Characteristics of ITO electrode films grown on PET substrate by Roll-to-Roll Facing Target Sputtering system for flexible OLEDs

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Abstract

We report on electrical and optical properties of flexible ITO electrode grown on PET substrate using a specially designed roll-to-roll facing target sputtering (R2R FTS) system at room temperature without conventional cooling drum. Due to effective confinement of high density plasma between ITO targets, we can grow a flexible ITO electrode without cooling drum at room temperature.

1. Introduction

The flexible displays are of considerable interest as the next generation displays due to their lightweight, robust profile, ability to flex, curve, roll, and fold for portability, and ultimate engineering design freedom. To obtain high-performance flexible display on a polymer substrate, it is necessary to prepare flexible ITO electrode with a low resistivity, high transmittance and superior flexibility. Until now, amorphous ITO electrode grown by roll-to-roll sputtering or conventional DC/RF sputtering have been widely used as the flexible electrode in flexible OLEDs. However, conventional roll-to-roll sputtering system has a large size of cooling drum to decrease the polymer substrate temperature. For this cooling drum system, roll-to-roll sputter should be fabricated using large volume chamber. Therefore, the low temperature roll-to-roll sputtering technology without cooling drum system has been the subject of considerable attention as a continuous ITO electrode deposition [1].

In this work, we investigated electrical, optical, structural, and the surface properties of flexible ITO electrode grown on the PET substrate using a specially designed roll-to-roll facing target sputtering (R2R FTS) system. Without substrate cooling system, we can obtain high quality flexible ITO electrode with resistivity of 1.3 x 10^{-3} Ω-cm and transmittance of 89 % at 550 nm. This indicates that the R2R FTS technique is a promising continuous TCO sputtering process in the fabrication flexible OLEDs.

2. Experimental

The amorphous ITO electrode with a thickness of 200 nm was deposited on a flexible PET substrate using a specially designed roll-to-roll facing target sputtering system. Figure 1 shows picture of R2R FTS system equipped with facing cathode, rewinding roll, and unwinding roll system for deposition of flexible ITO electrode on roll type PET substrate.

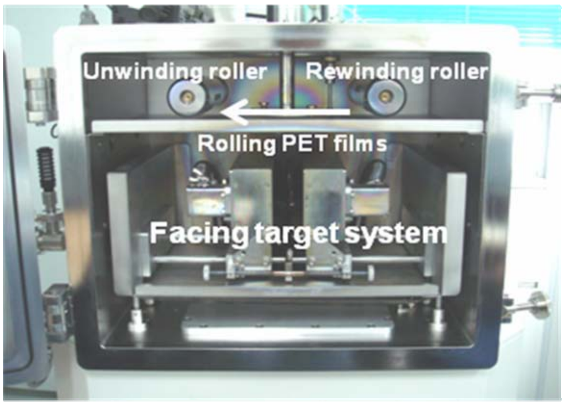

Fig. 1. Pictures of roll-to-roll facing target sputtering (R2R FTS) system.

Facing target sputtering system with a configuration of vertically parallel facing ITO targets and a PET substrate perpendicular to the ITO target plane has been designed to realize plasma damage-free and low temperature deposition on roll type PET substrate. R2R FTS system is developed by combining each advantage of R2R sputter and FTS system for applying in continuous ITO sputtering. In particular, the cooling drum system is not necessary in the R2R FTS system because the ITO electrode could be deposited at room temperature due to effective confinement of high density plasma between ITO targets.

The 200 mm width PET substrate with a thickness of 188 μm was passed repeatedly above the facing target by motion of unwind roller for the deposition of ITO electrode during R2R FTS process. The distance between two facing ITO (10 wt% SnO_2+90 wt% In_2O_3) target is fixed at 70 mm constantly. The ITO film was sputtered on the rolling PET substrate as a function of the DC power and Ar/O_2 ratio. The electrical properties of ITO were measured by means of a four point probe and Hall measurement at room temperature. The optical transmittance was measured in the wavelength range of 250 to 800 nm by a UV/visible spectrometer. The surface morphology of the ITO electrode was analyzed using a field emission scanning electron microscope (FESEM). To investigate the structural properties of a flexible ITO electrode, x-ray diffraction (XRD) examination were performed. Furthermore, the flexibility of the a-ITO electrode was analyzed by a laboratory made bending test system. The samples were clamped in a semicircle two parallel plate. One plate was mounted to the shaft of a motor, while the other was fixed to a rigid support. The distance of stretched mode was 80 mm and that of bended position was 30 mm. The bending radius was approximated to 8 mm and the bending frequency was 1 Hz. During bending test, the resistance of the samples was measured by a multi-meter.

3. Results and discussion

Figure 2 shows the sheet resistance and resistivity of the a-ITO electrode film grown by R2R FTS as function of DC power at constant working pressure of 3 mTorr, rolling speed of 0.5 cm/sec, and Ar/O_2 flow ratio of 20/1 sccm. It was found that the increase of DC power lead to decrease of sheet resistance and resistivity due to increase ITO film density. The improved electrical properties of flexible ITO electrode with increasing DC power could be attributed to the enhancement in kinetic energy of sputtered ITO [2]. At 800 W DC power, rolling speed 0.5 cm/sec, and working pressure of 3 mTorr, we could obtain flexible ITO electrode with the minimum sheet resistance of 64.5 ohm/square and resistivity of 1.3×10^{-3} ohm-cm.

