The Electrical and Optical Properties of SnO_2 – $Si_{(n)}$ Structure Solar Cells.

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1. Abstract:

- In this paper the SnO_2 will be examined to be used as a transparent antireflection coating with the n –type silicon wafer to fabricate the deposited SnO_2 silicon Solar cell using vacuum evaporation technique. This SnO_2 layer is simultaneously an antireflecting coating and a transparent upper contact. The oxidation of the Si surface takes place simultaneously with the evaporation process. A semiconductor – insulator – semiconductor (SIS) structure was obtained in such a way. The photoelectrical parameters of such SIS system of AM 1.5 conditions are: the short circuit current 18.5 mA/cm^2, the open circuit voltage 0.48 V and the efficiency is 7.0%. The subgap response of the resulted structure is particularly strong and extends to wavelength up to 1100nm.

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1. Introduction:

The wide band gap oxide semiconductor compounds such as In_2O_3, SnO_2 have a band gap more than 3eV and therefore are transparent to the radiation with the wave – length more then 0.4 μm, i.e for the wave – length from the region of the maximum solar intensity. Their conductivity could be changed within wide limits, from 10^{-1} ohm^{-1}. cm^{-1} up to 10^{4} ohm^{-1}. cm^{-1}. The above mentioned property permit to use these material in solar cell fabrication as frontal layer in SIS structures. The investigation of silicon based SIS structures began in 1979 [1]. It showed that the most efficient solar cells obtained by spray deposition of ITO on the frontal layers of silicon [2].

The electron tunneling from the silicon conduction band into SnO_2 conduction band occurs at the participation of traps in the depletion region as shown in fig. (1).

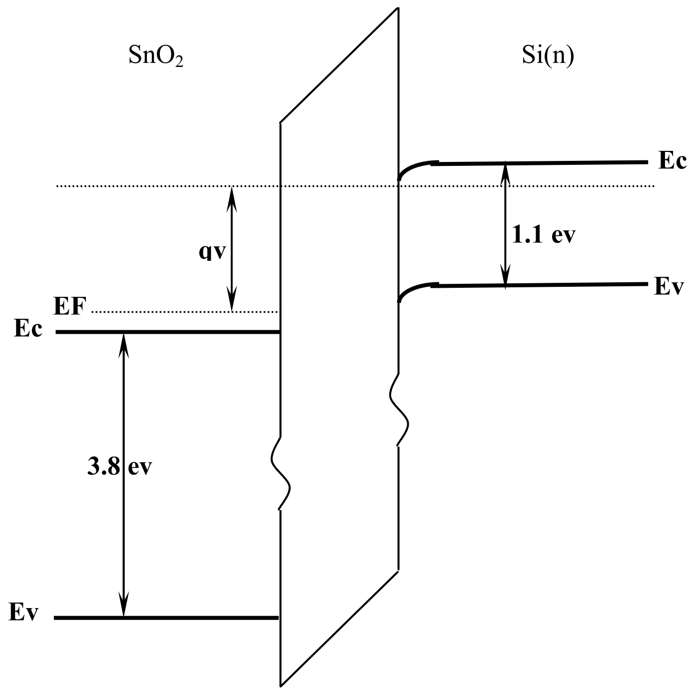

Fig .1. The Energetic diagram at forward bias of SnO_2 – $Si_{(n)}$ structures

The I-V dependence could be described by the expression [3] :

$$I = I_o \exp(AV) . \exp(BT) \quad ...(1)$$

Where: I is the output current, I_o is the saturation current, A and B are constants independent on temperature and voltage, A = 31.7 V^{-1} and B = 0.073 K^{-1}[3].
The reverse current is generated due to tunnel transition of electrons from the conduction band of SnO_2 into the conduction band in silicon. The reverse current is described by the expression:

$$I = C(-V)\exp[\alpha (V_d - V)^{1/2}] \quad ...(2)$$

Where: C and α are constant, V_d is the diffusion potential and V is reverse bias. The electrical and photoelectrical characteristics of the $SnO_2 - Si_{(n)}$ structure have been studied, and the samples represent asymmetrically doped barrier structures in which the wide band gap semiconductor plays the role of a transparent metal.
The spectral responsivity $S_{R(\lambda)}$ of a solar cell is defined as the short circuit current density per unit irradiance as a function of wavelength [4]. It's unit is ampere per watt and can be expressed as follow

$$S_{R(ë)} = EQE_{(ë)}/(hc/që) = [1 - R_t]\, IQE / (hc/q\, ë) \quad ... (3)$$

$$IQE(ë) = S_{R(ë)} .\, hC/ q\, .\, ë / (1 - R_t) \quad ... (4)$$

Where EQE is the external quantum efficiency, h is the plancks constant, c is the speed of light, q is the electron charge, R_t is the structure total reflectance, and IQE is the internal quantum efficiency.

