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Characterization of ZnO:Al layers for applications in thin film solar cells

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Thin films of zinc oxide doped with aluminium were obtained by using the magnetron sputtering technique on glass substrates. The changes in magnetron power influence the structural, optical and electrical properties of the ZnO:Al layers. The deposited films are characterized by very good homogeneity and high optical transmission. Thicker films with larger agglomerates on the surface exhibit lower resistivity with the remaining good transparency.

Keywords: transparent conductive oxide, magnetron sputtering, thin film solar cell.

1. Introduction

In thin film solar cells as well as in other optoelectronic devices like light emitting diodes or touch screens, transparent conductive oxide (TCO) layers characterized by high transparency and good conductivity are commonly applied [1]. In industry the mostly used TCO material is indium tin oxide (ITO) which however is expected to be substituted by more abundant material because of the increasing price and limited supply of indium. The most promising alternative to replace ITO, widely investigated in recent years is zinc oxide (ZnO) doped with trivalent elements such as Al or Ga and In. In the structure of a thin film solar cell, material of this type can substitute ITO as the top electrode or can be a part of double layer back contact consisting of ZnO doped with Al (ZnO:Al) and highly reflective materials such as aluminium or molybdenum. Back contact of double layer structure can also act as a back reflector of unabsorbed light increasing optical path length and finally enhancing the efficiency of the cell [2–4].

To obtain a thin film of TCO material, the following techniques among others are applied: evaporation, sputtering, chemical vapor deposition, sol-gel deposition, spray coating [5]. Compared to other deposition methods, magnetron sputtering, used in this work, provides large area uniform layers with good adhesion to the substrate. Operating the magnetron system allows to optimize numerous deposition conditions such as: substrate temperature, the pressure in the deposition chamber, power and target–substrate distance. The popular substrates usually applied for the growth of solar cell back contact layers using magnetron are glass [3] or stainless steel [2] and polymers [6] that make the cell flexible [7].

This article focuses on the investigation of ZnO:Al layers obtained in magnetron sputtering system on glass substrates. The best deposition parameters were determined by evaluation of two most important features of the layers, *i.e.*, their transmittance and resistance values. The microscopic study proved the correlation between microstructure and surface morphology of the layers and their optical and electrical characteristic.

2. Methods

ZnO:Al films were deposited using radio frequency (RF) magnetron sputtering system Aliance Concept AC 450 on 1 mm thick microscope slide glass cleaned with isopropyl alcohol, after that with ethanol, then rinsed with deionized water and dried in nitrogen. High purity Al-doped ZnO ceramic target with 2 wt% Al_2O_3 of 1016 mm diameter purchased from Bimo Tech was used. The preparation conditions were: presputtering time of 5 min, sputtering time was adjusted for 60 min, magnetron power changed in the range of 90–230 W. The target to substrate distance was 90 mm and the flow of pure Ar gas was set 20 sccm. Using a turbo molecular pump, base pressure was 1×10^{-4} mbar and the working pressure was maintained at 1.8×10^{-2} mbar. All deposition processes were performed at room temperature. The morphology of the layers was evaluated by AFM NT-MDT (Semi-contact, Tip NSG-03). Optical transmittance was determined by using Shimadzu UV-160A spectrophotometer. The electrical resistance was measured at room temperature using the four point probe method with Keithley 2000E multimeter.

3. Results and discussion

In order to obtain layers of different thickness and morphology, we deposited ZnO:Al at different RF magnetron power which is a fundamental factor for optimization of optical and electrical properties.

Figure 1 presents the optical transmittance spectra of ZnO:Al films grown on clean glass at power value in the range of 90–230 W which means 1–2.5 W/cm^2. In the visible region of the incident light, the transmittance is in the range of 75%–90% which is a good value. Occurring of the interference fringes in transmission spectra confirms a very good quality and homogeneity of the layers. The increase in the magnetron power is accompanied by the increase in the layers thickness which is reflected by higher interference frequency. The position of the interference fringes allows to determine the thickness of the studied films basing on the "envelope method" developed by MANIFACIER *et al.* [8] and successfully applied in indium-doped ZnO [9].