Figure 3 exhibited the optical transmittance spectra of the flexible ITO electrode grown as a function of DC power at constant working pressure of 3 mTorr, rolling speed of 0.5 cm/sec, and Ar/O_2 flow ratio of 20/1 sccm. The flexible ITO electrode grown at 800 W shows high transmittance of 88 % at 550 nm wavelength even though it was prepared at room temperature without cooling drum. To obtain transparent ITO film, conventional ITO film was generally grown at a high substrate temperature (200-300 °C) [3].

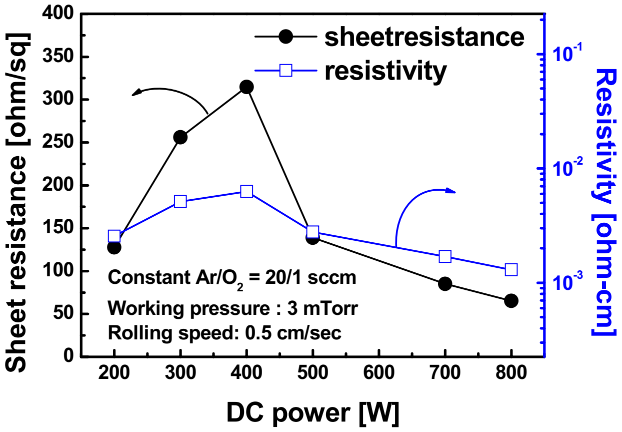

Fig. 2. Sheet resistance and resistivity of R2R FTS grown ITO electrode as a function of DC power.

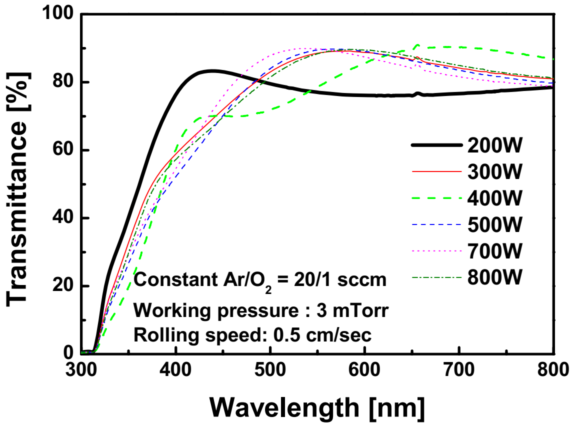

Fig 3. Transmittance of flexible ITO electrode grown by R2R FTS as a function of DC power.

To investigate the structural properties of R2R FTS grown ITO electrode, XRD examination was carried out. Figure 4 show XRD plots of flexible ITO electrode grown on a PET substrate as a function of DC power at constant working pressure of 3 mTorr, rolling speed of 0.5 cm/sec, and Ar/O_2 flow ratio of 20/1 sccm. Regardless of DC power, all XRD plots show only a PET substrate peak, indicating that the R2R FTS grown ITO electrode is an amorphous structure. Due to low substrate temperature during R2R FTS process, all flexible ITO electrode shows completely amorphous structure. The low substrate temperature maintained in the R2R FTS system without cooling drum system could be attributed to the effective confinement of high density plasma, which mainly increases the PET substrate temperature.

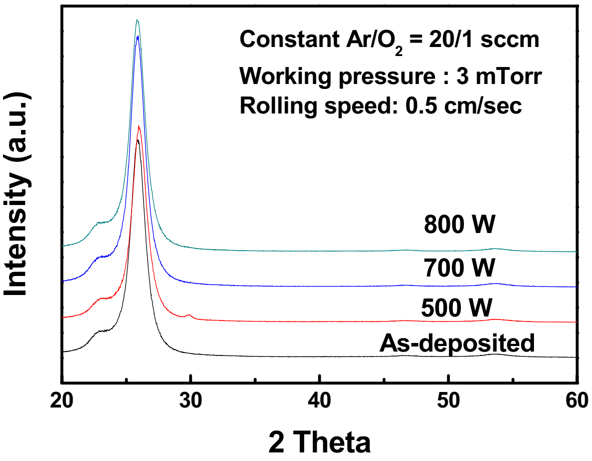

Fig. 4. XRD plot of flexible ITO electrode grown on a PET substrate as a function of DC power.

Figure 5 shows surface FESEM images of the reference ITO and R2R FTS grown ITO electrode on the PET substrate. It is shown that the reference c-ITO in Fig. 5(a) has a relatively rough surface due to preferred orientation of the ITO. However, in case of R2R FTS grown ITO film in Fig. 5(b), the surface is very smooth with very fine grains. In general, the temperature of PET substrate depends on how much thermal energy absorbed per unit area. Therefore, the smooth surface of the R2R FTS grown ITO electrode indicates that the temperature of PET substrate maintained below 50 ^{o}C because facing target sputtering system could minimize plasma damage to PET substrate. The smooth surface of the anode layer is very important in OLEDs and flexible OLED because anode spikes can cause breakdown or shorting of OLEDs [4].

