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Optical and Electrical Properties Dependence on Thickness of Screen-Printed TiO_2 Thin Films

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Abstract Effect of film thickness on the optical and electrical properties of TiO_2 thin films were studied. Thin films of different thicknesses were deposited by screen printing method on fluorine doped tin oxide coated on glass substrate. The film thickness was determined by surface profile measurement. The thicknesses were 3.2, 8.2, 13.5 and 18.9 µm. Transmittance, reflectance and absorbance spectra were studied using UV-VIS-NIR spectrophotometer in the photon wavelength range of 300-1500 nm for transmittance and reflectance and 350-1200 nm for absorbance. Band gap and refractive index of the films were determined using these spectra. It was found that reflectance, absorbance, band gap and refractive index increased with film thickness while transmittance decreased with increase in thickness. I-V characteristics of the films were also measured by a 4- point probe. Electrical resistivity (ρ) and conductivity (σ) where calculated from the I-V values. Resistivity was found to increase with thickness while conductivity decreased with increase in film thickness.

Keywords: *TiO_2 thin films, thickness, optical and electrical properties, screen printing*

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1. Introduction

Transparent conducting oxide (TCO) materials have greatly drawn the attention of material scientists as a result of their diverse industrial applications. Among these materials, TiO_2 remains the most promising in a number of research areas for its availability, chemical and physical stability, non-toxicity, high refractive index, efficient photo catalytic activity and low cost [1,2]. TiO_2 is a wide band gap semiconductor material which has been under far-reaching investigations due to its applications in diverse research fields namely dye sensitized solar cells [3] gas sensors [4] photo catalysts [5,6] wave guiding [7] antireflective coatings [8], dielectric [9] etc. Investigations have revealed that the optical performance of thin films can be strongly affected by film thickness [10,11]. There have been so many experimental reports on the dependence of optical properties for TiO_2 film [12,13,14,15], but not much has been reported on TiO_2screen printed thin films and their optical and electrical properties dependence on film thickness.

In this study, we shall report the effect of film thickness on optical and electrical properties of TiO_2 thin films deposited by screen printing method.

2. Experimental Details

Thin films of TiO_2 were deposited from commercially available TiO_2 paste (Ti-Nanoxide T/SP) purchased from Solaronix. TiO_2anataseconcentration is 18wt%, particle size of 18-20nm and transparent. 2.2mm thick glass substrates with 15Ω/sq fluorine doped tin oxide (FTO)coating on one side were ultrasonically cleaned in distilled water for 15 minutes, dipped in acetone for 15 minutes and finally rinsed in distilled water.TiO_2 films of 3.2, 8.2, 13.5 and 18.9µm thickness were coated onto FTO/glass by screen printing method. The films were annealed at 500 °C for 30 minutes in a tube furnace. Optical transmittance, reflectance and absorbance spectra of TiO_2 thin films were studied using Shimadzu UV-VIS-NIR Spectrophotometer (SolidSpec-3700/3700DUV, Japan, Inc.) Film thickness was measured by a surface profiler (alpha-step IQ). Sheet resistance of the films were measured by Jandel RM3-AR 4-Point Probe.

3. Results and Discussions

The optical properties of TiO_2 screen printed films were found to be affected by the film thickness. The samples showed high transparency in the visible region and a sharp fall in the UV. Transmittance spectra as shown in Figure 1 (a) decreased with increase in film thickness. This is in agreement with some previous investigations [16]. It has an average value of 78% for the thickest film and an average value of 62% for thinnest film. Figure 1 (b) shows that reflectance increased with film thickness. The thickest film has the maximum reflectance and thinnest film has the least reflectance. All the films have their maximum transmittance and reflectance at the wavelength of about 400nm. Figure 1 (c) shows a generally low absorbance in all the films but there is still a dependence.

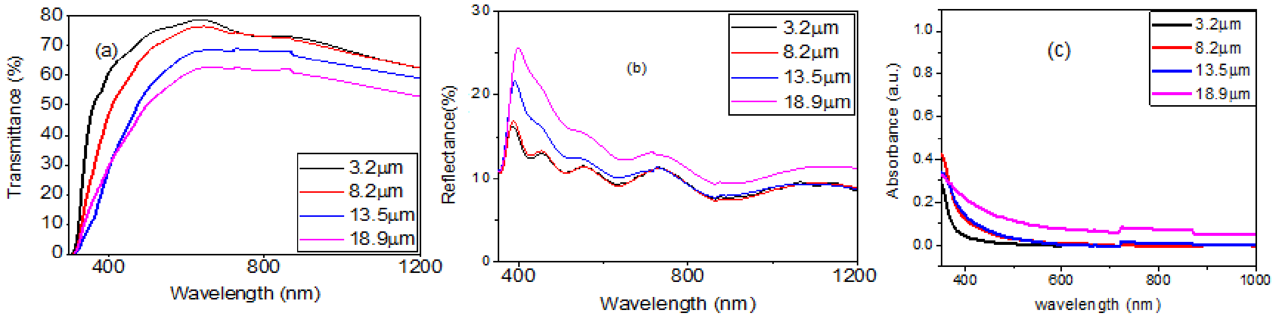

Figure 1. Transmittance, reflectance and absorbance spectra of TiO_2 films variation with film thickness

We found absorbance to increase with film thickness. All these trends are as a result of change in film density, light trapping or optical confinement and hence light absorption of the films. Figure 2 (a) and Figure 2(b) show the dependence of band gap on film thickness of TiO_2 thin films.

