Improving the Efficiency of Thin-film SiGe Solar Cells Through the Optimization of Intrinsic Layer Parameters

K. Kacha, F. Djeffal, T. Bentrcia, M. Meguellati and M. Chahdi

Abstract—**In this paper, we propose a thin-film SiGe-based solar cell design by including and optimization of a new intrinsic SiGe region in order to improve the electrical performance of the conventional SiGe solar cells. In the proposed design, the intrinsic region is created on the silicon layer (base) and filled with undoped SiGe material. The intrinsic region under the SiGe layer (emitter) improves the electrical performance of the proposed design. By 2-D numerical modeling and optimization, we have analyzed the electrical behavior of the proposed design and compared with it a conventional thin-film SiGe solar cell. Optimization shows that for appropriate Ge mole fraction and intrinsic region thickness, the efficiency of thin-film SiGe solar cell is enhanced by about 8.5% compared with the conventional thin-film SiGe solar cell. Maximum efficiency of 22.5% has been achieved, with short circuit current density of 36 mA/cm^2, open circuit voltage of 0.53V and fill factor of 0.7. The obtained results show that the proposed design can be considered as a potential candidate for high performance photovoltaic applications.**

Index Terms— **efficiency, fill factor, intrinsic SiGe region, mole fraction, solar cell, thin-film.**

I. Introduction

Recently, solar cell technology attracts much attention for reliable and high efficiency renewable energy applications. The increase in the photovoltaic market needs the development of new materials and designs based on the optimization of cost/efficiency ratio for larger scale mass production. In nowadays photovoltaic technology era, the thin-film SiGe is considered as promising candidate to meet the outstanding need for photovoltaic applications with enhanced adsorption characteristics and improved conversion efficiency [1-6]. This is mainly due to the low manufacturing costs of thin-film SiGe and its compatibility with the process developed for pure Si cells, and its excellent optic properties. However, a drop of the open-circuit voltage also cannot be avoided owing to the increase of the intrinsic carrier concentration due to the smaller band-gap of SiGe than that of Si [1-6]. Losses in open-circuit voltage and deficiencies in crystal performance play a crucial role, and are one reason for the present lack of practical SiGe solar cells [4]. Therefore, in order to get a global view of thin film SiGe solar cell performance, new models, designs and optimization approaches are indispensables for the comprehension of the fundamentals of such device characteristics. In this context, several studies have been proposed to analyze the thin-film SiGe solar cells and to make better understanding of its photovoltaic behavior and to overcome certain problems [1-6]. The improved absorption behavior of the SiGe leads to current gain, however reduction of the alloy bandgap causes voltage losses, which tends to cancel out the improved photocurrent of the thin film SiGe solar cell [4].

In this paper, a new thin-film SiGe-based solar cell design by including an intrinsic SiGe region is proposed, in order to improve the electrical performance of the conventional thin-film SiGe solar cells. Based on numerical investigation of the proposed design by the including of the intrinsic region, in the present work, a numerical model for I-V characteristics is elaborated to explain the impact of the new design on the electrical performances. The proposed accurate numerical results will be used to optimize the electrical performance of the SiGe-based solar cells. The key idea of this approach is to find out the best dimension and electrical parameters of the investigated solar cell that will yield the maximum power conversion efficiency (PCE).

II. Numerical analysis

In Figure 1, the schematic cross-sectional view of the proposed thin-film SiGe solar cell including the intrinsic region is illustrated. The doping profile (for this type of heterostructure thin-film solar cell) in each layer is designed and determined by in-situ gas, in the chamber during the fabrication process [1]. The Ge concentration (mole fraction) in the SiGe alloy for each layer film is checked by different techniques, such as Raman spectra and X-ray microanalysis (XRD) [1–3]. After the deposition of different designed Si and SiGe thin film layers, an indium tin oxide (ITO) film can be formed as an antireflection (AR) layer using the sputtering technique [1-3]. The back surface field contact is produced by printing the aluminum (Al) pasted on the back side of the solar cell, while the front finger contact can be released by firing silver or aluminum pasted through the ITO film [1].

Manuscript received March 03, 2014; revised April 10, 2014.

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ISBN: 978-988-19252-7-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

For the modeling computation, a 2D numerical simulator tool, 2D Silvaco simulator [7], was used for modeling and investigating the performance behavior of the proposed design. This proposed structure is investigated numerically in terms of electrical and optic performances. The 2D Silvaco simulator estimates the carriers transport mechanism based on the coupled equations (Poisson, hole and electron continuity equations) [7]. Recombination currents are calculated using the Shockley-Read-Hall (SRH) model. The radiation AM 1.5 with incident power density of 100mW/cm2 is used as illuminating source in our numerical investigation. In our simulation the parameters of ITO, buffer and silicon layers were held constant. Table.1 shows the values of the layer parameters used in this study. These values have been chosen basing on experimental data and published results [1-6]. All simulations are carried out at room temperature.

