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Electrical Behavior of Solar Cell Based on ZnO/PS

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ABSTRACT

Because of high loss of photovoltaic conversion due to reflection of incident photon by the silicon surface, we proposed in this work a single heterojunction solar cell model based on porous silicon (PS) and Zinc oxide to minimize this loss, which the ZnO could act like front n-layer as well as antireflection coating saving processing cost and complexity. In the experiment the ZnO layer was deposited by spray pyrolysis method on porous silicon (PS) using nitrate precursors with different molar concentration. The proposed treatment has also demonstrated a significant decrease in the reflectivity of ZnO/PS. To simulate a solar cell based on porous silicon and zinc oxide, we have used PC1D software. The variation of internal and external quantum efficiency, and I-V characteristics have been done by changing the reflectivity of ARC layer, The I-V results obtained by PC1D simulation was compared with the experiment results: Simulations anticipated conversion efficiency was 14,5% while by experiments was 12% for the device fabricated with 0.25 M.

Keywords-component; ZnO, PC1D, Characteristic I-V.

1 Introduction

The studies have focused on solar cells as an alternative energy sources to decrease the fossil fuels 'uses, but the high price of 1KWh of electricity generated by a solar cell prevents the wide propagation of this technology so the researches have concentrated on reducing this cost by using a cheaper materials as a cover layer .

Thin film nanostructure has unique proprieties make it capable to play a role as a cover layer. Zinc oxide (ZnO) is one of the most extensively studied materials as an alternative photo anode to TiO2 [1]. ZnO has a wide range of properties that depend on doping, including conductivity which may change at will from metallic to insulting (including n-type and p-type conductivity), high transparency [2], Piezoelectricity [3], room-temperature ferromagnetism [4], and huge magneto-optic effect [5] ,etc…

Without much effort, ZnO can be grown into many different nanoscale forms, thus allowing various novel devices to be achieved. It has a wide band gap energy of 3.37 eV, the larger exciton binding energy of 60 meV guarantees efficient luminescent and photovoltaic characteristics , a wide range resistivity, high electron Hall mobility (200 cm2 .V .s−1) , low toxicity , natural abundance , and highly stable wurtzite structure .

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ZnO thin films have been prepared using various methods as magnetron sputtering [6], spray plasma [7], sol gel spin coating[8], pulsed laser deposition[9], metal-organic chemical vapor deposition and spray pyrolysis[2].

Among this method spray pyrolysis is a versatile technique for the deposition of metal oxides because of its low cost and easy process control which gives the possibility of obtaining films with the required properties for different applications [10].

In this paper, we propose a new model of potentially cost effective and high efficiency single heterojunction solar cells based on porous silicon (PS) (rear region) and the emerging II–VI material ZnO(front region).The ZnO grown on porous silicon can work as an active n-layer as well as antireflection coating.

This model was simulated by PC1D software, the different electrical and optical characteristics as internal, external quantum and efficiencies are investigated by varying different key parameters.

2 Experimental

Experiments were carried out on p-type, boron-doped multicrystalline silicon substrate with a thickness of 350µm and a resistivity of 0.5 to 2 ? cm. Porous silicon was formed by electrochemical etching mc-Si wafers in HF 48% /ethanol (1V:2V) at a constant current density of 15 mA/cm2 for an etching time of 10 min. Immediately after PS formation, the samples were rinsed with DI water and dried under N2 flux[10].

ZnO thin films were prepared by spray pyrolysis process from a solution with different molar concentrations of Zn(NO3)2,6H2O precursor (0.05 M, 0.1M, 0.15 M , 0.2M and 0.25M) in 25 ml of deionized water. The spray system used in this work was fully described and schematically presented in [11]. The Zn (NO3)2,6H2O solution was sprayed with a solution spray rates of 2 ml/min onto a preheated silicon porous substrate at 500°C during 10 min, using compressed air as a carrier gas. The nozzle to substrate distance was about 45 cm. The ZnO thin Films thus obtained are transparent, exhibiting a good adherence to the substrate surfaces.

The reflectivity spectra of the different surface were measured using a LAMBDA 950 UV/ Vis/NIR spectrophotometer equipped with an integrating sphere. The effective minority lifetime (τeff) was measured using the Sinton WCT-120 lifetime tester in quasi-steady-state photoconductance (QSSPC) mode.

3 Simulation

Our experiment results were introduced in the PC1D simulation software to simulate the solar cell based on porous silicon and ZnO using the parameters illustrate in table 1.

