FABRICATION AND CHARACTERIZATION OF ZnO/Si FILM FOR SOLAR CELL APPLICATION

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Abstract

The crystalline state of undoped ZnO power was examined by X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM). Zinc Oxide thin film was fabricated on the p- Si (100) substrate structure by single wafer spin processor at 500^{o}C and 600^{o}C. The surface morphology and microstructural properties were examined by Scanning Electron Microscopy (SEM). I-V characteristics (illuminated I-V) were investigated by monochromatic halogen lamp (100W). From the current and voltage characteristics under illumination, conversion efficiency (η_{con}) and fill factor (F_f) were observed for the cell. The results obtainted were quite suitable and application in used for solar cell application.

Keywords: Fine ZnO powder, spin coating, ZnO/Si substrate, I-V characteristics.

Introduction

A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (in that its electrical characteristics e.g. current, voltage, or resistance vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source.

The term "photovoltaic" comes from the Greek meaning "light", and from "Volt", the unit of electro-motive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery (electrochemical cell). The term "photo-voltaic" has been in use in English since 1849.

Solar panels on the International Space Station absorb light from both sides. These Bifacial cells are more efficient and operate at lower temperature than single sided equivalents. The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of each of these individual efficiencies. A solar cell usually has a voltage dependent efficiency curve, temperature coefficients, and shadow angles.

The fill factor is defined as the ratio of the actual maximum obtainable power to the product of the open circuit voltage and short circuit current. This is a key parameter in evaluating the performance of solar cells. Typical commercial solar cells have a fill factor > 0.70. Grade B cells have a fill factor usually between 0.4 and 0.7. Cells with a high fill factor have a low equivalent series resistance and a high equivalent shunt resistance, so less of the current produced by the cell is dissipated in internal losses.

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Experimental Procedure

Preparation and Characterization of ZnO Powder

The material used in this research was undoped ZnO (Analar-grade) powder. The ZnO powder was added with some amount of ethanol (binding agent) and stirred for 30 min by using magnetic stirrer (500 rpm). The spherical shaped and fine powder was obtained by using ball milling and air-jet milling. The ZnO powder was performed by 3-step mesh-sieves to get uniform grain size. The crystallographic investigation and microstructural properties of ZnO powder were studied by using X-ray diffraction Scanning Electron Microscope.

Crystal structure and phase identification were examined by using RIGAKU model PINT 2000 X-ray diffractometer using CuKα radiation with wavelength of 1.54056 Å. The diffraction patterns of powder specimens were identified by using JCPDS (Joint Committee on Powder Diffraction Standards) data book. The XRD profile of ZnO powder was shown in Fig 1. The upper site of this profile was given for observed ZnO while the lower site was represented as standard ZnO. According the profile, nine reflections were clearly formed with respective diffraction angles. They were (100), (002), (101), (102), (110), (103), (200), (112) and (201), respectively. The most intense peak was caused by the (101) reflection and indicating the polycrystalline nature. All observed reflections were well-matched with these of standard peaks. Thus the specimen was confirmed that the crystal structure of ZnO standard. The crystallite size of ZnO powder was obtained from the calculation and the value was 47.8426 nm.

Fig 2 showed the SEM image of ZnO powder. This image consisted of circular features known as rosette structure in microstructure. In addition, all grains were clearly formed. Furthermore, uniform grain distribution was also found and the grain size was measured to be 0.25 μm.

