Fabrication of p-Si/ZnO Thin Films Solar Cell by CVD at Different Substrate Temperatures

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Abstract: Zinc Oxide is a prominent candidate to be used a window layer in Si based solar cell. In this study, Fabricated solar cell parameters with different substrate temperatures (400,450,500 ˚C) of Si/ZnO have been prepared by chemical vapor deposition method to find out the higher conversion. Moreover, it is found that I_{sc}, V_{oc} and η are increased for the substrate temperature increase at 500˚C. The best efficiency value calculated was 9.47% at substrate temperature 500˚C. Experimentally the electrical properties measured also ρ, σ and Φ_b as Si substrate temperature increased until 500˚C, the electrical resistivity of Si/ZnO solar cell was (0.231 ohm.m) at 400 ˚C and it is increased as Si substrate temp. increase, which leads to the decrease of conductivity.

Keywords: zinc oxide, p-Si absorber layer, p–n junction

تصنيع خلية شمسية للأغشية الرقيقة p-Si/ZnO بواسطة CVD عند درجات حرارة ارضية مختلفة

الملخص: اوكسيد الخارصين المرشح البارز الذي يستخدم كطبقة نافذة في قاعدة السيلكون للخلية الشمسية. في هذه الدراسة تم تحضير الخلية الشمسية المصنعة عند درجات حرارة الارضية المختلفة (400,450,500˚C) لـ Si/ZnO بطريقة الترسيب البخاري الكيميائي لإيجاد معاملات التحويل العالية. كذلك وجد ان I_{sc}, V_{oc} و η تزداد بزيادة درجة حرارة الارضية عند 500˚C. حُسبت افضل قيمة كفاءة 9.47% عند درجة حرارة ارضية 500˚C. قيست الخصائص الكهربائية العملية ايضا ρ, σ و Φ_b بزيادة درجة حرارة ارضية Si لغاية 500˚C، وكانت المقاومية الكهربائية للخلية الشمسية Si/ZnO (0.231 ohm.m) عند 400 ˚C وتزداد بزيادة درجة حرارة الارضية التي تؤدي الى نقصان التوصيلية.

الكلمات المفتاحية: اوكسيد الخارصين, الطبقة الماصة p-Si , وصلة p–n

Introduction:

Zinc oxide have been received wide attention because it was owning a direct band-gap [1-4]. It has used in the applications such as laser devices and light emitting devices [5,6]. In these fields the practical applications depend on the fabrication of p–n junctions homostructural ZnO. Moreover, for the electrical conduction it have been made good p-n junction with the absorber layer (p-type) and to allow the transmission of photons in these layer to generate electron-hole pair [7].

Several methods were used to synthesize ZnO films namely: Spray pyrolysis [8], CO-precipitation method [9], chemical bath deposition technique [10], evaporation method [11] and spray pyrolysis [12]. Among of these different techniques, CVD has the advantages such as easy to use, safe, low cost and can be used in a standard laboratory.

In this work we did a fabrication experimentally prepared using CVD method on Si/ZnO thin film solar cell. The aim of this paper is to find out the best electrical performances of Si/ZnO solar cells. The effect of different substrate temperatures of Si have been investigated for the Si/ZnO thin film solar cells.

Experimental:

Si/ZnO thin film solar cell was deposited on the cleaned glass substrate by CVD technique with different substrate temperatures (400,450,500 ˚C) at 20 minute. Zinc acetate ($Zn(CH_3COO)_2.2H_2O$) with high purity (99.9%) was used as a source in the CVD method.

First the glass substrates were rinsed in ethanol for 5 minute. Then they were rinsed in distilled water and dried in acetone just before they were loaded into the deposition system.

The preparation process is included by depositing Al layer (back contact) on glass substrate and followed by depositing p-type Si layer on the substrate with chemical vapor deposition (CVD) method, the window layer zinc oxide ZnO is deposited on Si layer with thickness (1μm) also by CVD. Schematic structure of the solar cell given in Fig 1.

The electronic temperature controller was used to controlee for the substrate temperature. Air flow was 0.5 L/min. Deposition time was kept constant at (10 minutes) for samples.

