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Influence of power and temperature on properties of sputtered AZO films

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ABSTRACT

Aluminum-doped zinc oxide films (AZO) were deposited on glass substrates by magnetron sputtering. The effect of RF power and deposition temperature on wettability and optical properties of AZO films are studied in detail. The increase of RF power from 60 W to 180 W (power density from 1.54 to 4.62 W/m^2) leads to evolution of (100), (002) and (101) textures of zinc oxide. The XRD results shows increased preferred orientation of (002) plane along c-axis for deposited AZO films. The grain size increases from 14 nm to 23 nm with increase of RF power from 60 W to 180 W and from 17 nm to 25 nm with increase in deposition temperature from 200 °C to 600 °C. The static and dynamic contact angle formed by water and ethylene glycol varies as a function of RF power and deposition temperature. AZO films with an optical transmission 80% to 60%, refractive index 1.49 to 1.51 and band gap values from 3.29 eV to 3.21 eV were obtained in the wavelength range of 350–800 nm. The electric resistivity varies from 3.9×10^{-2} to 1.1×10^{-2} Ω·cm depending upon variation of RF power and deposition temperature.

1. Introduction

The transparent conducting oxide (TCO) thin films have low resistivity, high transmittance in the visible region and high thermal/chemical stability. Due to these properties TCO are broadly used in solar cell, organic light emitting diodes (OLED), touch panel, liquid crystal (LC) flat panel display, plasma display panel (PDP) as well as low-E glass. The TCOs based on zinc oxide (ZnO) has excellent electro-optical performance. Aluminum-doped zinc oxide (AZO, ZnO:Al) thin films are intensively researched to replace indium tin oxide (ITO), because the materials consist of cheap and abundant elements, friendly and nontoxic alternative to the other ZnO-based TCO materials [1–7].

ITO, ZnO:X, SnO_2:X (where 'X' is a dopant) and IZO based TCO films have gained extensive consideration because of their higher energy bandgap (more than 3 eV), which permits for uses in the near-ultraviolet spectral and visible range and also have low resistivity of around $10^{-3}\Omega\cdot$cm. The possible substitutes for ITO and TCO materials are metal films that are very thin in combination with appropriate oxide films like ITO, ZnO or SnO_2 [8]. It was reported that the superior solar cell performances can be obtained using a front contact layer zinc oxide gallium doped (ZGO), which imparts solar cells with efficiencies around 9%, beyond in addition to 28% efficiencies achieved in other TCOs [9].

ZnO based thin films are investigated due to its easy availability in large quantity, safe to be used by human and in any environment. ZnO films can be developed with much naiver crystal-growth technology, subsequently leading to a possibly lower cost for ZnO based devices. ZnO based thin films can be deposited by doping with various elements using spray pyrolysis (SP) technique [10].

ZnO has band energy of more than 3.37 eV and more than 60 meV of exciton binding energy. Zinc oxide (ZnO) is versatile for numerous commercial applications, for example as an additive in various industrial products ranging from plastics, ceramics, glass, cement, rubber, lubricants, paints, ointments, adhesives, sealants, pigments, foods, batteries, first aid tapes, etc. In addition, ZnO has been attractive as an alternative window material for solar cells and thermoelectric element for thermoelectric generators. These devices have been recognized as promising technologies for clean energy production [11]. Currently, there is more curiosity in substituting glass with polymer substrates, mostly in flat-panel display technology, where lower volume, light weight and robustness are important. The investigation of various properties for aluminum-doped zinc oxide (ZnO:Al) thin films produced by RF magnetron sputtering on polymeric substrates observed an increase in electrical resistance depending on number of cracks, as well as the crack width that in turn depended on the film thickness [12].

Wettability has substantiated to be an important property of solid surfaces and has subsequently growing research interest in the last few years. Wetting properties can be modified by deploying the morphology and chemistry of any substrate. By controlling the wettability of surface we can modify the surface behavior between hydrophilicity

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and hydrophobicity depending on specific application [13]. Hydrophobicity and transparency are complicated properties that are inversely proportional to each other. Translucent hydrophobic coatings may be used in several industrial applications such as anti-rusting, anti-wetting, anti-fogging, anti-ice adherence, and moderated friction resistance coatings [14] Ethylene glycol is used as a medium for convective heat transfer in automobiles [15].

The studies for wettability property of water and ethylene glycol on AZO thin films are insufficient in literatures. The purpose of this paper is to reconnoiter this area of AZO thin films specifically with water and ethylene glycol. It is aimed to develop water repellent hydrophobic AZO films that may have potential application as self-cleaning glass. The objective of the current work is to prepare transparent and hydrophobic AZO thin films by reactive RF magnetron sputtering using argon and helium as inert gases. AZO thin films were deposited at different RF power and deposition temperature on corning glass substrate; their effect on structural, wettability and optical properties of deposited films have been explored in this present work.

