Solid State Phenomena
ISSN: 1662-9779, Vol. 317, pp 477-482
doi:10.4028/www.scientific.net/SSP.317.477

Submitted: 2019-12-28
Revised: 2020-05-22
Accepted: 2020-07-13
Online: 2021-05-10

The Optical Properties of Thin Films Tin Oxide with Triple Doping (Aluminum, Indium, and Fluorine) for Electronic Device

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Keywords: Aluminum, Fluorine, Indium, Optical Properties of Thin Films, Tin Oxide.

Abstract. Tin oxide (SnO_2) thin film is a form of modification of semiconductor material in nano size. The thin film study aims to analyze the effect of triple doping (Aluminum, Indium, and Fluorine) on the optical properties of SnO_2: (Al + In + F) thin films. Aluminum, Indium, and Fluorine as doping SnO_2 with a mass percentage of 0, 5, 10, 15, 20, and 25% of the total thin-film material. The addition of Al, In, and F doping causes the thin film to change optical properties, namely the transmittance and absorbance values changing. The transmittance value is 67.50, 73.00, 82.30, 87.30, 94.6, and 99.80 which is at a wavelength of 350 nm for the lowest to the highest doping percentage, respectively. The absorbance value increased with increasing doping percentage at 300 nm wavelength of 0.52, 0.76, 0.97, 1.05, 1.23, and 1.29 for 0, 5, 10, 15, 20, and 25% doping percentages, respectively. The absorbance value is then used to find the energy gap of the SnO_2: (Al + In + F) thin film of the lowest doping percentage to the highest level i.e. 3.60, 3.55, 3.51, 3.47, 3.42, and 3.41 eV. Thin-film activation energy also decreased with values of 2.27, 2.04, 1.85, 1.78, 1.72, and 1.51 eV, respectively for an increasing percentage of doping. The thin-film SnO_2: (Al + In + F) which experiences a energy gap reduction and activation energy makes the thin film more conductive because electron mobility from the valence band to the conduction band requires less energy and faster electron movement as a result of the addition of doping.

Introduction

Industry 4.0 is characterized by an increase in a variety of technologies that are the result of the hard work of researchers. It is undeniable that these developments require a variety of supporting materials, one of which is a semiconductor material. The semiconductor material is a material that has a unique characteristic that is flexible, in one condition as a conduit and other conditions can not function as a conduit [1].

The effort made by researchers to maximize the function of semiconductor materials is to modify the shape of the material in the form of thin films. Utilization of thin layers of semiconductor materials including TCO (transparent Conducting Oxide) which is used in transparent electrodes [2], LEDs (Light emitted diode) [3], solar cells [4], LCD [5], gas sensors, [6], etc. Various types of materials used in the synthesis of thin films are aluminum, tungsten disulfide [7], titanium dioxide [8], and tin oxide [9].

The sensitivity of a thin layer is strongly influenced by the value of the energy bandgap of the thin layer. The lower the value of the energy bandgap layer, the more sensitive the material is to conduct current or as a conductor [10]. The energy band gap value of the tin oxide thin layer is still quite high at around 3.62 eV [11], so it needs to be modified by adding another atom to the material. Several other atoms were added namely, aluminum-zinc [12], Ferrum [13], fluorine [14], and indium [15]. The thin layer of tin oxide doped by aluminum has a less transparent surface, as does the addition of fluorine doping. To improve the transparent color of the tin oxide thin layer an investigation was carried out by adding aluminum, fluorine, and indium together as a transparent color enhancer.

Experimental

This research was conducted in several stages, namely synthesis, characterization, and analysis. In the first stage, the synthesis is carried out starting from making sol-gel, preparation of glass substrate, making layers by coating the glass substrate using sol-gel solution, and finally is maturation [16]. The second step, thin layer characterization was carried out to obtain data on the optical properties of the layer using thermoscientific Uv-Vis, and the data obtained also showed morphological appearance and percentage of composition contained in the thin film obtained with SEM-EDX. The third stage, the analysis of optical properties data, the morphological appearance, and the percentage of thin-film content.

