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Flexible transparent oxide electrode on regenerated cellulose

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ABSTRACT

The demand for flexible transparent conducting oxides (TCOs) for optoelectronic applications, such as touch panels, flat panel displays, organic light-emitting diodes (OLEDs) and other mobile devices, has been increasing continuously. To produce flexible TCOs electrodes, amorphous ZnO-doped ITO (ZITO) films were deposited on flexible transparent cellulose, PES and glass substrates by RF sputtering using a single target (In_2O_3 50.7/ZnO 44.4/SnO_2 4.9 mol%). With increasing oxygen ratio during ZITO film deposition, the sheet resistance increased linearly, whereas the carrier density decreased, which may be due to the rough surface of cellulose caused by the regeneration film process. The overall electrical performance of ZITO was found to be comparable to that of the other transparent substrates.
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1. Introduction

Transparent conducting oxides (TCOs) have attracted considerable attention because of their highly reliable and excellent electrical mobility as a transparent electrode in flat panel display devices and green energy devices, such as LCD displays, touch screens, photovoltaic cells, and light-emitting diodes (LEDs). To enhance the visual performance as display and green energy devices, the transmittance and mobility of the electrode layer are important parameters to be considered. As a transparent electrode material, it must transmit visible light over 80% over the entire area. For the electrical performance, it should have a high electrical conductivity in the range, 10^2–10^6 S [1,2]. Unfortunately, metal electrode materials are not transparent when deposited on the transparent substrates. In addition, to ensure transparency through the visible range, it is important to have a large band gap (>3.0 eV). Compared to the TCO materials in electronic devices, polycrystalline silicon exhibits stable electrical characteristics, whereas the overall film uniformity over a large area is still not satisfied. Therefore, to expand the potential of the TCO materials to industrial applications, the deposited films need to conduct electricity and be highly transparent.

Most thin TCO films are fabricated as a transparent electrode layer or a thin film transistor (TFT) structure on glass substrates, which is unsuitable for flexible devices due to the heavy weight and rigidity. Therefore, a flexible TCO-based electrode is another challenge in electronic devices due to performance degradation caused by external bending. For flexible electronic devices, several flexible polymer-based substrates, e.g., non-heat-stabilized polyethylene terephthalate (PET), polycarbonate (PC), polyethersulfone (PES) and polyethylene naphthalate (PEN), have been suggested [3].

Compared to the other polymer-based flexible substrates, cellulose is a natural resource re-discovered as flexible substrate with a range of applications. As flexible electronic devices, amorphous transparent electrodes on sustainable substrates, such as paper and plastic substrates, have attracted a great deal of interest for future electric applications. Recently, cellulose-based materials in electronics, such as actuators, transistors and energy storage devices used for high-performance electronic applications, were reported [4].

This paper presents flexible ZnO-doped TCO on cellulose substrates for electronic applications. Glass and PES were selected as comparison substrates.

2. Experimental details

Thin transparent ZnO doped ITO (ZITO) films were deposited on glass (Corning 1737), PES (Dupont) and regenerated cellulose substrates using a RF magnetron co-sputtering system (ULVAC,

