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Synthesis and Characterization of SnO_2 Thin Layer with a Doping Aluminum is Deposited on Quartz Substrates

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Abstract. In this research, SnO_2 and SnO_2:Al thin films have been successfully deposited on quartz substrates. Starting from Tin (II) chloride dehydrate as precursor, ethanol as solvent, and $AlCl_3$ as dopant substance. The film was deposited by spin coating method. Structural and morphological analysis was carried out by X-Ray Diffraction (XRD) measurement and Scanning Electron Microscope (SEM). Optical characteristics were analyzed from the study of transmission and absorption spectrum data obtained by UV-Vis Spectrophotometer. Aluminum was added by various concentrations (5%, 10%, and 15%). Transmissions of visible light were better on the low concentrations of Al, but absorptions were low too. The band gap energy was decreased by increasing the Al concentration. From XRD measurement, there were crystal system alterations. They were confirmed that SnO_2 and SnO_2 doped Al have cubic structure (by material phase classification of Al_2O_4Sn) because of the substrate compositions contained Al. In this study, XRD pattern indicates that grain size of thin film decreased just after the Al dopant was added. EDX analysis confirms the presence of SnO_2 and Al in thin film material deposited on quartz substrate.

INTRODUCTION

For decades, nanotechnology is a key priority in the field of science and technology. Nano technology is one of them realized in the form of a thin layer or thin film. A thin layer is made of organic materials, inorganic, metal, or metal-organic mixture of very thin (scale of nanometers to millimeters) and can have the properties of conductors, semiconductors, superconductors, and insulators [1-3]. This thin layer technology already undergone many developments, both in terms of the materials used, method of manufacture, and its application in people's lives since it was introduced by M Faraday, W. Grove, T.A.Edison in 1850 [4,5]. In materials engineering, there has been some metal oxide materials are often used in thin film technology, both pure and that has been doped with other materials [6,7]. Studies on the synthesis and characterization of thin layers has always attracted the attention of researchers because of its application widely in everyday life, both in the field of decoration, construction, and electronics [8,9]. In the field of electronics, thin film used to make semiconductors. The application of thin layers for semiconductors developed in the form of transparent conductive oxides (TCO), capacitors, diodes, transistors and sensors. Application TCO develop rapidly and has been applied to electronic devices such as LCD TVs, Plasma TVs, organic electroluminescence (EL), for example touch screen monitors on automatic teller machine (ATM), ticket vending machines were installed in train stations, car navigation systems, handheld game consoles, mobile phones, and electrodes in solar cells [10-14]. SnO_2 attractive for development because it is transparent to light (the energy gap 3.6 eV) [15], obstacles electricity is low, and has chemical stability is, the price is cheap, is responsive to a number of gas, durable, and requires only a simple electronic device in its application [16].

This research is used to determine the characteristics of SnO_2 thin film material by adding a dopant variations Aluminium (Al). Aluminum is an extrinsic n-type dopant used in thin film technology. This element is the third largest after oxygen and silicon. Aluminum, like copper, silver and gold, has a crystalline structure with atomic arrangement face center cubic surface (fcc).

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METHOD

The synthesis was done by using sol-gel spin coating, with variations in dopant concentrations of Al (in%) of 5; 10; and 15 in the annealing temperature of 400 °C. Materials used are $SnCl_2.2H_2O$ as a precursor, C_2H_5OH as solvent and $AlCl_3$ as a dopant. For washing the substrate, the necessary soap and distilled water. Stages of research as follows: $SnCl_2.2H_2O$ (0.902 gram) dissolving in 40 ml C_2H_5OH (ethanol) using a hot plate magnetic stirrer for 15 minutes to obtain samples without doping SnO_2.$AlCl_3$ dissolves as much as 0.027, 0.053, and 0.08 gram respectively in the previous solution, to obtain a dopant concentration (in%) 5; 10; and 15 at 80 °C for 15 minutes. Labeling solution, the solution A was SnO_2 without doping, solution B, C, and D respectively is a solution of SnO_2 with a dopant concentration of Al 5, 10 and 15%. The solution was left to stand for 24 hours. Each solution labeled A, B, C, and D will be used as a coating material on a quartz substrate [17]. Dripping the solution onto a substrate of quartz and rotate with a speed of 2000 rpm for 3 minutes. The characterization using a UV-Vis Spectrophotometer, x rays diffraction (XRD) and SEM-EDX.

