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Lithium hydroxide doped tris(8-hydroxyquinoline) aluminum as an effective interfacial layer in inverted bottom-emission organic light-emitting diodes

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ABSTRACT

Lithium hydroxide doped tris(8-hydroxyquinoline) aluminum (Alq_3:LiOH) is used as an effective interfacial layer for the fabrication of efficient inverted bottom-emission organic light-emitting diodes (IBOLEDs). When 15% LiOH was doped into an Alq_3 electron-transporting layer, the device properties such as the turn-on voltage, maximum luminance, and device efficiency improved, becoming better than those obtained with LiF doping and comparable to those of β-naphthylphenylbiphenyl diamine (NPB)/Alq_3-based OLEDs with conventional geometry. Electrical analysis reveals that LiOH-doped Alq_3 layers have an enhanced electron injection and transport ability. X-ray and ultraviolet photoelectron spectroscopy results clearly show that the dipole layer formed at the indium tin oxide (ITO)/organic interface contributed to the reduction of the ITO work function, resulting in a decrease of the electron injection barrier. The enhanced electron injection and transport efficiency improves the charge carrier balance in IBOLEDs and leads to better device efficiency. Furthermore, improved morphology of the organic layer can be obtained by doping LiOH into Alq_3, which improves device operational stability under thermal stress.

1. Introduction

Organic light-emitting diodes (OLEDs) have attracted a lot of attention for application in full-color displays, backlights, and solid-state lighting sources. For full-color displays, the fabrication of large-size active-matrix (AM) OLEDs is of interest [1,2]. Amorphous silicon (a-Si) thin-film transistor (TFT) backplanes are more appealing than low-temperature polycrystalline silicon (LTPS) for developing large-size AMOLEDs because of their good uniformity and low manufacturing cost [3,4]. Since a-Si TFT backplanes have n-channel transistor characteristics, the inverted OLED structure with a bottom cathode is preferred over conventional OLEDs for integration with n-channel TFTs [5–7].

For inverted OLEDs, finding a suitable bottom cathode has been a challenging task. Several researchers have chosen a reflective metal (such as Al) as the bottom cathode and have tried to sputter transparent indium tin oxide (ITO) onto organic layers to fabricate inverted top-emission OLEDs (ITOLEDs) [8,9]. Nevertheless, the sputter deposition of ITO is known to induce radiation damage in the organic layers [10]. ITO is also used as the bottom cathode in inverted bottom-emission OLEDs (IBOLEDs) because of its transparency. However, its work function is much higher than the lowest unoccupied molecular orbital of organic materials, which can limit the injection of electrons. In order to enhance electron injection, various methods have been reported, such as the insertion of thin metallic layers with low work functions (such as Mg and Ca) to lower the injection barrier [11], and the use of electron transporting layers (ETLs) doped with Li or Cs to produce ohmic injection via band bending at the interfaces [12,13]. Nevertheless, such methods can cause operation instability induced by the oxidation of the metal or the diffusion of metal dopants [14]. Recently, it has been shown that the use of alkaline metal salts such as cesium carbonate (Cs_2CO_3) or cesium hydroxide (CsOH), either individually vacuum deposited or co-deposited with ETLs, leads to better electron injection and transport properties, and such salts have thus been applied in conventional OLEDs and IBOLEDs [15–17]. However, other alkaline metal compounds used as dopants to improve electron injection and transport in IBOLEDs have seldom been reported [18]. In a previous work, we have reported the advantage of interfacial LiOH layer between ITO anode and β-naphthylphenylbiphenyl diamine (NPB) hole transport layer on electrical properties of conventional OLEDs [19]. The present study reports the effect of using an LiOH-doped Alq_3 (Alq_3:LiOH) layer for IBOLED applications. The electron transport in the Alq_3:LiOH layer is analyzed based on the space-charge-limited current (SCLC) model. Ultraviolet photoelectron spectroscopy (UPS) and X-ray photoelectron spectroscopy (XPS) measurements were performed on ITO/Alq_3:LiOH films to elucidate the changes in electronic states and determine the variation in the vacuum energy level, which reflects the change of the electron injection barrier. Atomic force microscopy (AFM) experiments were

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conducted on organic films to determine the changes in the surface morphology.

