ENHANCED BACK-CONTACT BACK-JUNCTION CRYSTALLINE SILICON SOLAR CELL PERFORMANCE WITH A SILICON-CARBIDE (SIC) BASED FRONT SURFACE PASSIVATION

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ABSTRACT

In this work, a novel surface passivation scheme has been discussed with Back-Contact Back- Junction (BC-BJ) 10µm thin crystalline silicon Solar Cell which is 10-15 times thinner than the conventional c-Si solar cell. Presence of SiC as a surface passivation layer shows high quality passivation as compared to conventional antireflective front surface passivation layers. The hole concentration of 13-14 cm^{-3} *has been achieved at the interface resulting in a significant 13.5% power conversion efficiency (PCE). Simulation results reveals that the presence of SiC makes BC-BJ silicon solar cell less prone to surface recombination of carriers. All the simulations have been done using DEVEDIT and ATLAS device simulator.*

Keywords: ATLAS, Back-Contact Back-Junction (BC-BJ), Passivation, Simulation, Solar Cell.

I. INTRODUCTION

One of the growing research topic in the field of photovoltaics is the development of low cost and high efficiency silicon solar cell. In order to maximize solar cell efficiency, it is necessary to optimize both the electrical device characteristics and the optical absorption of the device [1-3]. There are several different cell concepts, such as PERL [4]. Sunpower corp. shows that it is posible to achive average cell efficiency upto 22% [5-6] in mass production with BC-BJ silicon solar cell structure. In BC-BJ solar cell, both the emitter and back surface field (BSF) are situated at the back side, opposite to the illuminated face of the device. The BC-BJ solar cell has many advantages, such as avoidance of optical shading losses at front side, higher absorption and current density. Here, we discussed new surface passivation scheme for BC-BJ silicon solar cell, which shows remarkably good characteristics over the conventional passivating antireflective coating of thermal SiO_2 or SiNx:H layers, higher field as well as low surface recombination is observed in simulation results. The new surface passivation scheme makes the device less prone to surface recombination by decreasing the concentration of holes at the interface. We have not incorporated the defected state which exists in silicon- silicon carbide heterojunction, since here, SiC layer is used for surface passivation.

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II. DEVICE STRUCTURE AND MODELS

The simulation device structure i.e. BC-BJ Si solar cell is shown in Fig.1. To simulate the solar cell properties, we specified the following: substrate was n type silicon with dimensions (100µm x 10µm) with doping density ($3x10^{15}$ cm^{-3}). The n+ and p+ region have a depth of 3µm and 2.5µm respectively, with doping density of $4x10^{20}$ cm^{-3}. Front surface of the device consists of passivation layer. We have defined our contacts as ohmic. This is done to avoid schottky barriers, and thus unnecessarily higher computation time. Table 1 shows the parameter used in simulations. Shockley-Read-Hall, Concentration dependent mobility and Auger recombination mechanisms were taken into account. Auger recombination is modeled according to [7] using the expression:

$$R_{Auger} = AUGN\,(pn^2 - nn_{ie}^2) + AUGN\,(np^2 - pn_{ie}^2) \quad (1)$$

Where, AUGN and AUGP are the Auger recombination coefficient for electrons and holes, respectively and nie is the intrinsic carrier concentration. The Shockley-Read-Hall recombination is modeled according to [7] using the expression:

$$R_{SRH} = \frac{pn - n_{ie}^2}{TAUP0\left[n + n_{ie}\exp\left(\frac{ETRAP}{kT_L}\right)\right] + TAUN0\left[p + n_{ie}\exp\left(\frac{-ETRAP}{kT_L}\right)\right]} \quad (2)$$

Where, ETRAP is the difference between the trap energy level and the intrinsic Fermi level, T_L is the lattice temperature in degrees Kelvin and TAUN0 and TAUP0 are the electron and hole lifetimes. The AM1.5G spectrum was used to simulate the current-voltage, (I-V) curve under one-sun illumination condition with intensity of $100mW/cm^2$.

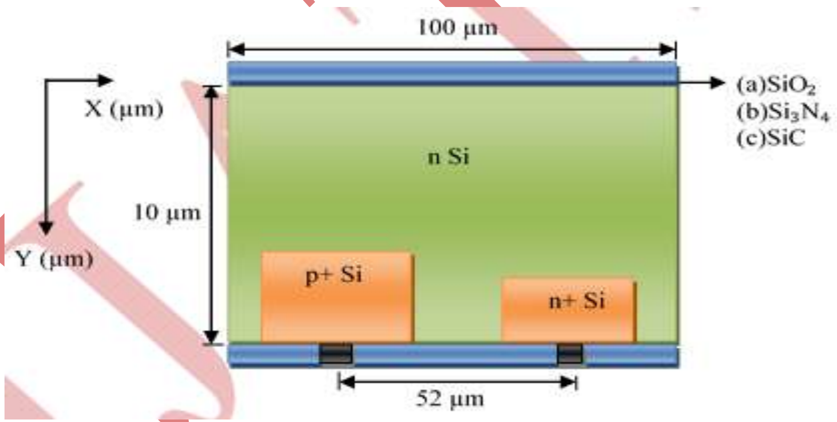


Fig. 1: Simulated device:-BC-BJ Si solar cell with surface passivation layer: (a) SiO_2 (b) Si_3N_4 (c) SiC

