Fabrication and Solar Cell Properties of ZnO Thin Films

Hnin Wai Hlaing[1], Aye Aye Lwin[2], Win Kyaw[3], Win Win Thein[4]

Abstract

In this paper, fabrication of Zinc Oxide (ZnO) on p-Si thin films and their solar cell properties are reported. Firstly, ZnO layers were coated on p-Si substrates by using screen printing technique. The prepared layers were fabricated by thermal diffusion technique at 500°C, 600°C and 700°C for 1 h each. Current-voltage (I-V) characteristics of the films were investigated in the voltage range of -5 V to 5 V under the influence of different illuminations. Solar cell properties of the open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), conversion efficiency (η_{con}) and fill factor (F_F) were investigated. The efficiency of the thin film prepared at 500°C was greater than that of the thin film prepared at 600°C. It was obviously found that the film prepared at 700°C exhibited as the photodiode characteristics.

Key words: ZnO Thin Films, Thermal Diffusion, Solar Cell Properties, Efficiency

INTRODUCTION

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon [Morales, (2008)]. A thin-film (TF) solar cell is a second generation solar cell that is made by depositing one or more thin layers, or thin film of photovoltaic material on a substrate, such as glass, plastic or metal. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light [Alhamed, (2010)]. Solar cells are a promising and potentially important technology and are the future of sustainable energy for the human civilization. Solar power generators are simply distributed to homes, schools, or businesses, where their assembly requires no extra development or land area and their function is safe and quiet.

Wide band gap II–VI semiconductors have been the focus of interest of many research groups during the past few years due to the possibility of their applications in light-emitting diodes (LEDs) and laser diodes [Sharma, (2013)]. The first utilization of ZnO for its semiconductor properties was detectors in build-your-own radio sets. A thin copper wire, known as “cat’s whisker,” is placed in contact to sensitive spots on a ZnO crystal. ZnO is a direct band-gap semiconductor with a wurtzite structure. The metal/semiconductor junction allows current to flow only one direction, converting the incoming radio waves from alternating current to direct current in the radio circuit [Oriaku, (2009)]. Research focused mainly on growth, characterization and applications that do not require single crystals such as varistors, surface acoustic wave devices and transparent conductive films. The present study deals with the ZnO layers which were coated on p-Si substrates by using screen printing technique and which were fabricated by thermal diffusion technique at three different temperatures. Solar cell properties of the films were investigated by current-voltage characteristic measurements using -5 V to +5V biasing voltages under various illuminations.

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MATERIALS AND METHOD

Preparation of ZnO/p-Si Thin Films

Firstly, 1 g of analytical reagent (AR) grade ZnO, HCl and 2-methoxythanol were mixed in a beaker. The mixture was stirred and boiled at 100ºC to get the sol-gel state. Then, the solution was cooled down at room temperature (28ºC). p-Si (100) wafers with the dimension of (0.50 cm × 0.50 cm) were used as the substrates. These wafers were cleaned by using standard wafer cleaning process. Then the precursor solution was coated on substrates by screen-printing method. Later, the coated-layers were dried at room temperature. ZnO was deposited on p-Si at 500ºC, 600ºC and 700ºC for 1 h each. After the deposition, the ZnO/p-Si thin films were etched in the mixture of ethanol, DI-water and HCl (1:1:1) for 10 – 15 min to get the homogeneously surface of the film and substrate. Then, the film was dried at room temperature. The flow-diagram of the ZnO/p-Si thin film preparation procedure is shown in Fig 1.