Table 1 resumes the parameters was optimized for the solar cell based on the some values obtained in the experiments characterization and the other based on the ZnO proprieties.

The several adjustable parameters in the PC1D can be iterated, to introduce the EQE, IQE, I-V and efficiency of solar cell.

Table 1: Optimized Parameters for the Solar Cell used by PC1D

Varying parameters	Value
Device parameters	
Device area	1 cm²
Surface texturing	None
Surface charge	None
Front reflectance	18%-9%
Emitter contact resistance	10^{-6} Ω
Base contact resistance	0.4 Ω
Front region (ZnO)	
Region thickness	0.015µm
Electron/hole mobility	50 cm²/Vs
Dielectric constant	8.66
Bandgap	3,64- 3,14 eV
Refractive index	2-2,38
n-type background doping	3.10^{13}
bulk electron/hole recombination time	1,2 -1,6 -5- 57- 90µs
electron/hole front surface recombination velocity	1.107 cm/s
Rear region (Si)	
Region thickness	350 µm
Carrier mobilities	From internal model of PC1D
Dielectric constant	11,9
Bandgap	1,124eV
Intrinsic concentration at 300 K	1.1010 cm^{-3}
p-type background doping	1.1016 cm^{-3}
peak rear p-type doping	3.1018 cm^{-3}
bulk electron/hole recombination time	100µs
electron/hole front surface recombination velocity	1.1016 cm/s
electron/hole rear surface recombination velocity	300 cm/s

4 Results

4.1 Experimental results

Some parameters were changed when we have changed the molar concentration of the Zn, these parameters have influenced on the simulated results as EQE, IQE, I-V, and solar cell's efficiency, where the reflectivity parameter of the thin film ZNO/PS is the most important. Lower is the reflection from the front surface higher is the EQE and IQE.

Figure.1 Shows AFM images of the ZnO/PS surface treatment and a reference sample (untreated PS layer) for comparison. It can be seen from the different AFM topography a clear evolution of the microstructure and the surface has an important roughness, the reported roughness (RMS) was found to be around 425 nm for PS wafer and increases to 556 nm after ZnO deposition. The RMS enhancement is attributed to the increase of the nanoparticle size when increasing ZnO molar concentration.

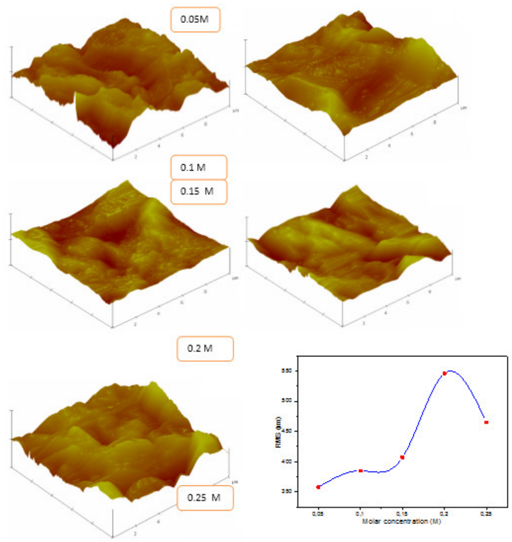

Figure.1 (3D) AFM images of PS and ZnO/PS with various Zn concentrations

Figure. 2 shows that the average reflectivity reduced from 18 % to 9% when the molar concentration decreases from 0.25M to 0.05M. The measured refractive index and extinction coefficient values changed, the former from 2 to 2.38 which is very close to the ideal value and the later from 0.01 to 0.04 for λ = 500 nm [10]. This can eliminate requirement of additional antireflection coating, resulting in reduced fabrication process steps and cost. For Babar et al. [14] the refractive index of ZnO at 600 nm equal 2 is very suitable to play role of antireflection coating AR for Si. The effective carrier lifetime also another important parameter influences on the simulated result (figure 3 shows the values of the each sample obtained on the experimental results).

The different experiment results obtained have introduced using PC1D to simulate the different parameters as EQE, IQE, I-V, and solar cell's efficiency.

B.Hassain in his work [14] also observes that the VOC , Jsc and efficiency (η) have influence by change of ZnO thickness using PC1D software , where the optimized modeled thickness was obtained as 0.1µm for minimum reflection, they have achieved an efficiency of 19,3% , a Voc of 622 mV , a Jsc of 38,5 mA .

