Synthesis of Tin Oxide Thin Layer by Doping Aluminum, Fluorine, and Indium Using Sol-Gel Spin Coating Technique

Aris Doyan[1,2*], Susilawati[1,2], Lalu Muliyadi[2]

[1]Physics Education, Faculty of Teacher Training and Education, University of Mataram, Lombok, West Nusa Tenggara, Indonesia.
[2]Master of Science Education Program, University of Mataram, Lombok, West Nusa Tenggara, Indonesia.

Abstract: The synthesis of tin oxide thin films with doping aluminum, fluorine, and indium (SnO_2: Al + F + In) by sol-gel spin coating technique has been successfully carried out. This synthesis aims to determine the quality of the thin film formed by adding doping aluminum, fluorine, and indium. The basic material used is $SnCl_2.2H_2O$, while the doping material used is $AlCl_3$, NH_4F, and $InCl_3.4H_2O$. The comparison of the basic ingredients and doping mixture of aluminum, fluorine and indium (SnO_2: Al+F +In) used were 100: 0%, 95: 5%, 90: 10%, 85: 15%, 80: 20% and 75: 25%. The synthesis uses a glass substrate with size (10 x 10 x 3) mm. Coating synthesis includes substrate preparation, sol-gel making, film making, and sample heating. The layers that are made consist of 1 to 4 layers. The results showed that the layer formed had a high degree of transparency along with the increasing concentration of the doping material percentage. The higher the doping concentrations of aluminum, fluorine, and indium, the higher the transparency of the resulting layer. Besides, the greater the number of layers, the lower the transparency level of the layers.

Keywords: Thin layer; SnO_2; aluminum; fluorine; indium; sol-gel; spin coating.

Introduction

Tin oxide (SnO_2) is a semiconductor material that has unique characteristics with low resistivity, high optical transparency, and has an energy bandgap of about 3.6 eV (Doyan et al, 2017). SnO_2 is widely applied to transistors (Liu et al, 2020), diodes (Gullu et al, 2020), capacitors (Doyan et al, 2018), liquid crystal displays (Andrade et al, 2019), solar cells (Bittau et al, 2017), and other optoelectronic equipment (Ikraman et al, 2017). Also, SnO_2 is widely applied as a gas sensor (Rebholz et al, 2015) because it is very sensitive to gas (Susilawati et al, 2020).

The characteristics of SnO_2 can be modified as needed by adding another element called dopant (Ikraman et al, 2017). SnO_2 is usually doped with aluminum (Imawanti et al, 2017), fluorine (Kendall et al, 2020), and indium (Hakim et al, 2019), zinc (Hegazy et al, 2019), and antimony (Khorshidi et al, 2019) . Also, SnO_2 can be doped with a mixture of aluminum and zinc (Doyan et al, 2018), a mixture of antimony and zinc (Medhi et al, 2019), a mixture of aluminum and fluorine (Susilawati et al, 2020), and a mixture of aluminum and indium (Munandar et al, 2020).

The characteristics of SnO_2 itself can be influenced by doping aluminum, fluorine, and indium, which is called doping which can stabilize the particles and change the energy bandgap that SnO_2 has. Besides, doping with this material is known to change the structure, increase the response, selectivity and stability of the gas sensor, increase electrical conductivity and optical transmission, and can reduce the energy band gap of SnO_2 (Muliyadi et al, 2019). However, it is not yet known how the combined effect of these three dopants on the characteristics of the SnO_2 thin layer itself, so that further investigation is needed regarding

Email: aris_doyan@unram.ac.id

the effect of the three dopants on the characteristics of the SnO_2 layer.

Method

The basic material used in this study is $SnCl_2.2H_2O$. Doping materials use Aluminum Chloride ($AlCl_3$), Ammonium Fluoride (NH_4F), and Indium (III) Chloride ($InCl_3.4H_2O$). The solvent used is ethanol (C_2H_5OH). The substrate used is glass with size (10x10x3) mm. The synthesis of thin films includes substrate preparation, sol-gel manufacture, thin-film manufacture, and heating processes (Muliyadi et al, 2019).

The sol-gel preparation uses doping variations (0, 5, 10, 15, 20, and 25)% which are dissolved in ethanol using a magnetic stirring at room temperature. After that, the sol solution was left to stand for 48 hours. The next process is making a thin layer using a spin coater at a speed of 2000 rpm for 3 minutes. After that, the sample is heated in a furnice at a temperature of 150 °C for one hour (Susilawati et al, 2019).

Result and Discussion

Synthesis of SnO_2 thin films with doping mixture of aluminum, fluorine, and indium (SnO_2: Al+F+ In) using the sol-gel spin coating method. The basic material used is $SnCl_2.2H_2O$ as tin oxide (SnO_2), while the doping materials used are $AlCl_3$, NH_4F, and $InCl_3.4H_2O$ as aluminum, fluorine, and indium. The comparison of the basic ingredients and doping mixture of aluminum, fluorine and indium (SnO_2: Al+F+In) used were 100: 0%, 95: 5%, 90: 10%, 85: 15%, 80: 20%, and 75: 25%. The synthesis of this thin layer uses glass with a size (10x10x3) mm as a substrate.

This synthesis stage includes the preparation of the glass substrate, making sol-gel, making thin films, and the process of heating the thin films. Substrate preparation is done by washing the glass substrate with detergent then cleaning it with alcohol and drying it in an oven. This preparation aims to remove the remnants of dirt attached to the glass substrate (Muliyadi et al, 2019).

