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THE INFLUENCE OF SHEET RESISTANCE AND TEXTURED SURFACE ON THE CHARACTERISTICS OF SILICONSOLAR CELLS USING PC1D SIMULATION PROGRAM

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ABSTRACT

In this work we studied the effect of a laterally varying emitter sheet resistance on solar cells characteristics such as,(I-V)parameter and Internal quantum efficiency (IQE). Then they were analyzed by simulation program (PC1D). The best efficiency we reached during this study is (21.2%) under (AM1.5G) illumination with high sheet resistance (100Ω/sq) and textured surface. It was shown that the texturing have important effect for light management for the best efficiency value. The results obtained in this study were in a good agreement with the experimental studies done by other researchers.

INTRODUCTION

The cost performance targets of Si photovoltaic's (PV) can be reached by enhancing the cell efficiency while utilizing high throughput processing [1]. Most industrial multi crystalline silicon(mc-Si) solar cells are fabricated with a phosphorus-doped n+-emitter layer having a sheet resistance of(40-50)Ω/sq. The relatively low sheet resistance in conventional mc-Si cells is chosen to promote a low-resistance ohmic contact between the screen-printed metallization and the emitter layer[2]. However the heavy doping increases carrier recombination in the emitter layer and increases the emitter surface recombination velocity [3]. It has been shown, that the combination of front-surface texturing and high sheet-resistance emitters with good surface passivation can significantly enhance the solar cell performance [4-5]. Besides that an improvement to solar cell efficiency can be achieved if the emitter doping can be reduced to minimize recombination, without degrading the

A recent study has shown that the (Jsc) and (Voc) of mc-Si solar cells can be increased if the emitter sheet resistance is increased [6]. High quality screen-printed solar cells have been achieved recently on even higher sheet-resistance emitters (100 Ω/sq.) on single crystal Si[7]. We have previously demonstrated high fill factors (>0.78) on high sheet resistance planar emitters through understanding and optimization of an appropriate Ag paste and firing recipe[7]. The result achieved an efficiency of 17.4%.[7]. In this paper we report on the investigation of textured surface and high sheet resistance emitters. Both (I-V) characteristics and the internal quantum efficiency (IQE) behaviour for high sheet resistance emitter textured cells have been investigated by simulation program(PC1D). A study of these factors has been also performed for planer cells

THEORETICAL MODEL

Modelling of Solar Cell

The modelling of solar cell has been made by computer program (PC1D). For one successful simulation, input parameters include: the thickness of p-type or n-type material, the doping density, band gap, electron affinity, effective conduction and valence band density,

The absorption coefficient for the sun light spectra, temperature, and mobility's, the electrons and holes recombination velocities. The cell parameters chosen for the simulation for the present model are summarized in Table (1).

Table 1:,Parameters used in the Silicon solar cells simulation

Parameter	Values
Relative permittivity (εr)	11.9
Area of cell (cm^2)	1
Mobility μe,μp(cm2.V^{-1}.S^{-1})	μ_e=1350, μ_p=450
Doping density Na, N_D(cm^{-3})	Na=(10^{16}), N_D= (10^{20})
The electron and hole front surface recombination velocities(cm/sec)	Sn=Sp=1.5x10^5
The electron and hole Rear recombination velocities(cm/sec)	Sn=Sp=600
Band gap Eg,(eV)	1.12
ARC(Si_3N_4),Refractive index	n=2
Junction depth (μm)	0.28
Thickness of cell(μm)	300
Affinity (x),(eV)	4.05
Effective density Nc, Nv(cm^{-3})	N_c=2.80x10^{19}, N_v=1.04x10^{19}
Temperature T(K)	300

Simulation using (PC1D)

The first process is applying the voltage by using simulation program PC1D to compute open circuit voltage (Voc) ,short circuit current(Isc) and efficiency(η).Then the (900) incident light angle was applied on top of silicon solar cell to trace the reflectance in silicon solar cell. The next step is to simulate internal quantum efficiency(IQE) the antireflection (ARC) layer thickness (85)nm to plot the graph of (IQE). Table 1 shows the input data to calculate the result of each case. The complications in applying textured surface on (Si) solar cells is well known, but it has the potential to increase the efficiency, especially for improving the short-circuit current through the following effects[8];

o Reduction of front surface reflection.
o Absorption of base of photons closer to the collecting junction.
o Trapping of weakly absorbed photons within the thin cell (light trapping).

