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Bottom-emission organic light-emitting diodes using semitransparent anode electrode by O_2 plasma

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ABSTRACT

To improve the performance of bottom-emission organic light-emitting diodes (BEOLEDs), the effect of oxygen plasma treatment duration on the electrical properties of multi-metal Ni/Ag/Ni thin film anode was investigated. The results revealed that a Ni/Ag/Ni thin-film layer formed upon oxygen plasma treatment for 60 s. Our indium-free bottom-emission OLEDs effectively increased the electrical and optical properties by improving their electron–hole recombination and doing a strong micro-cavity effect with the semitransparent multi-metal anode. The green bottom-emission OLEDs show a luminance of 14,280 cd/m^2, a luminous efficiency of 8.5 cd/A, external quantum efficiency 2.6% EQE, a Commission Internationale de L'Eclairage coordinates of (0.32, 0.58) on flexible substrate.

1. Introduction

Organic light-emitting diodes (OLEDs) are fascinating an extensive degree of attention. In particular, OLEDs due to the nature of the organic materials in the application of flexible electronics are one of the most suitable candidates for use in flexible light-emitting devices due to high-brightness, high-contrast, bendable, and low-cost fabrication [1–3]. However, a growing trend towards flexible OLEDs for lighting applications, the structural defects of indium tin oxide (ITO) electrode and the limited supply of indium are major issues for the commercialization of ITO electrode based OLED technology on flexible substrate [4–7]. The brittleness of ITO is also a critical problem that causes mechanical instability of the flexible devices. Another critical issue is the low conductivity of ITO on plastic substrates [8,9]. OLEDs with a large emission area require a low sheet resistivity of the transparent anode which is similar to the conductivity of the cathode. However, when ITO is deposited on plastic substrates, the annealing temperature is limited due to the low temperature threshold resulting from the mechanical stability of the plastic substrate [6,10]. Because of the lower annealing temperature, the conductivity and sheet resistivity of an ITO layer on plastic substrates are significantly declined. Therefore, additional metallic structures, such as ITO/metal/ITO, ITO/metal, transparent conductive oxide (TCO), and TCO/metal/TCO structures, or additional processes are required to produce the required conductivity on plastic substrates [11,10]. For these reasons, the thin metal anode and cathode are desirable to have a thin metal structure which also produces a micro-cavity effect [12,13]. In addition, appropriate multi-metal structures have a low sheet resistivity and a reasonable transparency of the electrode [14].

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Moreover, semitransparent multi-metal structures can have a higher transparency than thin single metal layers [15]. Therefore, suitable material choices for the multi-metal layer can surpass restricted standard ITO in the fabrication of optical electronics.

In our research, multi-metal stack composed of a semitransparent nickel/silver/nickel (Ni/Ag/Ni) surface treated with oxygen plasma were used as the anode in bottom-emission organic light-emitting diode (BEOLED) on flexible substrate. The current density, luminance, luminous efficiency, external quantum efficiency (EQE), Internationale de L'Eclairage (CIE*x*,*y*) coordinates, and EL spectra of flexible BEOLED were characterized and compared to conventional BEOLED with ITO anode on glass substrate.

2. Experimental

In this study, Ni/Ag/Ni thin film anode was formed on PET film in BEOLED device. The Ni/Ag/Ni (3/6/3 nm) anode was fabricated at a rate of 1.0 Å/s by vacuum evaporation through a shadow mask. To investigate the improvement on hole injection, the anode layer was treated with oxygen plasma at 2×10^{-2} Torr and 125 W for four durations: 0, 60, 120, and 240 s. All the organic layers were fabricated by high-vacuum (5×10^{-7} Torr) thermal evaporation of organic materials onto the surface of the Ni/Ag/Ni film after plasma treatment. Furthermore, a 50-nm-thick layer of *N*,*N*′-bis-(1-naphyl)-*N*,*N*′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) was used as the hole transporting layer (HTL), a 45-nm-thick layer of tris[8-hydroxyquinolinonato]aluminum (III) (Alq_3) was used as the electron-transporting layer (ETL), and a 2-nm-thick layer of lithium quinolate (Liq) was used the electron-injecting layer (EIL). The aluminum (100-nm-thick) cathode was deposited at a rate of 10.0 Å/s. The emissive active area of the devices was 3×3 mm^2. All measurements were carried out under ambient conditions at room temperature. The BEOLED of devices I–V were fabricated under five different conditions according to oxygen plasma treatment duration and cathode, as follows: device I (0 s), device II (60 s), device III (120 s), device IV (240 s) with PET/ Ni/Ag/Ni and device V (60 s) with ITO/ glass. The optical and electrical properties of BEOLEDs, current density, luminance, external quantum efficiency, and CIE*x*,*y* coordinates, were measured using a Keithley 2400 Source Meter and a Chroma Meter CS-1000A. The transmittance and reflectance spectra of bare glass, ITO coated glass and Ni/Ag/Ni coated glass were measured by UV–visible absorption spectroscopy (Shimadzu, UV-2450). NiO layers formed by oxygen plasma treatment were analyzed with X-ray photoelectron spectroscopy (XPS; Thermo Scientific, K-Alpha). The resistivity and sheet resistance of Ni/Ag/Ni film were measured using a four-point probe (AIT, CMT-SR2000N). The surface morphology of the NiO film was observed by atomic force microscopy (AFM; Park Systems, XE-150).

