JPPIPA 8(6) (2022)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Analysis of the Energy Band Gap of Tin Oxide Thin Layers as Semiconductor Base Materials in Electronic Devices

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Received: November 10, 2022
Revised: November 23, 2022
Accepted: December 17, 2022
Published: December 31, 2022

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DOI: 10.29303/jppipa.v8i6.2657

Abstract: The purpose of this study is to analyze the quality of optical properties such as energy band gap of thin layer of tin oxide doped with aluminum, tin oxide doped with fluorine, tin oxide doped with indium, tin oxide doped with aluminum-fluorine, tin oxide doped with aluminum-indium, and tin oxide doped with aluminum-fluorine-indium. The thin layer was synthesized using the sol-gel spin coating method. The ratio of basic ingredients and doping used in this study was 95:5% and 85:15%. The thin layer that has been formed is then heated at a temperature of 100 and 200 ^{0}C. The results of the analysis of optical properties showed that the largest values of direct and indirect energy band gap are in a thin layer of tin oxide doped with indium at a percentage of 95:5% for a temperature of 100 ^{0}C, namely 3.62 and 3.92 eV. The lowest values of direct and indirect energy band gap are in a thin layer of tin oxide doped with aluminum-fluorine-indium at a percentage of 85:15% for a temperature of 200 ^{0}C, namely 3.36 and 3.51 eV. These results indicate that the resulting energy band gap decreases with increasing doping concentration and sintering temperature. Based on the optical properties obtained, the thin layer can be used as the basic material for semiconductors in electronic devices.

Keywords: Enegy band gap; Tin oxide; Semiconductor; Electronic devices

Introduction

The 21st century is marked by the development of information technology. One of the information technologies that is currently developing rapidly is nanotechnology (Vijayakumar et al., 2022). Nanotechnology is a science that studies objects that are very small in size (Bhattacharya, 2022). In simple terms, nanotechnology is a technological leap to engineer new objects from existing objects. A form of nanotechnology is a thin layer (Kirtane et al., 2021).

Thin layers can be made of organic, inorganic, metallic materials, or very thin metal-organic mixtures with a nanometer scale and have the properties of conductors, semiconductors, superconductors, and insulators (Doyan et al., 2017). Studies that explain the synthesis and characterization of various materials are very interesting for researchers to study, especially those using the basic precursor material, namely SnO_2, where these materials are closely related to various technologies that support community needs, which of course will increase and develop every year (Doyan et al., 2021). SnO_2 is widely applied to electronic devices such as diodes (Lee et al., 2019), transistors (Dou et al., 2019), capacitors (Dai et al., 2021), solar cells (Mikolášek, 2017; Altinkaya et al., 2021; Luo et al., 2022), liquid crystal displays (Zhang et al., 2021; Chu et al., 2021; Zhang et al., 2018), gas sensors (Zhou et al., 2018; Zhang et al., 2018; Karabulut et al., 2018), and other optoelectronic equipment (Rana et al., 2019).

SnO_2 is a semiconductor material with a tetragonal structure and a wide energy gap greater than 3.6 eV at room temperature (Doyan et al., 2021). In addition, SnO_2 is transparent conducting oxide, the outstanding characteristics of transparent conductive oxide materials are low electrical resistivity and high transparency at visible light wavelengths. The behavior of changing optical properties in non-linear materials is unique, namely, its refractive index is easy to change when exposed to different light intensities. However,

How to Cite:
Doyan, A., Susilawati, S., & Muliyadi, L. (2022). Analysis of the Energy Band Gap of Tin Oxide Thin Layers as Semiconductor Base Materials in Electronic Devices. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2772–2777. https://doi.org/10.29303/jppipa.v8i6.2657

these materials generally cannot be applied directly to various nanotechnology. This is because there are still some characteristics that need to be changed or modified, especially related to the energy band gap which is still relatively high. To overcome this, in a study it is necessary to do a material doping process (Doyan et al., 2018).

Doping is adding an impurity to the semiconductor material intentionally (Doyan et al., 2018). Doping is the process of adding impurities to pure semiconductor materials to change their electrical properties (Doyan et al., 2021). To change the characteristics of SnO_2, typically doped with indium (Hakim et al., 2019), fluorine (Muliyadi et al., 2019) and aluminum (Doyan et al., 2017). Additionally, SnO_2 may be doped with a mixture of zinc and aluminum (Ikraman et al., 2017), as well as a mixture of fluorine and aluminum (Susilawati et al., 2020).

