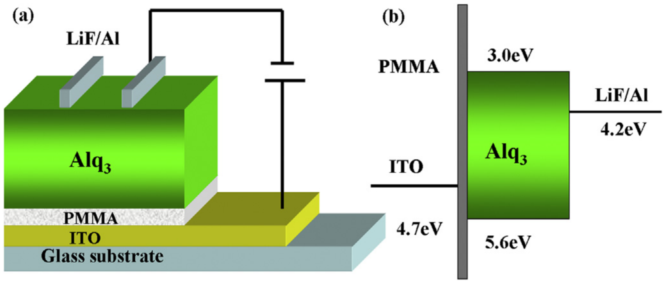

Fig. 1. (a) Device structure of the OLEDs (b) Energy level diagram of the OLEDs.

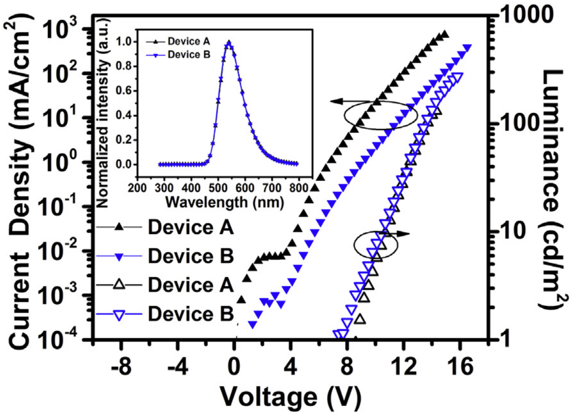

Fig. 2. Current density–voltage–luminance (*J–V–L*) curves for device A (without PMMA) and device B (with PMMA). The inset is the EL spectra of both devices.

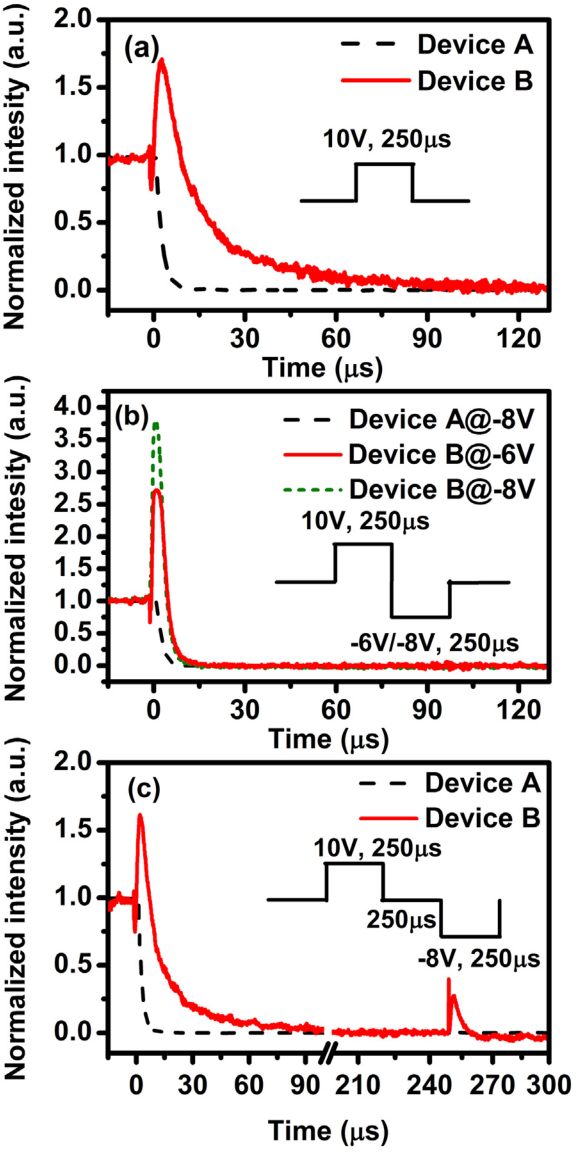

Fig. 3. (a) The transient EL under a single driven pulse of 10 V, 250 μs (b) the transient EL followed by a reversed post-pulse of −6 V/−8 V, 250 μs (c) the transient EL under a reversed post-pulse of −8V, 250 μs with a delay interval of 250 μs.