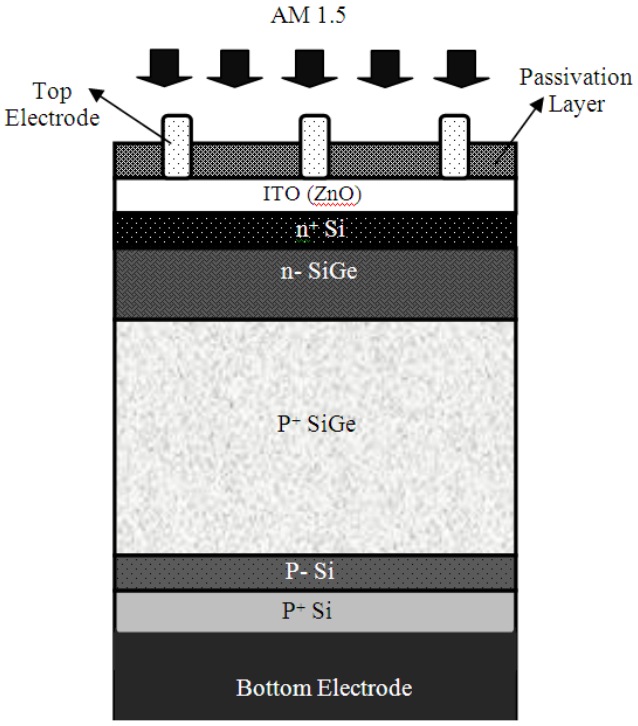

Fig. 1. Cross sectional view of the investigated thin-film SiGe/Si solar cell.

TABLE I
MAIN DESIGN PARAMETER VALUES USED FOR NUMERICAL SIMULATION

Parameters	Values
Si region doping (n+-Si)	$N_1=10^{19}$ cm^{-3}
SiGe region doping (n-SiGe)	$N_2=10^{16}$ cm^{-3}
SiGe region doping (p-SiGe)	$N_3=10^{10}$ cm^{-3}
Si region doping (p- Si)	$N_4=10^{15}$ cm^{-3}
Si region doping (p+- Si)	$N_5=10^{19}$ cm^{-3}
Si region thickness (n+-Si)	t_1=30 nm
SiGe region thickness (n-SiGe)	t_2=300 nm
intrinsic region thickness (SiGe)	variable
Si region thickness (p- Si)	t_4=300nm
Si region thickness (p+- Si)	t_5=100 nm
Ge mole fraction (n-SiGe)	x= 0.5
Ge mole fraction (intrinsic SiGe)	variable

III. RESULTS AND DISCUSSION

Figure. 2 illustrates the I-V characteristics of the investigated solar cell for both cases, with and without intrinsic SiGe region. It is clearly shown the impact of the introduced layer on the photocurrent behavior. This result means that the forward current in SiGe solar cells is dominated by the drift carrier mechanism. This improvement in the photocurrent behavior can be explained as: 1) Increasing the width of the depletion layer by introducing the intrinsic region (where the generated carriers can be transported by drift mechanism) increases the area available for capturing light; 2) Reducing the ratio between the diffusion length and the drift length of the solar cell, by introducing the intrinsic region, results in a greater proportion of the generated current being carried by the faster drift process.

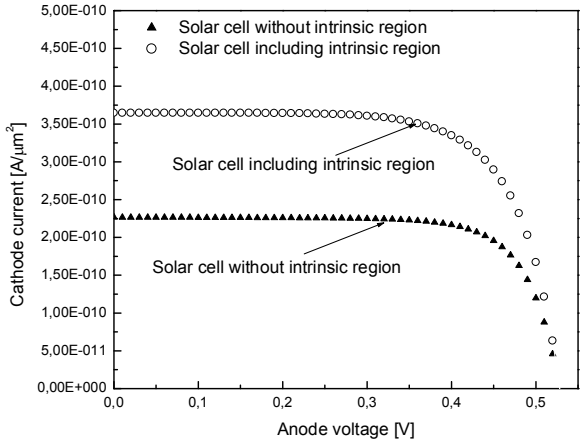

Fig. 2. I-V characteristics for different SiGe-based solar cell designs, intrinsic region thickness=1µm and Ge mole fraction=0.5.

The mole fraction, Ge concentration *(x)* in SiGe alloy, and the intrinsic region thickness are found to be important parameters that directly influence the proposed solar cell design. Therefore, an investigation about the impact of these parameters on solar cell behavior should be carried out. In this context, at first, the mole fraction for the intrinsic region is varied from 0 to 1 in order to show the impact of this parameter on the solar cell efficiency. The obtained results from this analysis are shown in Fig.3. It is shown that a high increase in the efficiency occurs for $x=0.5$ followed by a strong decrease for $x>0.5$. The same phenomenon can be observed for low mole fraction values, $x<0.5$. In order to study the effect of intrinsic region parameters on the proposed solar cell performance, the intrinsic region thickness is varied from 0.1µm to 1µm. The obtained results indicate that the efficiency increased with the intrinsic region thickness, where the optimal thickness is about 1µm.

