Effect of annealing on plastic substrate with ITO used in flexible OLEDs

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Introduction

Organic light emitting diodes (or devices) (OLEDs) have many unique characters such as self-emission of light, practically no dependence on the viewing angle, thin and lightweight structure, and quick response. Many types of OLEDs with these characteristics are now available in the market. For example, some OLEDs have a high contrast ratio of approximately one million. Therefore, these OLEDs are capable of displaying true black color.

The total thickness of the organic layers is only several hundred nanometers. Therefore, the total thickness of device is strongly depend on the thickness of substrate and encapsulation cap or film. One of the key requirements of next-generation flat panel dispays (FPDs) is a thin and lightweight structure. Hence, many studies have attempted to fabricate OLEDs with a plastic substrate [1–2]. In general, the glass transition temperature (T_g) of a plastic substrate is around 100 °C, which is significantly less than the T_g of a glass substrate. Due to a high demand for thin-film fabrication on a plastic substrate, there is a need for low-temperature film fabrication technology and an appropriate heat-treatment or annealing process. In this study, we have attempted to evaluate the effect of annealing on the plastic substrate used in flexible OLEDs.

Experimental

Annealing process for plastic substrate

We chose the biaxial stretching polyethylene naphthalate (PEN) substrate as the plastic substrate because it has a higher T_g than polyethylene terephthalate (PET). The PEN substrate was coated with indium tin oxide (ITO) having a sheet resistance of 12Ω/sq. (PECF-IP, Peccell Technologies Co., Ltd). The thickness of the base film was 200 μm. (Teijin DuPont Films Co., Ltd) [3].

The annealing process was carried out using a hot plate in air at 150 °C calibrated by the thermo-couple.

Fabrication of OLEDs

OLEDs were fabricated on ITO coated PEN films, with and without annealing. 50 nm of 4,4,4-tris(N-3 –methylphenyl –N -phenyl-amino)-triphenylamine (m-MTDATA) was deposited on the substrate by vacuum evaporation Then, a 30-nm-thick Bis[N-(1 -naphthyl)-N-phenyl]benzidine (NPB) film (hole transportation layer) and a 40-nm-thick tris[8 -hydroxyquinolinato] aluminum (Alq_3) film (emissive electron transport layer (ETL) were successively deposited on the substrate. The 40nm of The metal cathode was an Al alloy doped with Li (0.2 wt%). Finally a100-nm-thick layer of Al metal was deposited.

Characteristic measurements

For evaluation, the work function of the films were measured by the PESA (photo-electron spectroscopy in air) system (AC-1, Riken Keiki Co.). The crystallization of the ITO on film was evaluated by X-ray diffraction analysis (model RINT-2500 V, Rigaku) with a Cu target (40 kV, 300 mA) and a graphite monochromator. The luminance-voltage (*L-V*) characteristics of the OLEDs were measured using an organic EL luminous efficiency measuring system (Precise Gauges, EL-1003).

Results and Discussion

Fig.1 shows the X-ray diffraction patterns of the PEN film with ITO obtained after annealing at 150 °C and 200 °C for 3 h. Below 150 °C, ITO was in an

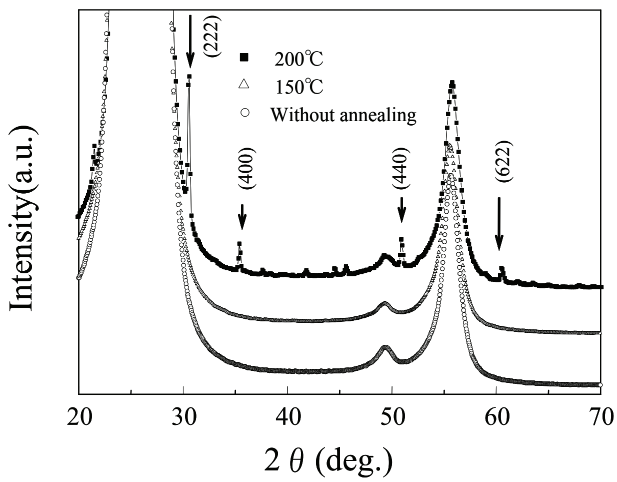

Fig.1 X-ray diffraction patterns of PEN film with ITO.

amorphous state. Its transformation from amorphous to crystalline began at 200 °C. Each arrow in Fig. 1 indicates the peak of ITO (cubic bixbyite structure) of (222), (400), (440), (622).

