

Dielectric Characterization of ZnO: TiO₂ Nanocomposites

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We have carried out the electronic and optical properties of ZnO doped TiO₂ nanocomposite thin films produced by sol-gel technique. The real and imaginary parts of the dielectric function display the same characteristics in each dielectric spectra pattern. However, the values of the real part are higher than that of the imaginary part. The variation of the dielectric constants with the photon energy points out that there are some interactions between photons and electrons in the undoped and ZnO doped TiO₂ thin films. The spectral distribution of n and k wavelength for the TiO₂ thin films with ZnO doping are calculated. The obtained values of both n and k show that these parameters are depending on ZnO doping concentration.

Keywords: ZnO nanoparticles; ZnO:TiO₂ nanocomposites; Dielectric constants

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1. Introduction

Thin films are essential parts of nanotechnology and electronic devices. Basically, thin films can be defined as protective layers which are composed or formed on surfaces for various purposes [1]. Different types of films can be seen in the literature such as organic films, inorganic films, composite films, multilayered films, etc. Each film has specific purposes and properties. For example, organic films tend to be vulnerable to external factors [2]. They can easily be scratched and removed from surface, and they can also lose their physical properties after exposition of excessive heat and / or temperature. They can also be affected from humidity and moisture. However, they can be cheap; and some organic films can exhibit outstanding electric and optic properties with low-bandgap energy. Metal and metal oxide thin films found to be more reliable and stable compared to organic thin films [3]. They are mostly scratch and shock resistant and they also show good electrical properties and high conductivity. They also show good optoelectronic properties with low band gap energy and high

transmittance with low absorbance values. Dielectric properties such as dielectric constants, refractive index and absorption coefficients are important parameters, which were used to determine the electrical, and optoelectronic properties of the materials [4]. Therefore, investigation of such properties may reveal important information about intrinsic properties of such materials.

In this regard, ZnO thin films attracts the attention of researchers from different field. ZnO thin films have low absorbance value with low bandgap energies. Therefore, they can widely be used in optoelectronic device applications such as photodiodes, photodetectors, solar cells, etc. They are very efficient and can be produced with minimum cost [5]. TiO₂ thin films is another type of metal oxide thin films, which also has good transmittance values with minimum absorbance [6]. TiO₂ thin films are also durable therefore; they can be used in glasses as scratch resistant and antireflection layer.

In this work, we aim to combine two different metal oxide and produce a composite thin film with good optoelectronic properties. Therefore, we aim to produce ZnO: TiO₂ composite thin films to benefit

from optoelectronic properties of two good metal oxide thin film. In this regard, we used sol gel method to produce ZnO: TiO₂ thin films in various concentrations and applied them on Si wafers. Spin coating methods were used in the application of the materials. After the production of composite thin film, layers investigated the refractive index, absorption coefficient, and dielectric constants of the thin films. Such properties are important properties, which were used in the determination of optoelectronic characteristics of the materials. Here, we aimed to assess dielectric related optoelectronic properties of ZnO: TiO₂ thin films.

2. Materials and Methods

0.5M Titanium (IV) isopropoxide (Ti[OCH(CH₃)₂]₄) were dissolved in 10ml 2-methoxyethanol a beaker; and 0.5M zinc acetate dihydrate ((CH₃CO₂)₂Zn) were dissolved in 10ml 2-methoxyethanol in another beakers. Each beaker was stirred using a magnetic stirrer for 10 mins. 0.5ml ZnO solution was added 2.5ml TiO₂ and 1ml ZnO solution was added to 2ml TiO₂ solution where ZnO doped TiO₂ solution in 1:5 molar rates ZnO doped TiO₂ solutions in 1:2 molar rates were obtained. Substrates were chemically cleaned before the coating of ZnO doped TiO₂ solutions. To clean the residual dirt, Si wafers were stirred using deionized water. Sonication was applied to the p-type silicon wafers for 5 mins in deionized water. Si wafer then, sonicated in ethanol for 5 mins and sonicated in deionized water. Lastly, HF:H₂O (1:10ml) were prepared and sonicated for 5 mins and washed using pure water [7, 8]. Samples were then dried using N₂ gas. 2 cm x 2 cm wafers were cut; 6 layers of film were then spin coated on substrates. Spin coating was applied at 3000 rpm for 30 secs for each layer.

