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Simulation and optimization of the nSiC layer's thickness in a nSiC/Si photovoltaic cell

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Abstract : Simulations of the emitter layer in 3C-SiC heterostructure solar cells were performed by means of SCAPS to model the optimal thickness and predict the influence on cell's behaviour. Then, the cells have been elaborated by chemical vapor deposition and characterized. The opto-electrical measurements showed an improvement of the absorption of photons in the short wavelengths thanks to the thin layer of the emitter, and the non-degradation in bulk of the base cell. On the front side, the using of Ti/Au contacts also leads to an improvement in the absorption of photons thanks to the low series resistance.

Keywords : SiC thin layer, heterostructure, solar cell

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Introduction

Silicon remains the most used material in photovoltaic field. However, its applications are limited in the visible photo-conversion range. Thus, research is venturing into experimenting with wide band gap semiconductors such as silicon carbide in order to widen the spectral band from visible to ultraviolet, by using the polytype 3C of the silicon carbide (3C-SiC). Indeed, silicon carbide is a wide

band gap semiconductor material with exceptional properties in terms of temperature resistance, and chemical stability. 3C silicon carbide, with 2.36 eV bandgap could be a potential candidate and also, this material has been extensively studied due to its potential applications in variety of fields (1). SiC is known for its ability to resist to high radiation level (2), making it suitable to work in solar concentrators. 3C-SiC/Si heterojunctions have already been studied in the domain of power

diodes (3), as window layer or as emitter for photovoltaic cells in several configurations (4). The opportunity to make 3C-SiC/Si tandem cells has been studied theoretically (5) even if according to (6), a tandem cell formed of an SiC cell superimposed on a silicon cell would hardly achieve the performance of a single silicon cell. The first step in order to realize 3C-SiC/Si tandem cells is to masterize the deposition of 3C-SiC on Si wafers.

We carried out simulations first in order to optimize the emitter layer to have a better conversion of the photons in the field of ultra-violet, and to understand the degradation of the Si bulk properties during the SiC film deposition. Then, characterizations were performed on cells developed by the CRHEA (Center for Research on Heteroepitaxy and its Applications). The present work presents the results.

Simulation results

In order to predict the properties of the cells to be developed by CRHEA, we performed simulations using SCAPS software. SCAPS is a software for modeling solar cells based on CdTe and CIGS (7), developed by Marc Bulgerman of the Department of Electronics and Information Systems (ELIS), University of Gent, in Belgium. Our simulations thus consisted in the optimization of the emitter layer of the heterojunction 3C-SiC/Si. We optimized also the influence of the diffusion length of the carriers in the bulk of Si following the deposition temperature during growth of the SiC/Si deposition process by the CVD method.

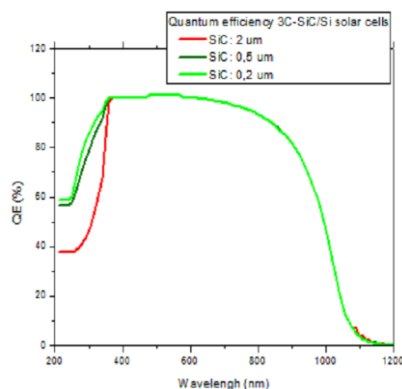


Figure 1: Influence of SiC thickness on EQE

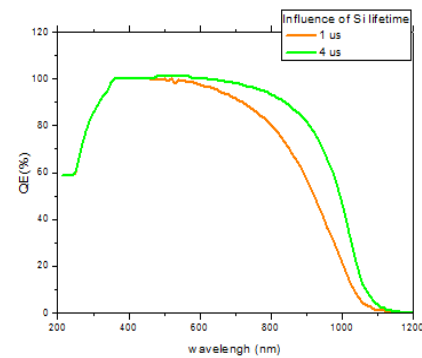


Figure 2: Influence of the lifetime in the Si bulk

These simulations have shown, first the improvement of the spectral response in the short wavelengths, especially for an optimal thickness of the emitter of 0.2 μm . Secondly, a degradation in the visible response for $\lambda > 600\text{nm}$ could be observed in the bulk of Si during the growth of SiC. Similar results were obtained by Touré et al (8).