A quarter wavelength thickness of (ARC) layer effectively reduces the reflection to minimum at normal incidence. The optimal thickness for minimum reflection at wavelength(λ) is defined by the equation:

$$d=\frac{\lambda}{4n} \qquad (1)$$

where;
d - Optimal thickness of the (ARC)layer
n – Refractive index of the material
λ – Wavelength of the material
the reflectance is given by the general equation (2);

$$R=\left(\frac{n_0 n_{si}-n_1^2}{n_0 n_{si}+n_1^2}\right)^2 \qquad (2)$$

Where,
n_1 -is refractive index of the material layer.
no –is refractive index of air.
nsi - is refractive index of silicon .

Internal quantum efficiency is due to photons incident on surface is given as[9]:

$$IQE=\frac{EQE}{1-R(\lambda)-T(\lambda)} \qquad (3)$$

When,
R(λ) is the reflectivity of the Si,
T(λ) is the transitivity of the Si.
EQE- External quantum efficiency is the current generated due to the photon absorption at the surface.

$$J=J_L-J_s\left(e^{qV/nkT}-1\right) \qquad (4)$$

The ideal equation that represent (J-V) characteristics of p-n junction solar cell is characterized by [10].

J_L:photocurrent density

Js: saturation current density($A.cm^{-2}$)
q: The electron charge=$1.602x10^{-19}$(C);
T: PV module temperature(K)
n:Ideality factor of the PV module
k: Boltzmann's constant= $1.380x10^{-23}$($J.K^{-1}$)
Short circuit current (Isc): When V=0, the current is the short circuit current(Jsc). From equation (4), we can get:

$$Jsc = J_L \qquad (5)$$

In general,(J_L)is strongly dependent on the illumination conditions, absorption and transport properties of each region .(JL) generated by and proportional to the amount of light absorbed by the solar cell.
Open circuit voltage (Voc): When J=0, (Voc) is the open circuit voltage, which is the maximum voltage available for given conditions. From equation (4) set J=0:

$$V_{OC} = \frac{nkT}{q}\ln\left(\frac{J_L}{J_s}+1\right) \qquad (6)$$

Fill factor in simple terms is the ratio of the area of the purple actual maximum power density rectangle over the orange ideal maximum power density rectangle. The Fill factor of the solar cell is calculated using the equation:

$$FF=\frac{\text{power density}_{max}}{V_{oc}J_{sc}} \qquad (7)$$

The efficiency (η)of the solar cell is a follow on from the Fill factor, also using the maximum point of power density and is calculated using the equation:

$$\eta=\frac{\text{power density}_{max}}{\text{input power density}}\% \qquad (8)$$

Where Power DensityMAX = maximum point of power density ($mW.cm^{-2}$)
Input power for (air mass) AM1.5 sun (assumed) =$1kW.m^{-2}$ = $100mW.cm^{-2}$[9].