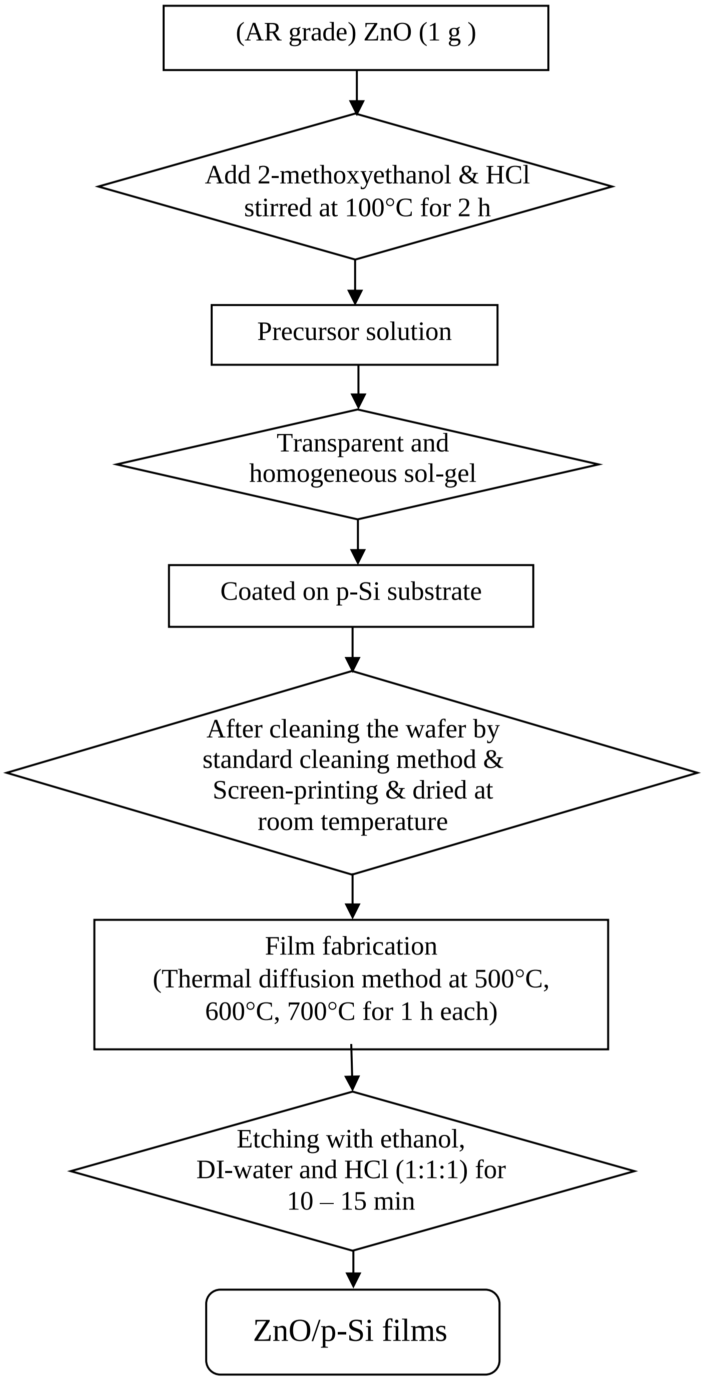


Fig. 1 Flow-diagram of the ZnO/p-Si semiconductor heterostructure

Current-Voltage Characteristic Measurement

Current – voltage (I-V) characteristics of ZnO/p-Si thin films prepared at 500ºC, 600ºC and 700ºC for 1 h each under dark and illumination conditions were observed in the bias voltages of (-5 V to +5 V) with the step voltage of 0.5 V to study the solar cell properties of the films. In this measurement, DT-830B and FLUKE 189 digital multi-meters were used as the ammeter and voltmeter. In this work, white light fluorescent tube was used as the light source. The light intensity sensor of Si-photodiode (Light meter 2330LX, SEW) was placed near the sample with parallel position to record light intensity from the light source throughout the measurement. Photograph of the experimental setup of I-V characteristic measurement is shown in Fig 2.

Fig. 2 Experimental setup of I-V characteristic measurement

RESULTS AND DISCUSSION

Study on Solar Cell Properties

A solar cell is a p-n junction diode which is made up of two layers of different semiconductors (p- n-type). When the cell is illuminated, the light energy sets electrons in the semiconductors into motion and a voltage appears. Photons, particles of light, collide with the surface of the semiconducting material (e.g., in this work p-type Si and n-type ZnO), setting electrons in the solar panel into motion and creating a continuous electric current.

Current-voltage characteristics of ZnO/p-Si thin films prepared at 500ºC, 600ºC and 700ºC for 1 h each under dark and different illuminations are shown in Figures 3, 4 and 5. In the I-V characteristic curves, the output current exponentially increased with increase in bias voltage. From the I-V characteristic curves, it was obviously found that the thin films prepared at 500ºC and 600ºC exhibited as the photovoltaic cells but the films prepared at 700ºC exhibited as the photodiode.

