The Effect of Indium Doped SnO$_2$ Thin Films on Optical Properties Prepared by Sol-Gel Spin Coating Technique

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Abstract. This study aims to investigate the optical properties of SnO$_2$ thin films doped with Indium synthesized using the sol-gel spin coating technique. The optical properties of thin films were measured using Thermo Scientific GENESYS UV-Vis Spectrophotometer. The results of characterization of optical properties showed that the thin films of Indium doped SnO$_2$ experienced an increase in transmittance from 75 - 96.6% at wavelengths 300 - 350 nm and increased maximum absorbance at a wavelength of 300 nm from 3.19 - 4.32 with an increase in doping percentage. This shows that thin films absorbance the maximum wave at a wavelength of 300 nm. Increasing the percentage of doping causes the thin films of SnO$_2$ to experience a decrease in energy gap both in the direct energy gap of 3.64 - 3.57 eV and indirect energy gap i.e from 3.92 - 3.87 eV. The optical activation energy of the SnO$_2$ thin films decreased with increasing doping percentage from 2.91 - 2.35 eV. The results of this study indicate that SnO$_2$: In thin films is high-quality because it has high transmittance and low energy gap.

1. Introduction

The study of semiconductor materials has a significant contribution to the development of technology. Semiconductor materials are widely used as electronic devices. One of the semiconductor materials is tin oxide. Semiconductor SnO$_2$ is an N-type semiconductor material. As a development, semiconductor materials can be modified to micro-size to nano-size in the form of a thin film. Energy gap SnO$_2$ thin films is 3.60 - 3.98 eV [1, 2], the energy gap value is large enough for thin films of semiconductor material.

Modification of semiconductor materials into thin films makes the use of semiconductor materials more diverse. Some uses of semiconductor materials in the form of thin films such as solar cells, touch screens [3], and gas sensors [4].

The function of SnO$_2$ thin films will be more optimal to be used as an electronic device that has high quality, so doping is needed which is expected to reduce the energy gap so that electronic devices become more sensitive. Some of the doped of SnO$_2$ thin films have been studied such as Fluoride Dehydrate [5], Aluminum [6], Aluminum-Zinc [7], Cesium [8], Fluorine [9], and Indium [10].
The results of the research on SnO\textsubscript{2} thin films which stated that doped SnO\textsubscript{2} thin films had increased conductivity and decreased gap energy. The selection of Indium material as doping on SnO\textsubscript{2} thin films because Indium has fairly high transparency [11], temperature reflexes [12], and it can be synthesized in low temperatures [13].

Thin films growth techniques are as diverse as Pulsed Laser Deposition [14], RF sputtered [15], Enhanced Plasma RF Reactive Thermal Evaporation [16], Reactive Magnetron Sputtering [17], Dc and RF Sputtering [18] which are less efficient in electric power [19], Dip-Coating [20], and the Spin-Coating Technique [21]. From all of these methods, the spin-coating is the most efficient, economical, and simple technique [22]. Although the method is simple, it can produce high-quality thin films with adjustable thickness according to the rotation speed and playback time [23].

2. Experimental

Synthesis thin films are carried out by a sol-gel spin coating technique that utilizes centrifugal forces in flattening films across the surface of the substrate. The sol-gel injected on the glass substrate is assembled in one place, in order that spin process made the sol-gel spread smoothly. The thickness of films can be controlled by the speed of spin. This synthesis process was by speed 3000 rpm for all of thin-film percentage doping. The basic material of the thin films is SnO\textsubscript{2}.2H\textsubscript{2}O which is doped with InCl\textsubscript{3}.4H\textsubscript{2}O which is dissolved using C\textsubscript{2}H\textsubscript{5}OH. The main ingredients of the SnO\textsubscript{2} thin films are doped with Indium with a mass percentage of 0, 5, 10, 15, 20, and 25% [24].

The optical properties of the thin films consist of absorbance and transmittance. Thin-film transmittance and absorbance measuring instruments using Thermo scientific Genesys 150 UV-Spectrophotometer with a wavelength range of 200 - 1100 nm. The energy gap is obtained from the absorbance spectrum. The amount of energy gap is the minimum amount of energy absorbed by the material so that electrons from the valence band can jump to the conduction band. The magnitude of the gap energy can be obtained from the sloop graph \((\alpha h\nu)^n\) on the energy of the photon \(h\nu\). The energy gap can be either direct optical \((n = 1/2)\) and indirect optical band gap \((n = 2)\) [25].

Mathematically, the energy gap is obtained using equations
\[
\alpha(\nu)h\nu = C(h\nu - E_g)^n
\]
where: \(h\nu\) is incident photon energy, \(h\) is Planck's constant, \(E_g\) is energy gap, and \(C\) is a constant.

3. Result and Discussion

The following figure 1 show that SnO\textsubscript{2}:In thin film with percentage of doping 0, 5, 10, 15, 20, and 25%, respectively.

![Figure 1. Thin Films SnO\textsubscript{2}:In with Percentage of Doping (a). 0:100, (b). 5:95, (c). 10:90, (d). 15:85, (e). 20:80, and (f). 25:75%](image)

The optical properties of the thin films obtained from UV-Vis Spectrophotometer equipment are transmittance and absorbance properties of thin films indium doped SnO\textsubscript{2}.