3. Results and discussion

The device configuration of the BEOLED were shown as (glass/ITO) or (PET /Ni/Ag/Ni)/NPB/Alq_3/Liq/(Al) in Fig. 1(a).

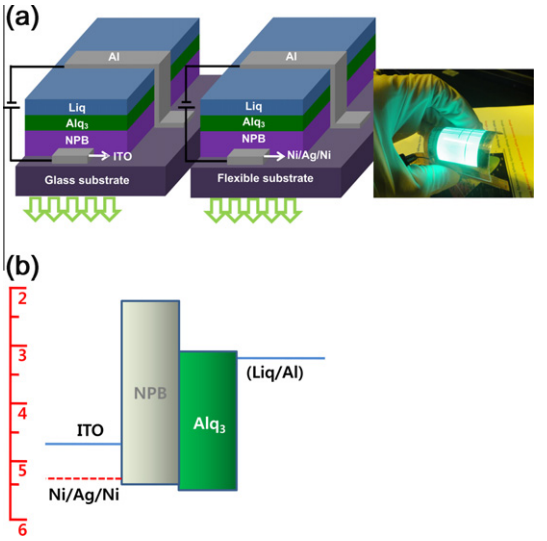

Fig. 1. (a) Device structure of BEOLEDs and (b) corresponding energy band diagram.

Of these layers, to improve hole injection, the Ni/Ag/Ni anode plays an important role because a thin NiO film is

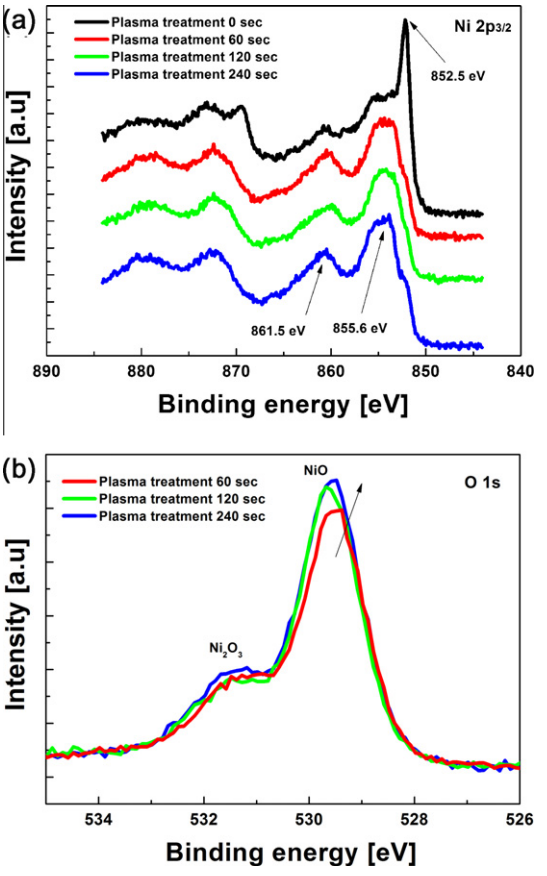

Fig. 2. (a) XPS spectra of Ni $2p_{3/2}$ and (b) O 1s measured from four kinds of NiO layers with different durations by oxygen plasma.