The photovoltaic properties of the open-circuit voltage V_{oc} and short-circuit current I_{sc} can be deduced by using these I-V curves. The conversion efficiency η_{con} and fill factor F_F were calculated by using the following equations:

$$\eta_{con} = \frac{V_m I_m}{P_{in}} \times 100\% = F_f \times \frac{V_{oc} I_{sc}}{P_{in}}$$

$$F_f = \frac{P_m}{P_{in}} = \frac{V_m I_m}{V_{oc} I_{sc}} = \frac{P_m}{V_{oc} I_{sc}}$$

where I_m and V_m are maximum current and maximum voltage at maximum power point and P_{in} is the input power in W m^{-2}. Experimental results of solar cell properties are tabulated in Table 1. The conversion efficiency η_{con} of the film prepared at 500ºC was found to be the largest one and it is suitable for solar cell application among the investigated samples of three different deposition temperatures. The fill factors F_f of the present study were found to be nearly equal to 0.70 and it was accepted due to the practical solar cell property.

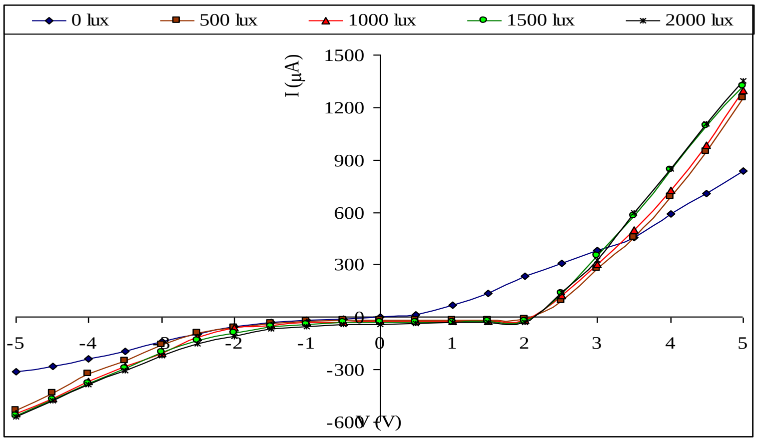


Fig. 3 Comparison of the current-voltage characteristics of ZnO/p-Si thin film prepared at 500ºC under different illuminations

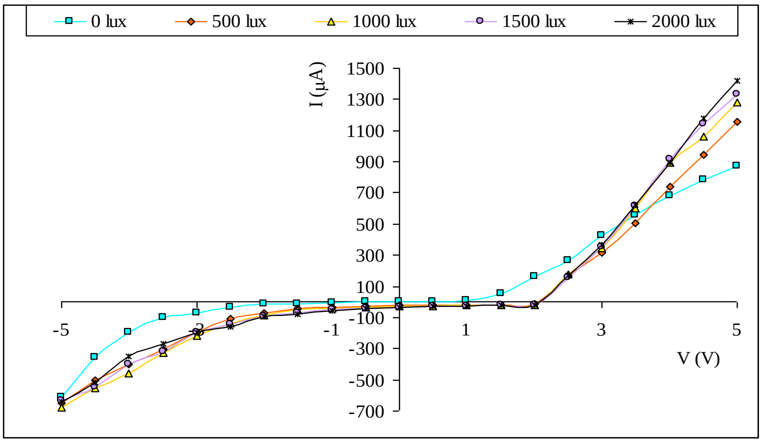


Fig. 4 Comparison of the current-voltage characteristics of ZnO/p-Si thin film prepared at 600ºC under different illuminations

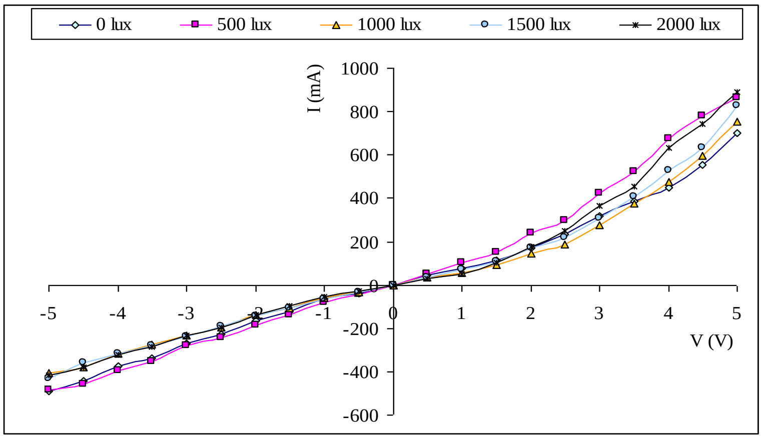


Fig. 5 Comparison of the current-voltage characteristics of ZnO/p-Si thin film prepared at 700ºC under different illuminations

