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SnO_2 THIN FILM DEPOSITION FOR N-TYPE AND WINDOW OF CIS SOLAR CELL

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ABSTRACT

SnO_2 THIN FILM DEPOSITION FOR N-TYPE AND WINDOW OF CIS SOLAR CELL. SnO_2 thin film deposition on glass substrate has been carried out using DC sputtering technique. This research has purpose to find the three sputtering parameters such as deposition time, pressure of Ar gas and substrate temperature. By controlling these parameters, it is expected that the SnO_2 thin film has low resistivity and high transmittance which can be used for the CIS solar cell. Ar ion bombarded on SnO_2 target, placed on the vacuum chamber, hence the sputtered SnO_2 target atom forms the SnO_2 thin film on glass substrate. The resistivity and conduction type were measured using four point probe, the transmittance by UV-Vis and the crystal structure by XRD. The microstructure and thickness were observed using SEM, while the chemical composition using EDS. The results show that the lowest resistivity with N conduction type is 5 x 10^{-2} ohm.cm, the highest transmittance is 83.59 % at λ = 600 nm, the grains are distributed homogeneously, the thickness of thin film is 1 μm, the crystal structure of SnO_2 thin film is tetragonal while composition of thin film consists of 38.42 % Sn atom, 60.96 % O atom, and 2.61 % Fe atom.

Key words : Thin film, Sputtering, CIS solar cell

ABSTRAK

DEPOSISI LAPISAN TIPIS SnO_2 SEBAGAI LAPISAN TIPIS TIPE-N DAN JENDELA SEL SURYA CIS. Telah dilakukan deposisi lapisan tipis SnO_2 pada substrat kaca menggunakan teknik DC sputtering. Tujuan penelitian ini untuk mencari tiga parameter sputtering yang menghasilkan lapisan tipis SnO_2 yang mempunyai resistivitas rendah dan transmitansi tinggi. Target SnO_2 ditempatkan dalam tabung vakum ditumbuki dengan ion Ar, sehingga atom target SnO_2 terpercik membentuk lapisan tipis SnO_2 pada substrat kaca. Untuk mengukur resistivitas, tipe konduksi menggunakan probe empat titik transmitansi menggunakan *UV-Vis* dan struktur kristal menggunakan *XRD*, strukturmikro dan ketebalan lapisan tipis menggunakan *SEM* dan analisis unsur menggunakan *EDS*. Dari hasil pengukuran didapat resistivitas terendah 5 x 10^{-2} ohm.cm dengan tipe konduksi n, transmitansi tertinggi 83,59 % pada λ = 600 nm, strukturmikro terdistribusi homogen, ketebalan lapisan tipis 1 μm, terbentuk kristal SnO_2 dengan komposisi 38,42 % Sn, 60,96 % O dan 2,61 % Fe.

Kata kunci : Lapisan tipis, *Sputtering*, Sel surya CIS

INTRODUCTION

A number of researches and developments on the making of solar cell with high efficient of other solar cell have been done for years. This activity is not only limited on the use of the semiconductor material, but also on the combination of conductor and semi conductor materials. One kind of developed solar cell is the CIS (CuInSe) solar cell. The CIS solar cell is extensively investigated and developed in the developing countries, because it has low resistivity (10^{-2} ohm.cm - 10^{-6} ohm.cm) and transmittance (80 % - 90 %), it also has higher efficiency (18 %) than other solar cell type (a-Si-H that is 13 %) [1] and it can be made in thin film, hence the cost and the dimension could be reduced.

The CIS solar cell usually consists of thin film substrate which is made from glass, thin film of rear electrode, P-type thin film, N-type buffer thin film, N-type thin film and transparent electrode film. Substrate of thin film is made from glass. Thin film of rear electrode is made from Mo materials and it has a functions as reflector. P-type thin film is made from CuInSe, buffer thin film is made from CdS materials, N-type thin film is made from ZnO or SnO_2 materials and transparent electrode is made from ZnOAI materials [2].

The most important part of the solar cell is the P-N junction. The P-N junction consists of the P-type and N-type thin films. Solar power generation exploits the properties of solar cells, which generate DC electricity when light falls on a cells made from the P-N junction material as is used for transistors and integrated circuits elements [3].

