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An Analysis of RF Sputtering Power and Argon Gas Pressure Affecting on ITiO Films Characteristics

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Abstract
Titanium-doped indium oxide (ITiO) is widely used as a contact for photovoltaics as a high-performance transparent conducting oxide. The titanium-doped indium oxide (ITiO) films were deposited on corning glass substrates using RF magnetron sputtering method. In this research, we verified the effect of RF sputtering power and argon gas pressure on the structural and electrical properties of the films using a 2.5 wt% TiO2 -doped In2O3 target. The deposition rate was in the range of 0 to 35 nm/min under 2.5 to 12.5 mTorr of gas pressure and 100 to 250 W of RF power. As a result of the lowest volume resistivity of 4.9×10-4 Ω-cm and the average optical transmittance of 75% were obtained for the ITiO film, using 200 W RF power and 10 mTorr Ar gas pressure. This volume resistivity is low enough for being transparent conducting layer in various electro-optical devices.
Keywords RF sputtering, Argon gas pressure, Transparent conducting oxide, Titanium-doped indium oxide, TiO_2, In_2O_3

1. Introduction

Interesting of material science for semiconducting transparent thin films is increasing every day and it is one of the most fields applied for industry. Such materials are highly conducting and exhibit high transparency in the visible region of the electromagnetic spectrum. According to their unique characters, transparent conducting oxides (TCOs) are finding wide range of applications in research and industry. They are essential part of technologies that require large area electrical contact and optical access in the visible portion of the light spectrum. The important TCO semiconductors are impurity-doped ZnO, In2O3, SnO2 and CdO, as well as the ternary compounds Zn2SnO4, ZnSnO3, Zn2In2O5, Zn3In2O6, In2SnO4, CdSnO3, and multi-component oxides consisting of combinations of ZnO, In2O3 and SnO2. Sn doped In2O3 (ITO) and F doped SnO2 TCO thin films are the preferable materials for most present applications.

Current work is an attempt to understand the photovoltaic behaviour of as grown and surface modified metal oxide thin films. Indium tin oxide (ITO) and titanium oxide (TiO2) are chosen for the study. These two metal oxides are grown by an industrially viable technique RF magnetron sputtering. The electric and optical properties along with photovoltaic properties of these thin films have been investigated. The other interesting metal oxide thin film undertaken in the present study is titanium oxide (TiO2). It is a bio compatible, wide band gap semiconductor having high dielectric constant, high refractive index, low optical absorption coefficient and high chemical stability. It may be noted that the contrasting nature of electrical conductivity: high conductivity of ITO and high resistivity of TiO2 are chosen for the photovoltaic study. The photovoltaic study gives information on the

photo-generation of electron hole pairs and their transport onto the interface and subsequent charge transfer in these metal oxides.

In this study, we hope to develop a quality of TCO with low resistivity and high optical transmittance, ITiO thin films are deposited on glass substrates by RF magnetron sputtering, which has many advantages, such as high density and low-temperature plasma production at low gas pressures, using a 2.5 wt% TiO2-doped In2O3 target. The influences of RF sputtering power and Ar gas pressure on the structural and electrical properties were mainly studied

2. Method

The ITiO target – 80 mm diameter used in experimental is consisting of 97.5 wt% In_2O_3 and 2.5 wt% TiO_2 with a purity of 99.999%. The chamber was made from stainless steel with internal diameter of 375 mm. The target was placed 60 mm far away from the substrate. The substrate temperature was controlled as circulating through the target and chamber preventing overheating during operation. The sample was applied with variety of RF powers from 100 to 250 W for 60 minutes under the condition of 1×10^{-5} Torr or lower exhausted of the chamber and 2.5-12.5 mTorr of gas pressure.

