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Synthesis and Characterization of SnO_2 Thin Film Semiconductor for Electronic Device Applications

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Abstract: Synthesis and characterization of SnO_2 thin films with various types of doping materials such as aluminum, fluorine and indium have been successfully carried out. This study aims to determine the effect of various types of doping materials on the quality of thin films such as the energy band gap produced. The results showed that the higher the doping concentration, the more transparent the layer formed. In addition, the optical properties of thin films such as band gap energy are affected by the applied doping. The direct and indirect values of the largest band gap energy for the percentage of 95:5% are 3.62 eV and 3.92 eV are found in the SnO_2: In thin layer. Meanwhile, the lowest direct and indirect values of band gap energy are in the thin layer of SnO_2:(Al+F+In) for a percentage of 85:15%, namely 3.41 eV and 3.55 eV. The greater the amount of doping given, the smaller the bandgap energy produced. In addition, the more combinations of doping mixtures (aluminum, fluorine, and indium) given, the smaller the bandgap energy produced. This shows that the quality of a thin film of SnO_2 produced is influenced by the amount of concentration and the type of doping used.

Keywords: Thin film; SnO_2; aluminum; fluorine; indium; band gap energy.

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Introduction

The industrial revolution 4.0 is being hotly discussed lately. The reason is, the industry can change drastically only with technology. With technology such as artificial intelligence, automatic machines, and the internet that can be applied in everyday life, it can change the way individuals, companies, and governments operate, sparking the industrial revolution 4.0. The development of this technology is certainly inseparable from the role of scientists in finding semiconductor materials (Doyan, et al, 2020).

Semiconductor material is a material with an electrical conductivity that is between an electrical insulator and an electrical conductor (Doyan, et al, 2017). One type of semiconductor material that is often used today is SnO_2. SnO_2 is a semiconductor material with an energy band gap of about 3.6 eV and is sensitive to the presence of gas (Susilawati, et al, 2020). Based on these properties, SnO_2 is widely applied to gas sensors (Rebholz, et al, 2015), optoelectronic equipment (Ikraman, et al, 2017), solar cells (Bittau, et al, 2017), capacitors (Doyan, et al, 2017), liquid crystal displays (Andrade, et al, 2019), diode (Gullu, et al, 2020), and transistor (Liu, et al, 2020).

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Utilization of SnO_2 as a semiconductor material can be made according to the needs by changing its characteristics. That is, the characteristics possessed by SnO_2 can be changed by injecting other atoms as doping. Based on several studies that have been carried out, SnO_2 is usually doped with aluminum (Imawanti, et al, 2017), fluorine (Muliyadi, et al, 2019), antimony (Khorshidi, et al, 2019), indium (Hakim, et al, 2019), and zinc. (Hegazya, et al, 2019). In addition, SnO_2 can be doped with a mixture of antimony and zinc (Medhi, et al, 2019), a mixture of aluminum and zinc (Hegazya et al, 2019), a mixture of aluminum and indium (Munandar, et al, 2020), a mixture of aluminum and fluorine (Susilawati, et al, 2020). al, 2019), and a mixture of aluminum, fluorine, and indium (Doyan, et al, 2020).

Method

This research consists of four processes, namely substrate preparation, sol-gel manufacturing process, thin layer manufacturing process, and thin layer characterization.

Substrate preparation

The substrate used for the synthesis of doped (Al, In and F) SnO_2 thin films is glass. The glass substrate was cut with a size of 10 x 10 x 3 mm. The glass surface were thoroughly washed to remove dirt/fat adhering to the substrate with a mixture of clean water and detergent and further sonicated in ultrasonic cleaner for an hour. Then the glass slides were cleaned with 99% alcohol while being sonicated again with an ultrasonic cleaner for 1 hour. Then it is dried in an oven with a temperature of 100 ^oC for 1 hour to be free from impurities that adhere to it and then put it in a plastic clip (Muliyadi, et al, 2019).