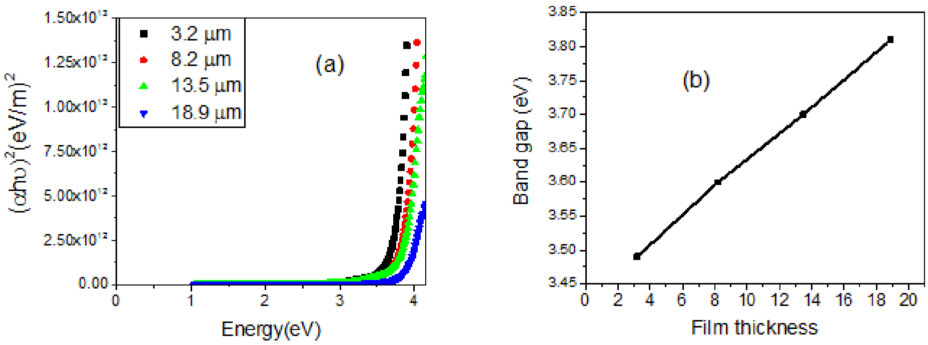

Figure 2. Band gap dependence on film thickness of TiO_2 thin films

Though band gap is an intrinsic property of a material which ordinarily should not be affected by film thickness, we found the optical band gap to increase slightly with film thickness due to dependence of absorption coefficient on film thickness [17].The increase of band gap with film thickness is in agreement with similar observations by Granqvist et al. on TiO_2 films studied by combined reflectance, transmittance spectra, and Forouhi-Bloomer (FB) method [18]. The same observation with band gap was also reported for ZnO thin films [19].Some investigations on temperature dependence of TiO_2 thin films on band gap also revealed that optical band gap increases with film thickness [20].Band gap of the four films were estimated by Tauc's equation to be 3.5, 3.6, 3.7 and 3.8eV. Though we found these optical band gaps to be a little higher than the theoretical values reported in literature, wide band gap lowers recombination in dye sensitized solar cells. The difference might be due to grain size, methods of preparation or impurities.

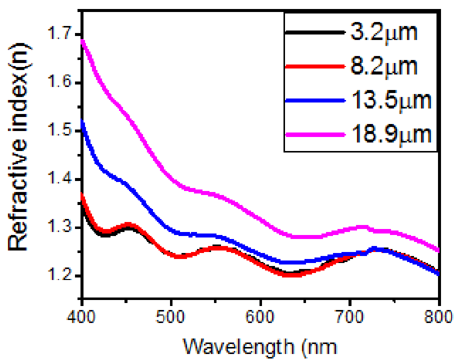

Figure 3. Refractive index versus wavelength of TiO_2 at different film thickness

The refractive indices of TiO_2thin films of different thickness were calculated from the transmittance spectra and plotted in Figure 3.

From this figure, refractive indices increased with increase in film thickness, for example, the thickest film has the highest refractive index value whereas the thinnest film has the least value. The deposited TiO_2 thin film can be seen as a composite layer consisting of air and TiO_2 paste [21]. The volume ratio of air in the composite layer decreases with increase in film thickness [22]. Therefore the thicker layer is more compact, resulting in the increase inrefractive index of the thin film. The dependence of refractive index with film thickness is in agreement with some previous similar investigations [23].

From the measured I-V by a 4 point-probe, electrical resistivity of the thin films was calculated and results are tabulated in Table 1.

Table 1. Resistivity and conductivity dependence on film thickness of TiO_2 thin films

Film Thickness (μm)	Resistivity (Ωcm)	Conductivity (Siemen's cm^{-1})
3.2	3.39E-2	2.94E1
8.2	6.18E-2	1.61E1
13.5	13.53E-2	0.73E1
18.9	22.63E-2	0.44E1

We found that resistivity increased with film thickness. Conductivity of TiO_2 thin films is the reciprocal of resistivity. The values for conductivity are also tabulated in Table 1. It was found that conductivity decreased with increase in film thickness. The values obtained for both conductivity and resistivity are plotted in Figure 4.

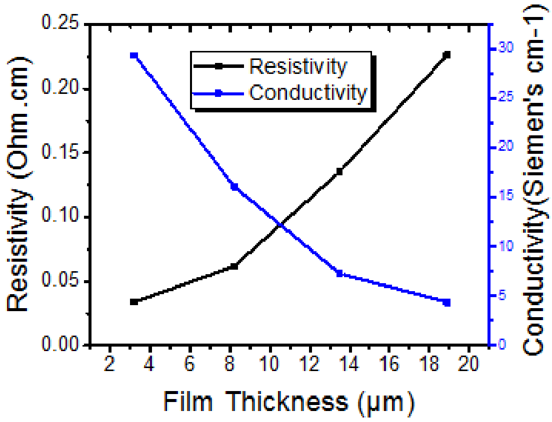

Figure 4. Resistivity and conductivity dependence on film thickness of TiO_2 thin films

As the film thickness increased, resistivity is raised from its least value to its highest value with the thickest film. Whereas for conductivity, increase in thickness decreased the value from its highest value to its least value with the thickest film.

4. Conclusion

TiO_2 thin films of different film thickness (3.2, 8.2, 13.5 and 18.9µm) were deposited on glass substrate by screen printing method and annealed at 500°C for 30 minutes. Film thickness effect on optical and electrical properties of the films were investigated. UV-VIS-NIR spectrophotometer studies revealed that the films where highly transparent in the visible region and decreases with increase in film thickness. The transmittance values range between 62% and 78%. Reflectance and absorbance increased with film thickness. Reflectance varied between 25% and 15%. The computed band gap raised slightly from 3.5 to 3.8 eV with increase in film thickness. Refractive as determined from the studied spectra also increased with the film thickness showing its highest values at 400nm wavelength. Electrical resistivity was found to directly depend on film thickness while conductivity was the reverse.

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