Thin-film SnO_2:(Al+F+In) consist of pure SnO_2, 95% SnO_2 doped with a mixture of 5% Al+F+In with a percentage of 33.3% each from 5% mixture, SnO_2 90% doped with a mixture of 10% Al+ F+In with a percentage of 33.3% each from 10% mixture, 85% SnO_2 were doped with a mixture of 15% Al+F+In with a percentage of 33.3% each from 15% mixture, 80% SnO_2 mixed with a mixture of 20% Al+F+In with a percentage of 33.3% each of the 20% mixture, and 75% SnO_2 were doped with a mixture of 25% Al + F + In with a percentage of 33.3% each from the 25% mixture. The thin-film were synthesized using a sol-gel method that is placed on the surface of the glass and the layer smoothing process is rotated using a spin coater [17]. The synthesis was carried out with several variations of doping material, namely 0, 5, 10, 15, 20, and 25%. Thin-film material that has been attached evenly to the glass surface is then heated at a temperature of 150 ^oC using a furnace for 1 hour for all doping concentrations.

The optical properties of the coating are obtained from the thin Uv-Vis thermoscientific which includes the transmittance and absorbance of the thin film. The absorbance value is then used to obtain the energy band gap value [18] and thin-film activation energy [19]. The energy value of the thin layer gap is classified into two, namely direct energy bandgap and indirect energy bandgap. The amount of energy band gap is obtained from the eq. 1 [20].

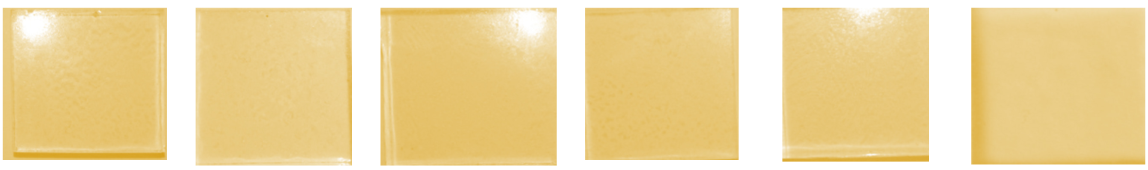
$$\alpha(hv)hv = C(hv - Eg)^n \quad (1)$$

Note: α is the absorbance coefficient, hυ is the incident energy of the photon, C is a constant, n = 1/2 for direct and n = 2 for indirect band-gap energy [21].

Energy gap is also obtained through the graph method $(\alpha hv)^n$ to the photon energy. The bandgap energy is shown by the slope of the photon energy graph concerning $(\alpha hv)^n$. While the thin-film activation energy is obtained from 1/m or one per photon energy gradient graph towards ln α, where α were founded from equation $\alpha = 2.303A/d$ (note: A is absorbance, d is thickness).

Result and Discussion

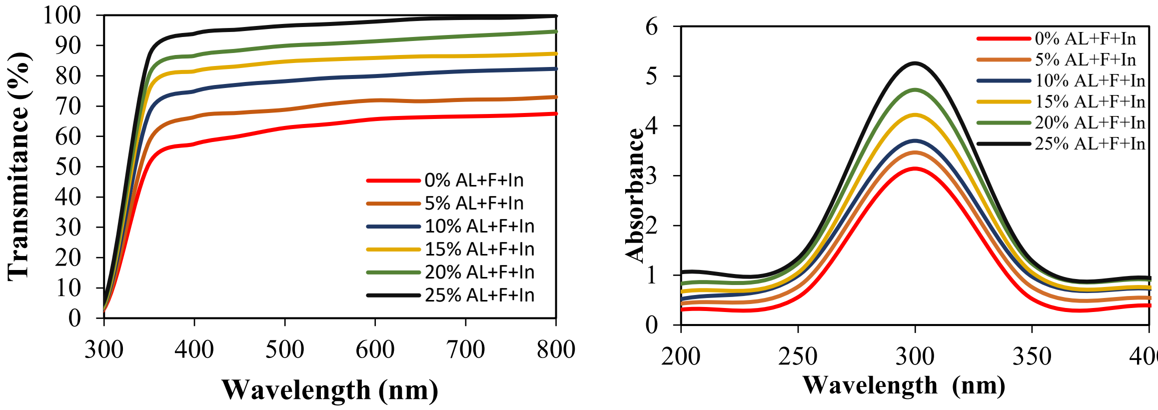
The synthesis of SnO_2 thin film with three aluminum, fluorine and indium doping materials with doping variations causes the thin film to become more transparent, as doping concentrations increase. More clearly the results of the synthesis can be seen in Fig.1.