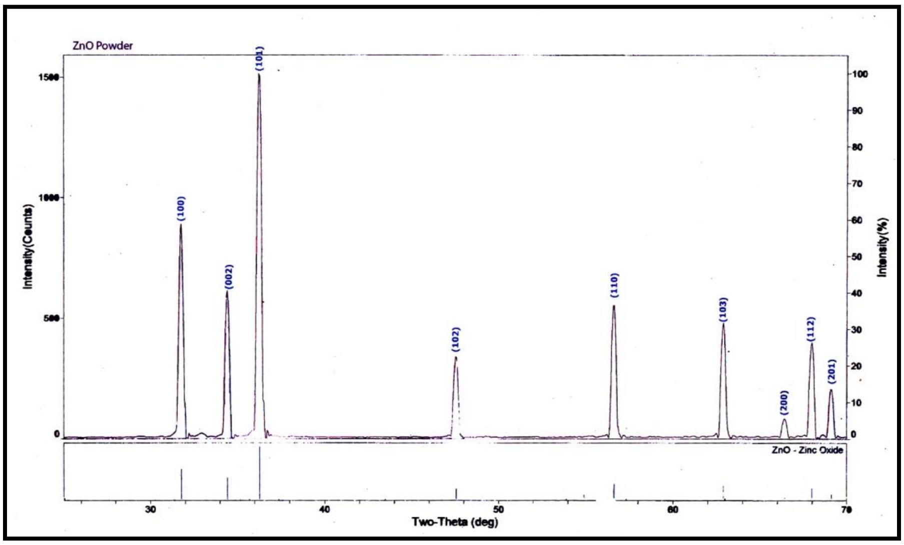

Figure 1 XRD profile of ZnO powder

Figure 2 SEM image of ZnO powder

Preparation of ZnO Solution

The ZnO solution was firstly prepared by mixing ZnO powder and ethanol solvent. The mixed solution was stirred with magnetic stirrer for 4h and refluxed at 110°C for 1h in a three-neck flask assembly to remove water of crystallization. Finally, ZnO precursor solution was obtained.

Preparation of Si Substrate

Defect-free and highly polished p-Si (100) (0.5cm x 0.5cm) wafer was used as a substrate. To remove the native oxide and contamination, cleaning process was made as follow:

(1) the Si wafer was washed in boiling acetone (60°C), then in boiled proponal (50°C) for 5 min to remove greasy film.

(2) it was immersed in nitric acid HNO_3 for 3 min in order to remove ionic contamination.

(3) it was etched in buffered hydrofluoric acid (34.6% NH_4F: 6.8% HF: 58.6%H_2O) for 2 min to remove oxide film.

(4) it was cleaned in DIW and dried on flat-oven at 100°C in a few minute.

Deposition of ZnO Film

ZnO sol solution was deposited on Si substrate by Single Wafer Spin Processer (WS-400BZ-6NPP/LITE). The substrate was placed on fragment adapter and the ZnO sol solution was poured onto substrate. The spin speed or rotational speed was set 2000 rpm and spinning time was 30 s. After spin coating, they were annealed at 500°C and 600°C for 1 h respectively. Eventually, ZnO/Si cells were formed at different process temperatures.

Table 1 ZnO film preparation condition

Substrate	Spin speed (rpm)	Spinning Time (s)	N_2 gas pressure (psi)	Vacuum (inches of Hg)	Annealing Temperature (^oC)
Si	2000	30	60	25.3	500, 600

Characterization of ZnO/Si Film

The XRD profiles of ZnO/Si Films with different temperatures were shown in Fig 3 & 4. The Brag angle 2θ value was measured between 10° and 70°. On the XRD pattern, fourteen peaks were clearly observed. Among these peaks, nine peaks were well-consisted with the JCPDS library file of # 89-7102> Zincite, Syn-ZnO. They were (100), (101), (002), (102), (110), (103), (200), (112) and (201) respectively. The most dominant peak was occurred at (101) reflection.

In this profile we considered within the defection limit from 10° to 70°. There were fifteen peaks in this profile. According to this profile, nine peaks were clearly formed and they were well–matched with JCPDS library file of # 89-7102>Zincite, syn-ZnO. The most intense peak was caused by the (101) diffraction plane. They were (100), (002), (101), (102), (110), (103), (200), (112) and (201) respectively. Theirs corresponding Bragg's angles were 31.616, 34.276, 36.098, 47.397, 56.444, 62.720, 66.225, 67.833 and 68.944, respectively. Remaining five profiles were well- matched with those of # 75- 0841> Si and 40-0932 > Si library. They were (300), (002), (330), (331)and (302) reflections. Their corresponding Bragg's angles were 35.869, 44.659, 51.900, 62.481 and 67.438. The (401) peak was caused at about 69.257 and couldn't be identified. Some important parameters for XRD patterns of ZnO/Si films were indicated in Table 2.

