Characterization of Silicon and Simulation of III-V Sub-Cells for Double Junction Photovoltaics

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Abstract—**Coupling III-V solar cells to silicon (Si) is a promising approach for the future of commercial solar cells. There are a number of approaches to couple III-V to silicon, each with its own challenges. In this work we explore configurations of III-V solar cells to optimize the coupling with a silicon one. Simulation of III-V solar cells was performed using the software SCAPS to design a III-V device that best matches a Si solar cell, similar to commercially available ones. Through the simulations, we determined the optimal thickness and doping level for the base layer of the device, resulting in an efficiency of 25.0%.**

Keywords— solar cell; III-V on Si; SCAPS

I. INTRODUCTION

Coupling of III-V semiconductors and Si has been of great interest in optoelectronics due to the potential benefits of exploiting both material's strengths. III-V semiconductors have a high photon absorption efficiency, due to their high crystal quality and bandgap configuration, while Si has a very low production cost, due to the technology maturity and existing large-scale production infrastructure.

The concept of photovoltaics using III-V on Si exists since the 1980s [1-2] when the technology for the epitaxy of III-V semiconductors with high crystalline quality arose, leading to the development of solar cells with high energy conversion efficiency. However, production costs relegated their use to niche applications, such as satellites. In order to reduce the costs, attempts were made to grow III-V solar cells on Si, with no major success. Additionally, the record efficiency for Si solar cells has only improved 0.6% in 15 years, while III-V solar cells gained 1% efficiency per year in the same period. Therefore, different approaches to couple III-V photovoltaic cells to silicon have attracted much investment, since it has potential to combine high efficiency with low cost.

In this work, we chose the stacking approach to couple III-V with Si solar cells. We present characterization results of Si solar cells produced at Pontifícia Universidade Católica do Rio Grande do Sul (PUC-RS) and simulation results of a III-V solar cell to be grown at Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), which should be later stacked with the investigated Si cells.

II. METHODOLOGY

Figure 1 shows the four-terminal structure for coupling the III-V and the Si solar cells. In this approach, a transparent insulating adhesive is used between both cells to stack them.

The simulation of the top GaAs solar cell was performed using the software Solar Cell Capacitance Simulator (SCAPS) [3] to find an appropriate III-V structure to be coupled with the bottom Si solar cell. As a first trial, the performance of GaAs solar cells with varying active layer thicknesses was calculated.

The software supplies the *I-V* characteristics of the device, from which the figures of merit efficiency (E_{ff}), short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and maximum extracted power (P_{max}) are extracted.

Characterization of the solar cells was performed using an experimental setup with a solar simulator (Sciencetech SF300A, London, ON, Canada) and a semiconductor parameter analyzer (HP 4145B, Palo Alto, CA, United States). With this setup it is possible to measure the solar cell's current density-voltage J-V characteristic curve under 1 sun irradiance to extract the relevant figures of merit (J_{sc}, V_{oc}, FF, P_{max}, E_{ff}).

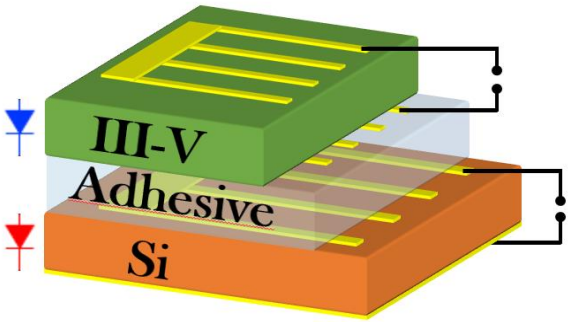

Fig. 1. Schematic of a tandem III-V on Si solar cell coupled with a transparent insulating adhesive.

