The effect of annealing temperature thin films indium doped SnO$_2$ to optics properties and material composition

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Abstract. This study aims to analyze the effect of annealing of tin oxide thin film doped with Indium. SnO$_2$ thin film has many benefits as electronic devices, solar cells, LPG sensors, etc. Preparation of SnO$_2$: In a thin film using a sol-gel spin coating technique that produces a thin film of high quality. The transmittance of the thin film experienced decreases with increasing ripening temperature with the transmittance of 96.6, 94.7, 89.6, 87.1, and 78.2% at a wavelength of 350 nm with annealing temperature increase, respectively. Thin-film absorbance has increased with higher heating temperatures i.e 3.01, 3.34, 3.41, 3.62, and 3.77, respectively. SnO$_2$ thin film gap energy: In decreases due to increased ripening temperature at room temperature (35), 50, 100, 150, and 200 $^\circ$C ie 3.65, 3.61, 3.59, 3.58, and 3.56 eV for direct energy gap and 3.96, 3.94, 3.93, 3.91, and 3.89 eV for indirect energy gap, respectively. The decreasing value of the gap energy makes the SnO$_2$: In thin-film material faster in carrying current. The activation energy are decreased by increasing annealing temperature with value 2.91, 2.73, 2.15, 2.11 and 2.09 eV, respectively for increase temperature which makes electrons flow faster. Furthermore, thin-films composition with mass percentage Sn are 16.97% with atomic 2.77% and In are 1.46% with atomic 0.25%.

1. Introduction

These Tin oxide (SnO$_2$) is a semiconductor material consisting of Sn and Oxygen atoms. Various attempts have been made by the researchers to find that SnO$_2$ thin films have the advantage of a high degree of transparency and flexibility because SnO$_2$ material which was originally N-type can change to P-type by adding doping P-type semiconductor materials with high calcination temperature [1].

The advantage of SnO$_2$ material as a thin film is to have high transparency. Even though it has a high transparency of 85-89% [2], the thin film of SnO$_2$ has a disadvantage, which is a high energy gap for semiconductor materials, namely 3.62 - 4.02 eV [3,4]. The energy gap is large enough for semiconductor materials, so the sensitivity of the thin film is high. SnO$_2$ thin film has been widely used as an electronic device and sensor device [5], solar cell [6], LPG sensor [7], etc.

A thin film of SnO$_2$ has been frequently researched by adding doping to other atoms. Several doping substances that have been added are sulfur [8], Argentum (silver), copper [9], fluorine [10] and Al-Zn [11].
The addition of indium doping to the thin film of SnO$_2$ aims to increase the transmittance of the thin film and can reduce the gap energy. The semiconductor materials that have lower bandgap energy make the current conduct faster so that not much energy is needed and the material becomes more sensitive. Making thin films is carried out with various methods such as pyrolysis spray [12], SILAR [13], pulsed laser deposition [14]. The simplest method for making thin films is spin-coating. Although the spin-coating method is simple, it can produce a thin film that has high quality [15].

2. Method
This study aims to identify the optical properties of SnO$_2$ thin films doped using indium. What was investigated from this study was the optical properties of Indium (SnO$_2$:In) SnO$_2$ thin films with a material ratio of 85: 15%, respectively. Constant doping variation, but controlled is the calcination temperature variation that is room temperature (without heating), 50, 100, 150, and 200 °C.

Thin-film products were tested for optical characterization using Thermo scientific UV-Spectrophotometer obtained data of transmittance and absorbance values. Absorbance data is used to analyze the energy gap and thin-film activation energy.

The energy gap value is obtained from the slope graph of the incident energy of photons to $(\alpha h\nu)^n$, with the value n = 1/2 for the direct energy gap and n = 2 for the indirect energy gap [16]. The activation energy of the thin film is obtained from the graph analysis method of photon energy against the value of ln $\alpha$. The slope size of the line (m) in the graph can be obtained by the activation energy $E_a = 1 / m$.

3. Result and Discussion
The following figures are that thin-films SnO$_2$:In with annealing temperature shown in figure 1.

![Figure 1](image)

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

**Figure 1.** Thin Films SnO$_2$:In with annealing temperature (a) Room Temperature, (b) 50 °C, (c) 100 °C, (d) 150 °C, and (e) 200 °C.

Optic characterization of SnO$_2$: In thin films with ripening temperature variations namely room temperature, 50, 100, 150, and 200 °C, with the increasing of the heating temperature of the thin film, the surface of the thin film appears increasingly unclear.

The optical characterization data obtained is the transparency and absorbance of thin films.
3.1. Transmittance

![Graph of wavelength Versus Transmittance thin films SnO\textsubscript{2}:In with annealing temperature variation.](image)

The transmittance value of the SnO\textsubscript{2}: In thin films shown in Figure 2 shows that the SnO\textsubscript{2} thin film doped with Indium changes transmittance due to changes in the annealing temperature change. The higher the temperature annealing the level of transparency of the thin film decreases [17, 18, 19] with transmittance value 96.6, 94.7, 89.6, 87.1, and 78.2% at a wavelength of 350. This is caused by the surface color of the thin film being annealed with higher temperatures becoming darker.