Sol-gel manufacturing process

The process of making sol-gel was carried out with doping variations of 10 and 15%. The process was carried out using magnetic stirring, with the aim that the solution was homogeneous, and then left it for a whole day (Muliyadi, et al, 2019).

Thin film manufacturing process and characterization

The process of making a thin layer was carried out using a spin coater at a speed of 2000 rpm for 3 minutes (Hakim et al, 2019). The thin layer that has been formed is then dried at 100^{o}C (Muliyadi, et al, 2019). The layers formed were characterized using a UV-Vis Spectrophotometer Thermo Scientific Genesys 150 with a wavelength of 200-1100 nm.

Result and Discussion

Synthesis of a thin layer of SnO_2 doped with aluminum (Al), fluorine (F), indium (In), a combination of aluminum and fluorine (Al and F), a combination of aluminum and indium (Al and In), and a combination of the three dopant aluminum, fluorine, and indium (Al, F, and In) has been successfully carried out. Figures 1. and 2 show a thin layer of SnO_2 for various types of dopants. Based on the figure, it can be seen that the higher the number of dopants, the higher the level of transparency formed (Muliyadi, et al, 2019).

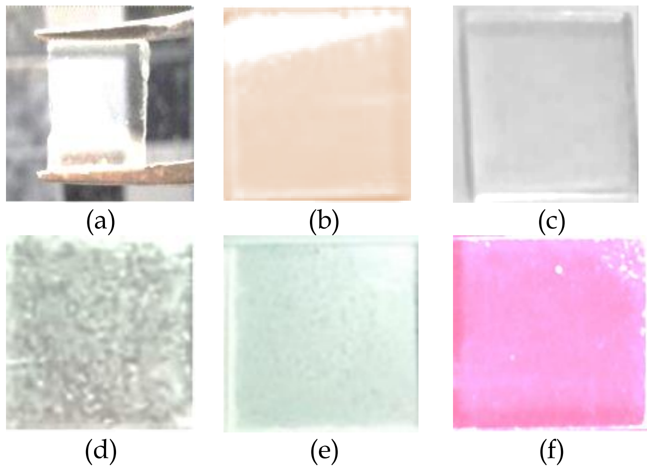

Figure 1. SnO_2 thin film: dopant material (95:5%). (a) SnO_2: Al, (b) SnO_2: F, (c) SnO_2: In, (d) SnO_2: (Al+F), (e) SnO_2: (Al+In), (f) SnO_2: (Al+F+In).

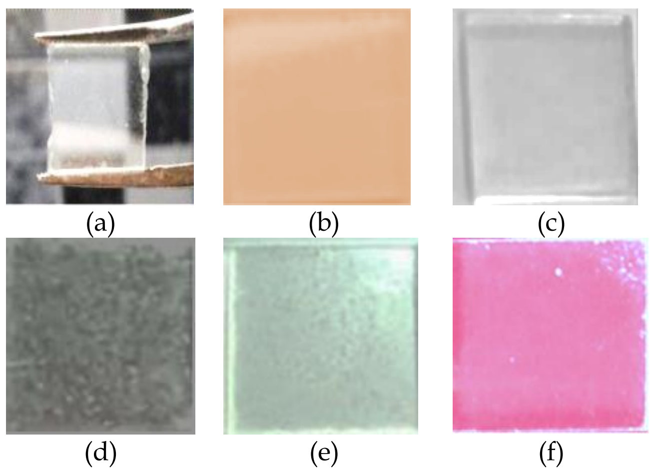

Figure 2. SnO_2 thin film: dopant material (95:5%). (a) SnO_2: Al, (b) SnO_2: F, (c) SnO_2: In, (d) SnO_2: (Al+F), (e) SnO_2: (Al+In), (f) SnO_2: (Al+F+In).

The results of the characterization of SnO_2 thin films with various types of doping consist of transmittance and absorbance. As research conducted by (Doyan, et al, 2021) the absorbance value obtained is used to obtain the energy band gap value using equation 1 (Tiwary, et al, 2019). The equation consists of absorbance coefficient (ɑ), photon energy (hʋ), and constant (C). The energy band gap value consists of two, namely direct energy bandgap and indirect energy bandgap. The difference between direct energy bandgap and indirect energy bandgap lies in the value of m, for direct energy bandgap the value of m = 1/2, while for indirect energy bandgap m = 2 (Tiwary, et at, 2019; Tiwary et al, 2020).

