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Growth of Tin Oxide Thin Film by Aluminum and Fluorine Doping Using Spin Coating Sol-Gel Techniques

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Abstract: The growth of tin oxide thin film by Aluminum doping and Fluorine has been carried out with the sol-gel spin coating technique. The growth aims to determine the quality of the thin layer formed based on variations in doping aluminum and fluorine. The basic ingredients used were $SnCl_2.2H_2O$, while the doping materials used were Al (Aluminium) and F (Fluorine) with variations in dopant concentrations (0, 5, 10, 15, 20 and 25)%. The growth of a thin layer using measured glass (10x10x 3) mm as a substrate. The growth of thin films includes substrate preparation, sol-gel making, thin film making, and heating processes. The growth of thin layer was dripped on a glass substrate with sol-gel spin coating technique at 1 M sol concentration and treated with maturation for 24 hours. The next step is making a thin layer using a spin coater at a speed of 2000 rpm for 3 minutes. After that, the substrate is heated in an oven at 100°C for 60 minutes. The results showed that the transparency level of the tin oxide layer increases with increasing amounts of doping Aluminum and fluorine.

Key words: Aluminum, Fluorine, Sol-gel, Spin Coating, Thin Film, Tin Oxide.

Introduction

The tin oxide (SnO_2) is a semiconductor material that has high optical transparency and low resistivity (Doyan et al, 2017). In addition, tin oxide has an energy band gap ranging from 3.6 eV (Schell et al, 2017). Because of its uniqueness, tin oxide is widely applied to capacitors, transistors, diodes, and sensors (Doyan et al, 2018). In addition, tin oxide is very sensitive to gases so that it is widely applied as a sensor gas (Rebholz, 2015).

The advantages of Tin oxide can be modified as needed by providing additional elements (dopants) (Ikraman et al, 2017). Tin oxide is usually doped with indium (Ma et al, 2018), fluorine (Banyamin et al, 2014) and aluminum (Gahtar et al, 2014). Tin oxide thin films doped with Aluminum and Fluorine are known to affect the properties of Tin Oxide itself, including stabilizing Tin oxide particles and changing the energy band gap. In addition, the exposure with Aluminum and Fluorine is known to increase optical transmitance and electrical conductivity, change the structure, and improve response, selectivity, and stability in sensor gases. The addition of Aluminum doping and Fluorine has been carried out by several previous researchers such as Onkundi et al (2018), Doyan et al (2018), Lin et al (2017), Bakr et al (2016) and stated that the growth of Tin oxide layers with doping Aluminum and Fluorine can reduce the Tin oxide energy band gap. But it is not yet known how the effect of the combination of these two dopants on the characteristics of the Tin oxide layer itself. Because of this, further investigation is needed on the effect of these two dopants on the characteristics of the Tin oxide layer.

The method of preparation and growth of Tin oxide layers both pure and with doping additions have been carried out by several previous researchers such as DC sputtering (Mawarani et al, 2006), chemical bath deposition (Maddu et al, 2009), dip coating (Carvalho et al, 2012), RF sputtering (Xu, et al. 2016), and sol-gel spin coating (Doyan et al, 2018). Of the three techniques, the sol-gel spin coating technique has the advantage that the resulting thin layer is homogeneous because the solution dripped on the substrate is rotated at a certain speed and the influence of the centrifugal force away from the center of rotation (Imawanti et al, 2017).

Method

The basic material used in this study was 23.697 grams of Tin (II) chloride dihydrate ($SnCl_2.2H_2O$ with a molar mass of 225.63 g/mol, purity of 98%, Merck). The solvent uses 20 ml ethanol ((C_2H_5OH) with a molar mass of 46.07gram /mol, purity of 98%, Merck) at room temperature. Materials for doping were used 0.999 grams of Ammonium Fluoride (NH_4F) with a molar mass of 37 g/mol and 0.444 grams of Aluminum Chloride ($AlCl_3$) with a molar mass of 133.34 g/mol (98% purity, Merck). The substrate used is glass with size (10x10x3) mm. Other supporting materials are alcohol, distilled water, and detergent which are used to clean the substrate. Thin layer growth includes substrate preparation, sol-gel making, thin film making, and heating process. The sol-gel maker uses Ammonium Fluoride (NH_4F) and Aluminum Chloride ($AlCl_3$) with doping variations (0, 5, 10, 15, 20 and 25)% dissolved in 20 ml ethanol. Then the solution is homogenized using stirring magnetic at room temperature. Sol solution is divided into six parts, namely tin (II) chloride dihydrate with variations in doping Ammonium Fluoride (NH_4F) and Aluminum Chloride ($AlCl_3$) of (0, 5, 10, 15, 20 and 25)%. After that, the sol solution was left to stand for 2 days. The next step is making a thin layer using a spin coater at a speed of 2000 rpm for 180 seconds. After that, the substrate is heated in an oven at 100 °C for 60 minutes.