(a) (b) (c) (d) (e) (f)

Fig. 1 Thin film SnO_2: (Al+F+In) (a) 100: 0%, (b) 95: 5%, (c) 90: 10%, (d) 85: 15%, (e) 80: 20%, (f) 75: 25 %.

The optical properties of SnO_2:(Al+F+In) thin film characterized by UV-Vis Spectrophotometer obtained transmittance and absorbance values as shown in Fig. 2.



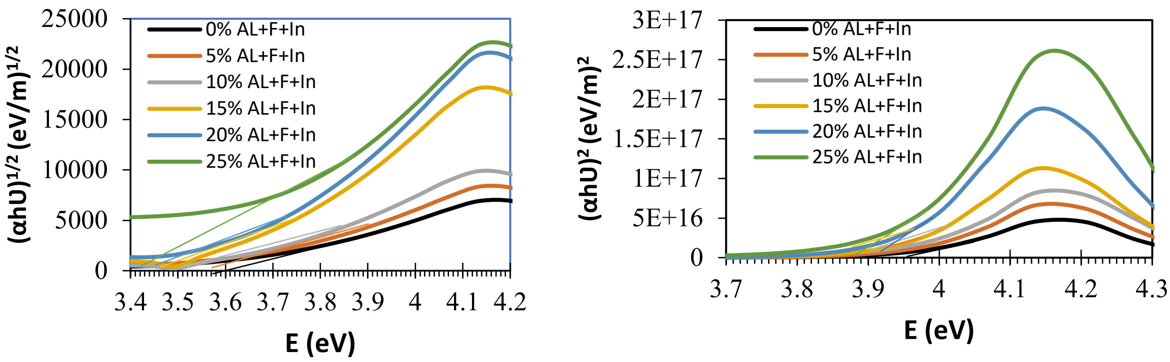
(a) (b)

Fig. 2 Optical properties of SnO_2 and SnO_2: (Al+F+In) thin films in 60 nm, (a) Transmittance of one layer, (b) Absorbance of one layer.

The transmittance value of SnO_2: (Al+F+In) consist of thin films in the wavelength range of 300-800 nm are shown in Fig. 2a. The value of transmittance for the percentage of doping 0-25% is 67.50, 73.00, 82.30, 87.30, 94.6, and 99.80% respectively. This means that the higher the amount of doping aluminum, fluorine, and indium the higher the transmittance value produced [22].

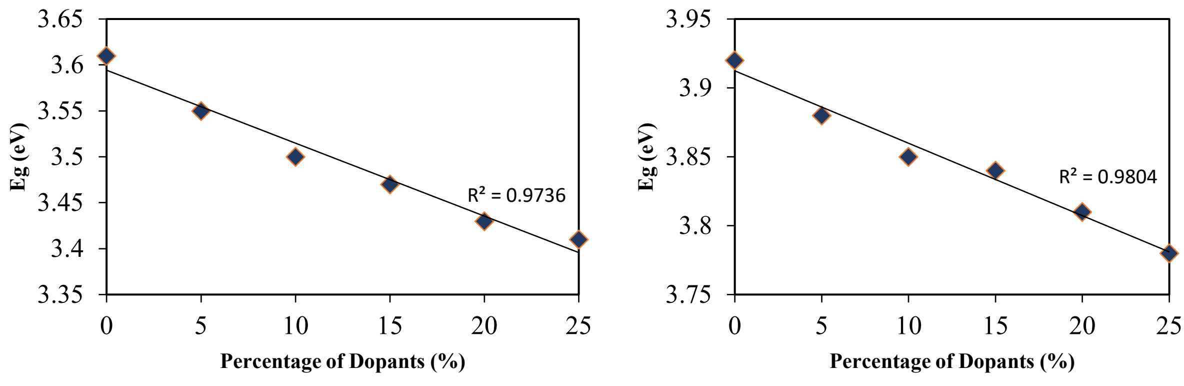
The absorbance value of SnO_2: (Al+F+In thin films in the wavelength range of 300-800 nm is shown in Fig. 2b. The absorbance value for doping percentage is 0-25%, each of them is 0.52, 0.76, 0.97, 1.05, 1.23, and 1.29. This means that the higher the amount of aluminum, fluorine, and indium doping additions the higher the absorbance value produced [23].