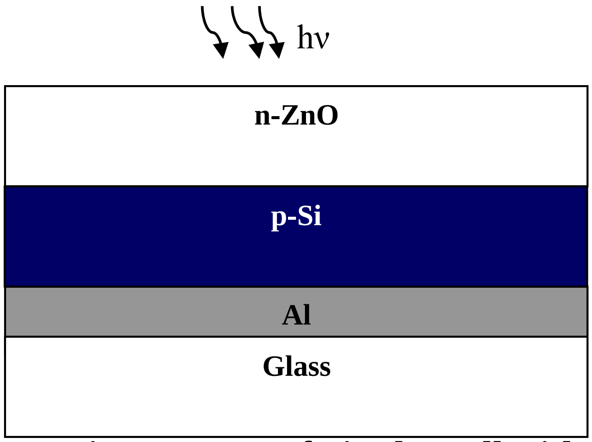

Fig. 1: Schematic structure of Si solar cell with ZnO window layer

Electrical measuring done of the sample at illumination then with 100 mw/cm^2 on input power 100 walt.

We demonstrated the effect of different substrate temperatures (400,450,500 ˚C) on the parameters of thin film solar cell such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor and conversion efficiency (η).

Results and Discussions:

The forward and reverse bias current –voltage characteristics for Si/ZnO solar cell at substrate temps. (400, 450, 500 ˚C) are shown in Fig.2 and the measurements are shown in Table1.

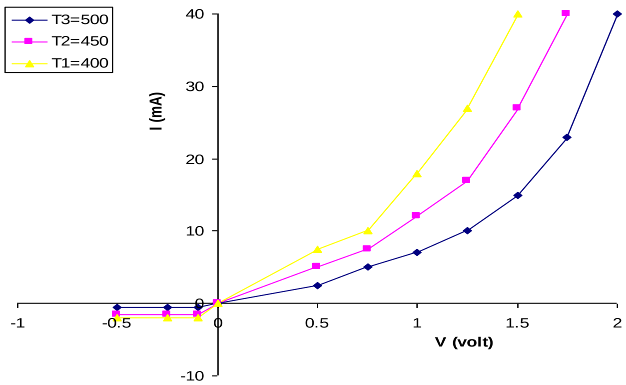

Fig.2: I.V characteristic of Si/ZnO solar cell at (400,450,500 ˚C) in the dark.

Table 1. Fabricated solar cell of Si/ZnO at (400, 450,500 ˚C) at reverse bias in dark.

Temp./˚C	$I_s \times 10^{-3}$ (Am) at V= -0.5 V	ρ (Ω.m)	σ $(\Omega.m)^{-1}$	Φ_B (eV)	n	E_g (eV)
400	**-1.875**	**3.349**	**0.298**	**0.749**	**7.208**	**0.079**
450	**-1.25**	**5.024**	**0.199**	**0.867**	**5.332**	**0.089**
500	**-0.625**	**10.048**	**0.099**	**1.003**	**3.729**	**0.099**

The ideality factor (n) is determined from eq. (1) [13].

$$n(V) = \frac{qV}{kTLn(I/I_0)} \quad \text{---}(1)$$

Where q is electron charge (C), K Boltezman's constant (J/K), T room temperature (K) and n(V) ideality factor in term voltage.

It is found the shown the n depended to the Si/ZnO structured solar cell and which affected by changed substrate temperature. The ideal factor was be decreased from 7.208 to 3.729 in the solar cell which prepared by CVD at

400 to 500˚C respectively, that mean the ideal factor have minimum value with increasing substrate temperature as shown in Fig (3).

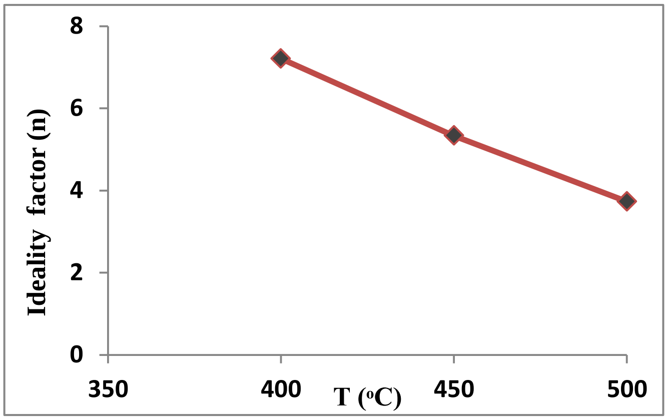

Fig.(3): The ideality factor verses of the substrate temperatures.