3. Results

Absorbance and transmittance values of the composite thin films were presented in our previous paper [9]. Using the data, refractive and refractive index n and absorption index k were calculated. Refractive index was calculated as follows: strand absorbance of the materials were obtained by using the following equation:

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \quad (1)$$

Where refractive index was obtained using the following eq.

$$n = \left(\frac{1+R}{1-R} \right) + \left(\frac{4R}{(1-R)^2} - k^2 \right)^{1/2} \quad (2)$$

In the formula, value of absorption coefficient k was calculated using the relation $k = \alpha\lambda/4\pi$. where $\alpha = A/t$, and A is the measured absorbance and t is the thickness of the thin film [10]. Wavelength related refractive index was presented in Figure 1 where wavelength related absorption index was presented Figure 2. It was seen that both n and k values are affected from wavelength where the highest refractive index and were obtained in ultraviolet region which indicates that thin films are not capable of working in this region. No apparent difference could be observed for ZnO doped samples where in the low wavelength undoped samples had slightly better performance.

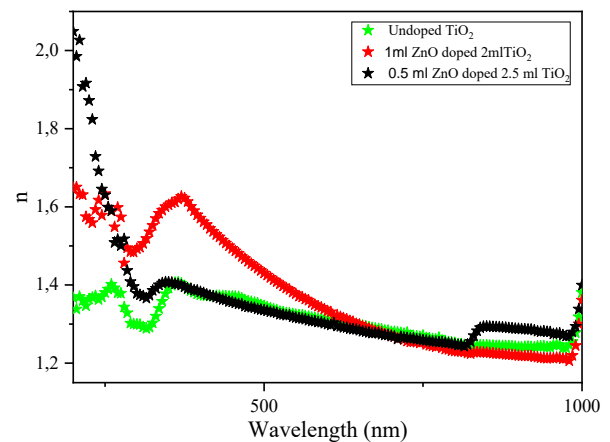


Figure 1: Wavelength related variation of refractive index of the undoped and ZnO-doped TiO₂ thin films.

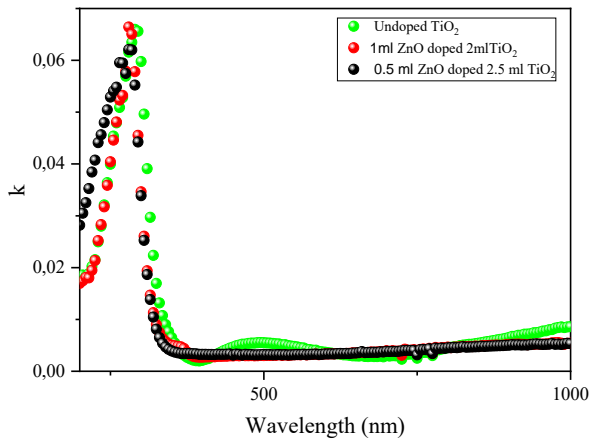


Figure 2: Wavelength related variation of absorption coefficient of the undoped and ZnO-doped TiO₂ thin films.