4.2 Simulated results

We can distinguish between two types of quantum efficiency: external and internal (EQE and IQE), in other words the external quantum efficiency is defined as the ratio of the charge carrier's number collected by the solar cell to the photon's number of a given energy incident on the solar cell from outside. The second kind (IQE) is the ratio of the charge carrier's number collected by the solar cell to the number of photons of a given energy that shine on the solar cell from outside and are absorbed by the cell. A low value of thin film's IQE indicates that the active layer of the solar cell is unable to make good use of the photons.

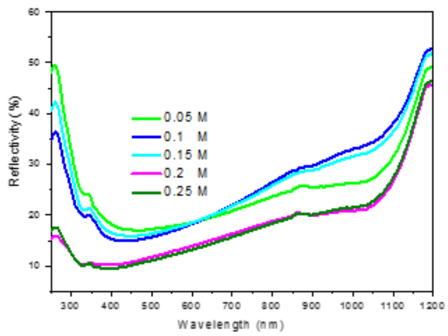

Figure.2 Total reflectivity ZnO/PS film

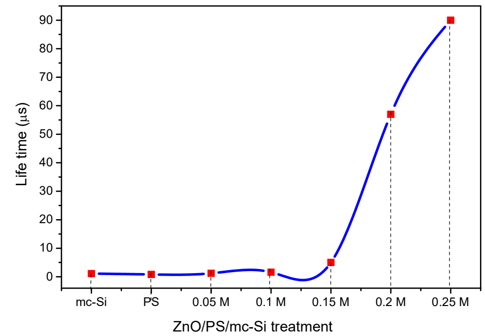

Figure 3: Effective minority carrier lifetime evolution of ZnO/PS

Figure 4 shows the variation of IQE with different front back. The graph indicates that the IQE augments with the increase in the molar concentration of ZnO thin film due to the low value of reflection. The low reflectivity of the thin film ZnO/SP fabricated with a high concentration of Zn (0.25M and 0.2M) also influences on the wide of the band. So the thin film with a high molar concentration has absorbed the photons with long wavelength. In a similar way EQE also increases with the increasing of molar concentration (these results are shown in Figure 5). The absorption of high energy photons in ZnO is mainly responsible for poor EQE at short wavelengths.

Table 2 The Eg values of different n-ZnO

Sample molar concentration (M)	0.05	0.1	0.15	0.2	0.25
Eg (eV)	3.64	3.56	3.34	3.15	3.15

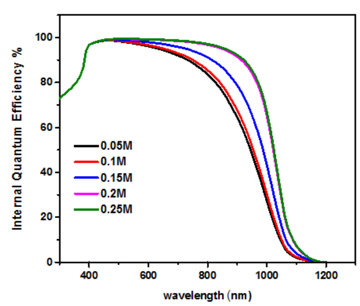

Figure. 4 Internal quantum efficiency (IQE) of the solar cell device with different front back.

The EQE was clearly improved in which the values of EQE increased from 80 to 90% at a wavelength of 500 nm .This result might be explained by the decreased reflectivity of ZnO/SP. Babar has explained in his work [13] the improvement of EQE and front surface reflection with taking into account antireflection effect of ZnO layer, therefore, the EQE was increasing from 84% to 98% around wavelength of 600nm when he adds the ZnO layer.

When the Eg decreases, the wideness of band gets larger, therefore, the IQE and EQE got influenced. All this due to fact the solar cell could absorb more the photons characterized with lower energy. Thus, the number of photons absorbed increases, (table 2 shows the value of the Eg of each sample).The decrease in band gap energy with increase in molar concentration could be due to increase in crystalline size and reduction of defect sites and increase in film thickness [2, 10] .

Figure 6 shows the comparison between the experimental I-V curve and the simulated one. The slight increase in the I-V simulated curve due to the front contact of solar cell is ideal in the simulation.

Based on life time values obtained in the experiment and reflectivity data, we have stimulated by PC1D the I-V spectra of ZnO /SP heterojunction under AM1.5 illumination.

The simulated I-V curves of the HJ solar cell of ZnO/SP treated with different molar concentration are shown in figure 7. The enhancement in the value of the short-circuit current density (JSc) from 26,8 mA to 34, 77 mA and the open circuit voltage Voc from 526,1mV to 536,9 mV .The Jsc increase monotonically with increased Zn molar concentration because of significant increase in number available photons in space charge region as shown in figure 4.