We noted that the saturation reverse current (Js) decreased for the increasing substrate temperature and have small value at 500˚C substrate temperature and this lead to the barrier height have maximum value at this point. Barrier height is calculated by eq.(2) [14].

$$\Phi_B = \frac{kT}{q}\ln\frac{A^{**}}{J_s}T^2 \quad \text{----------------------------------}(2)$$

A* : Richardson constant which equal (32 A. cm^{-2} K^{-2}) for p-Si [15].

The increasing of barrier height is also due to the inter face between ZnO (n-type) layer and Si substrate, which makes the defect in the interface and caused to decrease the saturation current, and this lead to the increasing of barrier height of Si/ZnO solar cell shown in Fig.(4).

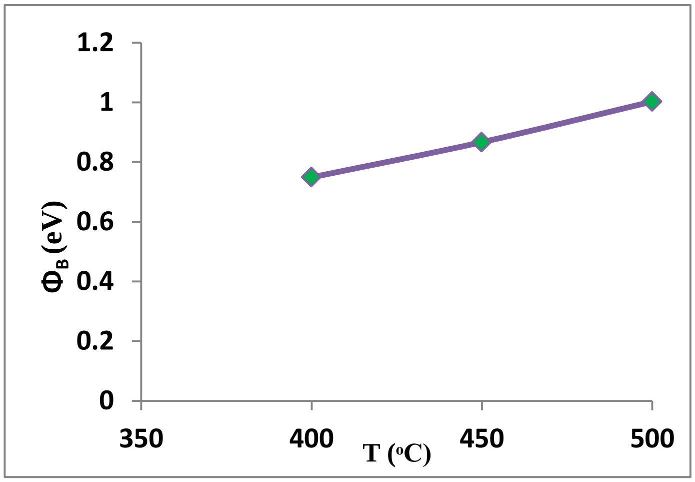

Fig.(4): Variation of the barrier height as a function of substrate temperatures.

The electrical resistivity of the samples have been conducted by using a standard four-point probe method. It is determined by connecting the current in to the outer pair of probes and determining the voltage between the inner pair of probes with a distance (s = 2 mm), by using the equation [16] and the electrical results are shown in table 1.

$$\rho = 2\pi s \frac{V}{I} \quad \text{--(3)}$$

It is clear that the resistivity of Si/ZnO solar cell has the maximum resistivity of (10.048 Ω.cm) at 500˚C substrate temperature in comparison with the resistivity of the solar cell (3.349 and 5.024 Ω.cm) at 400 and 450˚C substrate temperatures respectively. This means the resistivity of the solar cell was drastically increased despite that the substrate temperatures is increased and this shown in Fig.(5), which leads to the decrease the electrical conductivity (σ) of the Si/ZnO solar cell with increasing substrate temperatures.

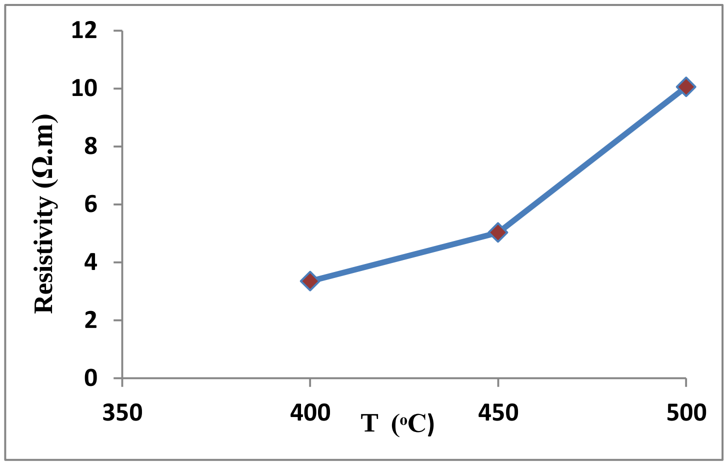

Fig.(5): Variation of the resistivity as a function of substrate temperatures.