RESULTS AND DISCUSSION

The Figure 1. in a row (from left to right) is a thin layer without dopant SnO_2, SnO_2 with a dopant Al concentration of 5, 10 and 15 (in%).

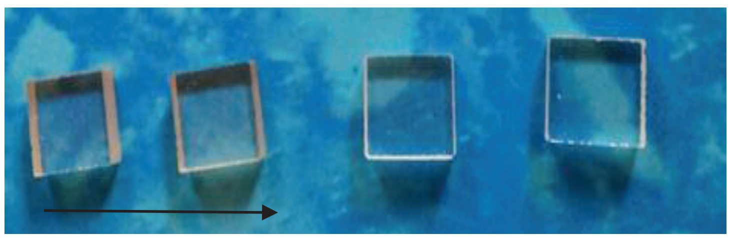


FIGURE 1. Sample thin layer of SnO_2 and SnO_2:Al is deposited on a quartz substrate

Material Characterization Tests using UV-Vis Spectrophotometer

Figure 2. Shows the graph of the absorption of light energy to each of the samples increased at a temperature of 220 °C and decrease exponentially at a wavelength of 320 nm. The pattern of absorption of this sample showed a sharp peak in the wavelength range 231 to 235 nm. In SnO_2 without dopant Al, an absorbance low at around 0.16, while the absorbance of SnO_2 with a dopant concentration of aluminums by 5, 10, and 15% respectively are 0.21, 0.28, and 0.45. Based on Figure 3, obtained a description that the lower the dopant concentration of aluminums, the greater the transmitance. Samples with high transmittance is SnO_2 without dopant Al is about 98.1 %, followed by aluminum-doped SnO_2 5, 10 and 15 % in the amount of 96.9, 92.9 and 92.5%. Quartz is a crystalline solid with a regular arrangement of atoms and repeated periodically that bind to each other is very strong. The temperature may still be accepted by the quartz substrate is 110-1200 °C with a visible light transmittance > 90%. This causes more light is transmitted rather than absorbed. Atoms in a solid material, there are electrons occupy each trajectory. If there is an external electromagnetic radiation with a specific energy of the electrons of a material, there will be absorption and emission of electromagnetic radiation. Absorption and emission of electromagnetic radiation would involve the transition of an electron from one energy level to another energy level. Changes experienced by the electron energy is equal $E = h\nu$, so that only photons with a frequency corresponding to those experiencing energy by atomic absorption through the transition of electrons.

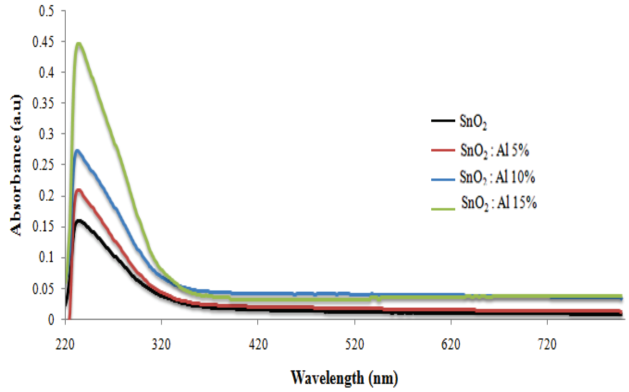


FIGURE 2. Graph of the relationship wavelength and absorbance of SnO_2 doped SnO_2 and Al with a concentration of 5, 10, and 15 % on a quartz substrate.

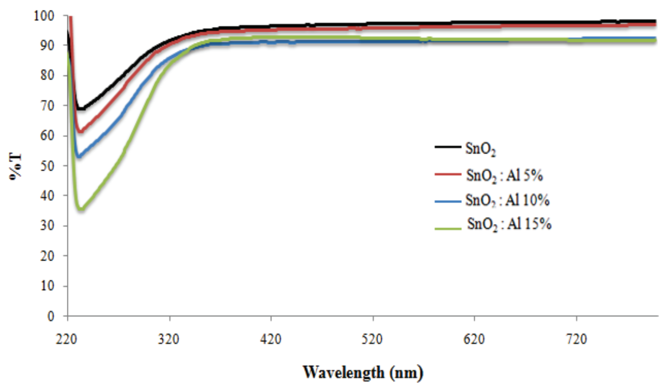


FIGURE 3. Graph of relations wavelength and transmittance of SnO_2 doped SnO_2 and Al with a concentration of 5, 10, and 15 % on a quartz substrate.

