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The effect of ITO films thickness on the properties of flexible organic light emitting diode

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Abstract

Indium tin oxide (ITO) thin films were deposited on cyclic olefin copolymer substrate at room temperature by an inverse target sputtering system. The crystal structure and the surface morphology of the deposited ITO films were examined by X-ray diffraction and atomic force microscopy, separately. The electrical properties of the conductive films were explored by four-point probing. Visible spectrometer was used to measure the optical properties of ITO-coated films. The performance of the flexible organic light emitting diode device with different thickness anode was investigated in this study.

Keywords: Indium tin oxide; Cyclic olefin copolymer; Flexible organic light emitting diode; Atomic force microscopy; Electroluminescence

1. Introduction

Indium tin oxide (ITO) thin films were found in a wide range of applications in optoelectronic devices, because of their unique transparent and conducting properties. These films have been deposited by a variety of methods, such as RF (Radio frequency) magnetron sputtering [1–3], direct current (DC) magnetron sputtering [4], pulse-laser deposition (PLD) [5,6] and reactive thermal evaporation (RTE) [7].

Glass is very brittle, cannot be easily deformed, and is too heavy, especially for large area displays. These disadvantages can be overcome using flexible substrates, which are robust, lightweight and cost effective. For these reasons, flexible plastic substrates have been used in flat plan displays such as liquid crystal displays and polymeric and molecular organic light-emitting diodes (OLEDs) [8–12].

Recently, a new amorphous engineering thermoplastic, nominated cyclic olefin copolymer (COC) has been used for many kinds of optical, electrical and mechanical applications, because this plastic has higher transparency, lower birefringence, lower dispersion and lower water absorption [13]. Optically transparent plastics with high glass transition temperatures are desired for many optoelectronic devices. In addition, they need to withstand the growth conditions of metal oxides, while maintaining their mechanical and optical properties.

We reported here a study of the electrical, optical and structural properties of ITO films deposited by RF magnetron sputtering inverse target system on flexible COC substrates as a function of deposition power and film thickness. Different thicknesses of ITO film were deposited on COC substrate as transparent anode electrodes for OLEDs in order to investigate the luminance power efficient for the flexible OLEDs.

2. Experimental

ITO thin films were deposition on COC substrates using a RF magnetron sputtering inverse target system (ULVAC Model: SH-250) at room temperature. The schematic of the deposition system used in this work is shown in Fig. 1. The

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system is equipped with both RF and DC sputtering sources. In this work, only the RF source is used. The chamber is pumped with a turbo molecular pump (TPU510) backed by rotary pump (EDWARDS E2M40). The pressure of the chamber is monitored by an ion gauge combination GI-TL3 analog ionization vacuum gauges.

The target was 4-in. diameter by 0.25 in.-thick sintered disk containing In_2O_3 (90%) + SnO_2 (10%). The distance between the target and substrate is about 50 mm. The cathode and chamber is cooled by running water. The RF power (P) was supplied by RF generator (AFX-600) from ATX tuner (advanced energy, $f = 13.56$ MHz). Argon gas flow was controlled by mass flow controllers at 10 sccm (standard cubic centimeter per minute).

The vacuum chamber is evacuated down to a pressure of 2×10^{-5} Torr prior deposition. The argon reactive gas is then introduced into the chamber and required pressure (2×10^{-3} Torr) is set. After that, the alloy target is pre-sputtered (50 W RF power) in an argon atmosphere for about 10 min with a shutter covering the substrate in order to remove the surface oxide layer formed during exposure to air.

The range of sputtering power was 250–350 W, the variations of power step was 50 W. The deposition process was carried out in a argon gas at low temperature, i.e. the substrate was not heated during and after the film deposition. The total pressure of sputtering gas was maintained at 2×10^{-3} Torr during the film deposition. After deposition, the film was cooled to a temperature below 50 °C under the deposition argon pressure before removing the sample from the chamber.