According to measuring the ITiO film occurred in this research, we used four-point probe (Dasol Eng., FPP=HS8) and hall-effect measurements (ECOPIA HMS-2000) for resistivity measuring. Transmit results of the films were detected by UV spectrophotometer (Hitachi Co., U-3000 with the range of 300-800 nm. Using Cu Kα irradiation (λ = 1.5418 Å) of X-Ray diffractometer (Rigaku Co., D/max 2100H).The particle morphology and size were defined by field emission scanning electron microscope (FE-SEM).

3. RESULTS

At 400°C of substrate temperature and 2.5 wt% of doping concentration, the lowest resistivity was obtained that we used this condition for film deposition.

3.1. Structural properties

We started studying the effect of RF power and Ar gas pressure on the X-ray diffraction patterns of ITiO films to optimize the deposition condition. In Fig. 1, discharging power from 200 w to 400 W at 10 mTorr of Ar gas pressure, strong peak (222) was produced by the thin ITiO films locating at 2θ=30.7°, which is very close to that of the standard In_2O_3 crystal (2θ=30.61°). The very weak peaks of (400) and (440) crystal planes were also observed, indicating a polycrystalline structure. It is a good result that there is no extra peak because of titanium in the indium oxide films occured.

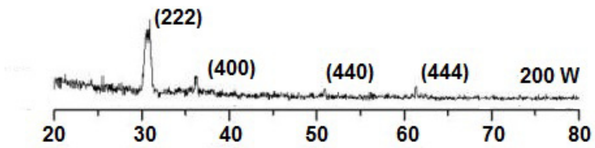

Fig. 1. XRD patterns of the ITiO films deposited at different RF powers.

At sputtering power of 200 W, the peak (222) is very sharp and intense as the crystalline is very pronounced. If the mobility can be increased, the conductivity will become optimum and the optical transmittance will increase while the boundary scattering is reduced.

As sputtering power increases, the effect of high energy electron bombardment on the growing film increases. This increasing electron energy can used to promote the sputtered atoms to grow resulting in the strong (222). The more sputtering power, the more growth of crystalline.

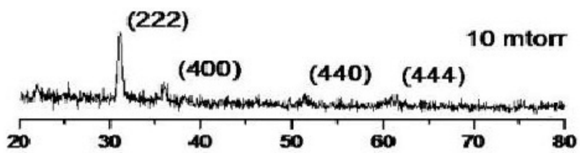

Fig. 2. XRD patterns of the ITiO films deposited at different gas pressures.

In Fig. 2, we studied the film depostition under 2.5 to 12.5 mTorr of Ar gas pressure. The stongest peak is shown in 10 mTorr gas pressure at 200 W RF power. The peak is weaker if gas pressure is higher than 10 mTorr because of high energy sputtering partical bombardment. This result can be explained by the following reasons. As the gas pressure decreases, the mean free path of electron increases. Electrons having the longer mean free path can store higher energy before collisions with Ar gas molecules, and they can produce active ionizations by collision. It follows that many positive ions with higher energy can collide to the target and can sputter more ITiO molecules from the target, giving an increment in deposition rate and an improvement in thin film quality.

Fig. 3 shows the deposition rate of ITiO film in the range of 0 nm/min to 35 nm/min under 100 to 250 W of RF power. At this condition of RF power, the number of ITiO atoms generated from the target by sputtering and the possibility of the ITiO atoms arriving on the substrate without hindrance by collisions increase. The highest deposition rate was 30 nm/min and it was obtained at the conditions of 200 W of RF power.

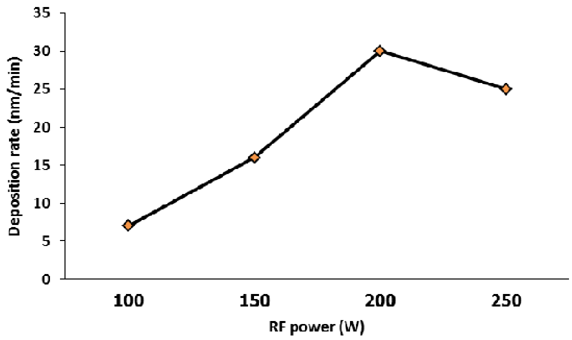

Fig. 3. Deposition rate of ITiO film at various RF power.

