Continuous Roll-to-Roll(R2R) sputtering system for growing flexible and transparent conducting oxide electrode at room temperature

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Abstract

We have investigated the characteristics of transparent indium zinc oxide(IZO)/Ag/IZO multilayer electrode grown on polyethylene terephthalate (PET) substrates using a specially designed roll-to-roll sputtering system for use in flexible device are described. By the continuous R2R sputtering of the bottom IZO, Ag, and top IZO layers at room temperature, we were able to fabricate an IZO-Ag-IZO multilayer electrode with a sheet resistance of 6.15 Ω/square, optical transmittance of 87.4 %, and figure of merit value of 42.03 10-3 Ω-1. In addition, the IZO-Ag-IZO multilayer electrode exhibited superior flexibility to the RTR sputter grown single ITO electrode, due to the existence a ductile Ag layer between the IZO layers. This indicates that the RTR sputtered IZO-Ag-IZO multilayer is a promising flexible electrode that can substitute for the conventional single ITO electrode grown by bath type sputtering for use in low cost flexible device, due to its low resistance, high transparency, superior flexibility and fast preparation by the R2R process.

1. Introduction

There is currently considerable interest in flexible electronic devices for use as a new generation of renewable energy sources and displays, due to their light weight, robust profile, superior flexibility, ability to be rolled and folded for portability, as well as their easy fabrication using roll-to-roll based thin film technologies. To fabricate high performance and low cost flexible electronic devices, it is necessary to prepare transparent conducting oxide (TCO) with low resistance, high transmittance, superior flexibility and a smooth surface on polymer substrate. In addition, the roll-to-roll based continuous TCO deposition process should be employed in deposition of the flexible TCO electrode for low cost and the mass production. Until now, batch direct current (DC) or radio frequency (RF) sputtering processes have been widely used as the TCO deposition process in flexible devices. However, batch type sputtering process for deposition of the TCO material cannot employ for mass production. In this work, we report on the preparation and characteristics of flexible indium zinc oxide (IZO)/Ag/IZO electrodes grown on PET substrates by the continuous RTR sputtering process at room temperature for the fabrication of low cost flexible electronic divides

2. Experimental

The flexible IZO/Ag/IZO multilayer electrode was deposited on a flexible PET substrate using a specially designed RTR sputtering system at room temperature. Figure 1 shows the schematics of the roll-to-roll sputtering system equipped with a rewind roller, unwind roller, cooling drum, tension controller (load cell), three sputtering guns, two main diffusion pumps and a cold cathode type ion gun system for PET surface treatment. The 200 mm width PES substrate with a thickness of 200 m was passed repeatedly over the cooling drum by the motion of the unwind and rewind roller for the deposition of the IZO/Ag/IZO electrodes during the roll-to-roll sputtering process. The rolling speed of the PET substrate can be kept constant by adjusting the speed of the motor used for the unwind and rewind roller, which is controlled exactly by a load cell, as shown in Fig. 1. Before the sputtering of the bottom IZO layer, the surface of the PET substrate was pretreated by the irradiation of an Ar ion beam at a DC pulsed power of 200 W to enhance the adhesion between the bottom IZO layer and PET substrate. The bottom IZO layer was sputtered on the rolling PES substrate using a ceramic IZO target with a composition of 10 wt % ZnO + 90 wt % In_2O_3 (DNT Korea) at a constant DC power of 800 W, working pressure of 3 mtorr, Ar flow rate of 30 sccm, and rolling speed of 0.3 cm/sec without introducing oxygen gas in order to avoid the oxidation of the Ag target. During the RTR sputtering process, the PES substrate is mechanically attached to the cooling drum in order to keep the substrate temperature below 50°C. Subsequently, a very thin Ag layer was continuously deposited on the bottom IZO layer as a function of DC power of the Ag cathode gun to optimize the Ag thickness. Then, the top IZO layer was continuously deposited on the Ag layer under identical conditions to those used for the bottom IZO layer. Without breaking the vacuum, we are able to prepare the flexible IZO/Ag/IZO multilayer electrode on the PES substrate. For comparison, we also prepared RTR sputtered flexible ITO layer (150 nm) on a PES substrate under the optimized sputtering conditions. The optical transmittance of the flexible IZO/Ag/IZO electrode was measured at room temperature as a function of the Ag DC power by means of a portable four point probe and UV/visible spectrometer, respectively. In addition, the flexibility of the RTR sputter grown IZO/Ag/IZO electrode was analyzed using a bending test system (ZB100, Z-tech). The samples were clamped between two tilted Cu plates, as shown in the inset of Fig. 3. To avoid the formation of cracks in the clamped region, we employed two tilted Cu plates. One Cu plate was connected to the motor for repeated motion, while the other was fixed to a rigid support. The bending radius and frequency were approximately 8 mm and 1 Hz, respectively. During the bending test, the resistance of the samples was measured using a multi-meter.