Based on the problems above, the researchers synthesized a thin film with SnO_2 precursor material doped with various elements such as Indium, Aluminum, and Fluorine to obtain thin film characteristics that are good for use as a semiconductor and applied to various electronic devices.

Method

The thin layer of tin oxide doped with aluminum (SnO_2: Al), tin oxide doped with fluorine (SnO_2: F), tin oxide doped with indium (SnO_2: In), tin oxide doped with aluminum-fluorine (SnO_2: Al + F), tin oxide doped with aluminum- indium (SnO_2: Al + In), and tin oxide doped with aluminum-fluorine-indium (SnO_2: Al + F + In) was synthesized using the sol-gel spin coating method (Muliyadi et al., 2019). Precursor base material used in the synthesis process is Tin (II) Chloride Dihydrate and the doping materials used are aluminium chloride, Amonium fluorida and Indium Chloride with different doping concentrations (95:5 and 85:15%). A glass formulation with a size of (0.3 x 1.0 x 1.0) cm is used as the substrate material (Imawanti et al., 2017).

The thin layer synthesis process is carried out through several stages such as substrate-preparation, sol-gel fabrication, thin layer fabrication on substrates, and the sample heating process (Doyan et al., 2022; Munandar et al., 2020). Substrate-preparation was carried out by washing and soaking the glass substrate using several materials such as soap, detergent, and aquades before drying by heating in the oven. The purpose of washing and heating the glass substrate is because dirt on the surface of the substrate can cause the sol-gel to become uneven due to the presence of other particles.

The next stage is related to the sol-gel fabrication process which is carried out using ethanol as a solvent. The use of ethanol is due to the nature of this material which is neutral, non-toxic, can be dissolved in many types of compounds, have a good absorbance value, and the heat required for the homogeneity process is relatively low (Doyan et al., 2017).

The next step after obtaining the sol-gel solution is a thin layer fabrication process using the help of a spin coating tool. This process is carried out by depositing the sol-gel solution just above the surface of the glass substrate and then rotated with a spin coating tool. The working principle of this tool is to utilize the concept of centrifugal force so that the solution is spread evenly on the surface of the substrate. To maximize the formation of a thin layer on the surface of the glass substrate, the sample was heated in an oven at a temperature of 100 and 200 ^{0}C and then allowed to stand at room temperature. The finished thin layer was then characterized to determine the optical properties.

Result and Discussion

The thin layer of tin oxide doped with aluminum, tin oxide doped with fluorine, tin oxide doped with indium, tin oxide doped with aluminum-fluorine, tin oxide doped with aluminum-indium, and tin oxide doped with aluminum-fluorine-indium has been successfully synthesized using the sol-gel spin coating method. Precursor base material used in the synthesis process is Tin (II) Chloride Dihydrate and the doping materials used are aluminium chloride, Amonium fluorida and Indium Chloride with different doping concentrations (95:5% and 85:15%). The finished thin layer is then heated at temperatures of 100 ^{0}C and 200 ^{0}C, after which it is left at room temperature. The finished thin layer was characterized using a UV-Vis spectrophotometer to determine their optical properties.

The data in this study are optical properties obtained from the results of characterization using UV-Vis Spectrophotometer. The optical properties analyzed in this study are energy band gap values. The energy band gap is one of the important indicators that can be used to explain the photocatalytic ability by utilizing absorbance value data obtained directly through the UV-Vis Spectrophotometer test. The energy band gap value can be determined using equation 1 (Susilawati et al., 2019). Where m = 2 is the indirect allowed and m = ½ is the direct allowed, B = constant, h = Planck's constant, E_f = photon energy, E_g = energy band gap (Doyan et al., 2020).

$$\alpha(\upsilon)h\upsilon = B(E_f - E_g)^m \quad (1)$$

Table 1. Energy Band Gap of the Thin Layers for Doping Concentrations (90:10%) at 100 ^{0}C.

Doping Material	Direct (eV)	Indirect (eV)
In	3.62	3.92
F	3.59	3.90
Al	3.57	3.89
Al + F	3.56	3.88
Al + In	3.51	3.85
Al + F + In	3.50	3.81

Table 2. Energy Band Gap of The Thin Layers for Doping Concentrations (85:15%) at 100 ^{0}C.