2. Experimental details

AZO thin films were deposited in custom designed 16″ diameter × 14″ cylindrical vacuum chamber (Excel Instruments, India) on corning glass substrate by RF magnetron sputtering. AZO target of 50.8 mm diameter was kept at a distance of 50 mm from substrate. The flow of argon and helium were used as inert gas and kept constant at 12.5 sccm and 7.5 sccm respectively, which was measured and controlled using mass flow controller (Alicat, USA). The deposition was carried out for 60 min at working pressure of 2.0 Pa. AZO thin films were deposited at RF power of 60 W, 90 W, 120 W and 180 W at deposition temperature of 300 °C; the sample names for these coatings are 60 W, 90 W, 120 W and 180 W respectively. The second set was deposited at temperature of 200 °C, 400 °C, 500 °C and 600 °C at constant RF power of 150 W; the sample names for these coatings are 200 T, 400 T, 500 T and 600 T respectively. During each sputtering experiment, the mass flow rate of inert gas and working pressure inside the chamber was kept constant and cautiously observed since the sputtering current is very sensitive to the pressure of the sputtering gas.

The structural properties of AZO thin films were characterized by X-ray diffractometer (Bruker, Model D2 Phaser). The elemental analysis was done using an energy dispersive X-ray analysis (ZEISS, EVO 18). The surface topography was studied by atomic force microscopy (Nanosurf easyscan2). The wettability properties of AZO thin films were done by contact angle measuring system (Ramehart, Model 290). The optical properties of AZO thin films were recorded by UV–vis–NIR spectrophotometer (Shimadzu, Model UV-3600 plus). The electrical resistivity was measured using two- probe method.

3. Results and discussions

The XRD graphs of AZO thin films deposited at various RF powers of 60 W, 90 W, 120 W and 180 W at constant deposited temperature of 300 °C are shown in Fig. 1(a). Fig. 1(b) shows the XRD graphs of AZO thin films deposited at temperature of 200 °C, 400 °C, 500 °C and 600 °C at a constant RF power of 150 W.

The XRD pattern of AZO thin films deposited at RF power of 60 W show weak (002) peak of ZnO. Huang et al. [16] deposited ZnO thin films at different RF powers of 50 W to 190 W for a fixed deposition time of 15 min. They hardly observed ZnO (002) peak at 50 W but it was seen in all other ZnO thin films deposited at higher powers. So weakly crystalline AZO nanostructures films observed in our case at RF power of 60 W is in agreement with the literature. When the sputtering power is increased to 90 W; (100), (002) and (101) peaks of ZnO are observed. The intensity of (100), (002) and (101) peaks rises when the sputtering power is increased to 150 W. When RF power is increased to 180 W; (100), (002), (101) and (110) peaks of ZnO are observed. This shows that increase of the RF power improves crystallization of AZO thin films thereby resulting in formation of AZO thin films having various orientations. With increase in RF power from 60 W to 180 W, the proportion of ZnO atoms in the chamber increases which will have high kinetic energy thereby leading to evolution of various textures of ZnO.

At temperature of 200 °C; low intense (100) peak and well crystalline (002) peak of ZnO are observed. When temperature is increased up to 600 °C only (002) peak grows whereas (100) peak diminishes gradually. The deposited materials depend on temperature which effects diffusion and mobility of atoms during film growth. The amount of potential phase separation in material and the rate of surface reactions in deposition process are influenced by temperature as reported in literature [17–21].

When the deposition temperature is increased from 200 °C, 400 °C, 500 °C and 600 °C at constant RF power of 150 W, it may lead to mobility of ZnO atoms in the reaction zone with increase in deposition temperature. ZnO atoms may be free to move at higher deposition temperatures of 500 °C and 600 °C aligning themselves in the direction of preferred (002) orientation for ZnO peak. Hence higher deposition temperature (400 °C or more) may have led to separation of orientation along (100) peak of ZnO thin film resulting in preferred orientation along (002) peak for ZnO. Scherrer formula [22] was used to calculate the average crystallite size of AZO thin films as shown in Table 1. It increases from 14 nm to 23 nm when RF power is increased from 60 W to 180 W and from 17 nm to 25 nm when deposition temperature is raised from 200 °C to 600 °C.

The elemental and atomic composition of AZO films determined by energy dispersive analysis of X-rays (EDAX) is shown in Table 1. EDAX detects the presence of O, Al and Zn elements in AZO thin films. The

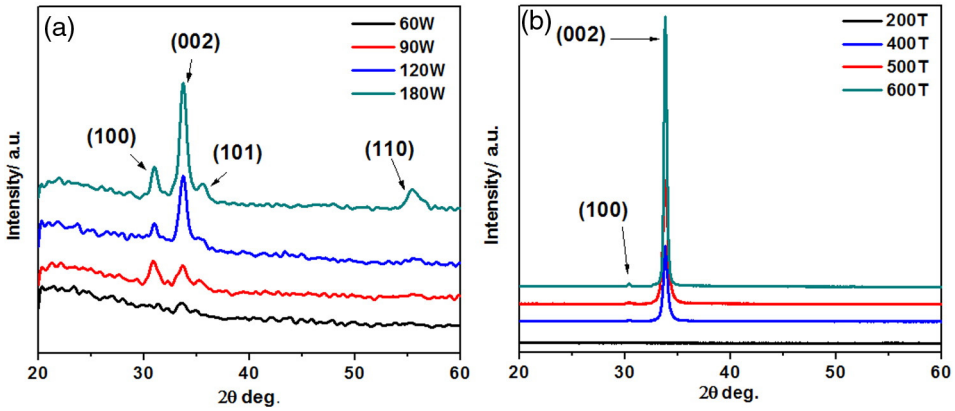

Fig. 1. XRD patterns of AZO films deposited at different (a) RF power and (b) temperature.

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