Table 1 Parameters Used In Simulation

Energy band gap (Eg)	1.08eV
Band density (Nc)	$2.8x10^{19}(cm^{-3})$
Band density (Nv)	$1.04x10^{19}(cm^{-3})$
Intrinsic carrier conc.	$1.45\ x10^{10}(cm^{-3})$
Minority carrier lifetime.	$1x10^{-5}s$
Minority carrier lifetime.	$1x10^{-5}s$
Electron mobility (μ_n)	$1000\ cm^2/Vs$
Hole mobility (μ_p)	$500\ cm^2/Vs$
Auger recombination coefficient for electrons	$2.8x10^{-31}\ cm^6\ s^{-1}$
Auger recombination coefficient for holes	$9.9x10^{-31}\ cm^6\ s^{-1}$

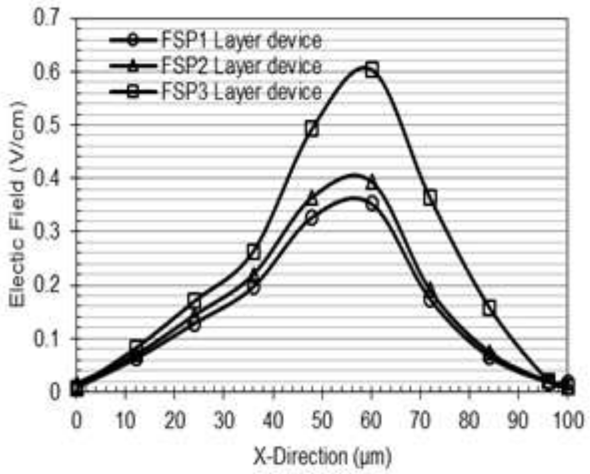


Fig. 3: Comparisons of electric field at interface for three different surface passivation layers

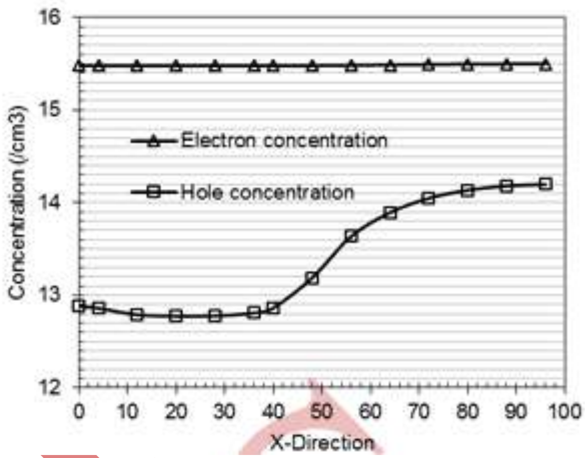


Fig. 4: Electrons and holes concentration at the interface in FSP3 layered device

III. RESULTS AND DISCUSSION

The front surface of most of the solar cell normally consists of well – passivated antireflective coating of thermal SiO_2 or Si_3N_4 layers [8-9]. Here we study the effect of front surface passivation (FSP) on photovoltaic properties of BC-BJ silicon solar cell. We compare the impact of three different (FSP) schemes: single SiO_2 named FSP1, Si_3N_4 named FSP2, and SiC named FSP3. Photogeneration rate contour within the device is shown in Fig.2. A higher generation rate as well as higher generation depth is observed in FSP3 layer device

