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Effect of Thickness on Conductivity of ($ZnO:AlCl_2$) TCO Thin Film

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Abstract

Massive materials engineering has been carried out to get a certain function of a material. One of the intensively carried out researches in the development of conductive glass as the base material for solar cells. based on these facts, this research was conducted to develop a functional material especially transparent conductive oxide (TCO). ($ZnO:AlCl_2$) TCO thin film has been deposited on a glass substrate using DC sputtering technique. The objective of this research is to study the effect of time deposition, the distance of substrate, morphology of surface, and microstructure ($ZnO:AlCl_2$) thin film, so that it can be used as a component in the solar cell. The characterization has been performed with Scanning Electron Microscopy to investigate the surface morphology and SEM-Energy Dispersive X-Ray Spectroscopy to expose the elemental compositions. Whereas, the electrical resistivity was done by using the four-point probe method. The result showed that the conductivity relies on the thickness of the ZnO:AlCl2 films. The Obtained $ZnO:AlCl_2$ films have high conductivity in thickness 0.22mm ($6.89\Omega^{-1}cm^{-1}$) with 30 minute vacuum time and 1 minute deposition. The Zn content is oxidized by high temperature as soon as the deposition time increases and Vacuum time is proven to reduce overheat during the deposition process.

Keyword: Thickness, Conductivity, Thin Film.

Abstrak

Rekayasa material telah dilakukan secara massif untuk mendapatkan material maju. Salah satu material yang banyak dikembangkan adalah kaca konduktif sebagai bahan utama dari sel surya. Berdasarkan fakta tersebut, penelitian ini dilakukan untuk mendapatkan pengembangan fungsi material salah satunya *Transparent Conductive Oxide* (TCO). Lapisan tipis TCO ($ZnO;AlCl_2$) di deposisi pada substrat kaca menggunakan teknik *Direct Current Sputtering*. Objek pada penelitian ini adalah mempelajari efek yang ditimbulkan oleh waktu vakum, waktu deposisi, morfologi permukaan, dan struktur mikro yang dihasilkan oleh lapisan tipis ($ZnO;AlCl_2$), sehingga dapat digunakan sebagai komponen solar sel. Karakterisasi dilakukan dengan menggunakan *Scanning Electron Microscopy* (SEM) untuk meneliti morfologi permukaan dan SEM-*Energy Dispersive X-Ray Spectroscopy* (SEM-EDS) untuk menampilkan komposisi elemen yang terdeposisi. Sedangkan, pengukuran resistivitas listrik diukur dengan menggunakan metode *Four Point Probe*. Hasilnya menunjukkan konduktivitas dan resistivitas bergantung pada ketebalan lapisan. Lapisan $ZnO:AlCl_2$ yang diperoleh memiliki konduktivitas tinggi pada ketebalan 0.22mm yaitu ($6.89\Omega^{-1}cm^{-1}$) dengan 30 menit waktu vakum dan deposisi selama 1 menit. Kandungan Zn akan teroksidasi oleh suhu tinggi setelah waktu deposisi meningkat dan lama waktu vakum terbukti dapat mengurangi panas berlebih selama proses pengendapan.

Kata kunci: Ketebalan, Konduktivitas, Lapisan Tipis.

1. Introduction

Transparent Conductive Oxide (TCO) was studied to produce a high conductivity thin layer [1]. Semiconductor materials that have a wide bandgap can be converted into materials with high transparency and conductivity close to metal by providing doping [2,8,9, and 10]. In order to produce a good substrate of TCO, the thin-film must have low electrical resistivity ($\sim 10^{-3}$-$10^{-4}\Omega$.cm) as well as high optical transparency to visible light (> 80% light transmittance) [16]. In general, most of the material used in TCO is Indium tin oxide (ITO). Because, the transparency of ITO almost 80%

and the resistance is 2,36x10^{-4}(Ω.cm) [11]. However, with the ITO development, the scarcity and the high price of Indium became the obstacles in the supply of ITO glass [17], so that an alternative material is needed in order to achieve low-cost material. Several zinc oxide materials are being researched as alternative solutions to Indium [18,19].

Many methods used in fabrication of TCO such as sol-gel method, spray pyrolysis, and vapor deposition [3,12,13, and 14]. In this paper, we will prepare the other method for deposition to make it more advantageous. DC Magnetron Sputtering method has been used for a long time to fabricate thin films because it produces high conductivity and the transmission up to 80% [4,5]. Asanithi et al. reported on growth of silver nanoparticles by using Direct Current and the result of High-resolution transmission electron microscopy image represented clear lattice fringes of Ag nanoparticles with a d-spacing of 0.203nm [7]. Thus, Direct current magnetron sputtering could be a potential technique for synthesis of nanoparticles on thin film TCO because of the advantages [15].