Results and discussions

Samples

3C-SiC, $\langle 100 \rangle$ oriented, epitaxial layers were grown on $\langle 100 \rangle$ oriented, 10 ohm.cm p-type silicon wafer by resistive heating hot wall chemical vapor deposition, under Hydrogen flux (15sml). Silane and Propane gases were used as precursors, under 200 mbar of pressure (C/Si ratio =1.1). Nitrogen was used in order to produce an n-type doping. The growing has been realized in two steps, first a carburization step at 1100°C, then a growing step at 1350°C. This process has been described in (9). The Nitrogen flux for the doping level was 50 sccm, producing an estimated doping level of $7\text{-}8 \times 10^{18} \text{ cm}^{-3}$ and 10^{19} cm^{-3} . The two highest doping levels have been controlled by FTIR method (10). The thickness of the emitter is varied: 2 μm , 1 μm , 0,5 μm , and 0,2 μm . One wafer was doped at 10^{19} cm^{-3} .

Photovoltaic cells were then produced in three steps: (i) Mesa-structures were realized by classical photolithography (Size 1.98x2.43 mm), (ii) the Ti/Au front contacts were deposited followed by a subsequent annealing at 460°C, (iii) an Al/Au layer was deposited on the backside of the wafer, followed by an annealing at 460°C. Some other cells were fabricated using Ni/Au as ohmic contacts on the front side.

Current-voltage characteristics

Current-Voltage measurements were performed using a Keithley 236 source-measurement unit. The curves in the dark are fitted with a single diode model based on the series and the shunt resistances, the ideality factor and the saturation current. A solar simulator with an AM 1.5 spectrum and an illumination power of 1000 W.m^{-2} allows measurements under light.

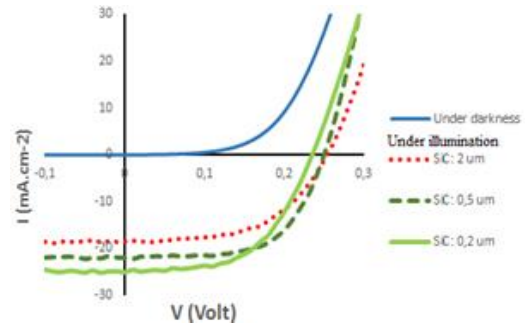


Figure 3: Current voltage characteristics

The parameters of the cells are presented in table 1. Table 2 shows the previous results obtained by Moussa and al, with diodes based on $2 \mu\text{m}$ SiC emitters and distinct doping levels (from $4.10^{17} \text{ cm}^{-3}$ to $3.10^{19} \text{ cm}^{-3}$) and Ni/Au layer as ohmic contact on front side (8).

Table 1: Parameters of the new diodes

| Emitter layer | V_{oc} (mV) | J_{cc} (mA.cm ⁻²) | FF(%) | η (%) | R_s (Ω) | R_{sh} (Ω) |
|--|---------------|---------------------------------|-------------------|-----------------|--------------------|-----------------------|
| 0,2 μm ($7.10^{18} \text{ cm}^{-3}$) | 220 ± 8 | $23,66 \pm 0,56$ | $0,502 \pm 0,062$ | $2,8 \pm 0,4$ | $27,625 \pm 7,06$ | $1247,83 \pm 202,77$ |
| 0,5 μm ($7.10^{18} \text{ cm}^{-3}$) | 245 ± 1 | $21,62 \pm 0,12$ | $0,58 \pm 0,039$ | $3,1 \pm 0,12$ | $20 \pm 10,42$ | $2906,53 \pm 1675,86$ |
| 1 μm ($7.10^{18} \text{ cm}^{-3}$) | $260 \pm 7,5$ | $16,27 \pm 0,52$ | $0,62 \pm 0,01$ | $2,63 \pm 0,13$ | $12,31 \pm 0,126$ | $4359,42 \pm 1175,82$ |
| 2 μm ($7.10^{18} \text{ cm}^{-3}$) | $260 \pm 3,8$ | $18,49 \pm 0,12$ | $0,52 \pm 0,012$ | $2,5 \pm 0,12$ | $56,88 \pm 18,93$ | $1194,27 \pm 399,065$ |
| n+, 2 μm ($1,5.10^{19} \text{ cm}^{-3}$) | 270 ± 1 | $16,66 \pm 1,04$ | $0,5 \pm 0,01$ | $2,37 \pm 0,12$ | $75,5 \pm 8,74$ | $1784,7 \pm 136,6$ |