2. The $SnO_2 – Si_{(n)}$ structure fabrication:

The samples were prepared by vacuum evaporation technique using Balzer unit (BA - 510). The silicon (n) type wafers are subjected to a rigorous cleaning cycle in three steps, in order to reduce the pin holes formation [4]. Phosphorus doped Si wafer with the thickness of 300µm and resistivity of 4.5 ohm. cm, orientated in (100) plane were used. A thin insulator layer was formed on the Si surface by thermal treatment. Aluminum thin film were deposited as back contacts for the fabricated samples. After the deposition of the aluminum film on the rough face of the wafer the samples were annealed under vacuum to a temperature of 350^{o}C for half an hour. This heat treatment is necessary to obtain an ohmic contact (back contact) between the aluminum and the wafers [5]. After the deposition of SnO_2 with the required thickness on the silicon wafer, the wafer is placed inside an evacuated champer for annealing purpose up to 400 ^{0}C.

3. Results and Discussion:

3.1 The Electrical properties of SnO2 – Si(n) structure.

The I-V characteristic of the $SnO_2 – Si_{(n)}$ structure for a thickness of 5000^{o}A is shown in fig. (2) . The dark forward I-V characteristic for the $SnO_2 – Si_{(n)}$ structure were measured in the temperature range (25-150)°C, the SnO_2 thickness was 5000°A. The independence of the slope of the forward branches of the I-V characteristics on the temperature is their peculiarity. Such behavior of the forward current is characteristic for the case of tunnel processes.

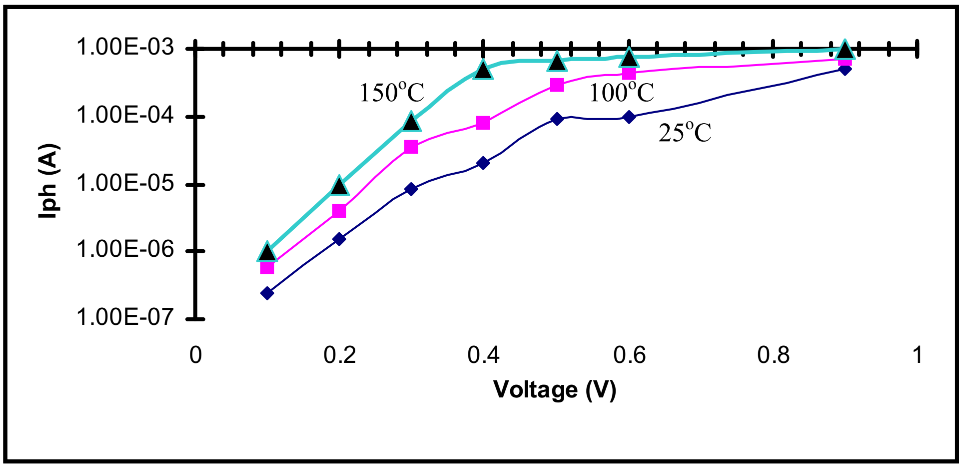

Fig . 2 . The forward I.V characteristic of the $SnO_2 - Si_{(n)}$ structures at different annealing temperature .

The doping level of $Si_{(n)}$ (10^{15}) is too small for direct tunneling through the barrier, and the electron tunneling from the silicon conduction band into SnO_2 conduction band occurs at the participation of traps in the depletion region [6]: fig. (3) shows the reverse (I-V) characteristic of the $SnO_2 - Si_{(n)}$ structure at different temperature.