SnO_2 material is the N-type semiconductor materials which has energy gap of 3.6 eV with the crystal structure of tetragonal [4]. The conductivity is determined by unwell-balanced between Sn and O atoms on the SnO_2 crystal. SnO_2 material has high conductivity and transmittance. When the surface of Sn materials interacts with oxygen, the point defect will be generated. The point defect is formed, because the materials surface is filled with two or more O ions which leads to the formation of the donor band laid at lower of conduction band in the structure of energy band surface. If the donor is much greater than the acceptor, then the thermal excitation will excite an electron to the conduction band. Its conductivity is determined by the electron. However, its conduction properties is N-type, therefore SnO_2 material is extensively used for the transparent electrode and also as thin film of the solar cell window [5].

To make the SnO_2 thin film, one of the methods used is sputtering technique. This material as a target was placed in the vacuum chamber. It was bombarded by Ar ion, hence materials atom will be sputtered forming layers on the glass substrate. This sputtered atom depends on the electrode voltage, substrate temperature, deposition time and pressure of Ar gas. By varying these parameters, SnO_2 thin film, which have N-conduction type with crystal structure, high conductivity and transmittance will be obtained [6]. Optimalization of these parameters was done for founding the lowest resistivity.

EXPERIMENTAL METHOD

There are two electrodes in the sputtering chamber. Glass substrate was put in the positive electrode, while target was put in negative electrode. Substrate of preparation glass was sliced with the size of 10 mm x 25 mm. The glass substrate was washed with water and detergent then it was cleaned with the alcohol in ultrasonic cleaner. Target was made of the SnO_2 powder which was placed in SS cup and pressed using hydraulic pump with 300 kg/cm^2 load. Diameter of cup is 60 mm and thickness of 3 mm and it was heated at 200 ^{o}C for 2 hours.

Glass substrate was put at the anode, provided by heater, while SnO_2 target was put at the cathode, cooled by circulated water cooler. The sputtering chamber was vacuumed until 2 x 10^{-2} Torr and flowed by Ar gas and also the electrode was applied by constant DC high voltage. Ionized Ar gas bombarded the SnO_2 target, which sputtered the target atom to form thin film on the glass substrate. Variation of resistivity to the deposition time was done. The deposition time was varied from 40 minutes up to 65 minutes at pressure of 8 x 10^{-2} Torr and temperature of 220 ^{o}C. The pressure of Ar gas was varied from 4 x 10^{-2} Torr up to 8 x 10^{-2} Torr at temperature of 220 ^{o}C and time of 55 minutes. Substrate temperature was also varied from 140 ^{o}C up to 220 ^{o}C at time of 55 minutes and pressure of 8 x 10^{-2} Torr.

Some properties of the SnO_2 thin film resulted were their character. The resistivity and conduction type were measured using the four point probe. The transmittance was measured using UV-Vis, while microstructure and thin film thickness was observed using SEM. The elemental composition was measured using the EDS and the crystal structure was measured using XRD.

RESULTS AND DISCUSSION

Figure 1 presents relationship between substrate temperature and resistivity of SnO_2 thin film. As the substrate temperature increases, the thin film resistivity will decrease. Due to the increasing of temperature from the room temperature to 140 ^{o}C, the molecular of SnO_2 thin film forming a larger grain [7], and also the mobility of electron progressively increases. In addition, the vibration of substrate atom also increases hence the sputtered target atom is easily to diffuse. The thickness of thin film increases which leads to the decrease of its resistivity down to the temperature of 200 ^{o}C. Increasing temperature also use decrement of transmittance, as shown in Figure 2. At the temperature of 220 ^{o}C, the resistivity and the transmittance increase. Data of the

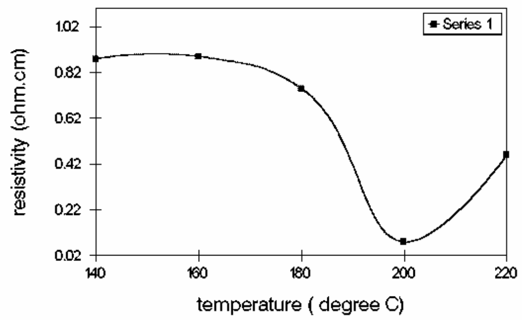

Figure 1. Relationship between substrate temperature and resistivity of SnO_2 thin film at Ar gas pressure of 0.08 Torr and deposition time of 55 minutes

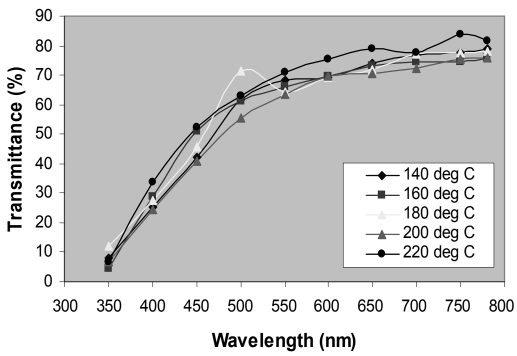

Figure 2. Relationship between the temperature and the transmittance for variation of the substrate temperature of SnO_2 thin film at Ar gas pressure of 0,08 Torr and deposition time of 55 minutes.