The depositio rate of ITiO film was obtained around of 0 nm/min to 35 nm/min under 2.5 to 12.5 mTorr of gas pressure as shown in Fig. 4. In this condition of gas pressure, the number of ITiO atoms generated from the target by sputtering and the possibility of ITiO atoms arriving on the substrate without hindrance by collisions increase. The highest deposition rate was 32 nm/min and it was obtained at the conditions of 10 mTorr of gas pressure.

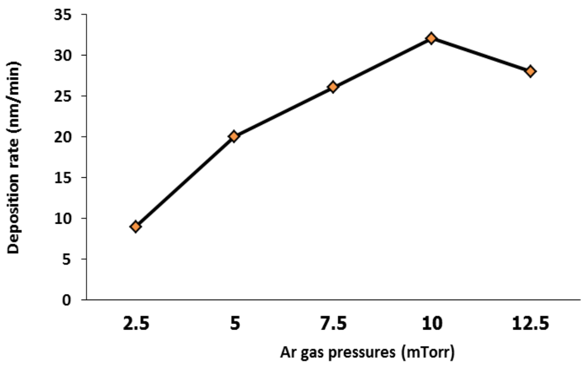

Fig. 4. Deposition rate of ITiO film at various gas pressure

3.2 Electrical properties

Fig. 5 shows the effect of the RF power on the electrical resistivity of the ITiO films sputtered with the target of 2.5 wt% of TiO2-content. The sputtering power increases from 100 to 250 W. The electrical resistivity of the

ITiO film decreases from 8.5×10-4 to 4.9×10-4 Ω-cm (low enough as TCO and it is comparable with that of ITO or ZnO:Al thin film) as the sputtering power Ω increases from 100 to 200 W, and 250 W. It slightly increases. For the analysis of the conduction mechanism, the hall mobility and the carrier concentration were measured.

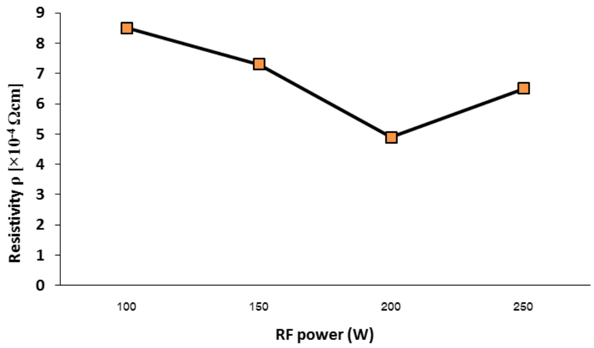

Fig. 5. Resistivity of the ITiO film at variety of RF power

Fig. 6 indicates the effect of Ar gas pressure on the electrical resistivity of the ITiO film. The electrical resistivity of the ITiO film decreases from 8.22×10^{-4} Ω-cm to 4.9×10^{-4} Ω-cm as the gas pressure increases from 2.5 to 12.5 mTorr. Higher that the electrical resistivity increases to 1.45×10^{-4} Ω-cm. film.

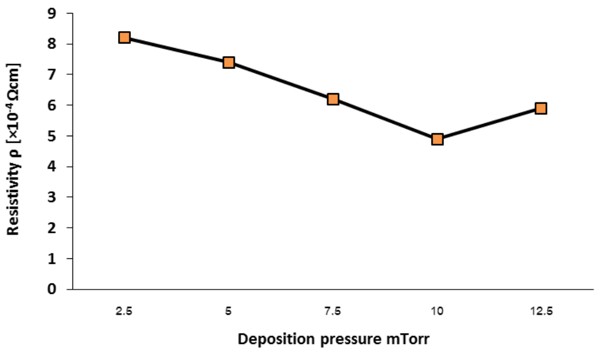

Fig. 6. Resistivity of the ITiO film at variety of Ar gas pressure.