The I-V curves simulated shows the dependency between I-V behavior and different parameters obtained in the experience those parameters can be cited as follows the reflectivity, life time and band gap of ZnO thin film deposited on Si/porous (table 1 and table 2) , optimizing these three parameters yields an optimum Jsc and Voc .

Salem et al. in his work [10] has demonstrated an improvement in the short-circuit current density (Jsc) from 23.4 to 30 mA/cm3 ,and the open circuit voltage Voc got increased from 526.1 mV to 536.9 mV, in which these values are close to the result obtained in this work.

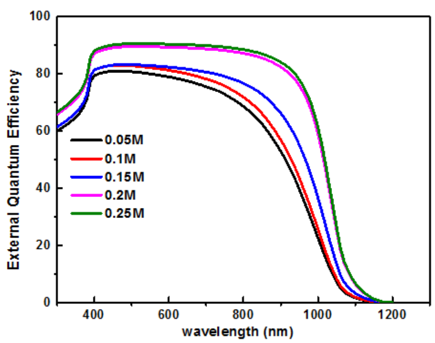

Figure.5 External quantum efficiency (EQE) of the solar cell device with different front back

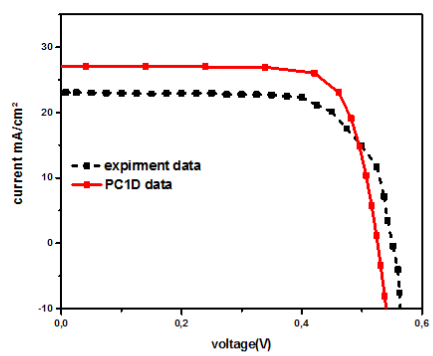

Figure . 6 I-V Experiment and PC1D spectra of ZnO /PS of 0.05M sample

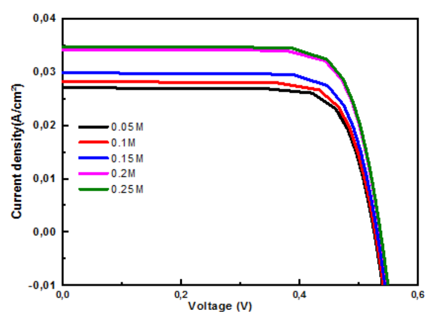

Figure .7 I-V Characteristics of ZnO / PS heterojunction under AM1.5 M

The quality of the solar cell is defined by it efficiency (η) of light conversion; the efficiency is the ratio of the energy output from the cell (Pmax) to the input energy from the sun (Pin). It was calculated by using the equation:

$$\eta = \frac{\mathrm{Im} * Vm}{Pi} \quad (1)$$

Where Vm is the value of the voltage for the maximum power from a solar cell, and Im is the value of the current for the maximum power from a solar cell.

The η values go up from 11.1% to 14.5%. The proposed treatment demonstrates a significant enhancement of this parameter after ZnO/PS treatment.

On the other hand the result of I-V and η in the experiment results are shown in the table 3, as it is seen there is the slight enhancement in the simulation results due to the ideal solar cell.

Table 3 Photovoltaic parameters from illuminated characteristics of solar cells obtained by PC1D software.

samples	Jsc(mA/cm3)	Voc(mV)	η(%)
0.05M	26,8	526,1	11,1
0.1M	28 ,19	527,8	11,6
0.15M	29,86	531,1	12,3
0.2M	34,13	536,4	14,3
0.25	34,77	536,9	14,5

Table 4 Photovoltaic parameters from illuminated (I–V) characteristics of obtained solar cells by experiment [10]

samples	Jsc(mA/cm3)	Voc(mV)	η(%)
0.05M	23,4	551	7 ,8
0.1M	23	552	9 ,1
0.15M	24	552	10 ,5
0.2M	28	553	10,9
0.25M	30	564	12

5 Conclusion

We have proposed a single hetero-junction solar cell model based on porous silicon and ZnO using modified PC1D software. ZnO has fabricated by spray pyrolysis from a solution of Zinc nitrate with different molar concentration. The influence of molar concentration full filled on the electrical and optical proprieties. We have obtained a low reflection with a high molar concentration of precursors, where the reflectivity of the device fabricated with 0.25 M is 9%. The effective carrier lifetime also increases in which the value of this device is 90µs. The different parameters introduced by PC1D software, the IQE, EQE, the I-V and the device efficiency value of this device have improved, in which the value of efficiency is 14.5% by PC1D software and 12% in the experiment.

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