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thickness for any samples and parameters are not showed, just in Figure 9.

Figure 3 show the relationship between deposition time and resistivity of SnO_2 thin film. The pressure of Ar gas, substrate temperature and electrode distance were made constant, while the time of deposition was variated. When temperature is 200 ^oC, points were not all N-type, hence temperature of 220 ^oC was taken. For the time of deposition of 45 minutes, the very thin film has been deposited on the substrate, hence the resistivity is still high. For the deposition time of 50 minutes, the resistivity is progressively decreasing. At the deposition time of 55 minutes, the resistivity decreases to the minimum.

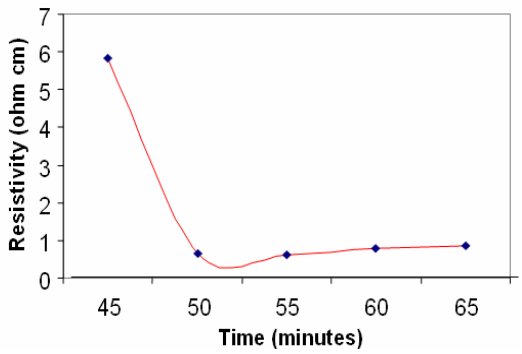

Figure 3. Relationship between the deposition time and the resistivity of SnO_2 thin film at Ar gas presure is 0.05 Torr and substrate temperature of 200 ^oC

Thin film transmittance also progressively decreases with the increase of the deposition time. For the deposition time of 60 minutes until 65 minutes, the thin film resistivity will increase. Ar gas which enter into the sputtering chamber greatly increases. Most of Ar ions were ionized, but some of which has not been ionized. Before bombarding the target, the Ar ion collide each other causing the energy of Ar ion decreases. In that case, the optimization of certain energy is happened for the deposition time above 60 minutes [7]. Ar ion which bombards the target decreases, the sputter result and the thickness decreases, while the transmittance will increase, as shown in Figure 4.

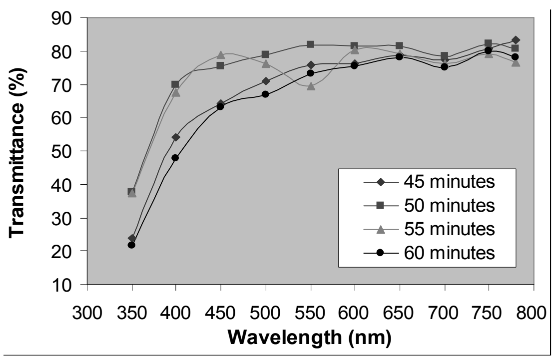

Figure 4. Relationship between the wavelength and the transmittance for variation of time deposition.

The gas pressure in sputtering chamber depends on Ar gas which is flown into the sputtering chamber. The greater Ar gas which flows into sputtering chamber, hence the pressure of the sputtering chamber progressively increases (vacuum decreases). The greater Ar gas flow into the sputtering chamber, the larger atoms of Ar gas ionized. Thereby, Ar ion that bombards the SnO_2 target will increase, but there are also many of which have not ionized. Sputtered target atom also increases. Thereby, the thickness of thin film formed on the glass substrate will increase. The decrement of thin film resistivity, as shown in Figure 5.

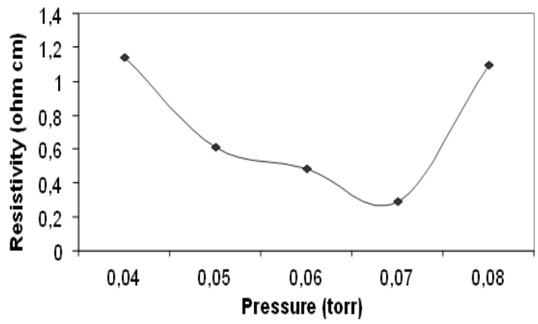

Figure 5. Relationship between Ar gas pressure and the resistivity of SnO_2 thin film at substrate temperature of 200 ^oC and time deposition of 55 minutes.