RESULTS AND DISCUSSION

As shown in figure 1 internal quantum efficiency (IQE) in the short-wavelength for a textured emitter is lower than that for the planar emitter. This is attributed to the higher front-surface recombination velocity because of the increase in surface area due to the textured surface. However, the lower reflectance due to texturing results in enhancement in current over the planar surface as shown in figure 2 .This is attributed to the higher absorbance of light then increase the short circuit current (Isc) caused the lower reflectance due to texturing as shown in Figure 2. In addition, reflectance,(R) of the textured (Si_3N_4)-coated surface was found to be (3.2%)while the planar surface gave an (R) value of (~12%)[11].As shown in Table 1 and 2 the enhancement in efficiency due to the (100 Ω/sq) emitter compared with a(45 Ω/sq) emitter is significantly more clear for textured cells compared with planar cells. The higher(Δη) shown in Table 2 for textured cells is a result of a higher(ΔIsc) by (~0.3 mA) for the textured cells compared with the planar cells .The improvement in (Isc)(ΔIsc) due to the (100 Ω/sq) over a (45 Ω/sq) emitter for textured cells is (~0.8 mA) while that for planar cells is(~0.5 mA).But the value of (Voc) textured cells is nearly the same as for the planar cells, with the same emitter sheet-resistance Table 3. From this table and figure 3 it is clear that the effect of textured surface on efficiency solar cells. Therefore, we investigated the effect of sheet resistance on(IQE) for the (45) and (100) Ω/sq textured cells to better understand the thedifference in(ΔIsc) between for the 45 and 100 Ω/sq. As shown from figure 4 the increasing in sheet resistance lead to increasing in(Isc) therefore increasing in (IQE) due to decreases front surface recombination velocity(FSRV) [12].The value of (FSRV) are (160000-60000)cm/sec for (45 -100)Ω/sq respectively[12]. One disadvantage of the textured surface is the higher (FSRV), resulting from an increase in the surface area of the cell. This results in a higher (FSRV) compared with planar cell[12]. However, raising the sheet-resistance from(45 to 100)Ω/sq may help in lowering the (FSRV) because it is easier to passivate the surface with lower surface concentration. The value of (IQE)in the short-wavelengths is inversely related to(FSRV), the textured cells should have lower (IQE)compared to their counterpart planar devices. However,(Isc) of the textured cells is higher than their planar counterpart, in spite of the higher (FSRV), because of the much lower integrated reflectance value. Such a reduction in front-surface reflectance can lead to increase in photocurrent and increase in cell efficiency. Model calculations were performed using the PC1D modelling program to estimate the benefit of a high sheet-resistance emitter. Model calculations in Figure 5 show that (100Ω/sq) emitter with good surface passivation (front-surface recombination velocity (FSRV) of (60 000 cm/s) can contribute to(~0.9%) increase in cell efficiency relative to a (45Ω/sq) emitter cell. Our results are in a good agreement with reference[11-12].

Table 2: Light I-V parameters textured and planar with 45 and 100 Ω/sq emitters

Emitter surface	**Sheet resistance Ω/sq**	**Voc (mV)**	**Δ Voc (mV)**	**Isc (mA)**	**Δ Isc (mA)**	**η%**	**Δ η%**
Textured	45	650.3	13.2	37.6	0.8	20.5	0.7
	100	663.5		38.4		21.2	
planar	45	653.7	9.3	33.9	0.5	18.6	0.4
	100	663.0		34.4		19.0	

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Table 3: Light I-V for the textured cells compared with theplanar cells(100 Ω/sq) emitters

Emitter surface	**Sheet resistance Ω/sq**	**Voc (mV)**	**Δ Voc (mV)**	**Isc (mA)**	**Δ Isc (mA)**	**η%**	**Δ η%**
Textured	100	663.5	0.5	38.3	3.9	21.2	2.2
planar	100	663.0		34.4		19.0	