The bandgap energy E_g which is calculated by using eq.(4) [17].

$$\log I_s = constant - 5.036\frac{10^3}{T} \times E_g \qquad (4)$$

The value of bandgap energy was found to increase from 0.079 eV to 0.099 eV with corresponding increase in the substrate temperature of the Si/ZnO solar cell at 400 to 500°C respectively, that mean the bandgap energy have maximum value with increasing substrate temperature as shown in Figure (6).

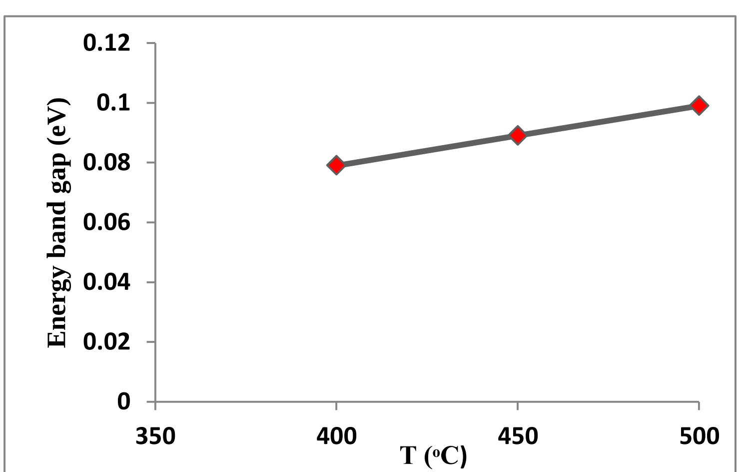

Fig.(6):Energy and gap as a function of substrate temperatures.

Table 2. Fabricated solar cell parameters with different substrate temperatures (400, 450,500 ˚C) of Si/ZnO under illumination.

Temp./˚C	$I_{max.}\times10^{-4}$ (Am)	$V_{max.}$ (volt)	$I_{sc}\times10^{-4}$ (Am)	V_{oc} (volt)	FF%	η%
400	9.5	61	11	74	68.41	5.56
450	10.5	70	13	92	61.45	7.34
500	12	79	15	120	52.66	9.47

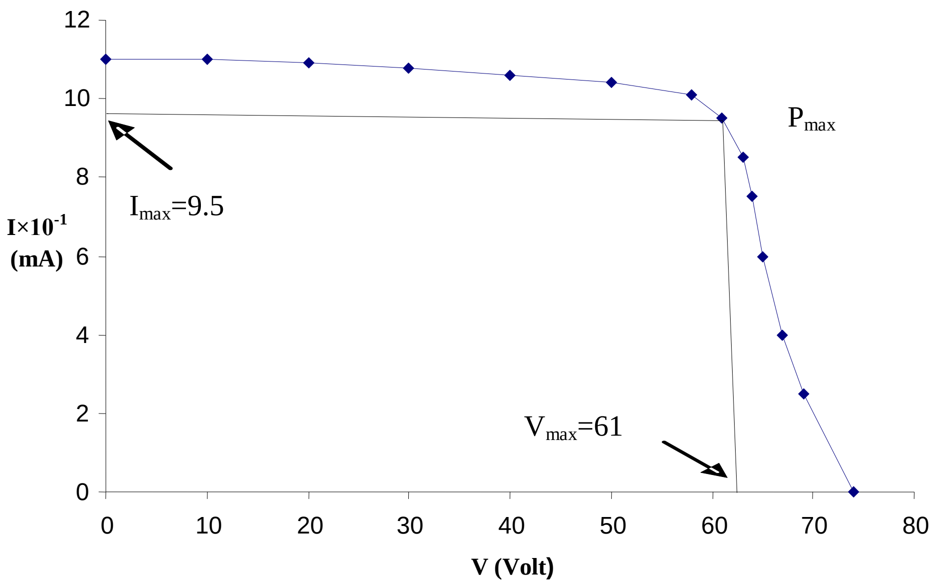

Fig.(7): I.V curve of Si/ZnO solar cell at substrate temperature 400˚C.