3.2. Absorbance

![Graph of Wavelength Versus Absorbance Thin Films SnO\textsubscript{2}:In Absorbance with Annealing Temperature Variation.](image)

Figure 3. is a graph of the photon wavelength of the absorbance of thin doping SnO\textsubscript{2} films with variations in room temperature (35), 50, 100, 150 and 200 °C. The graph explains that the energy of the photon absorbed by the thin film changes at each wavelength. Significant changes in wavelength in the wavelength range of 250 - 350 nm. The absorbance value increases at wavelength 250 - 300 nm with the highest absorbance value at 300 nm wavelength at an annealing temperature of 200 °C at 3.56 and the lowest absorbance at 300 nm wavelength, which is annealed at room temperature (35), 50, 100,
150, 200 °C are found absorbance value i.e. 3.01, 3.34, 3.41, 3.62. This shows that a thin film of SnO$_2$: In which is annealed at higher temperatures causes a thin film to have absorbance to increase [20].

3.3. **Bandgap energy**

![Graph of Incident Foton Energy Vs $(\alpha h\nu)^{1/2}$](image1)

Figure 4. shows the relationship of the energy wavelength of the photon that passes through the thin film sample to $(\alpha h\nu)^{1/2}$ the graphical slope line that intersects the energy axis of the photon used to determine the energy gap. The graph slope line affects the photon energy values 3.65, 3.61, 3.59, 3.58, and 3.56 eV for annealing temperatures 35, 50, 100, 150, and 200 °C, respectively.

![Graph of Incident Foton Energy Vs $(\alpha h\nu)^{2}$](image2)

Figure 5. shows a graph of the energy of the photon emitted in the thin film sample against the value $(\alpha h\nu)^{2}$. The slope intersection point with the photon energy axis line shows the value of the indirect energy gap of 3.96, 3.94, 3.93, 3.91, and 3.89 eV. Increased temperature annealing causes an indirect band energy gap to decrease [21]. The energy of the SnO$_2$: In a thin film with variations in temperature annealing is more clearly represented in figure 6.
Figure 6. shows that a thin film of SnO$_2$ calcined with a higher temperature indicates that the thin film has a decreased energy gap. The decrease in gap energy causes a thin film of SnO$_2$:In which is calcined with higher temperatures will become more conductive, because less energy hits the film so that there will be an electron flow towards the conduction band.

3.4. Activation Energy

Figure 7 shows that the activation energy of the thin film decreases with the increasing temperature of the thin film annealing [22]. The energy values of SnO$_2$:In thin-film activation decreased from 2.91, 2.73, 2.15, 2.11 and 2.09 eV. A thin film that has lower activation energy will cause the movement of electrons from the valence band to the conduction band faster.
3.5. Thin-films Material Composition (EDX)

Figure 8. SnO$_2$:In in the Thin-films composition diagram.

Table 1. Data Thin-films Composition SnO$_2$:In.

| Elements | Mass (%) | Atom (%) |
|----------|----------|----------|
| C K      | 25.08    | 40.44    |
| O K      | 34.08    | 41.25    |
| Na K     | 2.35     | 1.98     |
| Mg K     | 0.93     | 0.74     |
| Al K     | 1.56     | 1.12     |
| Si K     | 13.75    | 9.48     |
| Cl K     | 2.02     | 1.11     |
| Ca K     | 1.80     | 0.87     |
| In L     | 1.46     | 0.25     |
| Sn L     | 16.97    | 2.77     |

The presence of other elements in the thin film is caused by a thin film that has a very thin size, causing the glass elements to be read in EDX characterization. Some other impurity elements are SiO$_2$ (the main constituent component of glass), Na$_2$O (lowering the melting point), CaO and MgO (making the glass not dissolve quickly in water), Al$_2$O$_3$ (increasing elasticity and strength), and residues in the form of Cl and C which are precursors and solvents used to make solvent solutions [23,24,25].

SnO$_2$:In a thin film with 15% Indium doping percentage being annealed with different temperature variations. The transmittance of the thin film decreases with increasing temperature annealing. Absorption of SnO$_2$: In a thin film with annealing temperature variation higher makes the thin film has a higher absorbance. The energy gap and the activation energy of the thin film decrease with increasing temperature annealing.

4. Conclusions
SnO$_2$:In a thin film with a 15% Indium doping percentage being annealed with different temperature variations. The transmittance of the thin film decreases with increasing temperature annealing.
Absorption of SnO$_2$: In a thin film with annealing temperature variation higher makes the thin film has a higher absorbance. The energy gap and the activation energy of the thin film decrease with increasing temperature annealing.

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