The ITO film thickness was measured by alpha-step (Dektak 500), allowing the deposition rate be calculated. The resistivity of the film was calculated based on the resistance measured by a standard four-point probe technique at room temperature. The carrier mobility and concentration of ITO films were characterized by Hall Effect measurements using the van der Pauw technique. The optic transparency of ITO films were measured by UV/Vis/NIR Spectrophotometer (JASCO Model: V-570) in range of 300–800 nm. The crystal structure of ITO films was characterized by X-ray diffraction (XRD) (MacScience M03XHF[22], X-ray generator with Cu target 30 kV, 20 mA). Surface analyses of ITO thin film were scanned by atomic force microscope (AFM) and optical microscope after wet etching. The AFM image was performed in *tapping mode* using commercial *tapping mode* etched silicon probes and a 10×10 μm^2 scanner. The images were obtained with a resolution of 256×256 pixels. All AFM measurements were performed on 1×1 μm^2 areas under ambient conditions. The multimode was mounted on an optical table in order to isolate vibration. The root-mean-square roughness, R_q, of the sample surface was calculated from

$$R_q = \sqrt{\sum_i (Z_i - \bar{Z})^2 / N}, \tag{1}$$

where $\bar{Z}$ is the average height of the scanned area and Z_i is the height value of each point. N is the pixel of scanned area.

Different thicknesses of ITO film were coated on COC substrate as transparent anode electrodes for OLEDs. The sequential steps for patterning were carried out. At first step, the cleaning of COC/ITO substrates was subsequently done with isopropane alcohol (IPA), detergent, deionized water and methanol in ultra-sonic bath to remove the organic contaminants that act as fatal impurities on the COC/ITO substrates during the photolithographic patterning process.

The next step is the fabrication of patterned anode plate. The positive photoresist were spin-coated on the substrate to a thickness of about 1000 nm. After baked, it was placed on a mask aligner and exposed to ultra-violet (UV) light for 30 s. Then it was developed in a developer for about 60 s, followed by baking process for 2 min at 100 °C. Subsequently, the samples were etched by 60% hydrochloric acid solution (HCL (aq)). The active area of the device was 5 mm × 5 mm.

The OLED structure consists of a hole transport layer of NPB (*N*,*N*′-bis-(1-naphthyl)-*N*,*N*′-diphenyl-1,1′-biphenyl-4,4′-diamine), and an electron transport and emitting layer of Alq_3(tris(8-hydroxyquinoline)aluminum). The cathode contact deposited on top of the electron transport layer is an alloy of LiF/Al (thickness of LiF and Al was 1 and 500 nm, respectively). The device structure is ITO (x nm)/NPB (60 nm)/Alq_3 (50 nm)/LiF (1 nm)/Al (50 nm). The thicknesses of the deposition organic layer were monitored by a quartz crystal thickness tester. The electroluminescence (EL) characteristics of OLEDs were measured with a Photo Research PR-650 spectrophotometer and Keithley 2400 programmable current/voltage apparatus.

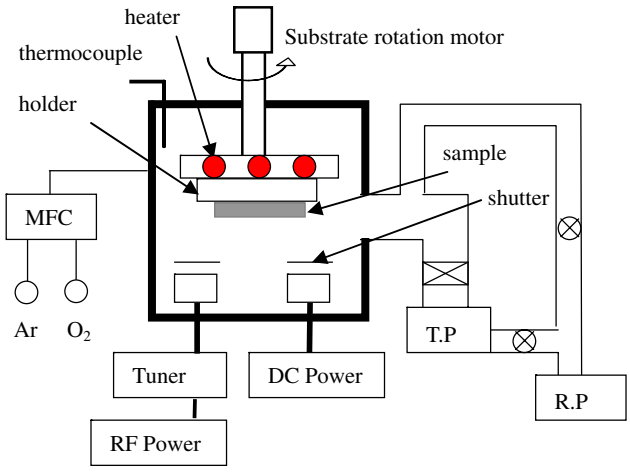

Fig. 1. Inverse target RF magnetron sputtering system.

3. Results and discussion

Fig. 2 shows the variation of the deposition rate and resistivity of the ITO coating versus the deposition sputtering power. The deposition rate was increased as sputtering