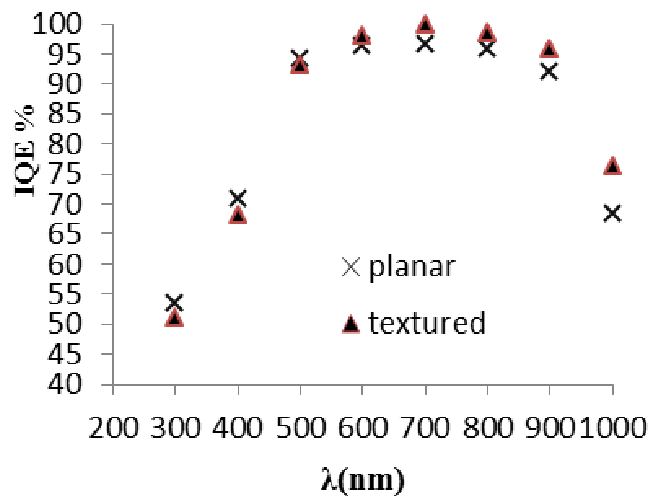

Figure 1: IQE of planar and texture surface with (100 Ω/sq) emmitters

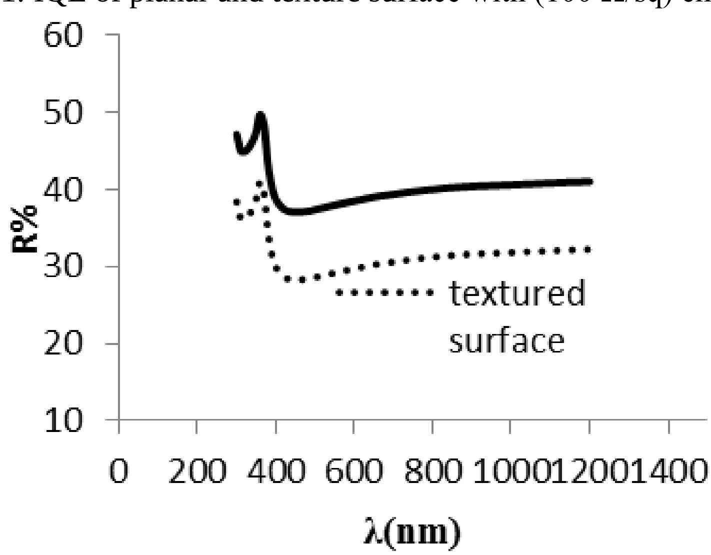

Figure 2: Reflectance of planar and textured emitter surface with Si_3N_4 single layer AR coating