Table 2 Some important parameters for XRD patterns of ZnO/Si films

Annealing Temperature (^oC)	Lattice parameter (Å)		Lattice strain "c/a"	Crystallite size (nm)
	"a"	"c"		
500	3.22	5.18	1.60	53.96
600	3.21	5.17	1.61	46.26

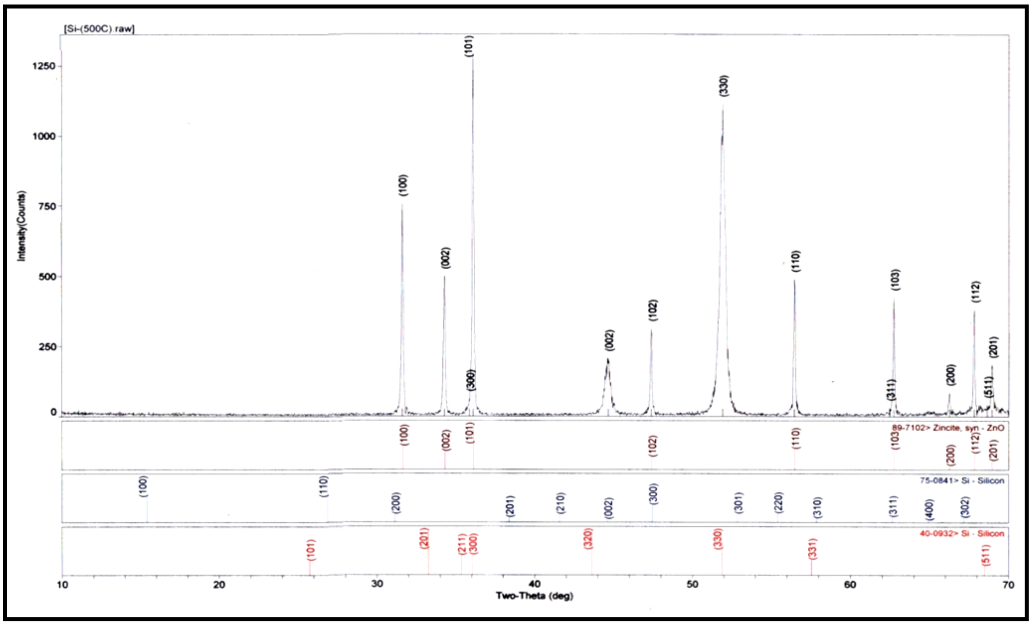

Figure 3 XRD profile of ZnO/Si film at 500°C

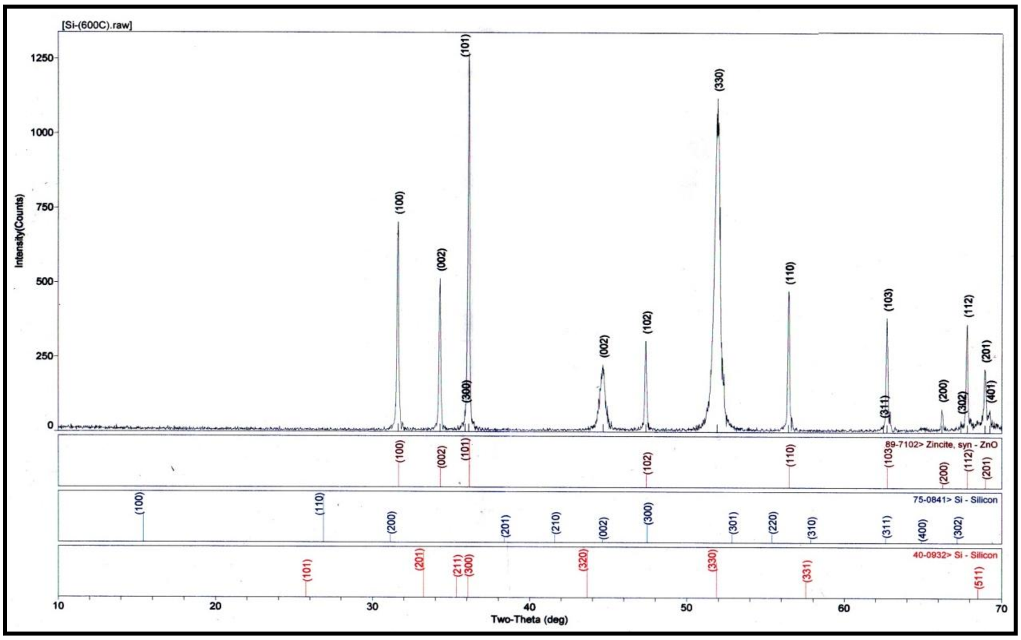

Figure 4 XRD profile of ZnO/Si film at 600°C

Microstructural Properties of ZnO/Si Films

Fig 5 & 6 showed the SEM microphotographs of ZnO/Si films at 500°C and 600°C. In these microphotographs, there were non cracking and some pores were formed among the crystalline grains. Grain sizes were little difference and they were measured by using well-known bar code system. The average grain sizes were determined to be 0.456 µm and 0.428 µm at 500°C and 600°C, respectively. The grain occurred at 500°C was oriented toward right site and uniform grain distribution was formed at 600°C. From the result, it was found that the grain size was the smallest for the annealing temperature at 600°C.

