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Enhancement of hole injection with an ultra-thin Ag_2O modified anode in organic light-emitting diodes

Xiao Buwen[a,b], Shang Yafeng[b], Meng Meng[a], Li Chuannan[a,*]

[a]National Laboratory of Integrated Optoelectronics, Jilin University, Changchun 130012, China
[b]Jilin Sino-Microelectronics Co., Ltd, Jilin city 132013, China

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Abstract

The interface between the organic layer and the Indium Tin Oxide (ITO) layer of an organic light-emitting diode (OLED) is crucial to the performance of the device. An ultra-thin Ag_2O film, used as an anode modification layer, has been employed on ITO surface through the UV-ozone treatment of Ag films. The insertion of this thin film with higher work function enhances the hole injection in the organic light-emitting diode and improves the performance of the devices effectively. The maximum electroluminescence (EL) efficiency of the device with the Ag_2O film is 4.95 cd/A, it is about 60% higher than that of the device without it.

Keywords: Organic light-emitting diode (OLED); Anode modification; Ag_2O

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1. Introduction

Organic light-emitting diode (OLED) is a very attractive candidate as display devices and for various applications, because it has a lot of merits such as low power consumption, light weight and thinness. Since the first report on the efficient bright emission obtained from a bi-layer organic device [1], considerable progress has been made in improving the material performance and in optimising the device structure. It is widely recognised that the I–V characteristics of the organic EL devices were governed by the carrier injection processes, and the properties of OLED could be improved by modification of the interface between the electrode and organic layers. Towards this goal, some organic materials and inorganic insulating materials have been adopted as hole injection buffer layers inserted between the Indium Tin Oxide (ITO) anode and the organic layer, such as copper phthalocyanine (CuPc) [2–4], polyaniline [5,6], Al_2O_3 [7], and so on. All the buffer layers can improve the OLEDs performance from several aspects, such as suppressing noisy leakage current, reducing the operating voltage, and enhancing the thermal stability and quantum efficiency. However, little has been reported about the semiconductive inorganic thin film as a buffer layer.

In this work, a semiconductive film (Ag_2O) [8] has been used to act as an anode modification layer, through the comparison between the device with the Ag_2O layer and that without it, the former device appears better in performance. We attributed it to the ITO/Ag_2O anode which enhances the hole injection substantially.

2. Experiments

The ITO-coated glass substrate was first cleaned by the ethanol-impregnated paper with mechanical rubbing and then cleaned sequentially with the acetone, ethanol and deionised (DI) water. After rinsing with DI water, the ITO glass was blown dry with filtered nitrogen. Then an

* Corresponding author. Tel.: +86 431 5168240-8217; fax: +86 431 5168270.
E-mail address: bw_xiao@sohu.com (L. Chuannan).

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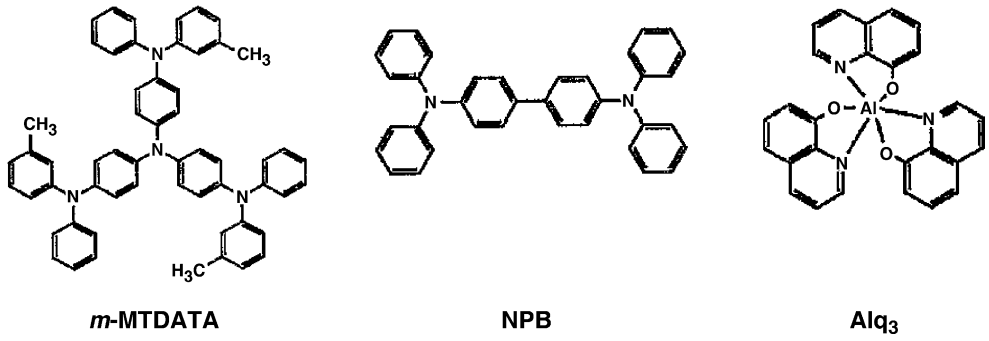

Fig. 1. Molecular structures of organic compounds for OLEDs.