Based on the analysis of UV-Vis Spectrophotometer instrument to sample without doping SnO_2 and SnO_2 with a dopant variations of Al, a thin layer transparency will decrease when the concentration of dopant added. As well as to measure the absorbance. Increasing the concentration of dopant causes more light energy is absorbed by electrons of the aluminum dopant. The more electrons from a substance that requires energy to excitation to a higher energy level, the higher the absorption. The electrical characteristics can be determined by the width of the gap between the valence band and the conduction band. It can be known by calculating the width of the energy gap or band gap energy is related to the absorption of energy from ultraviolet light and visible light in this study. Increased energy (in units of eV) causes the electrons in an atom undergo vibration and out of its original energy level to the energy level is higher [18]. It can be known from the graphical trend is increasing exponentially. From the data obtained, the decline in the value of energy gap occurs after the addition of aluminum dopant concentration. This indicates that when the width of the energy gap is reduced, allowing more electrons undergo electronic transitions from the valence band to the conduction band so that a thin layer of more conductive. It is also confirmed that aluminum is a type of metal that is a good conductor.

The relationship between the photon energy (hν) and the absorption coefficient (α) is expressed in the equation :

$$(\alpha h\nu)^{\frac{1}{n}} = A(E - E_g) \tag{1}$$

where A is a constant, E = hν is the photon energy and E_g is the band gap optics. Exponent n depends on the type of optical transitions. Magnitude n for direct optical transitions is equal to 1/2, to indirect optical transitions by 2 and a direct optical transitions forbidden is 3/2 [19].

Figure 4. is a graph of energy gap for SnO_2 layer without doping and aluminum-doped SnO_2 5, 10, and 15 % on a quartz substrate. Furthermore the value of energy gap as Table 1.

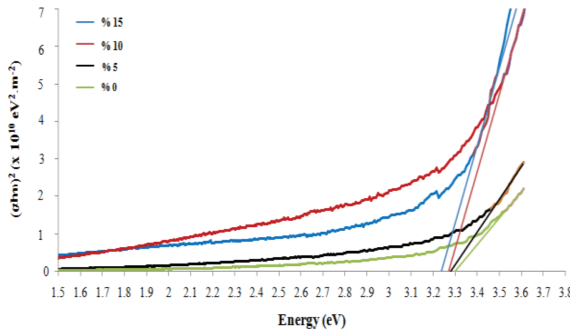


FIGURE 4. Graph of Energy Gap of SnO_2 doped SnO_2 and Al with a concentration of 5, 10, and 15 % on a quartz substrate

TABLE 1. Comparison energy gap of material thin layer of SnO_2 on some variation of dopant concentration of Al

Percent of Al (%)	Eg quartz ubstrate (eV)
0	3.30
5	3.28
10	3.25
15	3.24

The graph of comparison energy gap of material thin layer of SnO_2 on some variation of dopant concentration of Al as Figure 5.