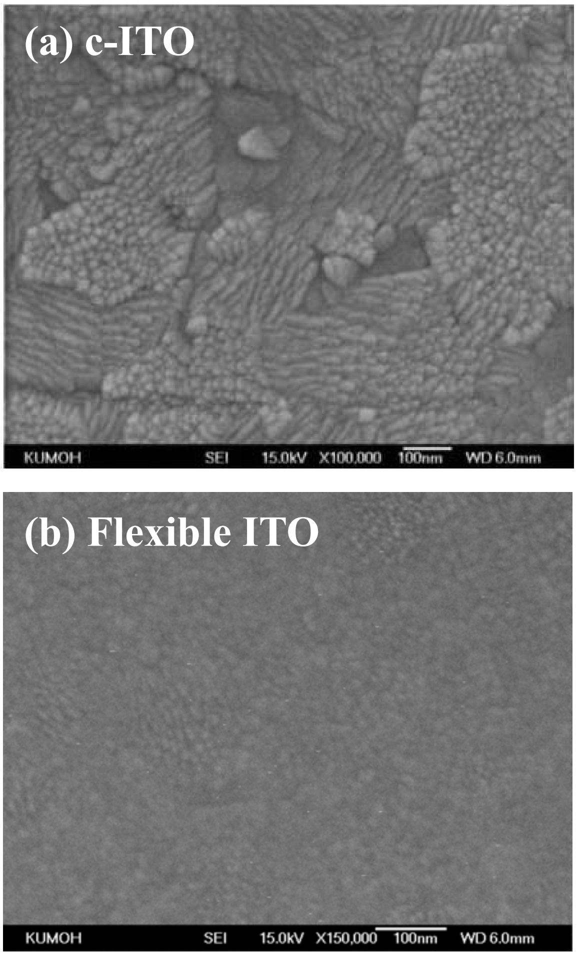

Fig. 5. Surface FESEM image of (a) reference crystal ITO and (b) R2R FTS grown ITO electrode at optimized conditions.

Figure 6 shows that the flexibility of the optimized a-ITO films on a PET substrate, a laboratory-made bending test system was employed. For comparison, ITO films were grown by both conventional sputter system and R2R FTS system, respectively. The change in resistance was expressed as ΔR (=$R-R_0$), where R_0 is the initial resistance and R is the measured resistance after bending. Fig. 6 shows changes in the resistance of the a-ITO film grown by conventional sputtering and roll-to-roll FTS on PET substrate.

It was noteworthy that the $\Delta R/R_0$ value of the ITO film grown by conventional sputtering system on PET substrate increased remarkably at initial bending cycles, due to the generation and propagation of cracks. However, the flexible ITO film grown by R2R FTS on the PET substrate showed a fairly constant $\Delta R/R_0$ value throughout the bending test. The better robustness of ITO films grown by R2R FTS system is attributed to existence of amorphous structure due to low process temperature

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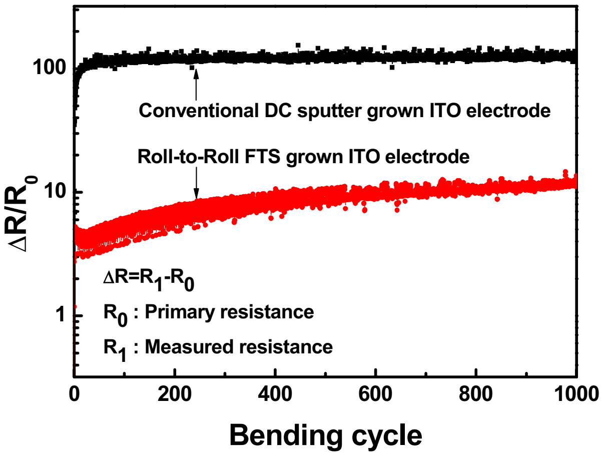

Fig. 6. Bending test results of ITO samples grown by R2R FTS and conventional sputter on the PET substrate.

4. Summary

In summary, this study has demonstrated the applicability of a R2R FTS technique as an alternative to conventional RF or DC sputtering for continuous sputtering of a-ITO electrode on a PET substrate. It was found that both the electrical and optical properties of the a-ITO electrode were critically dependent on the DC power during continuous R2R FTS. In addition, all ITO electrodes shows amorphous and very smooth surface area regardless the DC power, due to low substrate temperature which is maintained by damage-free facing gun. Even though the flexible ITO electrode was at room temperature, we can obtain the a-ITO electrode with a sheet resistance of 64.5 ohm/square and resistivity of 1.3×10^{-3} ohm-cm and optical properties transmittance of 89 % at the 550 nm wavelength. This indicates that the R2R FTS technique is a promising continuous sputtering process for a continuous production of low cost flexible displays.

5. References

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