Complex dielectric properties of the materials often characterize the optoelectronic properties and reflection, absorption and loss of the light which also characterizes the electronic structure of the materials. The optical properties of any solid material are characterized by the complex refractive index ($\hat{n} = n(\lambda) + ik(\lambda)$) and the dielectric function ($\hat{\epsilon} = \epsilon_1(\lambda) + i\epsilon_2(\lambda)$). The real part ϵ_1 (represents the normal dielectric constant) and the imaginary part ϵ_2 (represents the absorption associated with radiation by free carrier) of the dielectric constants were determined by the following relations in the absorption region ($k \neq 0$).

$$\epsilon_1 = n^2 - k^2 = \epsilon_\infty - \left(\frac{e^2 N}{4\pi C^2 \epsilon_0 m^*} \right) \lambda^2 \quad (3)$$

and

$$\epsilon_2 = 2nk = \left(\frac{\epsilon_\infty \omega_p^2}{8\pi^2 C^3 \tau} \right) \lambda^3 \quad (4)$$

where τ is the optical relaxation time and $\omega_p = 2\pi\nu$ is the photon angular frequency [11, 12]. The dependences of ϵ_1 and ϵ_2 on the photon energy ($h\nu$) for the TiO₂ thin films under ZnO doping were presented in Figure 3 and Figure 4.

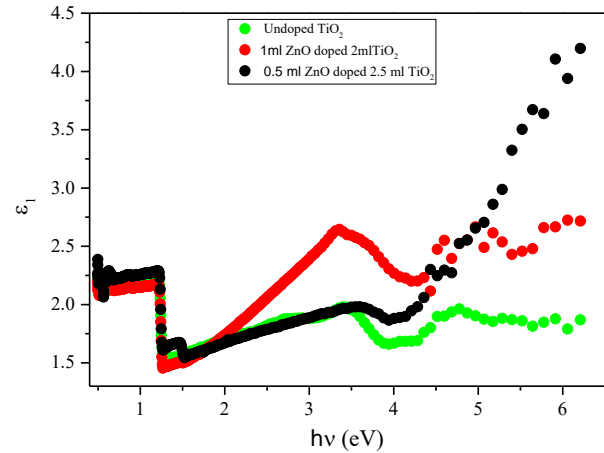


Figure 3: The plot of photon energy dependent real part of dielectric constant of the undoped and ZnO doped TiO₂ thin films.

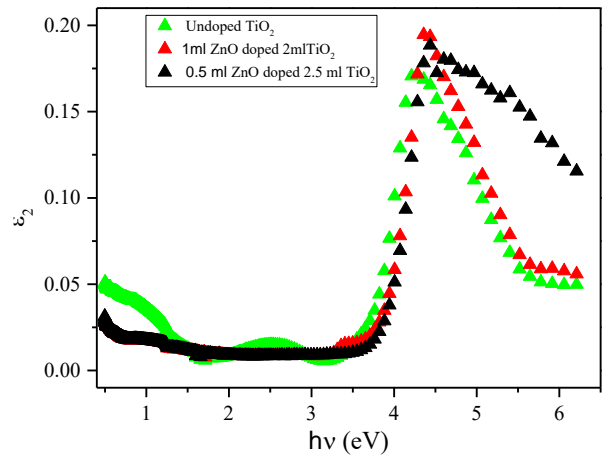


Figure 4: The plot of photon energy dependent imaginary part of dielectric constant of the undoped and ZnO doped TiO₂ thin films.

Energy related real and imaginary dielectric constants of the thin films were presented in Figure 3 and Figure 4, respectively. It was seen that there is relation between photon energy and dielectric constants where increased photon energy augments the dielectric constants for a certain region. After that in low energy regions, the highest dielectric constant was obtained for ZnO doped. It was also seen that both imaginary part and real part of the dielectric constant are affected from increased photon energy. It was concluded that photons are interacted with the electrons in the thin film structure which alters the dielectric characteristics.

Conclusion

In the study, TiO₂ and ZnO doped TiO₂ photodiodes were produced using sol gel method. Optic properties were checked, it was seen that photodiodes show good high transmittance with low

reflectance. Using UV-vis data bandgap energies of the photodiodes were calculated. ZnO doping decreases the bandgap energies of the photodiodes. Photovoltaic properties of the photodiodes confirmed that photodiodes are responsive to the light where increased photocurrent and photocapacitance were observed for increased illumination intensity. Such a case was confirmed that photodiodes have the potential to be used in solar tracking applications.

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