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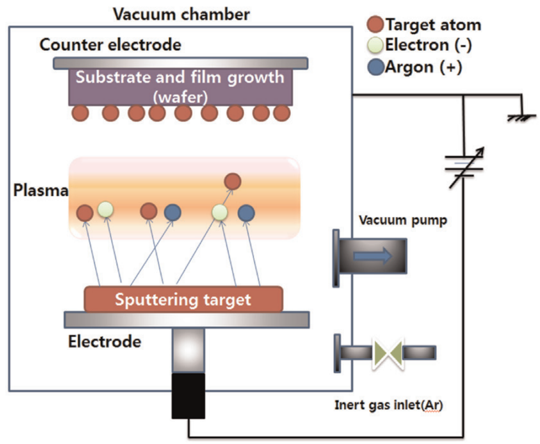
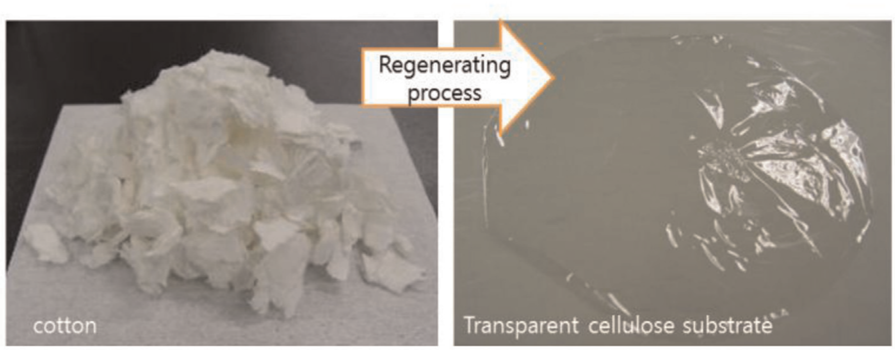


(a)



(b)

Fig. 1. (a) Sputtering system and (b) transparent flexible cellulose substrate used in this study.

MB07-4501) [5]. The flexible transparent regenerated cellulose substrates were prepared from natural cotton cellulose, as reported in a previous study. To resolve the cellulose source, LiCl was resolved in DMAc (*N,N*-dimethyl acetamide, Sigma–Aldrich). The cellulose then was mixed with a LiCl/DMAc solution with a cotton cellulose pulp/LiCl/DMAc ratio of 2:8:90. The cellulose was dissolved in a solvent by heating up to 155 °C with mechanical stirring, followed by cooling upto 40 °C for 2 h. Finally, a transparent cellulose solution was obtained. After a film process using a casting method, thin wet cellulose was regenerated and dried using an IR heater during the stretching process to align the cellulose chains [4].

In this experiment, a single ZITO target (In_2O_3 50.7/ZnO 44.4/SnO_2 4.9 mol%) was used to produce a stoichiometric ZITO film during sputtering. The deposition system was pumped to reach a base pressure $<5\times10^{6}$ Pa using a turbo-molecular pump. To deposit the ZITO films on three flexible substrates, the RF power

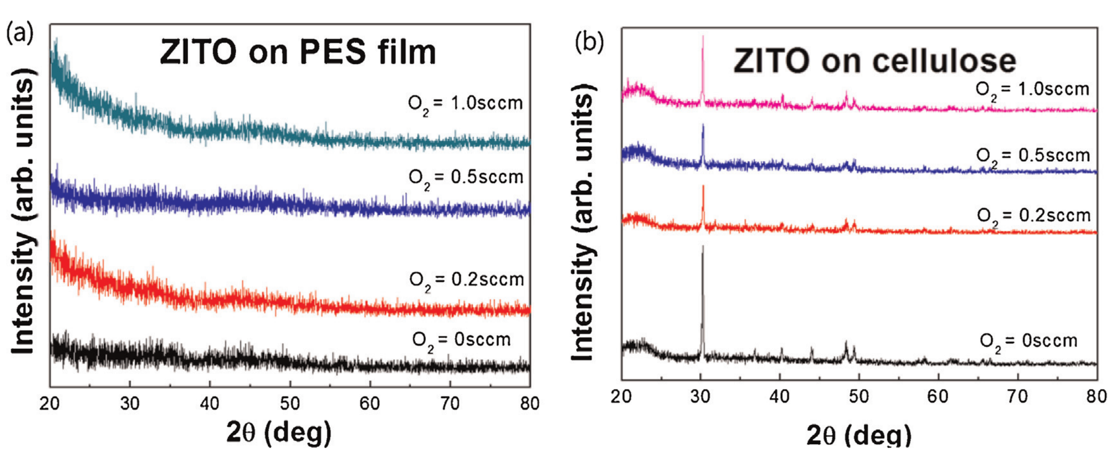


Fig. 2. Measured XRD pattern of the thin ZITO films on (a) PES and (b) regenerated cellulose substrates under different Ar:O_2 ratios.

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