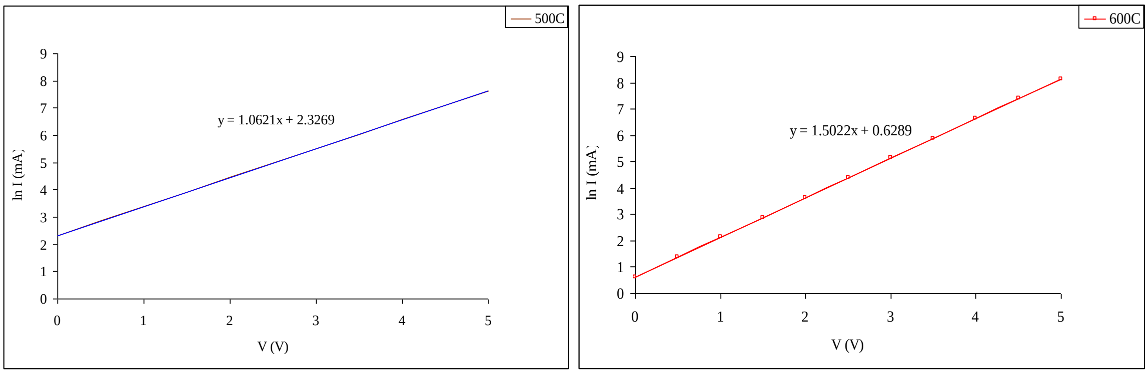
Table 1.(a) Experimental results of solar cell properties of the ZnO/p-Si thin film prepared at 500ºC

	Illumination 500 lux	Illumination 1000 lux	Illumination 1500 lux	Illumination 2000 lux
V_{oc} (V)	2.37	2.40	2.42	2.45
I_{sc} (μA)	18.00	25.00	29.00	40.00
η_{con} (%)	0.38	0.55	0.67	0.77
F_f	0.56	0.59	0.63	0.53

Table 1.(b) Experimental results of solar cell properties of the ZnO/p-Si thin film prepared at 600ºC

	Illumination 500 lux	Illumination 1000 lux	Illumination 1500 lux	Illumination 2000 lux
V_{oc} (V)	2.13	2.15	2.13	2.12
I_{sc} (μA)	22.00	27.00	34.00	37.00
η_{con} (%)	0.56	0.55	0.59	0.52
F_f	0.68	0.61	0.55	0.45

Furthermore, ln I - V characteristic curves are also shown in Figure 6. The reverse saturation current I_s can be obtained from the y-axis intersection of the ln I - V graph. The ideality factors η were calculated by using the slope of the curve. In the present work, the reverse saturation current (I_s) and ideality factors (η) of the films are listed in Table 2.



(a) (b)

Fig.6 ln I - V characteristic curves of ZnO/p-Si thin films prepared (a) at 500C and (b) at 600°C

Table 2. The reverse saturation current I_s and ideality factors η of the ZnO/p-Si thin films prepared at 500°C and 600°C

Preparation Temperature (°C)	I_s (μA)	η
500	2.33	1.06
600	0.63	1.50

CONCLUSION

In this research work, ZnO/p-Si thin films were successfully fabricated at 500°C, 600°C and 700°C for 1 h each and their solar cell properties were investigated by I – V characteristic measurements under different illuminations. From I – V characteristic results, the films prepared at 500°C and 600°C exhibited as the second generation silicon solar cells and the film prepared at 700°C exhibited as a photodiode. According to experimental results, it can be promised that the films prepared at 500°C and 600°C can be applied as the solar cells. Furthermore, the film prepared at 700°C can be applied as the photodiode.

Acknowledgements

We wish to express our sincere thanks to Dr Theingi Shwe (Rector, Hinthada University), Dr Yee Yee Than (Pro-Rector, Hinthada University) and Dr Cho Kyi Than (Pro-Rector, Hinthada University), for their kind permission to carry out this work.

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