Based on eq. 1, obtained direct and indirect energy gaps allowed SnO_2 dan SnO_2:(Al+F+In) thin layer by tauc plot method as shown in the Fig. 3.



(a) (b)

Fig. 3 The energy band gap of SnO_2 and SnO_2:(Al+F+In) thin films. (a) direct allowed, (b) indirect allowed.

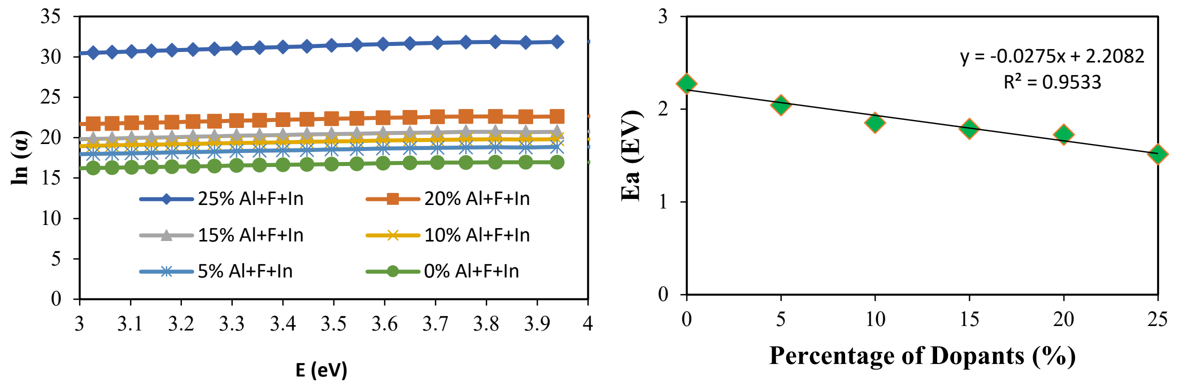


(a) (b)

Fig. 4 The relationship between the percentage of aluminum, fluorine and indium doping with energy bandgap (a) direct allowed, (b) indirect allowed.

The relationship between the percentage of doping with the energy band gap is shown in Fig. 4. Fig. 4a is the energy band gap direct allowed, while Fig. 4b represents the energy band gap direct allowed. The value of the energy band gap direct allowed for doping percentage is 0-25%, each of them is 3.60, 3.55, 3.51, 3.47, 3.43, and 3.41 eV, while energy bandgap indirect allowed values are 3.92, 3.89, 3.88, 3.84, 3.81, and 3.78 eV. This shows that the addition of aluminum, fluorine and indium doping can cause a decrease in the value of the bandgap thin film that were founded from sloope of graph photon energy versus $(\alpha h v)^n$. This means that the smaller the percentage of doping aluminum, fluorine, and indium energy bandgap produced the greater [24, 25]. The decrease in the bandgap energy value indicates that the electron jump from the valence band to the conduction band will be easier.

The value of ln α and activation energy SnO_2 : (Al+F+In) thin film, were follow Arrhenius plot is shown in Fig. 5.



(a) (b)

Fig. 5 Characteristics of optical properties of SnO_2 and SnO_2: Al+F+In thin films. (a) Ln (α), (b) activation energy.

Activation energy values obtained for the percentage of doping aluminum, fluorine and indium 0, 5, 10, 15, 20 and 25% are respectively 2.27, 2.04, 1.85, 1.78, 1.72, and 1.51 eV. In general, the activation energy decreases with increasing doping value. This value means that the electron mobile more quickly in semiconductor material to conduct electricity.

Conclusions

A thin layer of SnO_2 was doped with aluminum, fluorine, and indium (SnO_2: Al + F + In). The optical properties of the layer consist of transmittance, absorbance, energy bandgap, and activation energy. The value of transmittance for the percentage of doping 0-25% increased from 67.50 to 99.80% at 350 nm wavelength, as well as the absorbance increased from 0.52-1.29 at 300 nm wavelength. Besides that the energy bandgap and the resulting activation decreased with an increasing number of doping aluminum, fluorine, and indium.

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