3.1. Measurement of Transmittance and Absorbance

Transmittance and absorbance of thin films of SnO\textsubscript{2} by doping Indium measured using a UV-Vis spectrophotometer are shown in the graph below.
Figure 2. (a) Transmittance of SnO$_2$:In thin films with variations in percentage of doping (wt%) 0, 5, 10, 15, 20 and 25%, (b) Absorbance of thin films SnO$_2$: In with doping percentage 0, 5, 10, 15, 20 and 25%.

Based on the wavelength graph of transmittance in Figure 2 (a), thin films with a percentage of doping (wt%) obtained the transmittance of SnO$_2$:In thin films at a constant thickness of 120 nm with 0, 5, 10, 15, 20, and 25% doping concentrations experience an increase in transmittance in sequence. This phenomenon is in accordance with the research that has been done before [26].

Increased transmittance occurs at wavelengths of 300-350 nm. The highest peak transmittance value at 350 nm wavelength sequentially from the lowest to the highest doping percentage i.e. 75.0, 78.2, 87.1, 90.6, 94.7 and 96.6%. This means that the occurrence of electron movements due to the energy of photons at wavelengths of 300-350 nm. Whereas at wavelengths 350-800 nm the transmittance graph looks constant, meaning that the wavelengths of light photons 350-800 nm do not occur in the movement of electrons jump.

The wavelength graph of absorbance in figure 2 (b) shows that an increase in doping percentage makes the thin films increased in absorbance value. The highest absorptions were 25% doping percentage and respectively decreased to 0% doping percentage. Maximum absorbance value at a wavelength of 300 nm with an absorbance value of 4.32. The percentage of doping is 0, 5, 10, 15, 20, and 25% with absorbance values of 3.20, 3.31, 3.72, 3.91, and 4.32, respectively. Increasing the absorbance of photon energy with a wavelength of 200 - 300 nm.

3.2. Calculation of Energy gap

Energy gap thin films obtained from two types of analysis, namely the analysis of direct energy gap and indirect energy gap. The absorbance value of the Indium doping SnO$_2$ thin films can be used to find the thin films gap energy. The energy gap is obtained from the slop graph of the photon energy towards $(\alpha h\nu)^2$. 

![Figure 2](image-url)
3.2.1. Direct energy band gap (n=1/2)

The addition of Indium doping to the thin films of SnO₂ made the thin films gap energy decrease from 3.64 to 3.57 eV. The higher doping percentage i.e 0, 5, 10, 15, 20 and 25%, the decreasing gap energy from 3.64, 3.63, 3.62, 3.61, 3.58, and 3.57 eV; the higher the percentage of indium doping, the electron mobility in the thin films SnO₂ fast.

3.2.2. The indirect energy band-gap (n=2)

Another form of energy gap other than direct is indirect. The indirect energy gap is obtained from the slop graph $h\nu$ to $(ahu)^{1/2}$ with a value of $n=2$. 
Figure 4. allowed transition $(\alpha h\nu)^2$ versus $h\nu$ thin films SnO$_2$: In for (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, and (f) 25%.

In Figure 4, it can be seen that there are differences in the slope graph of each variation of doping. Increasing the percentage of doping made thin films gap energy values decrease the energy gap ranging from 3.92, 3.91, 3.90, 3.89, 3.88, and 3.87 eV, respectively.

Figure 5. Comparison of Direct (●) and Indirect (▲) Energy Gap of Thin Films SnO$_2$: In.
Figure 5 shows that the comparison direct and Indirect energy gap indicate that direct energy gap lower than indirect energy gap. The increasing doping concentration from 0 to 25%, obtained direct energy gap which decreased from 3.64 to 3.57 eV for the band's direct optical gap. While the indirect value of the energy gap decreased from 3.92 to 3.87 eV.

The direct energy gap the position of the valence band and its conduction is in one phase, for the energy gap indirect the valence band and its conductivity are at a different phase. The direct energy gap, the mobility of electron from the valence band to the conduction band with a straight path so that electrons reach the conduction band faster, whereas in the indirect energy gap there is an electron leap from the valence band to the conduction band in a direction that is not straight so that the arrival of electrons to the conduction band becomes longer and requires more energy. It causes direct bandgap energy smaller than indirect bandgap energy. This decrease in energy bandgap is due to the presence of impurity indium in the SnO$_2$ structure, which induces the formation of new recombination centers with lower energy emissions [27].

3.3. Optical Activation Energy

Optical activation energy is obtained by first finding the value of ln$(\alpha)$ ($\alpha$: absorbance coefficient). The magnitude of activation optical energy is obtained from the value of the gradient or slope of the line ($m$) of the graph of photon energy versus ln$(\alpha)$. Optical activation energy $E_a = 1/m$ [28].

![Figure 6. The graph of the percentage of doping versus activation energy of Thin Films SnO$_2$: In.](image)

The graph gradients $m$ of each doping percentage (0, 5, 10, 15, 20, and 25%), namely 0.343, 0.344, 0.363, 0.378, 0.413 and 0.425, respectively. From the value of the gradient, optical activation energy obtained in Figure 6 is 2.91, 2.90, 2.75, 2.64, 2.42 and 2.35 eV. The reduced activation energy makes the electron rate from the valence band to the conduction band increasingly toward the semiconductor properties [29, 30].

4. CONCLUSION

The addition of the indium doping percentage to the thin films of SnO$_2$ causes thin-film absorbance and transmittance to increase. The energy band gap of thin films SnO$_2$ decreases with Indium doping increase. The reduced energy gap from 3.64 to 3.57 eV and the activation energy 2.91 to 2.35 eV, it makes the thin films be high-quality.

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