ultra-thin Ag film with thickness of 1 nm was deposited by thermal evaporation using shadow mask. The ITO substrate with Ag film or that without Ag were sent into the UV-ozone chamber for 1 min treatment, the main purpose of this process is to form Ag_2O on the ITO with Ag film through the reaction of $2Ag_{(s)}+O_{3(g)}\rightarrow Ag_2O_{(s)}+O_{2(g)}$ [9,10], the UV emission is generated from the UV lamps (40 W). Following, organic layers of 4,4′,4″-tris {*N*,-(3-methylphenyl)-*N*-phenylamin}triphenylamine (*m*-MTDATA)(30 nm), *N*,*N*′-bis-(1-naphthyl)-*N*,*N*′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB)(20 nm), tris(8-hydroxyquinoline) aluminium (Alq)(50 nm), were deposited on the ITO with Ag_2O in a high vacuum (10^{-6} Torr) thermal deposition system. The layer thickness and the rate of the deposited materials was monitored by an oscillating quartz thickness monitor, and the deposition rate was maintained at 0.1–0.2 nm/s. Finally, a LiF (1.0 nm)/Al (150 nm) cathode were vapor-deposited at a background pressure of 10^{-6} Torr after all the organic films deposited. In order to compare, we named the above device as device (c), and other two devices were fabricated on the bare ITO substrate simultaneously by the same way, the device ITO/NPB (50 nm)/Alq (50 nm)/LiF (1.0 nm)/Al (150 nm) named device (a) and the device ITO/(*m*-MTDATA)(30 nm)/NPB (20 nm)/Alq (50 nm)/LiF (1.0 nm)/Al (150 nm) named device (b), respectively. Electroluminescent spectra and commission international De L'Eclairage (CIE) coordination of these devices were measured by a PR650 spectroscan spectrometer. The luminance-current density–voltage characteristics were recorded simultaneously with the measurement of the EL spectra by combining the spectrometer with a Keithley model 2400 programmable voltage-current source. All the measurements were carried out at room temperature under ambient conditions.

3. Results and discussion

All these three devices emit green light. Fig. 1 shows the chemical structures of the organic materials. *m*-MTDATA, NPB act as the hole injection layer (HIL) and hole transporting layer (HTL), respectively, Alq as electron transporting layer (ETL) and emitting layer (EML). The current density–voltage characteristics and the luminance–voltage characteristics of these devices under forward bias are shown in Fig. 2. All these three devices exhibit typical rectifying characteristics and the brightness of device (a) is the lowest at the same driving voltage. As well known that *m*-MTDATA with very low solid-state ionisation potential (Ip) of 5.1 eV is an very effective hole injection organic material and can improve the brightness of the device dramatically [11], it was well proved in our experience by comparing the device (a) with (b). However, we also know that the work function of ITO is only approximately 4.7 eV, decreasing the interface barrier between ITO anode and organic layer is a valid way to improve the injection efficiency. Generally, although high work function metal such as Au or Pt maybe the idea anode material, it is incapable as anode of OLEDs not only its poor transparency, but also dipole barriers between the metal and organic layer [12]. Ag is also not considered as ideal hole-injecting anode due to its rather low work function (~4.3 eV) [10], however, previous investigation of the electronic structures and optical properties of Ag_2O reveal that it exhibits p-type semiconducting properties and has a higher work function (approximately 5.0 eV) than ITO [13,14]. The device (c) was built on ITO glass substrates precoated with Ag (1 nm),

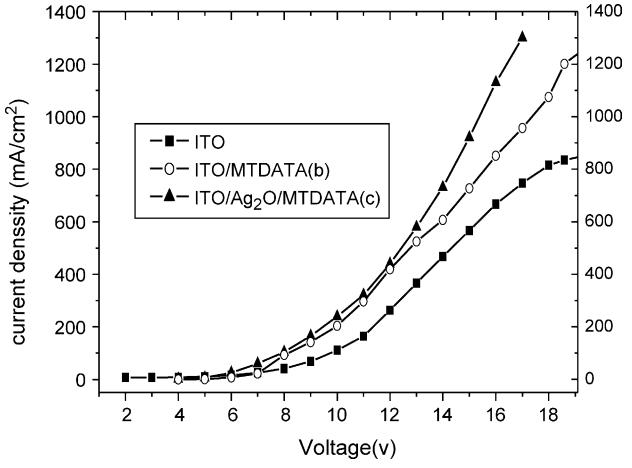

Fig. 2. Current density–voltage characteristics of devices (a)–(c).