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Surface properties of treated ITO anodes for organic light-emitting devices

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Abstract

The effect of oxygen plasma treatment on the surface properties of indium-tin oxide (ITO) anodes and the changes in surface properties of treated ITO anodes with aging time were investigated by X-ray photoelectron spectroscopy (XPS) and ultraviolet photoelectron spectroscopy (UPS) measurements. It was observed that oxygen plasma treatment increased the oxygen concentration, decreased the carbon concentration and raised the ITO work function, and thereby improved the surface properties of ITO. With the increase of aging time, however, the improved ITO surface properties tended to decay and the ITO work function decreased. In addition, the aging effect of treated ITO anodes on the performance of organic light-emitting devices (OLEDs) was studied with respect to the driving voltage, electroluminescent luminance and efficiency. Experimental results reveal that the ITO anodes aged for various times result in significant differences in electrical and optical characteristics, which become worse as the aging time increases.

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Keywords: Surface properties; Indium-tin oxide (ITO); Organic light-emitting device (OLED)

1. Introduction

Indium-tin oxide (ITO) is an important material in the construction of organic light-emitting devices (OLEDs) because it combines many technologically interesting properties such as high optical transmittance over the visible wavelength region, good electrical conductivity, excellent adhesion to the substrates, and easy patterning ability [1–8]. It is well known that an OLED usually consists of a sandwich structure with the organic thin film deposited onto the ITO transparent anode and covered by patterned top metal cathode contacts [1–8]. Since the organic thin film is in direct contact with the ITO anode, the electroluminescent characteristics of the OLED are greatly influenced by the surface properties

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of the ITO. Many studies have been reported on modifying the surface properties of the ITO. They include plasma treatment [7–11], ultraviolet-ozone cleaning [12,13], wet treatment [7,14], annealing process [15–18], mechanical polishing [7,14,18], and coating treatment with self-assembled monolayers [19,20]. Among them, oxygen plasma was considered as a promising treatment because it results in the highest work function, the lowest sheet resistance, and the smoothest surface [7].

In this study, oxygen plasma treatment was carried out on the ITO anodes for OLEDs. The effect of oxygen plasma treatment on the surface properties of ITO anodes and the changes in surface properties of treated ITO anodes with the aging time were investigated by X-ray photoelectron spectroscopy (XPS) and ultraviolet photoelectron spectroscopy (UPS) measurements. Furthermore, we studied the aging effect of treated ITO anodes on the device performance of OLEDs, in terms of the electrical and optical characteristics of the devices.

2. Experimental details

2.1. Surface treatment of the ITO substrates

Commercial (Merck-Taiwan Co.) ITO-coated glasses with film thickness and sheet resistance of 150 nm and 30 Ω/square, respectively, were used and cut into 20 mm × 20 mm plates in this experiment. Prior to their use, the ITO substrates were routinely cleaned by rubbing in a detergent, rinsing in deionized water, successive ultrasonification with acetone and isopropanol each for 10 min, and finally dried in a flow of nitrogen. Then, the ITO substrates were transferred into the vacuum chamber and exposed to the oxygen plasma in a home-made parallel plate plasma generator at room temperature. The parameters of the oxygen plasma treatment were as follows: excitation frequency, 13.56 MHz; plasma power, 30 W; chamber pressure, 16 Pa; gas flow rate, 20 ml/min; and treatment time, 3 min.

2.2. Surface characterization of the ITO substrates

Using a VG ESCALAB MK II spectrometer, the chemical compositions and work functions of the ITO substrates were measured by XPS and UPS at 0, 2, 21 and 48 h after oxygen plasma treatment, respectively. During the measurements period, the ITO samples were stored in a desiccator with a drying agent at the pressure of 30 Pa and exposed to atmosphere about 2 min when being transferred from the desiccator into the analysis chamber of spectrometer. The ITO work functions were determined from the secondary electron cut-off in the UPS using He I radiation with an incident photo energy of 21.22 eV when the samples were biased at −4 V. Thin evaporated gold films on silicon were used as a reference (work function 5.20 eV) for calibration. The chemical compositions were determined by XPS using a monochromatic Al Kα excitation ($h\nu$ = 1486.60 eV). For the calculation of the atomic concentrations, a linear background correction was done, the peak areas were corrected with empirical sensitivity factors, the instruments transmission function and the specific mean free path lengths [21].

2.3. Fabrication of the devices

In order to study the aging effect of oxygen plasma treated ITO anodes on the device performance, the ITO samples aged for various times were used as hole-injecting electrodes to fabricate OLEDs with an electron-transporting and light-emitting layer of tri-(8-hydroxyquinoline)aluminum (Alq_3), and a hole-transporting 4,4′-bis(*N*-(1-naphthyl)-*N*-phenyl-amino)-biphenyl (NPB) layer. Devices with a configuration of NPB (50 nm)/Alq_3 (50 nm) covered with Mg (20 nm)/Al (150 nm) were prepared by thermal evaporation under vacuum at 2.7×10^{-4} Pa without breaking vacuum. Emission area of each OLED was 9 mm^2. Al was used as a metallic cap to protect oxidation of the reactive Mg underneath. The deposition rates were controlled by a quartz oscillating thickness monitor to be 0.1–0.2 nm/s for organic materials and metals. The Alq_3 and NPB were purchased from Aldrich Company and used as received. After the fabrication, the devices were encapsulated with a glass slide and epoxy sealed under purified nitrogen atmosphere, and the voltage–current–luminance (*V–J–L*) characteristics of the devices were measured at room temperature in ambient air.