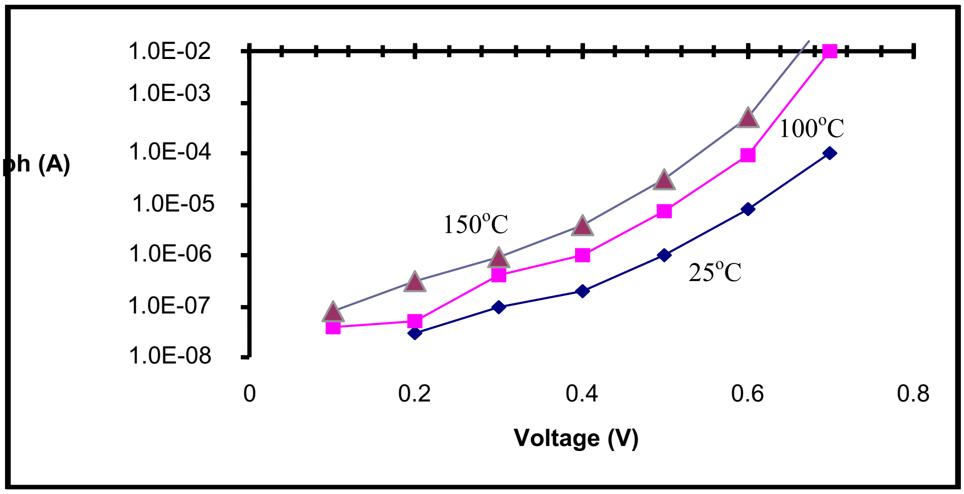

Fig . 3 . The reverse I.V characteristic of the $SnO_2 - Si_{(n)}$ structures at different annealing temperature .

It is clear that for voltage less than 0.65v the reverse current is proportional to the voltage, but at voltage greater than 0.65v, a sharp rise of current due to tunnel transition of electron from the conduction band of SnO_2 into the conduction band of Si is noticed. The reverse current is determined by the transport of the minority carries from the Si valance band to the SnO_2 conduction band for the small indirect bias up to 0.65 V. For large values of reverse voltage, the voltage drops due to the semiconductor and insulation film characteristics.

3-2: The photo – response of SnO2 – $Si_{(n)}$ structure

The sensitive spectral response measurements technique is utilized to investigate the photo – response characteristic of $SnO_2 – Si_{(n)}$ structure. Such spectral response measurements enable the calculation of internal quantum efficiency (IQE), which is crucial to understand and improve the production of solar cells .
Fig. (4) shows the relative current response of the $SnO_2 – Si_{(n)}$ structure with different thickness and at 150^{o}C for a 30 minutes.

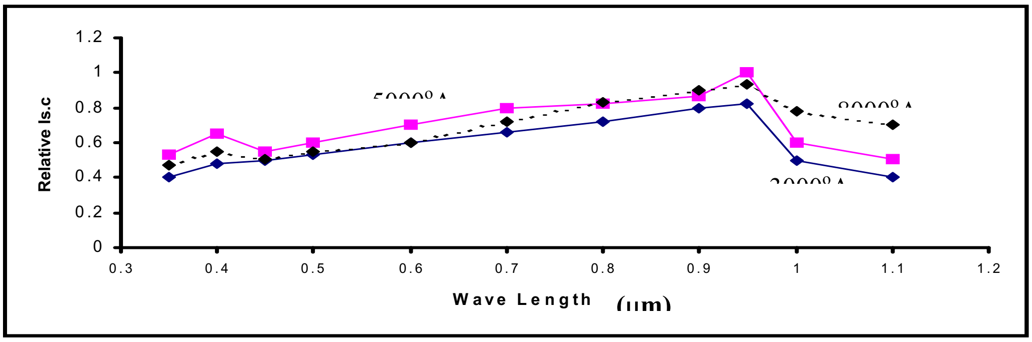

Fig .4. The relative current response of the $SnO_2 – Si_{(n)}$ structure at different thicknesses (T = 150^{o}C) .

It can be noticed that the maximum generated current occurred with SnO_2 thickness equal to 5000^{o}A. Increasing thickness of SnO_2 layer will lead to lower the generated current. The SnO_2 layer acts as a filter or a dead layer on the top surface, which prevents incident light from passing deeply into the sample.

The photoelectric properties have been investigated at the illumination of the structures through the wide gap semiconductor (SnO_2). The short circuit current density depends on illumination intensity. The current starts increasing at $\lambda > 0.5$ µm and the maximum current obtained at wavelength equal to 0.95µm. As λ increases above 1.0µm the relative current starts decreasing and still have a significant value of 35% at wavelength equal to 1.1µm.