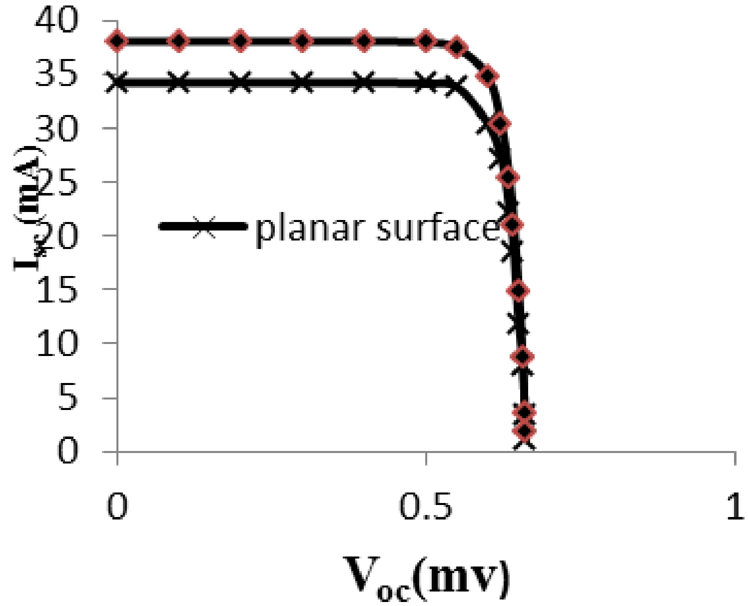

Figure 3: I-V Characteristic of plenar and textured emitter surface with 100Ω/sq

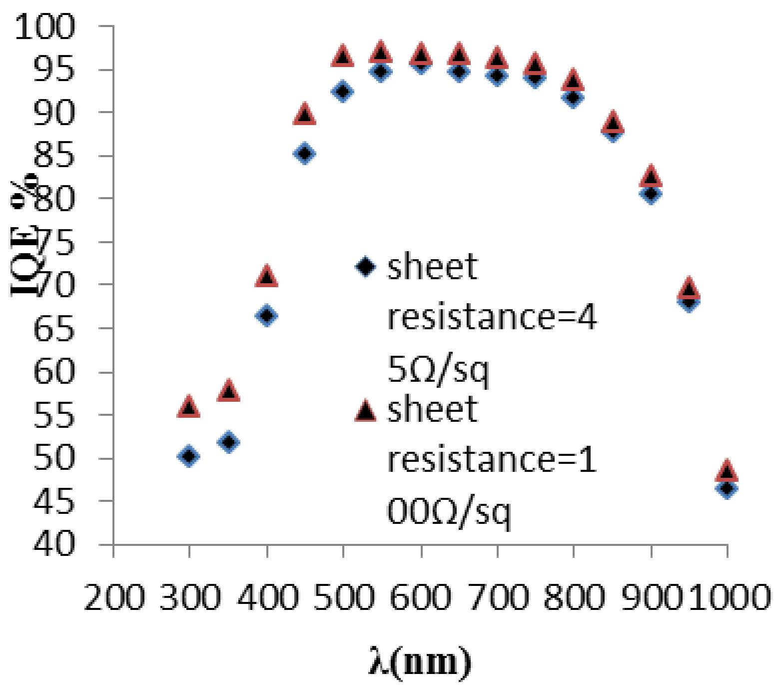

Figure 4: IQE of textured surface with different sheet resistance

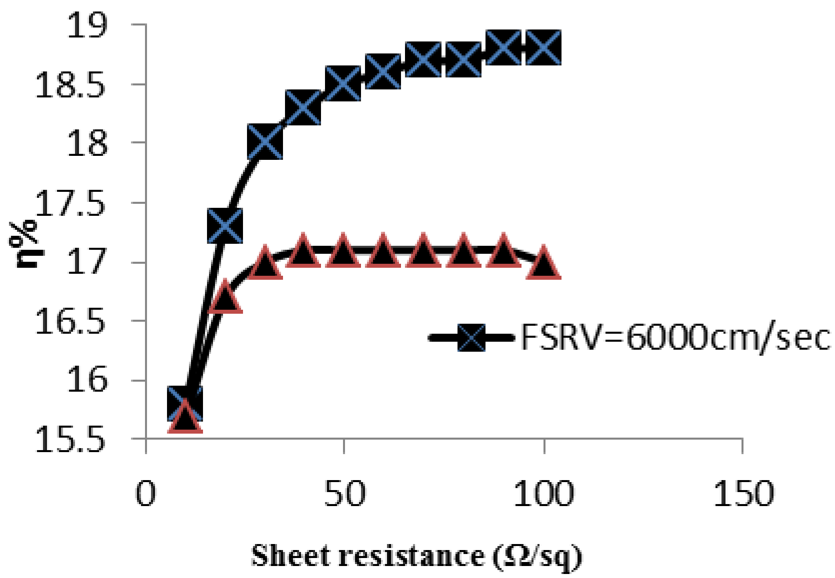

Figure 5: The effect of emitter sheet-resistance and front surface recombination velocity (FSRV) on planar cell efficiency modeled using PC1D

CONCLUSION

Our results show rotation between high sheet resistance emitter and a textured front-surface, which results in a greater efficiency enhancement due to the lightly absorbed textured emitter lightly doped textured emitter compared with the enhancement due to the lightly absorbed emitter for planar cells. This is mainly attributed to the greater increase in (FSRV) due to texturing of the heavily doped emitters. This work resulted in a high efficiency of (21.2%) for (100) Ω/sq textured emitter and high (IQE). These results were primarily made possible due to the high quality contacts resulting in a low series resistance, low junction leakage, and a high efficiency [11]. The textured surface also showed more robustness in achieving consistently low series resistance compared with the planar emitter surface[12]. Our model calculations indicate that improving the (FSRV) from (150 000)cm/s to (60 000)cm/s would increase the cell efficiency to (21.2%)at sheet resistance (100) Ω/sq for textured surface.

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