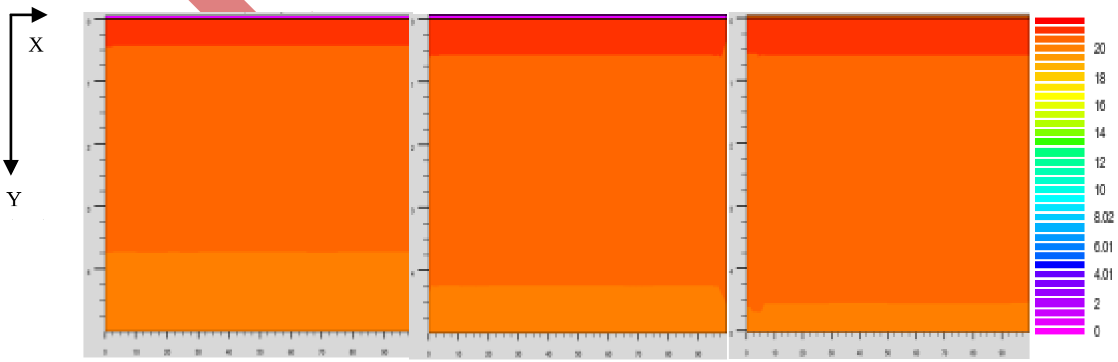
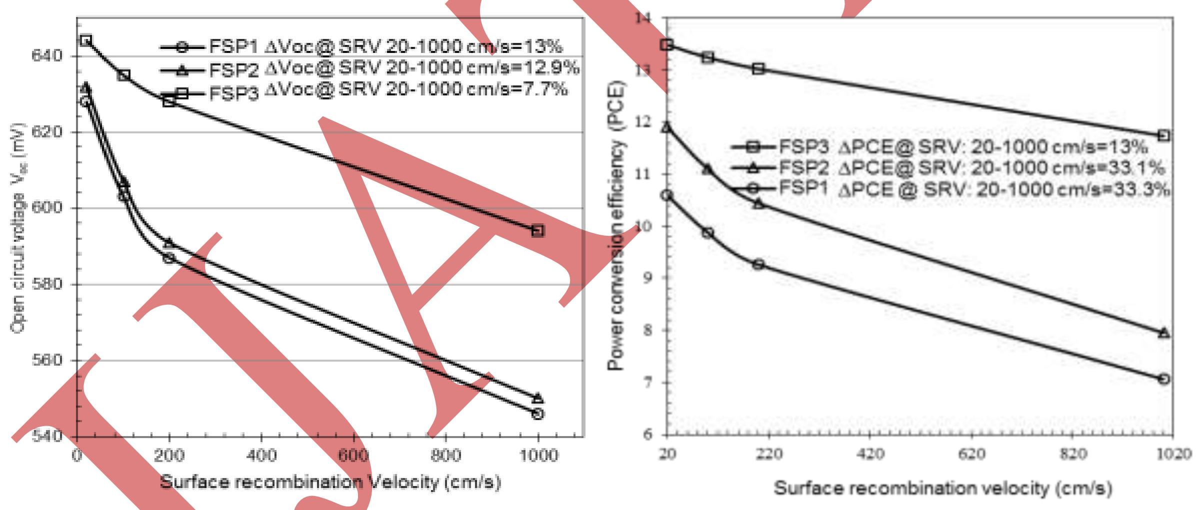


Fig.2: Photogeneration rate (/cm3s): (a) FSP1 layer device (b) FSP2 layer device (c) FSP3 layer device

because of the less reflectance at SiC layer. In surface recombination process, an electron from conduction band recombines with the hole in the valance band via a defect level within the bandgap [10]. This kind of recombination requires one electron and one hole for recombination and it would be maximum if no. of electrons is equal to the no. of holes at the interface. In addition, increased electric field at the interface is observed in FSP3 layer device (Fig.3), which assist the holes to moves towards the junction, resulting in low concentration of holes at the interface (Fig.4) and hence a lower surface recombination rate.

Furthermore, if the concentration of one comrade electrons or holes is drastically reduced, then recombination rate reduces strong. Fig.4, shows that the concentration of electrons at the interface is higher than the concentration of holes, resulting in low surface recombination rate in case of FSP3 layer device. Further, we obtained the influence of surface recombination velocity (SRV) on photovoltaic cell parameters as plotted in Fig. 5 (a) and (b). The open circuit voltage, in case of FSP3 layered device is less affected by SRV Fig.5(a), Also with surface recombination velocity of 20cm/s, FSP3 layer device shows 13.5 % power conversion efficiency (PCE), whereas for FSP1 and FSP2 layered devices, PCE is 10.59% and 11.9% respectively. Moreover, as the SRV is increased from 20 to 1000 cm/s, the efficiency of FSP3 changes from 13.5 to 11.73 with a percentage change of 13, whereas for FSP1 and FSP2 layered devices, it went down to 7.06% and 7.95% respectively, showing a percentage change of 33.1% and 33.3% respectively.



(a) (b)

Fig.5: Influence of SRV on: (a) Open circuit voltage (b) Power conversion efficiency

V. CONCLUSION

In this work, a novel surface passivation scheme for thin BC-BJ silicon photovoltaic has been proposed, and influence of front surface passivation scheme has been discussed based on TCAD analysis. For improving Front surface passivation of thin BC-BJ solar cells, it required to decrease the concentration of one partner electrons or holes at the interface. We achieved the concentration of electrons and holes, 15.5 cm^{-3} and 13-14 cm^{-3} respectively, at the interface, which makes the device insensitive to surface recombination phenomena, The presence of SiC layer improves all photovoltaic parameters: EQE> 85% spectrum range of 400-650 nm wavelength, fill factor 80% and a power conversion efficiency of 13.5%.

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