The next process is to make a sol-gel with a variety of doping materials for aluminum, fluorine, and indium, then dissolve it with ethanol using a magnetic stirring so that the solution is quickly homogeneous and becomes a sol. After the solution is homogeneous, then the solution is allowed to stand for 48 hours at room temperature so that it becomes a gel. The sol that is formed is shown in Figure 1.
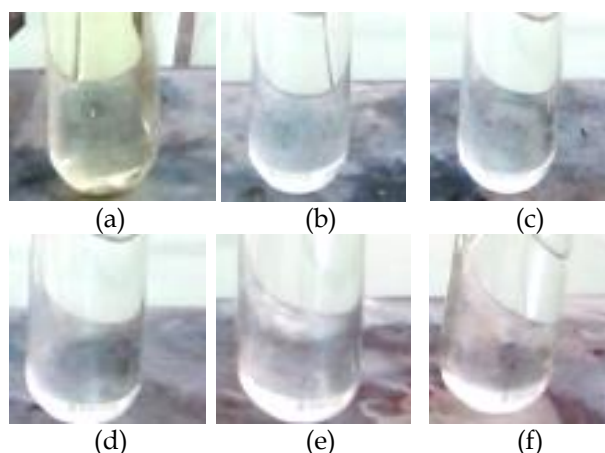

Figure 1. Sol SnO_2: Al+F+In. (a) 100: 0%, (b) 95: 5%, (c) 90: 10%, (d) 85: 15%, (e) 80: 20%, (f) 75: 25%.

Based on Figure 1, it is clear that the level of transparency of the resulting sol is higher as the amount of doping of aluminum, fluorine, and indium increases. This is because the reaction of $SnCl_2$ with ethanol is reduced by the addition of aluminum, fluorine, and indium dopants (Muliyadi et al, 2019).

The next process is to make a thin layer using a spin coater that is rotated at 2000 rpm for 3 minutes. After that, the sample is heated in a furnace at a temperature of 150 ° C for one hour.
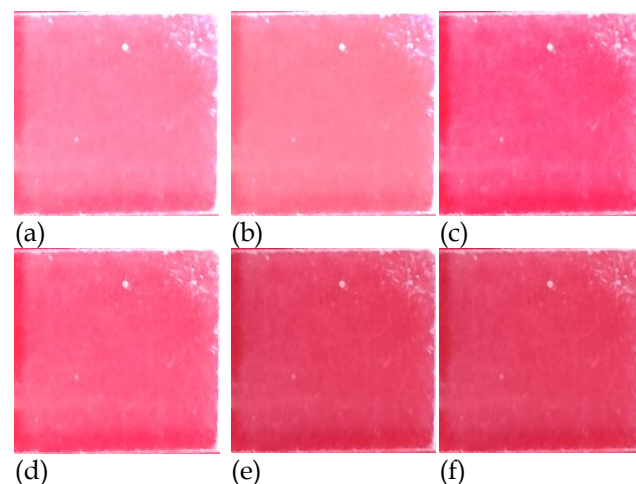

Figure 2. SnO_2: Al+F+In thin layer (a) 100: 0%, (b) 95: 5%, (c) 90: 10%, (d) 85: 15%, (e) 80: 20%, (f) 75: 25%.

Figure 2 shows a thin layer of SnO_2 with doping variations of aluminum, fluorine, and indium. The addition of doping aluminum, fluorine, and indium resulted in a change in the transparency of the thin layer (Muliyadi et al, 2019). The level of transparency of the layers formed is greater with the increasing doping concentrations of aluminum, fluorine, and indium (Susilawati et al, 2019).
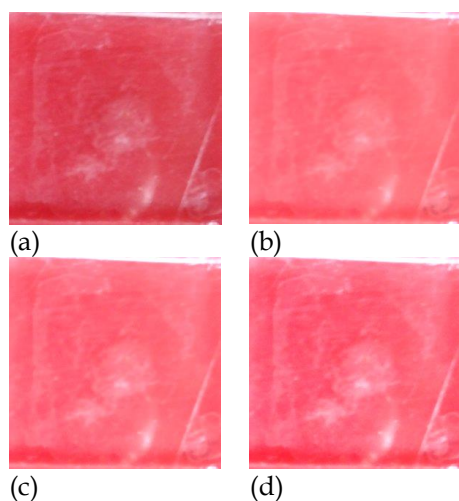
(a)   (b)

(c)   (d)

Figure 3. Thin-film SnO_2: Al+F+In layer variation. (a) 1 layer, (b) 2 layers, (3) 3 layers, (d) 4 layers.

Figure 3 shows that the sample of the thin layer SnO_2: Al+F+In layer variation. The greater the number of layers, the more opaque the layer formed. This means that the transparency level of the layer is getting lower. This is because the grain size of the layers is getting bigger as the number of layers increases (Muliyadi et al, 2019).

Conclusion

The synthesis of SnO_2 thin films with doping aluminum, fluorine, and indium (SnO_2: Al+F+In) using the sol-gel spin coating technique has been successfully carried out. The results showed that the layer formed had a high degree of transparency along with the increasing concentration of the doping substance percentage. The higher the doping concentrations of aluminum, fluorine, and indium, the higher the transparency of the coating. The greater the number of layers, the more opaque the layer formed. This means that the transparency level of the layer is getting lower.

Acknowledgements

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