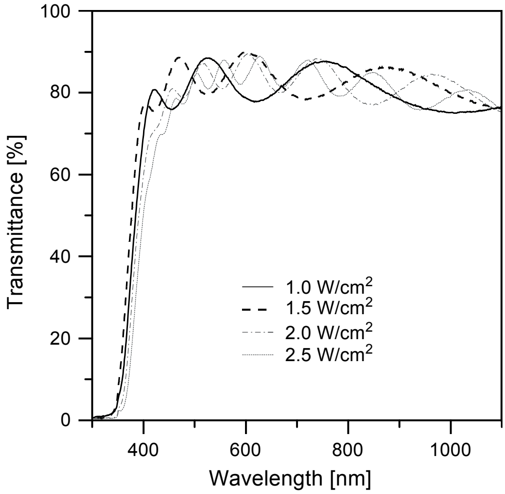

Fig. 1. Optical transmission spectra of ZnO:Al films deposited at different RF power.

The thickness of the layers was determined using the following equation:

$$d = \frac{\lambda_1 \lambda_2}{2(\lambda_1 n_2 - \lambda_2 n_1)}$$

where λ_1 and λ_2 are the wavelengths at the two adjacent maxima or minima of a transmittance curve. Assuming the average value of refractive index for ZnO $n = n_1 = = n_2 = 1.87$ [3], we estimated thickness of the films that is presented in Table 1. As can be seen in Fig. 1, the transmission is not affected by an increase in the films thickness.

T a b l e 1. The properties of the ZnO:Al films obtained at various magnetron power values.

Power [W/cm^2]	Thickness [nm]	Resistivity [Ωcm]	RMS	Agglomerate size [nm]
1	448	42000	5.97	50
1.5	523	11000	8.43	120
2	860	800	12.63	120
2.5	1276	390	18.87	150

Another important characteristics of the investigated ZnO:Al films which is electrical resistance, seems to be significantly influenced by the layers thickness (Table 1). The resistivity values change from 42 kΩ to 390 Ω which corresponds to a threefold increase in thickness. Lower electrical resistivity is usually characteristic for better crystalized films with larger grains in which carrier transport is less influenced by grain

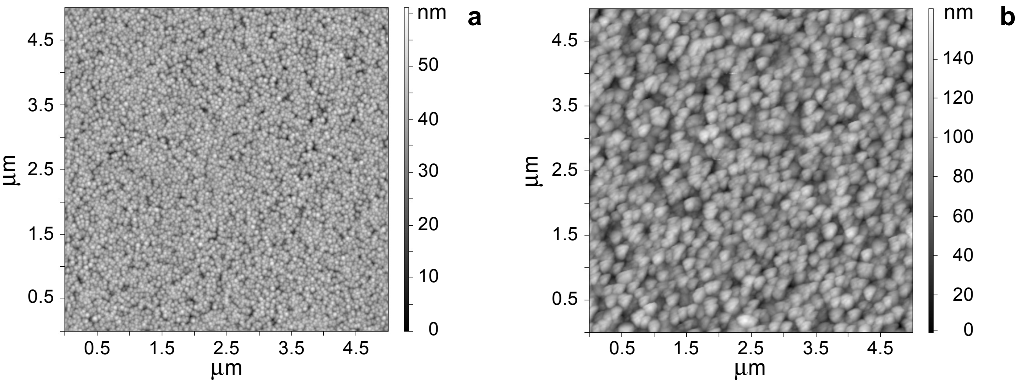

Fig. 2. AFM images of ZnO:Al films prepared at the highest and the lowest RF power: 1 W/cm^2 (**a**) and 2.5 W/cm^2 (**b**).

boundaries [1, 10]. Our investigations, taking into account also AFM images analysis, confirm that observation. Regarding the structural analysis, Fig. 2 presents example AFM images of the thickest and thinnest obtained ZnO:Al layers which reveal the increasing size of agglomerates on ZnO:Al surface with increasing thickness. In all cases, the agglomerates consist of smaller nanoparticles visible at 1×1 µm zoom (not shown here). The more detailed data (root mean square RMS, approximate agglomerate size) derived from AFM analysis are included in Table 1.

4. Conclusions

The ZnO:Al films of good quality and homogeneity were deposited on glass substrates from Al-doped ZnO ceramic target by RF magnetron sputtering at room temperature. The influence of magnetron power on the optical and electric properties of the films were investigated. The increase in the power value results in the increase in the layers thickness and mean size of agglomerates in the surface structure. The changes in films morphology accompaning the growth of power value influence the improvement of resistivity. The obtained ZnO:Al films exhibit high optical transmittance which is crucial for application in thin film solar cells.

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