From Fig.4, at the thickness of 1µm, the recorded efficiency is 22.5%. Comparing the results with 22.5% efficiency at 0.5 µm, it was found out that a decrease in 0.5µm of the intrinsic region thickness resulted in 4.5% decrease in efficiency. It is to note that the proposed investigation can be extended for high intrinsic region thickness values. However, high thickness values can increase the solar cell cost, and therefore, the ratio

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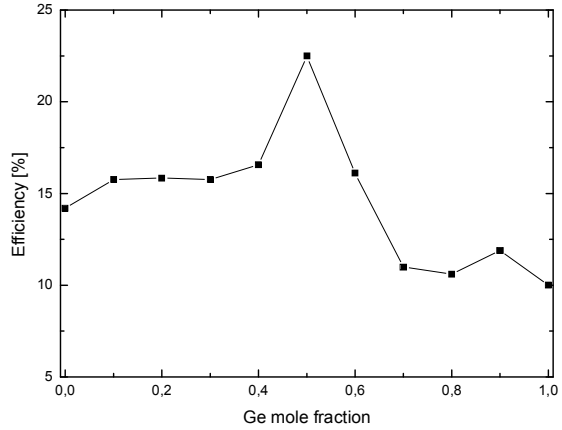

Fig. 3. Cell performance with different Ge mole fraction values, intrinsic region thickness=1µm.

cost/efficiency can be increased. The improvement in solar cell performance can be explained by the fact that the efficiency is highly affected in long-wavelength region (which is the red response) with the increase of intrinsic region thickness. In this context, when the intrinsic region thickness is increased more photons are absorbed, especially in long-wavelength illumination. Thus a greater percentage of electron-hole pairs would be produced from the absorbed photons; consequently an increasing in the drift current values can be obtained.

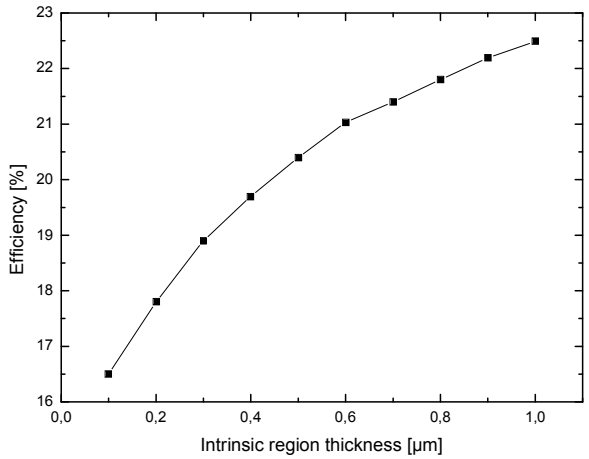

Fig. 4. Cell performance with different intrinsic region thickness values, Ge mole fraction =0.5.

Table.2 shows the comparison between the sol cell parameters obtained in our study with those presented in literature.

Lattice mismatch between the Si layer and the SiGe material can lead to nonconformist dislocation formation and interface defects, which affect the electron transport performances. None of these effects have been taken in consideration in this study. It is to note that with the development of new epitaxy methods, refinement in lattice matching could be achieved by grading the mole fraction profile in the SiGe layers from given Ge content to pure Si material.

TABLE II
OPTIMIZED SOLAR CELL DESIGN PARAMETERS

Solar cell structure	Efficiency
SiGe solar cell with intrinsic region (our work)	22.5%
SiGe solar cell [8]	18.4 %
SiGe solar cell [9]	13.2 %

IV. CONCLUSION

In this work, a comprehensive numerical investigation has been proposed to investigate the SiGe solar cell behavior including a new intrinsic SiGe region. The impact of the introduced intrinsic region on the solar cell performance was presented and discussed. The optimization shows that for appropriate Ge mole fraction and intrinsic region thickness, the efficiency of thin-film SiGe solar cell is improved by about 8.5% compared with the conventional thin-film SiGe solar cell. Maximum efficiency of 22.5% has been achieved. Therefore, the proposed design has excellent electrical performances compared with the conventional thin-film SiGe solar cell, and it can be taken into consideration for high performance photovoltaic applications. It is to note that the proposed investigation can be extended to achieve the global maximum efficiency (which can be provided by the proposed design) by including other design and electrical parameters (like: doping, mole fraction and thickness of each layer). However, new analytical and optimization approaches should be developed, in order to develop the appropriate fitness functions for the multiobjective-based optimization.

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