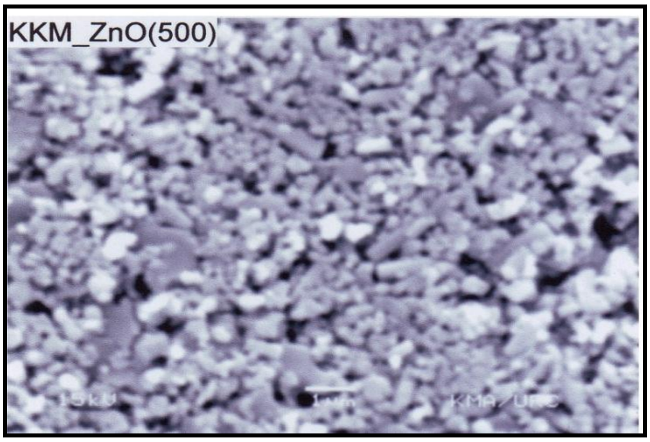

Figure 5 SEM image of ZnO/Si film at 500°C

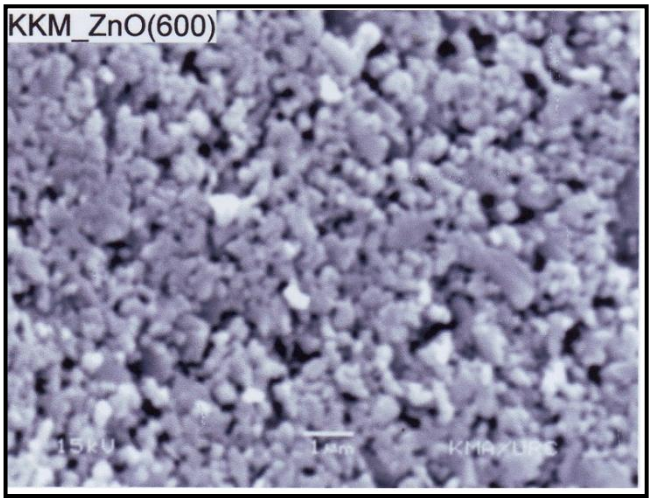

Figure 6 SEM image of ZnO/Si film at 600°C

Solar Cell Evaluation of ZnO/Si Films

Photocurrent and cell voltage were investigated by using a voltmeter (MULTMETER DT 9208) and an ammeter (FLUKE 196 SCOPEMETER). For illumination low pressure halogen lamp (100 watt) was used as a light source. A solar cell with a ZnO/Si structure provided power conversion efficiency (η) of 0.434 % and 0.497 % respectively. Fig 7 & 8 showed I-V curves of ZnO/Si thin films. The I-V characteristics of ZnO/Si films were indicated in Table 3.

Table 3 I_m, V_m, I_{sc}, V_{oc}, η_{con}, F_f of ZnO/Si films under illumination at 400 Lux

Annealing Temperature (°C)	I_m(μA)	V_m (V)	I_{sc} (mA)	V_{oc} (mV)	η(%)	F_f
500	0.918	1.001	1.039	1.167	0.434	0.758
600	0.917	1.147	1.035	1.337	0.497	0.760