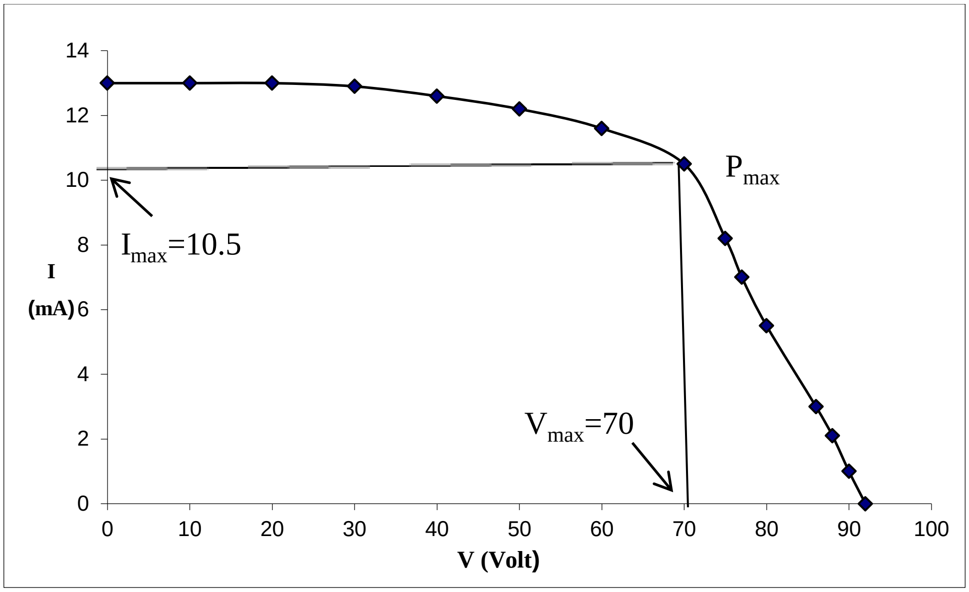

Fig.(8): I.V plot of Si/ZnO solar cell at substrate temperature 450 ˚C.

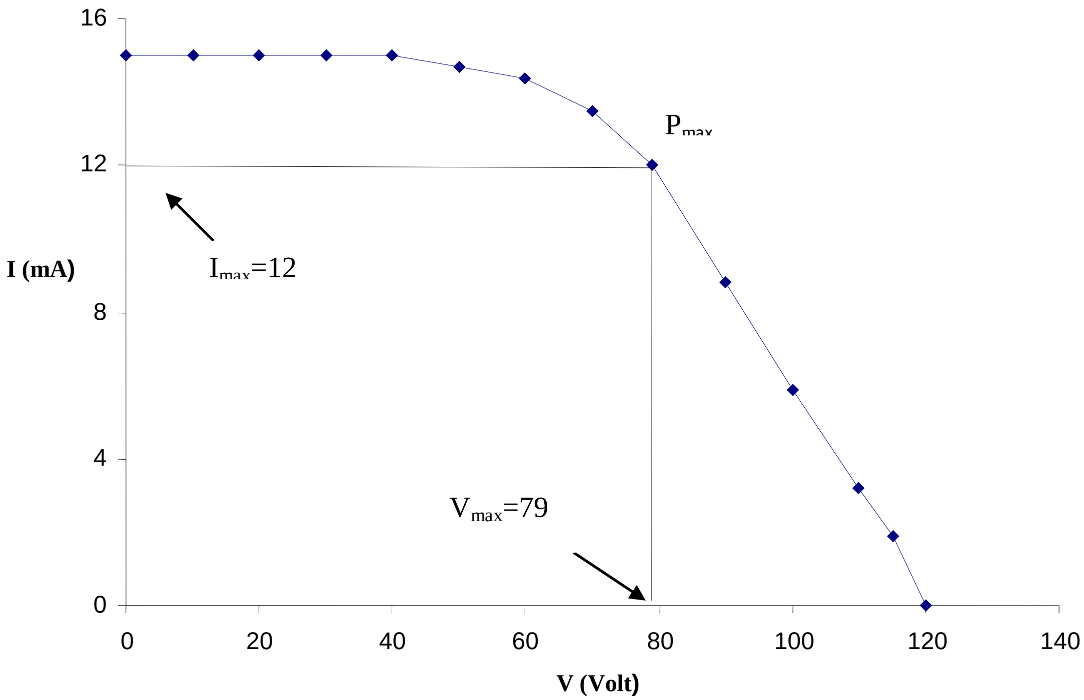

Fig.(9): I.V characteristic of Si/ZnO solar cell at substrate temperature 500 ˚C.