For the transmittance of thin film, whether the pressure of Ar gas increases, hence the transmittance decreases, as shown in Figure 6. For the pressure of 7 x 10^{-2} Torr, the transmittance exactly increases again, and resistivity of thin film too. This is caused by the formed thin film become thinner. The thinner of the thin film is due to the increase of the gas pressure, the greater the ionized gas will be.

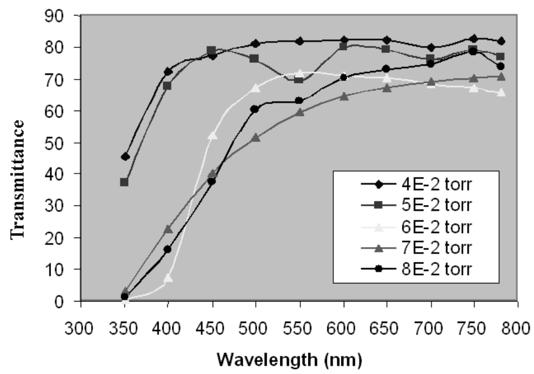

Figure 6. Relationship between wavelength and the transmittance for the variation of gas pressure.

This paper explains that deposition time influences many deposited target atoms in substrate, argon gas pressure influences Argon ion that bombards the target, temperature influences vibration of atom substrate and number of target atom that lay on substrate, the thickness influences thin film volume hence flow electron will be influenced (thick means low resistivity) and the thickness also influences the through light (transmittance).

To observe the crystal structure of SnO_2 thin film that is yielded by sputtering technique, XRD is used. From the observation a spectrum of X-Ray diffraction pattern was obtained as shown in Figure 7. The peaks appear at the angles of 26.60°, 33.90°, 37.70°, 39.05°, 51.75°, 54.62°, 57.72°, 64.57°, 65.90°, 68.92°, and 78.65°. Planes of SnO_2 crystal are [110], [101], [200], [111], [211], [220], [002], [112], [301], (311], and [321]. The appearance peak of thin film result is slightly different from the data of JCPDS (Joint Committee on Powder Diffraction Standards). This angle (2θ) shift is caused by the influence of substrate temperature at the time of crystal growth [9].

Another peak except SnO_2 peak appears at the angle of 36,15° and 81.65°. These peaks show the present of Fe and its compound with O, yielding appears at angle 36.15°. The appearance peak of Fe and FeO, because SnO_2 target was placed on cup made of SS. This SS target is also bombarded by Ar ion, hence it is also sputtered with Sn and O atoms.

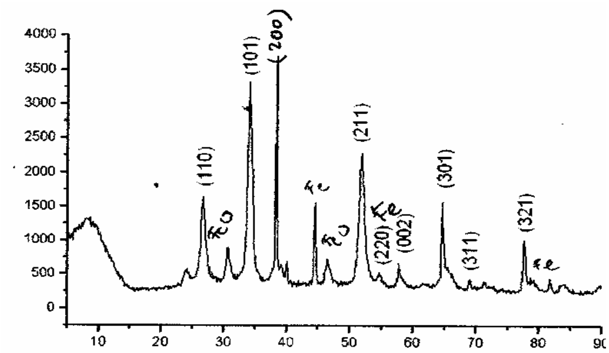

Figure 7. XRD spectrum of SnO_2 thin film sample on glass substrate at temperature of 220 °C, deposition time of 55 minutes and pressure 0,07 Torr

From the result of SEM photo shown in Figure 8 above, obviously that grains as the compound result of SnO_2 molecules deposited at the glass substrate are distributed relatively homogenous.

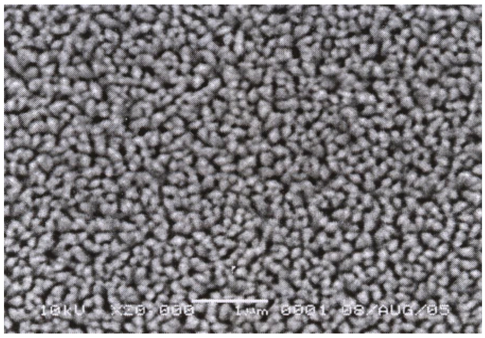

Figure 8. SEM photo of microstructure of the SnO_2 thin film surface on glass substrate at temperature of 220 °C, deposition time of 55 minutes and pressure of 0,07 Torr.