The photosensitivity region of the $SnO_2 - Si_{(n)}$ structures is limited by the photon energies [6], which correspond to the band gaps of SnO_2 and Si. The generation and separation of electron – hole pairs occurs only in silicon.

The reflectance of the fabricated SnO_2-$Si_{(n)}$ structure was measured using spectrophotometer type SP-H 1011. Figure (5) shows the relation between reflectivity and the incident light wavelength for a wavelength between 0.3 to 1.1ìm.

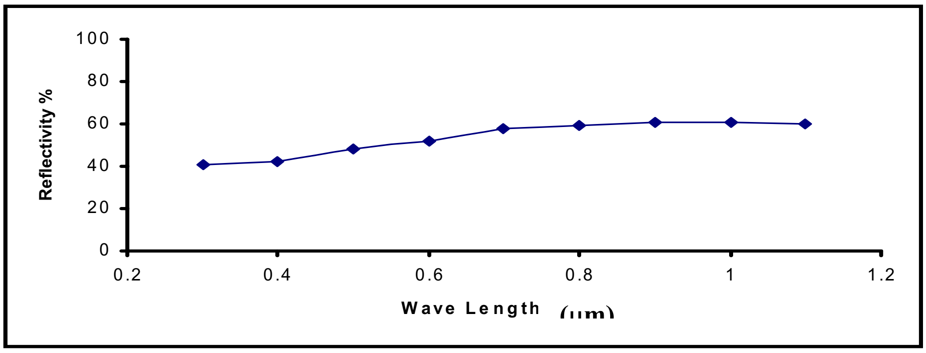

Fig .5. Reflectivity versus incident light wavelength characteristic

The reflectance of the fabricated cell increases as the wavelength is moved toward the transmission region of silicon .It has a value of 0.41 at short wavelength while this value increasing to about 0.61 at longer wavelength .The lower values of reflectivity can be attributed to the SnO_2 layer, which acts as an antireflecting coating as well as a transparent upper contact .

The relative internal quantum efficiency (IQE) of the fabricated cell is calculated according to equation (4) . Figure (6) shows the relative IQE for the fabricated SnO_2-$Si_{(n)}$ structure with 5000 ^oA thickness and at 150^oC.

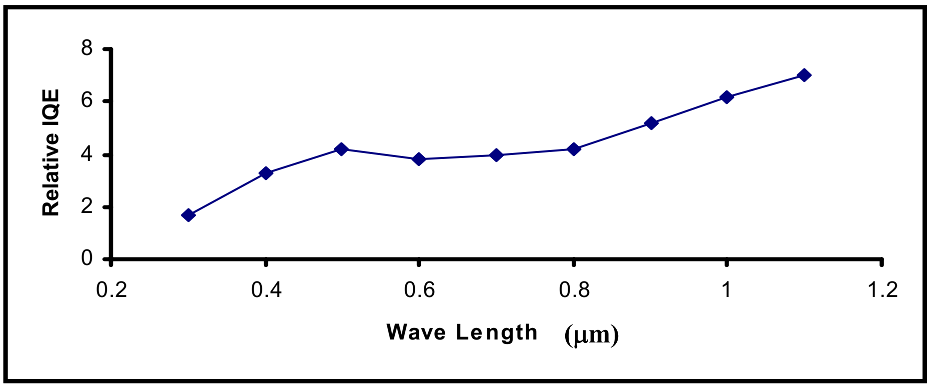

Fig .6. Relative IQE verses incident light wavelength for the fabricated SnO_2-$Si_{(n)}$ structure (TH = 5000 ^oA , Tan = 150 ^oC).

The IQE is a more fundamental quantity, which differs from EQE in the term (1- R_t), which accounts for reflection losses. It is clear that the IQE of the fabricated cell increases with the increasing of wavelength . The cell exhibit about 40 % IQE at wavelength of up to 750 $_{nm}$. The IQE start to increase at wavelength equal to 900 $_{nm}$, and the maximum IQE value occurs at wavelength equal to 1050 $_{nm}$ .In practice, IQE approaches minimum value at long wavelength because of parasitic absorption losses, such as absorption in the rear reflector and free carrier absorption [9] .

The current – voltage characteristic for the SnO_2 – $Si_{(n)}$ structure at AM 1.5 condition is shown in figure (7).