Doping Material	Direct (eV)	Indirect (eV)
In	3.59	3.67
F	3.56	3.64
Al	3.52	3.62
Al + F	3.50	3.60
Al + In	3.47	3.58
Al + F + In	3.41	3.55

Table 3. Energy Band Gap of the Thin Layers for Doping Concentrations (90:10%) at 200 ^{0}C.

Doping Material	Direct (eV)	Indirect (eV)
In	3.58	3.88
F	3.56	3.86
Al	3.54	3.84
Al + F	3.52	3.81
Al + In	3.48	3.79
Al + F + In	3.46	3.76

Table 4. Energy Band Gap of the Thin Layers for Doping Concentrations (85:15%) at 200 ^{0}C.

Doping Material	Direct (eV)	Indirect (eV)
In	3.55	3.63
F	3.53	3.60
Al	3.50	3.58
Al + F	3.47	3.56
Al + In	3.45	3.54
Al + F + In	3.36	3.51

Tables 1, 2, 3 and 4 show the values of the direct allowed energy ban gap and the indirect allowed energy band gap obtained based on Equation 1. It can be seen from Tables 1, 2, 3 and 4 that the resulting energy band gap decreased with increasing dopant concentration. This indicates that the higher the percentage of doping used, the smaller the energy band gap (Susilawati et al., 2020).

The difference in the value of the energy band gap that occurs is also related to the sintering temperature used. The higher the sintering temperature, the smaller the energy band gap produced (Doyan et al., 2019). This is because the temperature can change or affect the grain size of the resulting material. The higher the sintering temperature, the grain size will enlarge and subsequently result in higher conductivity values (Susilawati et al., 2020). The increasing value of this conductivity can be explained by the larger grain size causing the weaker nuclear bond with the electrons in the outer shell of the material so that the electrons are more easily released and their mobility increases or in other words, electrons are easier to conduct across the band gap, moving to the conduction band from the valence band (Susilawati et al., 2019).

Moreover, lowering the value of the energy band gap definitely affects the ability of thin layer in photo catalytic processes (Doyan et al., 2019). As the energy band gap becomes smaller, electrons move faster from the valence band to the conduction band, so the electrical conductivity of the layer increases, and in this state the thin layer is used as a semiconductor material (Doyan et al., 2020).

The properties of SnO_2 thin layer doped with indium, aluminum, and fluorine as semiconductor materials are applied to the development of various electronic devices as base materials (Doyan et al., 2019). One of the developments in electronic devices that is urgently needed today is related to touchscreen technology (Doyan et al., 2018).

The touch screen is a technological innovation that can function as output as well as input so that users can interact directly with the monitor screen on their device. The physical interaction is done by directly touching the screen of the viewer with the hand or a tool to access what is displayed on it. One part of touch screen technology related to thin-layer research is the touch sensor. In addition, when referring to the value of the optical energy band gap of the SnO_2 thin layer with relatively low Indium, Aluminum, and Fluorine doping (in the range of 3.31 eV), of course, this condition can improve the performance of photocatalysts in thin layers as semiconductor materials (Doyan et al., 2021).

Conclusion

The synthesis of a thin layer of tin oxide doped with aluminum, tin oxide doped with fluorine, tin oxide doped with indium, tin oxide doped with aluminum-fluorine, tin oxide doped with aluminum-indium, and tin oxide doped with aluminum-fluorine-indium using the sol-gel spin coating method has been successfully carried out. As for the analysis of optical properties obtained from the results of the characterization of the thin layer, one of which is the energy value of the band gap. The results of the analysis of optical properties showed that the largest values of direct and indirect energy band gap are in a thin layer of tin oxide doped with indium at a percentage of 95:5% for a temperature of 100 ^{0}C, namely 3.62 and 3.92 eV. The lowest values of direct and indirect energy band gap are in a thin layer of tin oxide doped with aluminum-fluorine-indium at a percentage of 85:15% for a temperature of 200 ^{0}C, namely 3.36 and 3.51 eV. These results indicate that the resulting energy band gap decreases with increasing doping concentration and sintering temperature. Based on the optical properties obtained, the thin layer can be used as the basic material for semiconductors in electronic devices.

Acknowledgements

Thank you to all those who have helped in making this article, especially "the Integrated Laboratory of Diponegoro University" and "the Laboratory of Analytical Chemistry, University of Mataram" who have facilitated the research.

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