The homogeneity of thin film plays an important role, because the junction between semiconductor of P-type and N-type are also homogeneous. The homogeneity of thin layer will increase the solar cell efficiency, whether the P-N junction is exposed to the light, hence the better occurrence of electron and hole current. To measure the thin film thickness is also used SEM by shooting a sample from cross direction. The thin film cross section above the glass substrate can be shown in Figure 9, where the thin film thickness is around1 μm.

The formed SnO_2 thin film on the glass substrate is caused by sputtering of Sn and O atoms of SnO_2 target. The number of sputtering SnO_2 molecules depend on

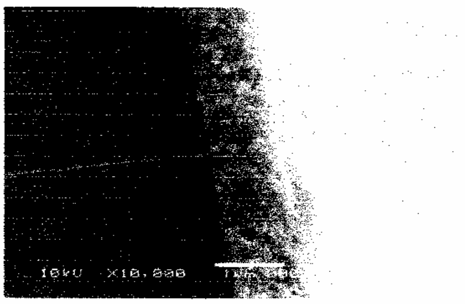

Figure 9. SEM photo of the cross section of SnO_2 thin film on glass substrate at temperature of 220 °C, deposition time of 55 minutes and pressure of 0,07 Torr.

Table 1. Comparison of the research data with the JCPDS data for the SnO_2 [8].

	Data				*JCPDS*			
No.	Peak to	2θ	*d (Å)*	Intensity	2θ	*d (Å)*	Intensity	*hkl*
1.	22	26.6000	3.3484	29	26.589	3.3498	100	110
2.	32	33.9000	2.64220	71	33.877	2.6439	76	101
3.	36	37.7000	2.38415	4	37.808	2.3775	20	200
4.	39	39.0500	2.30478	7	38.981	2.3087	4	111
5.	52	51.7500	1.76509	46	51.777	1.7642	55	211
6.	59	54.6200	1.67893	5	54.762	1.6749	13	220
7.	61	57.7209	1.59589	11	57.828	1.5932	6	002
8.	65	64.5730	1.49210	37	64.454	1.4444	11	112
9.	69	65.9000	1.41623	4	65.970	1.4149	14	301
10	71	68.9255	1.36127	5	68.947	1.3608	1	311
11.	74	78.6500	1.21552	4	78.714	1.2146	8	321

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deposition time, pressure of Ar gas, temperature of substrate and binding energy of target atom. SnO_2 target was placed in SS cup at the side of which is also bombarded by Ar ion, hence both of SnO_2 molecules and the side of SS cup are also sputtered. The area of whole SS cup is 3017.59 mm^2, while the area of sputtered SnO_2 target on SS cup is 2826 mm^2. It is obtained the area side of SS cup only 7 % to SnO_2 target area. The composition of observation results are 36.42 % Sn atom, 2.61 % Fe atom, 60.96 % 0 atom. The yielded Fe content is smaller than the area ratio because the work function of Fe atom is higher than of SnO_2 materials [4] ($\phi_{Fe} = 4{,}67$ eV; $\phi_{SnO_2} = 4{,}3$ eV), hence Fe atom is more difficult to escape than SnO_2 materials. Lips of target place is located outside, hence electric field is smaller than at center of target. It causes power of Ar ion is smaller than at center of target.

CONCLUSIONS

From the results of SnO_2 thin film deposition experiment and measurement can be concluded as follows :

1. SnO_2 thin film on glass substrate with N-type can be made using the sputtering technique.
2. The lowest resistivity of thin film is 5 x 10^{-2} ohm.cm at the deposition time of 55 minutes, pressure of Ar gas 7.10^{-2} torr and temperature of substrate is 220 ^{o}C, energy is 2 kV but by transmittance only 83.59 %.
3. The obtained crystal structure is poly crystal.
4. Microstructure of thin film surface is distributed homogenously with the thickness of thin film is 1 μm, while from the previous work, it was obtained the thickness is 0.5 μm.
5. Elements composition in thin film is 36.42 % Sn atom, 2.61 % Fe atom and 60.96 % O atom.
6. The results of this research are resistivity of 5 x 10^{-2} ohm.cm and transmittance of 83,89 %, crystal structure is SnO_2, thickness of thin film is 1 μm and can be used for CIS solar cell.

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