2. Experimental details

ITO-coated glass substrates (Merck Display Technologies) with a film thickness of 0.2 μm and a sheet resistance of approximately 15 Ω/square were used. Prior to organic film deposition, the substrates were scrubbed in a detergent solution (Merck Extran). They were then ultrasonically cleaned with detergent, de-ionized water, acetone and isopropanol, in sequence. Finally, the substrates were blown dry with nitrogen gas and then treated by UV-ozone prior to use. The electroluminescent and electron-only devices fabricated in this work had the following configurations: ITO/Alq_3:LiOH, or lithium fluoride (LiF) (10 nm, x%)/tris(8-hydroxyquinoline) aluminum (Alq_3) (20 nm)/NPB (40 nm)/MoO_3 (6 nm)/Al (100 nm) and ITO/Alq_3:LiOH or LiF (10 nm, x%)/Alq_3 (20 nm)/Al (100 nm). For comparison, an OLED with a conventional geometry of ITO/MoO_3 (6 nm)/NPB (40 nm)/Alq_3 (30 nm)/LiF (1 nm)/Al (100 nm) was also fabricated. A schematic of IBOLEDs was shown in the inset of Fig. 1(a). LiOH or LiF doped into Alq_3 as the electron injection layer (EIL) and MoO_3 as the hole injection layer were used in the IBOLEDs. All organic layers, inorganic layers, and metal anode were deposited using thermal evaporation at room temperature. The evaporation rate and film thickness were checked by quartz crystal monitor and calibrated by a surface profiler (Tencor Alpha-step IQ). The active area of the devices was 2.5×2.5 mm^2.

The interface electronic structure and variation in the valence band were determined using a VG Scientific Sigma probe photoelectron spectrometer using a monochromatic Al Ka X-ray source (1486.6 eV) for XPS measurement and a He discharge lamp (UV light of 21.2 eV) for UPS measurement, respectively. The low voltage electron flood gun in the system was used for charge compensation if the sample was charged slightly. The Fermi level of the UPS system was measured on a gold film. The surface morphology of the films was analyzed using AFM (Dimension 3100, Veeco Instrument, Santa Barbara, CA). The current density–voltage (J–V) and luminance–voltage (L–V) characteristics of the devices were measured with a source meter (Keithley-2400) and a luminance meter (LS-100). All J–V–L measurements were carried out at room temperature and in the ambient atmosphere without any protective coatings.