3.3 Optical properties

Fig. 7 shows the transmittance of the film deposited at various RF power. From the figures, the average transmittance is greater than 75% for the wavelengths in the 400 - 1100 nm range of the visible spectrum at 200 W of RF power. The titanium-doped indium oxide (ITiO) films under the different deposition conditions have been successfully deposited on glass substrate by RF magnetron sputter method. The dependence of optical properties of the deposited ITiO film on the RF power of the film was investigated. This shows the optical transmittance of 75%, low resistivity of 4.9×10-4 Ω-cm. The ITiO films deposited at 400˚C exhibited high mobility and relatively low carrier concentration, showing the high transparency in near-infrared region and the high conductivity.

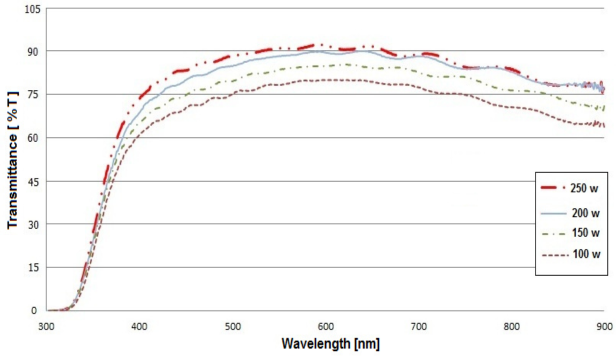

Fig. 7. Optical transmittance spectra of the ITiO film with different RF powers.

Fig. 8 shows the transmittance of the film deposited at various Ar gas pressure. From the figures, the average transmittance is greater than 75% for the wavelengths in the 400 - 1100 nm range of the visible spectrum at 10 mTorr of Ar gas pressure. The titanium-doped indium oxide (ITiO) films under the different deposition conditions have been successfully deposited on glass substrate by RF magnetron sputter method. The dependence of optical properties of the deposited ITiO film on the RF power of the film was investigated. This shows the optical transmittance of 75%, low resistivity of 4.9×10-4 Ω-cm. Moreover, this is a simple way to be analyze for some semiconductor and thin film solar cell as transparent conductive electrode.

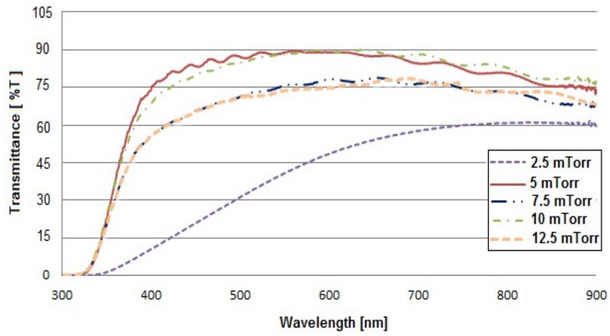

Fig. 8. Optical transmittance spectra of the ITiO film with different Ar gas pressure.

4. Discussion

Application of the titanium-doped indium oxide (ITiO) films as a transparent conducting oxide (TCO) prepared by RF magnetron sputtering method with ITiO target composited of 97.5 wt% In_2O_3 and 2.5 wt% TiO_2 was investigated. The optimal deposition conditions of ITiO film were 200 W of RF power and 10 mTorr of gas pressure applied for 60 minutes. The film showed the strongest XRD peak and the lowest volume resistivity under these conditions. When sputtering power or RF power promoting growth of crystalline increases, the electrical resistivity of film is improved more. If the sputtering power is over than 200 W, it may cause a degradation of the preferred orientation and limits the growth of crystalline grain. The lowest volume resistivity was 4.9 x 10^{-4} Ω-m which is sufficient with that of ITO or ZnO:Al transparent conducting layer as conventional. At low RF power and gas pressure as the cost is also low, the volume resistivity is high (10^{-4} Ω-m) but it is still acceptable. The average optical transmittance was around 80-90 [%T] in the visible wavelength range of spectrum.

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