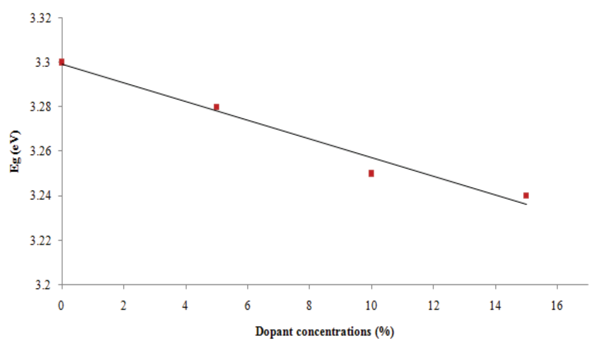
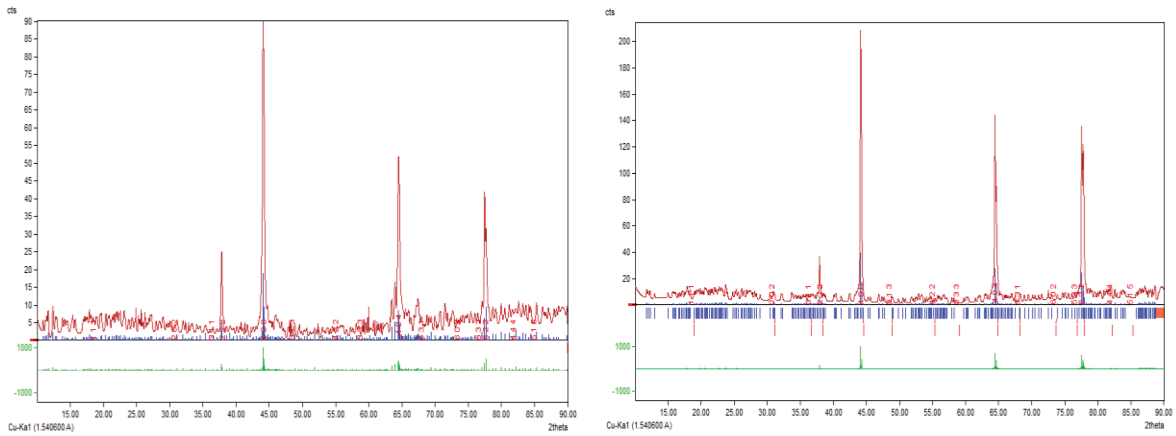


FIGURE 5. Graph of relations Al doping concentration of the energy gap SnO_2 on a quartz substrate

Tests using XRD Instrument

Measurements were performed using an X-Ray Diffraction (XRD-7000) Shimadzu brand Maxima, which is operated at a voltage of 30 kV and current of 30 mA with a target Cu (λ = 1.54060 Å). Figure 6(a) and 6(b) below shows the diffraction pattern for SnO_2 samples with dopant concentrations of 0 and 5% and the annealing temperature 400 ^{o}C.



(a) (b)

FIGURE 6. XRD diffraction patterns for material SnO_2 (a) and SnO_2 (b): Al 5% on a quartz substrate

Based on the results of XRD, the phase that is formed is Al_2O_4Sn cubic structure with the identity of a = b = c = 8.1200 Angstroms with α = β = γ = 90 °, referring to the crystallographic data is open database (COD). These results indicate that the addition of aluminum dopant to increase the intensity peak at an angle diffraction pattern (2θ) of about 44° and does not eliminate the constituent elements of SnO_2 thin layer that is the element of tin (Sn) and oxygen (O). Average crystal size can be obtained by Scherrer equation as follows:

$$D = \frac{k\lambda}{\beta cos\theta} \quad (2)$$

SnO_2 originally was 60.64 nm, and after the addition of dopant Al 5%, the crystal size becomes smaller at 57.50 nm. The position of constituent particles of material for each of the samples showed a thin layer of the loop with a regular pattern, which indicates that the sample material is crystalline solids [20].

Tests using a SEM-EDX

Tests using a SEM (Scanning Electron Microscopy) was conducted to determine the structure of the material surface morphology of thin layers. The tool is integrated with detector energy dispersive X-ray (EDX) that can be used to analyze the composition of materials making up the sample. Figure 7. shows the results of observations in the sample without doping SnO_2, and Figure 8. shows the surface morphology of SnO_2: Al with a dopant concentration of 5 % is deposited on a quartz substrate.