However, in the present as technology develops, Indium becomes a material that is quite difficult to find and causes increasingly expensive production prices. That is the main idea in this research to find other alternatives of TCO as a substitute for ITO which has a better advantage.

2. Methods

The thin film prepared by the low-pressure Direct current plasma sputtering method without inert gas consists of a high-voltage cylindrical plasma tube with a pair of electrodes. The target is sheet metal Zn in the form of a (5 × 5) cm, and the glass substrate with PVA-$AlCl_2$ dopant used size (2×20×200) mm. The distance of the glass substrate to the target surface is 5 cm with a variation of 20 minutes and 30 minutes of the vacuum time. The electrical resistivity was measured by the four points probe method shown in Eq. 1 and the surface morphology of the films were studied by Scanning Electron Microscopy.

$$\rho = \frac{\pi}{ln2}\ x\ R\ x\ t \qquad (1)$$

3. Result

Based on the experiment, data obtained from the substrate distance of 5cm and the variation of the deposition time of 20 and 30 minutes. Table 1 shows the vacuum time, deposition time, thickness, and conductivity of the sample. The distribution is identified based on the thickness. The thickness measured with a micrometer presents a range of 0.22 to 0.27mm. The layer thickness rose significantly over the deposition time to prove that the layer thickness is affected by the deposition time [11, 20].

Table 1: Resistivity on the sample

Vacuum time	**Deposition [Minute]**	**R [MΩ]**	**Δl**	**ρ**	**σ**
			[mm]	**[Ω.cm]**	**[$\Omega^{-1}cm^{-1}$]**
20 minutes	**1**	**1.2**	**0.23**	0.185	5,41
	2	**1.8**	**0.23**	0.245	4,09
	3	**2**	**0.24**	0,380	2,63
	2	**1.5**	**0.22**	0.163	6,13
	3	**2.3**	**0.27**	0.750	1,33
30 minutes	**1**	**2**	**0.22**	0.145	6,89
	2	**1.3**	**0.26**	0.330	3,03
	3	**1.5**	**0.24**	0.285	3,50
	2	**1.9**	**0.23**	0.258	3,87
	3	**1.6**	**0.24**	0.261	3,83

The sample thickness and the resistivity value to get the conductivity of the layer using the four-point probe method in the equation (1). The conductivity of the sample is affected by the film thicknesses, it can be seen that conductivity experienced a decline, while the thickness increased. The TCO substrate requires low resistivity to obtain high conductivity to conduct electrons. However, the resistivity relies on the thickness of the ZnO:AlCl$_2$ films [20, 23, 24]. In this study, the conductivity was obtained at 1.33Ω^{-1}cm^{-1} to 6.89Ω^{-1}cm^{-1}.

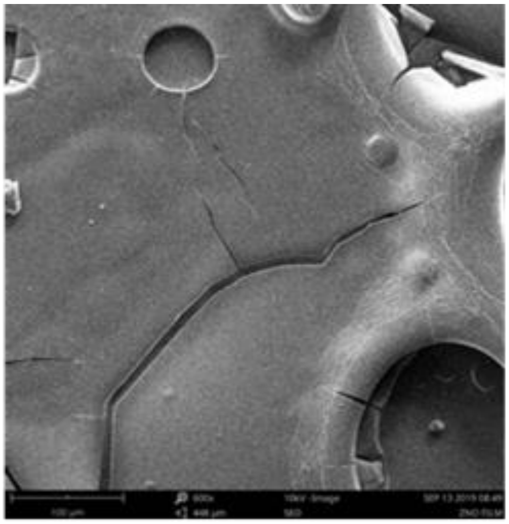

Figure 1 Scanning Electron Microscopy Sample After Deposition

The highest conductivity was shown by the sample with 30 minutes of vacuum time, two minutes of deposition, the value of conductivity received was 6.89Ω^{-1}cm^{-1}, and a layer thickness of 0.22mm. The longest deposition causes the layer to overheat, providing the conductivity decreases. The short deposition time controls the heat in the sample resulting in high conductivity [5, 26]. Moreover, the two vacuum times produce different conductivity. The varying vacuum time of the sample resolves the extreme conductivity reduction. Long-term vacuum produced a steady value with the high conductivity at the vacuum time of 30 minutes. Whereas, the brief vacuum has various conductivity with the lowest at 1.33Ω^{-1}cm^{-1}. Vacuum time is proven to reduce overheat during the deposition process [25].

In addition, the Al layer distribution and the Zn layer deposition identified the layer distribution. SEM of the sample tested in Fig. 1 to determine the surface morphology to the level of uniformity of distribution. Fig. 1 shows the morphology of the deposited films with metal Zn has a unique surface layer. Different surface features such as crater-like structures called etching arise due to less order and less compact grain boundaries, which have potentials for etching [20,22]. This phenomenon relates to the presence of ions and generates bubbles. During the deposition process, the bubbles will disappear and leave a layer structure with different thicknesses.