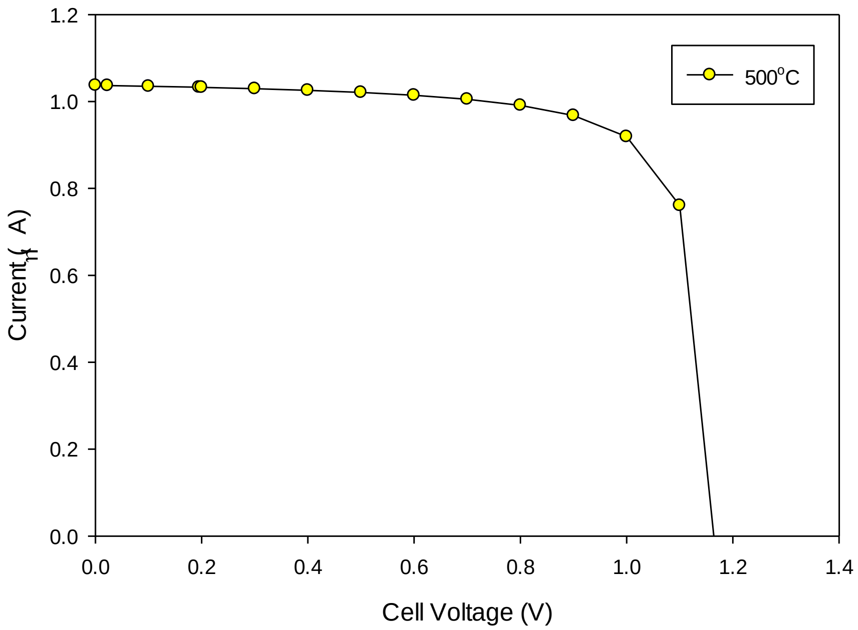

Figure 7 I-V curve of ZnO/Si at 500°C

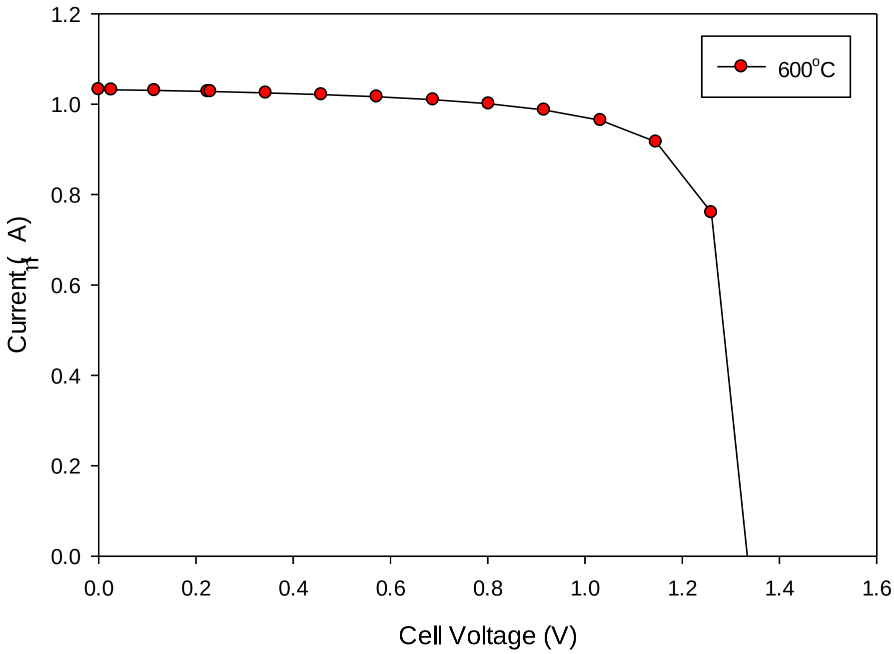

Figure 8 I-V curve of ZnO/Si at 600°C

Conclusion

The ZnO/Si films with different annealing temperatures have been successfully fabricated. The XRD result showed ZnO crystal structure with the crystallized size of 47.8426 nm. According to SEM result, ZnO powder exhibits circular shape with average grain size of 0.25 μm. The microstructural properties of ZnO/Si films were also confirmed by SEM technique and the average grain sizes were determined to be 0.456 µm and 0.428 µm at different annealing temperatures (500°C and 600°C), respectively. The I-V characteristics of ZnO/Si solar cells were measured under illumination condition. From the I-V graph, it was found that the power conversion efficiency (η) of 0.434 % and 0.497 % for ZnO/Si films with different temperatures. It was also found that the fabricated ZnO/Si films could be helped for thin film solar cell application.

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