Table 1. Values of direct and indirect energy bandgap (90:10%).

Thin films	Direct energy band gap (eV)	Indirect energy band gap
SnO_2:Al	3.62	3.92
SnO_2:F	3.59	3.90
SnO_2:In	3.57	3.89
SnO_2:(Al+F)	3.56	3.88
SnO_2:(Al+In)	3.51	3.85
SnO_2:(Al+F+In)	3.50	3.81

Table 2. Values of direct and indirect energy bandgap (85:15%).

Thin film	Direct energy band gap (eV)	Indirect energy band gap (eV)
SnO_2:Al	3.59	3.67
SnO_2:F	3.56	3.64
SnO_2:In	3.52	3.62
SnO_2:(Al+F)	3.50	3.60
SnO_2:(Al+In)	3.47	3.58
SnO_2:(Al+F+In)	3.41	3.55

Table 1. shows that the direct energy bandgap and indirect energy band gap values for variations in the ratio of SnO_2 and doping materials (90:10%). Table 2 shows that the direct energy bandgap and indirect energy band gap values for the variation of the ratio of SnO_2 and doping materials (85:15%). Based on the two tables, it is clear that the lowest energy band gap value is in the thin layer doped with a mixture of the three doping, namely aluminum, fluorine, and indium, while the lowest energy bandgap was observed only for the case of aluminum doped SnO2 thin film. In addition, when the thin layer is given a higher doping concentration, the energy band gap will be lower. For example, when a thin layer of SnO_2 is doped with aluminum or fluorine with a concentration of 10%, the resulting bandgap energy is greater than that of a thin film of SnO_2 doped with a concentration of 15%.

$$\alpha(h\upsilon)h\upsilon = C(h\upsilon - Eg)^m \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The decrease in the energy band gap is caused by the presence of Aluminum in the SnO_2 structure. This is because aluminum has the characteristics of a metal that is a good conductor of electricity (Doyan et al, 2021). In addition, the addition of fluorine doping on SnO_2 causes the bandwidth in each layer to increase (Muliyadi, et al, 2019). The decrease in the energy band gap value is also influenced by the presence of indium in the SnO_2 structure. This is because the presence of indium atoms will increase the population of electrons that occupy positions below the conduction band so that with the addition of a small amount of thermal energy, the electrons are able to jump into the conduction band. This condition causes the electrical properties of the surface of the material to be more conductive or the resistance value of the material to decrease (Doyan, et al, 2019).

The quality of a material is better used as a semiconductor material if it has a small energy band gap (Doyan, et al, 2017; Doyan, et al, 2021). This is because the greater the bandgap energy value possessed by the thin layer, the more difficult it becomes for electrons to move from the valence band to the conduction band. However, unlike a material that has lower bandgap energy, electrons will more easily move from the valence band to the conduction band (Doyan, et al, 2020; Susilawati, et al, 2020).

Conclusion

Synthesis and characterization of SnO_2 thin films with aluminum, fluorine, and indium doped has been successfully carried out. The results showed that the higher the doping concentration, the more transparent the layer formed. In addition, the optical properties of thin films such as bandgap energy are affected by applied doping. The direct and indirect values of the largest bandgap energy for the percentage of 95:5% are 3.62 eV and 3.92 eV are found in the SnO_2: In thin layer. Meanwhile, the lowest direct and indirect values of bandgap energy are in the thin layer of SnO_2:(Al+F+In) for a percentage of 85:15%, namely 3.41 eV and 3.55 eV. The greater the amount of doping given, the smaller the resulting bandgap energy. In addition, the more combinations of doping mixtures (aluminum, fluorine, and indium) given, the smaller the bandgap energy produced. This shows that the quality of a thin film of SnO_2 produced is influenced by the amount of concentration and the type of doping use.

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