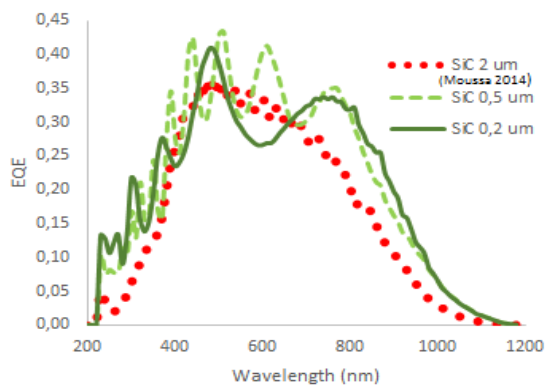
Table 2 : Parameters of the former diodes (8)

| Emitter (2 μm) doping level | Voc (mV) | Isc (mA/cm^2) | Fill Factor | Efficiency % | Rs($\Omega.\text{cm}^2$) | Rsh($\Omega.\text{cm}^2$) |
|---|----------|---------------------------------|-------------|--------------|----------------------------|-----------------------------|
| 4.0E+17 | 90 | 12.5 | 0.37 | 0.42 | 0.48 | 559 |
| 2.0E+18 | 103 | 14.7 | 0.41 | 0.62 | 0.27 | 769 |
| 7.0E+18 | 110 | 15.3 | 0.42 | 0.70 | 0.26 | 780 |
| 3.0E+19 | 108 | 14.7 | 0.44 | 0.67 | 0.34 | 690 |

One wafer with 2 μm SiC layer and a specific doping value of 10^{19} cm^{-3} was also developed by CRHEA. It can be noted that all the parameters of the cells with thicknesses lower than 2 μm are better, since the average quantum efficiency reaches 3%. In addition the highest photocurrent of the order of $24 \text{ mA}.\text{cm}^{-2}$, is related to the lowest thickness of the emitter layer (0,2 μm). The metallization of the front contact using Ti/Au rather than Ni/Au leads to two phenomena: the reduction of R_s and increasing of R_{sh} on one hand, the improvement of Voc on the other hand. Nevertheless, the V_{oc} remains weak, indicating that the recombinations at the interfaces are not negligible.

External quantum efficiency

The benchmark of quantum efficiency, is based on a Xenon UV-extended arc lamp, able to emit light from 200 to 1180 nm wavelengths, a monochromator, a chopper and a lock-in amplifier. The illumination power ranges from 80 nW cm^{-2} at 200 nm to $10 \mu\text{W cm}^{-2}$ from 400 to 1180 nm. The setup was calibrated using a Hamamatsu S1227 UV-extended photodiode. Samples lay on gold covered copper plate.

**Figure 4: External quantum efficiency of the 3C-SiC/Si**

As it can be seen on the graphs, the response is better in the ultraviolet between 200-400 nm for smaller emitter thickness. Moreover, in the higher wavelength range ($\lambda > 600 \text{ nm}$), an improvement in the response of the new cells compared to the former one diode is observed. This shows that the growth of SiC/Si has been improved since there is less degradation in the Si bulk. In addition, the metallization using Ti/Au, for the front contact, has made it possible to increase the performances in the cell's efficiency according to the table 1.

Conclusion

In order to improve the conversion efficiency of solar cells based on silicon carbide, a simple heterostructure has been studied. Simulations were performed, and then characterizations measured. The conclusion of this study shows that we obtain an improvement of the spectral response in the short wavelength domain thanks to the thinner layer of the emitter, then an improvement of the growth due to the non-degradation of electronic bulk properties in Si for wavelengths greater than 600 nm. The perspective of our work should consist of studying SiC-3C/Si tandem cells in order to better obtain a photovoltaic conversion of these cells in the short wavelengths.

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