Result and Discussion

Tin oxide thin films with aluminum doping and fluorine are grown using the sol-gel spin coating method. The basic material used was $SnCl_2.2H_2O$, while the doping material used was $AlCl_3$ and NH_4F with variations in dopant concentration (0, 5, 10, 15 and 20)%. The substrate used is glass with size (10x10x3) mm. The thin layer growth includes substrate preparation, sol-gel making, thin film making, and heating process. Substrate preparation is done by washing the glass substrate with detergent and drying it using an oven. The purpose of this preparation is to remove dirt and oil from the glass.

The next process is making sol-gel with a variety of Aluminum and Fluorine doping: 0, 5, 10, 15, 20 and 25%, then the solution is homogenized using magnetic stirred. The solution is left for two days at room temperature. The amount of mass each from $SnCl_2.2H_2O$, $AlCl_3$, and NH_4F is shown in table 1.

Table 1: Doping Percentage and Mass Amount

Material Percentage (%)	$SnCl_2.2H_2O$ (g)	$AlCl_3$ (g)	NH_4F (g)
100:0.0	4.5138	0.00	0.00
95:5.0	4.2880	0.0667	0.0185
90:10	4.0624	0.1334	0.0370
85:15	3.8367	0.1999	0.0556
80:20	3.6110	0.2667	0.0741
75:25	3.3853	0.3333	0.0926

The mass of table 1 is obtained from equations 1, 2 and 3 below.

$$(100-n)\% = \frac{(m_t SnCl_2{\cdot}2H_2O)\ x\ \frac{1}{Mr\ SnCl_2{\cdot}2H_2O})}{(m_t\ NH_4F)\ x\ \frac{1}{Mr\ NH_4F}} \quad (1)$$

$$(n)\% = \frac{(m_t\ AlCl_3)\ x\ \frac{1}{Mr\ AlCl_3})}{(m_t SnCl_2{\cdot}2H_2O)\ x\ \frac{1}{Mr\ SnCl_2{\cdot}2H_2O}} \quad (2)$$

$$(n)\% = \frac{(m_t\ NH_4F)\ x\ \frac{1}{Mr\ NH_4F})}{(m_t SnCl_2{\cdot}2H_2O)\ x\ \frac{1}{Mr\ SnCl_2{\cdot}2H_2O}} \quad (3)$$

Figure 1 show that the level of transparency of soles produced is higher as the amount of doping Aluminum and fluorine increases. This causes the reaction of $SnCl_2$ with ethanol to be reduced due to the addition of Aluminum and fluorine dopants (Ikraman et al, 2017).

The next step is making a thin layer with doping variations using a spin coater at a speed of 2000 rpm for 180 seconds. After that, a thin layer is heated in the oven at 100 °C for 60 minutes. Figure 2 shows a thin layer of tin oxide with variations in aluminum and fluorine doping.

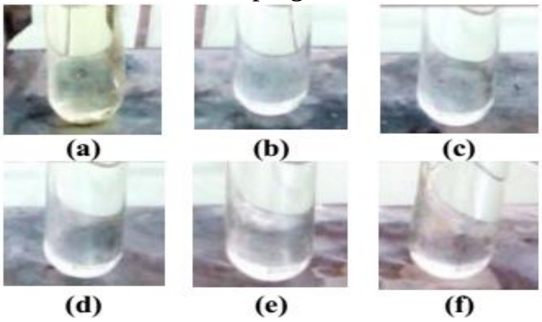

Figure 1. Sol SnO_2 for variations in doping Aluminum and Fluorine (a) 100: 0%, (b) 95: 5%, (c) 90: 10%, (d) 85: 15%, (e) 80: 20%, (f) 75: 25%

The thin layer formed shows that the addition of Aluminum and Fluorine dopants results in changes in transparency. The greater the concentration of doping aluminum and fluorine, the greater the level of transparency of the formed layer.

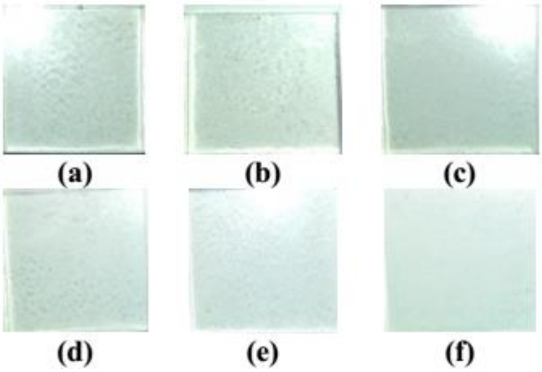

Figure 2 Tin oxide thin layer with variations in doping Aluminum and Fluorine 100: 0%, (b) 95: 5%, (c) 90: 10%, (d) 85: 15%, (e) 80: 20%, (f) 75: 25%.

Conclusion

The growth of Tin oxide thin layer by doping Aluminum and Fluorine using the sol-gel spin coating technique produced in this study has good transparency along with the increasing concentration of doping given. The higher the concentration of aluminum and fluorine doping, the higher the transparency of the layer.

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