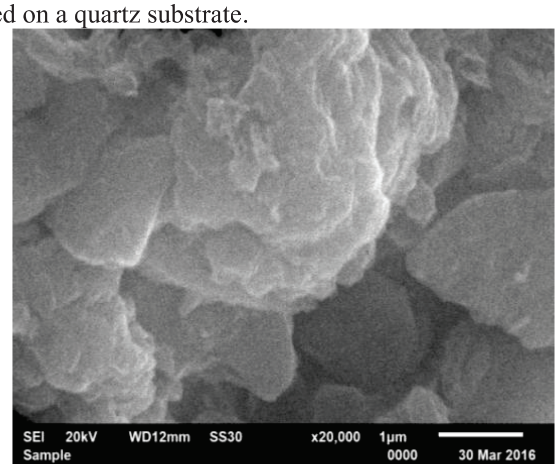


FIGURE 7. SEM observations on SnO_2 thin layer on a quartz substrate

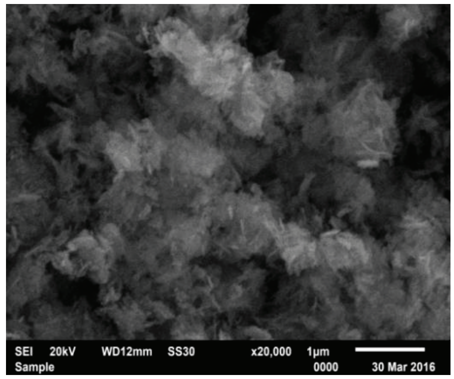
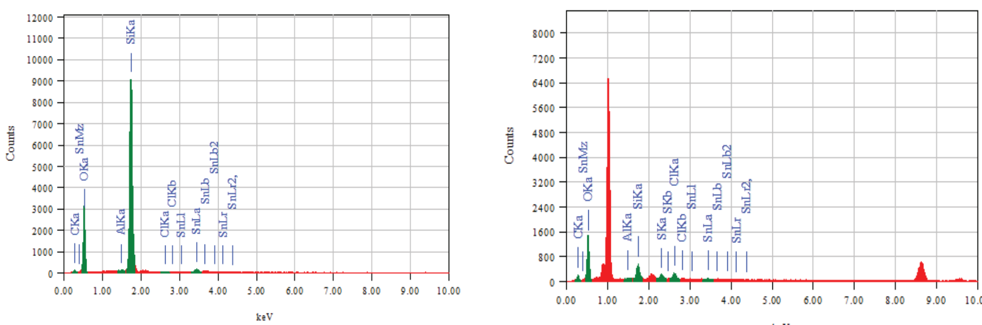


FIGURE 8. SEM observation results in a thin layer of SnO_2 : Al 5% on a quartz substrate with a magnification of 20000x

The contrast in the resulting image is the result of differences in reflectivity in a wide range of nano structured area. The resulting image is different from each other because of their differences in the orientation of the crystal surface. SnO_2 samples were deposited on a quartz substrate has a pattern resembling a wad of cotton, but is more rugged than the SnO_2 with 5% aluminum dopant that looks more smooth and flat. In addition, grain boundaries samples are not visible at all. This is due to the characteristics of the quartz substrate that is resistant to high temperatures up to 1200 °C so as to inhibit the speed of the evaporation process sol solution to make their porosity in thin layers. SEM-EDX analysis is used to confirm the presence of a thin layer of material constituent components. Here is the result of the identification of the distribution of material components of SnO_2 and SnO_2: Al 5% on a quartz substrate.



(a) (b)

FIGURE 9. The identification of the distribution of material components of SnO_2 (a) and SnO (b): Al 5 % on a quartz substrate

From EDX testing integrated with SEM on the distribution of material components of SnO_2 and SnO_2 : Al 5% on a quartz substrate, obtained by the fact that the presence of the element tin (Sn), oxygen (O) and aluminum (Al) can be identified. In addition to the elements Sn, O and Al, other elements identified in part derived from components of the sol solution are deposited on a substrate such as quartz C and Cl, and partly is forming part of a quartz substrate itself such as SiO_2 [21].

CONCLUSION

Based on the results of research and discussion, it can be concluded as follows:

The greater the concentration of aluminum dopant, the greater the absorbance of a thin layer of SnO_2. The level of transmittance of a thin layer of SnO_2 and SnO_2: Al is reduced by the addition of aluminum dopant concentration. Samples without doping SnO_2 and SnO_2: Al on quartz substrate has an energy gap in the range of 3.24 to 3.30 eV. The magnitude of the energy gap decreases as the addition of aluminum dopant concentration that causes the material is more conductive. Characterization of crystalline phase identification by XRD (X-ray diffractometer) showed the compound formed is Al_2O_4Sn, and have a cubic crystal system. Characterization of the structure of the surface morphology of thin layers with SEM did not show any grain boundaries on SnO_2 and SnO_2: Al 5%. The presence of dopant influences the grain size of the crystals. SnO_2 and SnO_2: Al is produced, can be applied as a basic ingredient material Transparent Conductive Oxide (TCO) in terms of transparency and its energy band gap.

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