Fig.2 shows the work function (WF) and resistivity dependency on annealing time for PEN substrate with ITO. There is no big change the work function and resistivity in amorphous ITO film. In these points, hole injection of the device not depend on annealing time in these conditions.

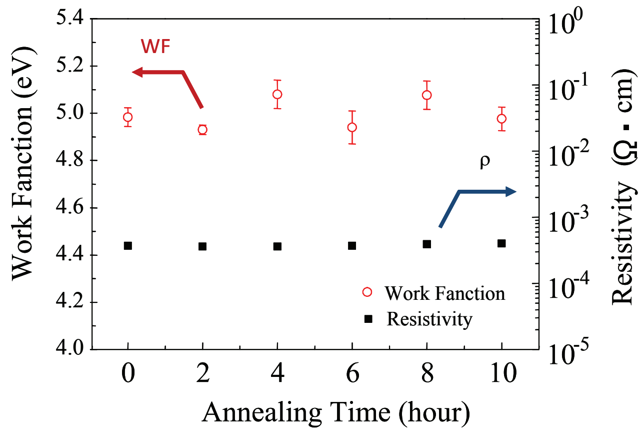

Fig. 2 WF and Resistivity dependency on annealing time for PEN substrate with ITO.

Fig. 3 shows the L-V characteristics of OLEDs after annealing the ITO substrate. The *L-V* characteristics show turn-on voltage shift to higher voltage and highest luminance shift to low luminance after annealing was carried out for more than 2 h.

Fig. 4 shows a plot of the turn-on voltage (1 cd/m^2) against the annealing time of the PEN substrate with ITO. The turn-on voltages shifted to the higher voltage with annealing time.

Shigesato et al. fabricated an amorphous ITO film sputter-deposited with introduction of water vapor, they detected In-OH bonds[4]. These bonds make a role

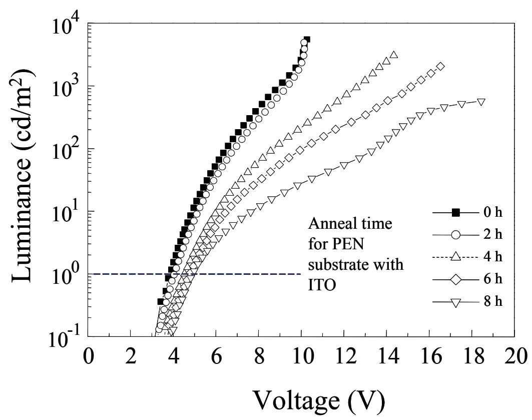

Fig. 3 Luminance-voltage (*L-V*) characteristics of OLEDs.

of terminator of fine ITO crystal. Therefore, introduction of water vapor in sputter-deposition process make promote to amorphous. In our previous study, we suggested that amorphous ITO is not the oxide($In(Sn)_2O_3$) but rather the oxyhydroxide [$In(Sn)_2O_{2.5}$)(OH) or $In(Sn)_4O_5(OH)_2$] [5].

At first, we expected these H_2O gas detected in IR measurement. However, these reaction only occur more than around 260°C which is near the crystallization temperature of ITO, against 150 °C in this study. Therefore, in this study, it is seems that almost moisture are only located at surface at ITO or PEN film.

Anyway, these moisture make the effect of OLEDs on PEN films properties. The annealing of plastic substrate at near T_g is one of the important process for flexible OLEDs.

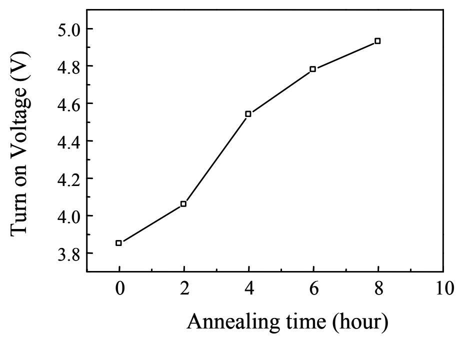

Fig. 4 The turn-on voltage (@1cd/m^2) vs annealing time for PEN substrate with ITO .

Acknowledgments

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