Fig. 1. Schematics of roll-to-roll sputtering system

3. Results and discussion

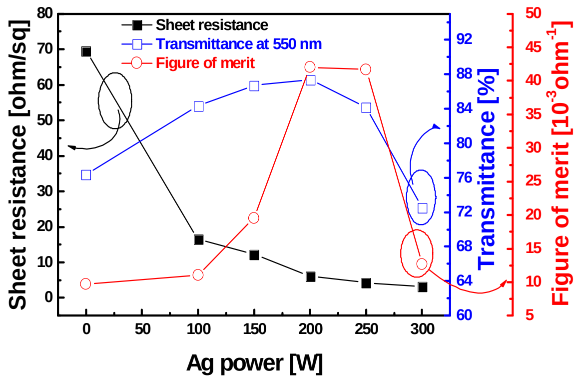

Fig. 2 Sheet resistance, transmittance, figure of merit value of IAI electrode

Figure 2 shows the electrical properties of the R2R sputter grown flexible IZO-Ag-IZO electrode as a function of the Ag DC power. Although the R2R grown IZO electrode without an Ag layer showed a fairly high sheet resistance of 69.5 Ω/square. Above an Ag DC power of 100 W, the flexible IZO/Ag/IZO electrode exhibits a sheet resistance of less then 6.15 Ω/square and transmittance of higher then 85%. Using the transmittance (T) at a wavelength of 550 nm and sheet resistance (R_{sh}) of the flexible IZO/Ag/IZO electrode, the figure of merit (ϕ_{TC}) value ($\phi_{TC} = T^{10}/R_{sh}$) suggested by Haacke was calculated.9 The maximum ϕ_{TC} value ($42.03\times10^{-3}\Omega^{-1}$) was obtained for the flexible IZO/Ag/IZO electrode grown at Ag DC power of 200 W. To compare the flexibility of the R2R sputter grown ITO/PET and IZO/Ag/IZO/PET samples, a laboratory-made bending test system. To avoid the formation and propagation of cracks in the clamped region of the TCO film, we used a tilted clamp, as shown in the inset of Fig. 3. The change in the resistance of the flexible electrode was expressed as (R-R_0/R_0), where R_0 is the initially measured resistance and R is the measured value after substrate bending. It was clearly shown that the R-R_0/R_0 value of the R2R grown ITO/PET sample increased remarkably up to over range within the initial 300 bending cycles, due to the generation and propagation of cracks, as shown in Fig. 3. However, the IZO/Ag/IZO electrode exhibited a constant R-R_0/R_0 value throughout the 10,000 bending cycles, showing a constant resistance during repeated substrate bending. Compared to the amorphous ITO/PET sample, the IZO/Ag/IZO electrode showed a much more stable resistance. Lewis et al. reported that the

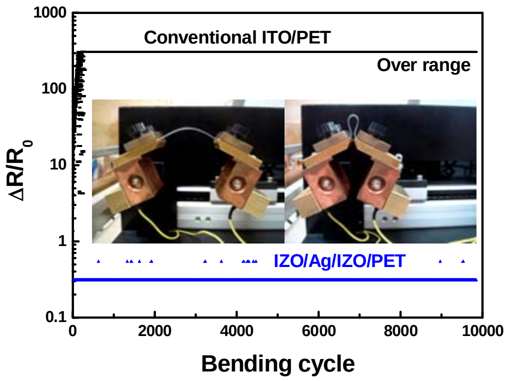

Fig. 3 Resistance change after repeated bending

presence of a ductile Ag layer between the ITO layers provides effective electrical conductivity, even after the ITO is beyond its failure strain (~0.8%), due to the higher failure strain of the bulk-like Ag film (4~50 %).

4. Summary

In summary, we suggested the use of a flexible IZO/Ag/IZO multilayer electrode grown by continuous RTR sputtering at room temperature as a viable alternative to amorphous ITO electrodes for the realization of low cost and high performance flexible devices. Although they were prepared at room temperature, it was possible to obtain high-quality IZO/Ag/IZO electrode with a low sheet resistance, high transmittance and superior flexibility even though the flexible IZO electrode was prepared at room temperature. This indicates that the continuous roll-to-roll process is a promising next generation technique for growing flexible transparent electronic material.

5. References

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