Table 2: Distribution Data of Zn and Al on the Sample with vacuum time 30 minutes and 1 minute deposition.

Spot	**Distribution Data (Weight Conc.)**	
	Zn	**Al**
1	33.79	6.04
2	23.92	6.89
3	39.10	8.97
4	33.61	5.94
5	20.63	9.17
Average	**30.01**	**7.402**

The layer that formed has a dark and bright colored side. The dark part shows a thinner layer than the bright one. The surface layer was tested at several sample points in Fig. 1 to determine the Zn and Al elements on the substrate deposited. The dark part has less deposition of Zn than the bright. The five sample points in Table 2 identified Zn and Al elements deposited. The Al concentration was at spot 5 is the highest content with 9.17, and the lowest was at spot 4 with 5.49, while the Zn concentration was at spot three is the highest with 39.10, the lowest content was at spot 5 with 20.63. The mobility of the atoms that are splashed onto the target is disparate. The thicker layer has more Zn because the lower part during deposition is exposed [7,21]. Based on the five sample points, the Zn distribution in the layers has an even distribution so that the layers are homogeneous.

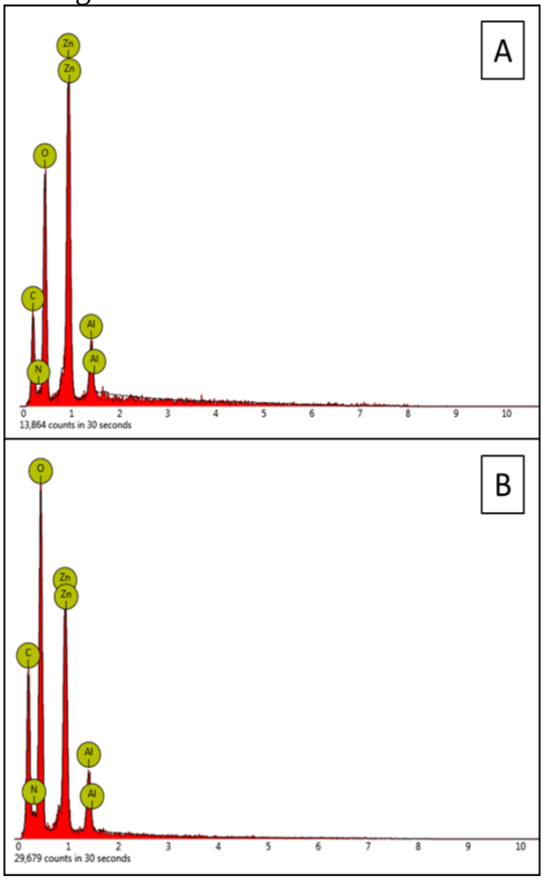

Figure 2 SEM-EDS Sample Analysis After 30 minutes Vacuum A. 1 minute deposition

The elemental compositions of the $ZnO:AlCl_2$, obtained by SEM-EDS analysis, are shown in Figure 2. The spectrum exposes the presence of Zn, Al, O, C and attendance of other elements, confirming the synthesized form. In Figure 2A the atomic concentrations obtained by this technique have the same elements: Zn, O, Al, C and N for all layers. Based on Figure 2B, the Zn content is oxidized by high temperature because the deposition time increases. The inhomogeneity of the sputtering process provided oxygen ions from the oxidized surface accelerated across the entire surface of the film [27]. The oxygen content of the layer increases with increasing deposition time. The content of Zn and Al is a factor as a conductor of electrons. The more metal content layers have the potential to get high conductivity. Although not entirely oxidized, the conductivity of the layers decreases with increasing deposition time.

4. Conclusion

The Zn distribution in these layers is homogeneous with an average distribution of 30.01. The layer thickness rose significantly over the deposition time to prove that the layer thickness is affected by the deposition time. Moreover, the conductivity affected the thickness of the ZnO:AlCl2 films. The Obtained ZnO:AlCl2 films have high conductivity in thickness 0.22mm (6.89Ω-1cm-1) with 30 minute vacuum time and 1 minute deposition. In view of the fact that the mobility of the atoms that are splashed onto the target is disparate. The thicker layer has more Zn because it is exposed during deposition. The long deposition causes the layers on the substrate to overheat so that the Zn deposition in the layer is oxidized. The conductivity of the layers decreases with increasing deposition time. The thickness of the layers increases followed by the resistivity of the deposition layers.

5. Suggestion

The next research must be characterized with XRD to know the crystal structure of TCO and UV-Vis to know the transmittance of the sample. It is necessary to vary the voltage so that the deposition layer can be thicker in a short time.

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