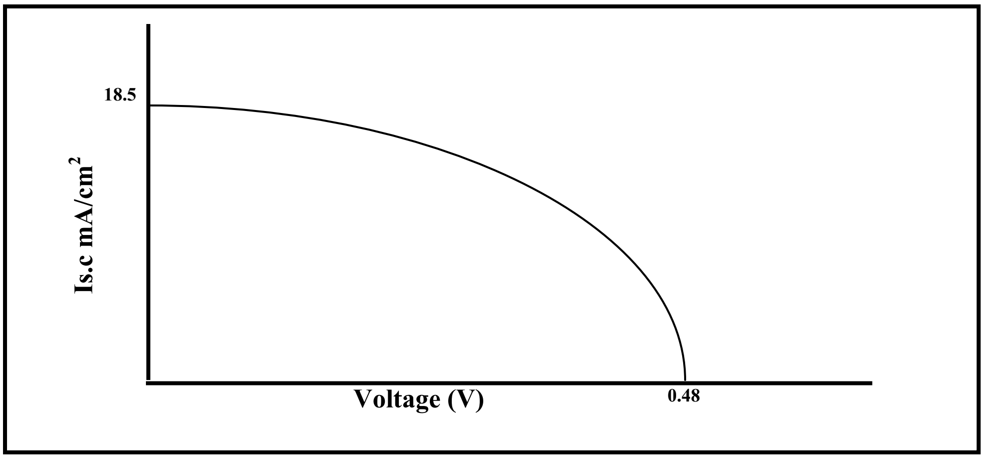

Fig .7. The I.V load characteristic of the SnO2-Si(n) structure .

The incident power is about 79mw/cm^2.and the SnO2 – $Si_{(n)}$ structure is fabricated with SnO2 thickness equal to 5000^{o}A, the temperature is 150^{o}C for 15 minutes. The photoelectric parameters determined from these characteristic are the open circuit voltage is equal to 0.48V, the short circuit current I_{SC} = 18.5mA/cm_2 and the efficiency of the cell is about 7%.

4. Conclusion:

The SnO_2 – $Si_{(n)}$ structure was fabricated using vacuum evaporation technique, the SnO_2 layer acts as antireflecting coating and a transparent upper contact. The oxidation of the silicon surface take place simultaneously by heat treatment during the evaporation process.

The photoelectrical characteristics of the fabricated SIS structure was studied and it is found that the I-V curves for small direct bias correspond to the tunneling mechanism of charge carries transport through the interface.

The fabricated structure have a maximum response at wavelenght between 0.8-1.05µm. The short circuit current is 18.5mA/cm^2, the open circuit voltage is 0.48V and the cell has an efficiency equal to 7%.

5. References:

1. Shewchun J., Dubow J., Wilmson C. W, Wager J. F. (1979). The operation of semiconductor – insulator – semiconductor solar cells. Experiments. J. Appl. Phys., 50, 2832-2839.
2. Plattner R., Stetter W. and Kohler P. (1988). Transparent Conductor Tin – Oxide Layers for Thin – Film Solar Cells . Siemens Forsch - Entwick – Ber Bd. 138-146.
3. Bobeico Euqenia. Spray – Deposited SnO_2 – Si Solar cell. ISES solar world congress 1999, Volume 1.
4. Fahren bruch A. L. and Bube R. H. (1983). Fundamentals of Solar Cells, PP. 417-463. Academic Press, New York.
5. William, D. and J. R. Callister (1985). Material s Science and Engineering. Ed. Wiley, J., Inc., New York.
6. Riben A. R. and Feucht D. L. (1966). Electrical transport in nGe – PgaHs heterojunction. Int. J. Elector.
7. Van der Pauw, L. (1958). H. A method of measuring specific resistivity and hall effect of discs of arbitrary shape. J. Phil. Res. Rep,13.
8. M. A. Green, "Silicon Solar Cells: Advanced Principles and Practice", Centre for Photovoltaic Device and systems. Sydney, (1995).
9. C.B. Honsberg ,F . Yon, M.A. Green, and S .R. Wenham, "Mechanically grooved ,Multi-Junction, Integrated Rear Contact Silicon Solar Cells For Low lifetime Substrate" . European Photovoltaic Solar Energy Confererrnce .1994.