It is clear from Fig.(7,8 and 9) and table 2 the values of I_{sc} and V_{oc} of the Si/ZnO solar cell parameters increase as substrate temp. increase, The conversion efficiency increased until the substrate temp. reached at 500˚C. Further increase in the substrate temperature of the films show an improvement in the efficiency. The optimum conversion efficiency is about 9.47 % at (500˚C) Si substrate temperature.

The fill factor (FF) is calculated from the equation 5 [18].

$$FF = \left[\frac{I_m V_m}{I_{sc} V_{oc}} \right] \times 100\% \qquad (5)$$

Where I_m : is the current at maximum power point on the curve.

V_m : is the voltage at maximum power point on the curve.

We observed that the values of the fill factor of Si/ZnO thin film solar cell are decreased as increasing the substrate temperature and this values are in agreement with the theoretical of Si solar cell.

The conversion efficiency (η) of the Si/ZnO solar cell is calculated by using the relation [19].

$$\eta = \left[\frac{I_{sc} V_{oc} FF}{P_{h\nu}} \right] \times 100\% \qquad (6)$$

$P_{h\nu}$: the power of the incident radiation.

Conclusion

The electrical performances for the Si/ZnO solar cells were investigated by different substrate temperatures at (400, 450,500 ˚C) in the dark and an illumination. The increasing of Si absorber layer substrate temperatures results in higher short circuit current, open circuit voltage and conversion efficiency also yields better performance (9.47%) at substrate temperature (500˚C) under illumination for Si/ZnO solar cell.

Reference

1. Yodhino Y., Makino T., Katayama Y., Hata T. (2000). *Vacuum* 59 (2–3), 538.
2. Rao B.B., *Mater. Chem. Phys.* 64 (1) (2000) 62.
3. Sang B., Dairiki K., Yamada A., Konagai M., (1999), *Jpn. J. Appl. Phys.* 38 4983.
4. Maldonado A., dela Olvera M.L., Asomoza R., Tirado Guerraj S. (2000), *J. Vac.Sci. Technol.*, A 18 2098.
5. Cook J.W., Schetzina F., (1996) *J. Electron. Mater.* 25 855.
6. Choopun S., Vispute R.D., Noch W., Balasamo A., Sharma R.P., Venkatesan T., Lliadies A., Look D.C., (1999). *Appl. Phys. Lett.* 75 3947.
7. Timoumi, H. Bouzouita, M. kanrazi, B. Rezig, (2005)” Fabrication and characterization of In2S3 thin films deposited by thermal evaporation technique”,Thin solid films, , pp. 124-128.
8. Rahmani M.B. (2009). *SENSOR LETTERS* **7** 1.
9. Ghosh A., Kumair N., Tewari S., ABhattacharjee. (2013). *Indian J. Phys.* **87** 1099.
10. Suchea M., Christoulakis S., Moschovis K., Katsarakis N., Kiriakidis G., (2006). *Thin Solid Films*, **515**, 551.
11. Sujino T.J., Homma N., Sugawara T., Shimono I., Abe Y., (2002). *Thin Solid Films* 407 (1-2) 86.
12. Belkhalfa H., Ayed H., Hafdallah A., Aida M., Ighil R. (2016). Characterization and studying of ZnO thin films deposited by spray pyrolysis: effect of

annealing temperature. Optik;127:2336–40.

13. Card H.C., Rhoderick E.H. *J Phys* D 1971;4:1589
14. Sze S.M. and Kwok K.Ng. (2007) ”physics of semiconductor devices” AJOHN WIEY and SONS,INC; publication. USA.
15. Rhoderick,E.H. & Williams,R.H. (1998). *Metal âA˘ S¸* Semiconductor contacts, Claredon Press Oxford.
16. Runyan, W. R. (1975). "semiconductor measurement and instrument. " Mc. Graw – Hil Kagokusha Instrumentation Ltd., Vol. 4 , PP. 70-86 , Tokyo (Japan).
17. Sze S.M. (2007). "Physics of semiconductor devices". 2nd ed. New York: Wiley .
18. Coutts T.J., (1978). *Sol. Energy Mater*. 50 , pp 99.
19. Dasand V.D., Damodare L., (1997). *J.Appl.Phys*. 81, pp.1522.