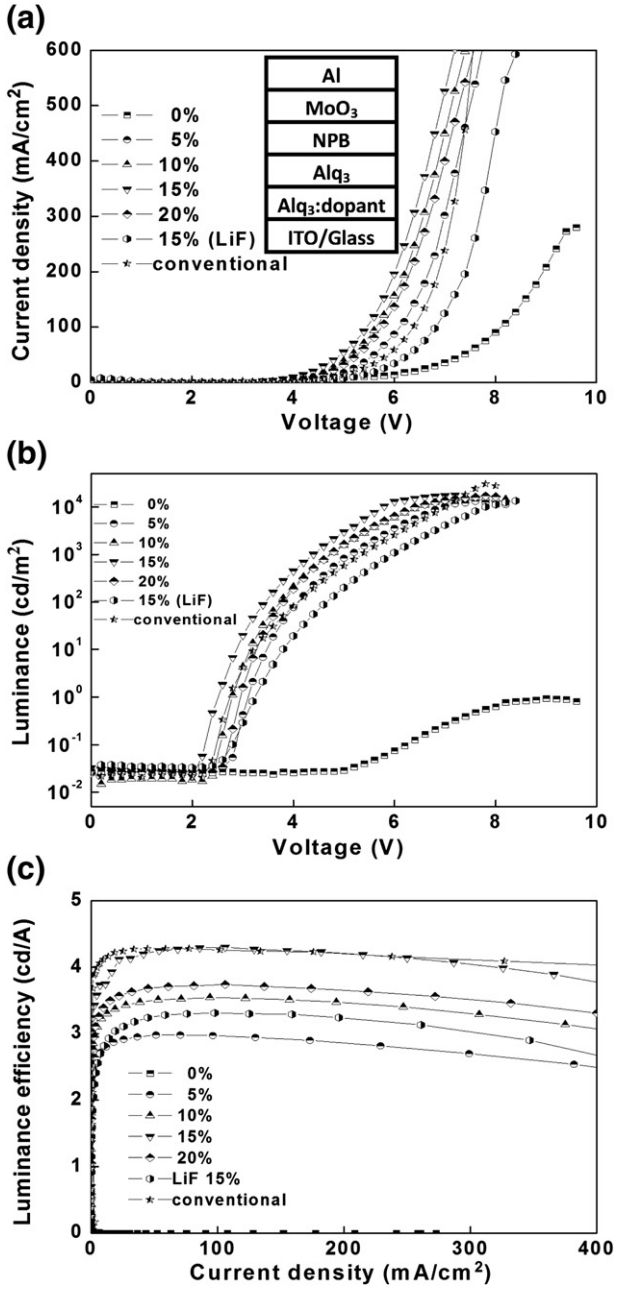

Fig. 1. (a) J–V, (b) L–V and (c) η–J characteristics for ITO/Alq_3:LiOH or LiF (10 nm, x%)/Alq_3 (20 nm)/NPB (40 nm)/Al (100 nm) IBOLED devices and the conventional OLEDs. Inset of (a) shows a schematic of the IBOLED.

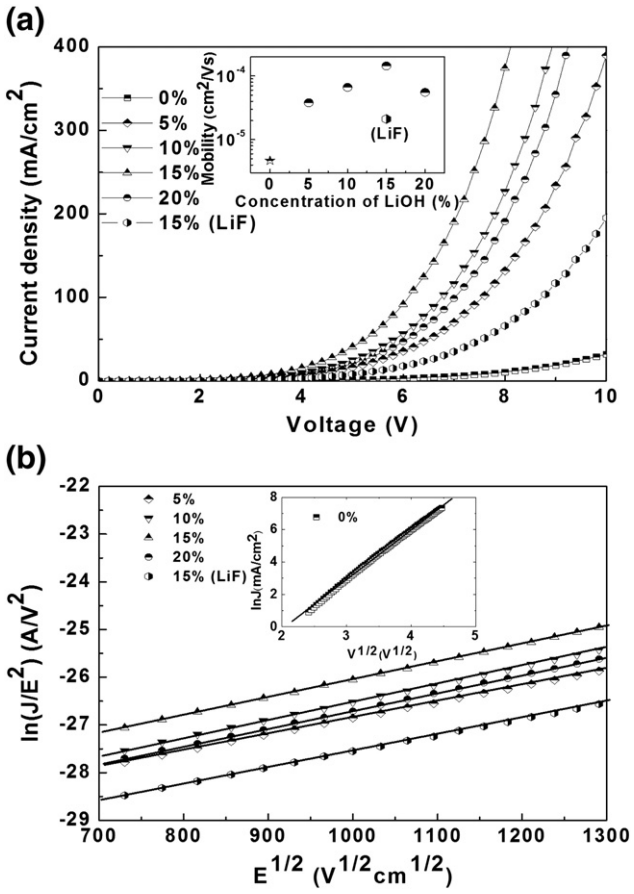

Fig. 2. (a) J–V and (b) J/E^2–$\sqrt{E}$ characteristics for ITO/Alq_3:LiOH or LiF (10 nm, x%)/Alq_3 (30 nm)/LiF (1 nm)/Al (100 nm) electron-only devices. Inset of (a) shows mobility variations with the concentration of LiOH at 1 MV/cm. Inset of (b) shows $\ln J$–$\sqrt{V}$ characteristic of the undoped sample.