III. RESULTS AND DISCUSSIONS

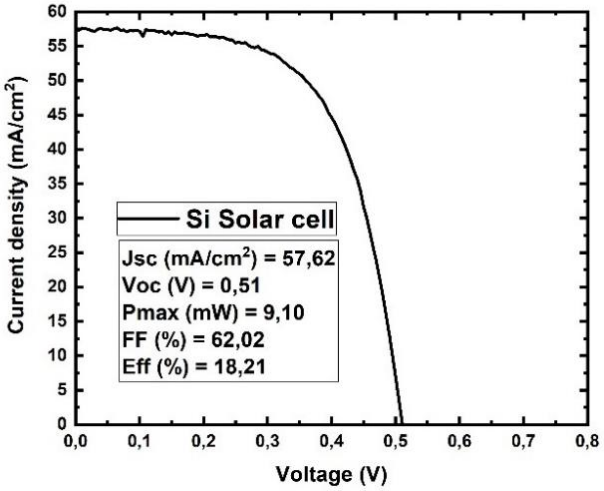

Fig. 2. J-V curve for a Si solar cell and its figures of merit.

The investigated Si solar cell is a 2x2 cm^2 bifacial PERT n^+pp^+ structure. Figure 2 displays its *J-V* characteristics along with the figures of merit. The current density measured is 57.62 mA/cm^2, which shall be reduced when coupled to the top III-V solar cell, given that photons with energy above the III-V material band gap will be predominantly absorbed by the top sub-cell.

Given that the program's objective is to simulate a realistic solar cell, it takes into account not only the parameters associated with the material structure but also various factors, including temperature, series resistances, solar spectrum, and surface transmission. However, it is important to highlight that the SCAPS software does not compute surface reflection. Nonetheless, it grants users the ability to input the spectrum for analysis.

According to the literature [4], GaAs, which has a 1.42 eV band gap, has proven be the best choice for a tandem cell with Si as the bottom sub-cell.

It is important to determine the optimal thickness of the base layer of the III-V sub-cell. We have used the SCAPS software to simulate the photo-generated current density as a function of the *p*-base layer thickness. A scheme of the III-V sub-cell structure is depicted in Figure 3. The thickness of the *n*-emitter layer was kept at 0.030 µm, and the doping levels were 1 x 10^{19} cm^{-3} and 9 x 10^{18} cm^{-3} for the *n*-emitter and *p*-base layers, respectively.

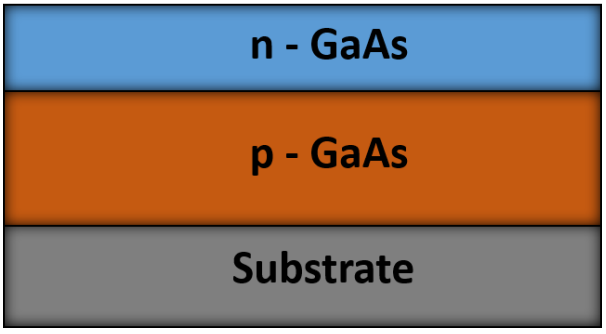

Fig. 3. Simulated structure for a pure GaAs solar cell.

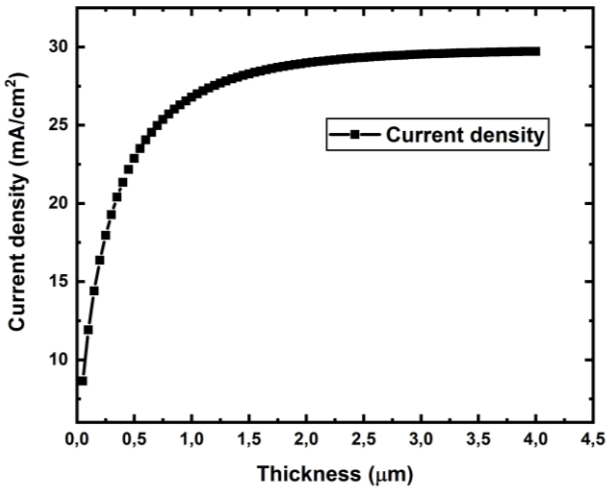

Fig. 4. Simulated current density as a function of the p-layer thickness for a pure GaAs solar cell.

The results of the simulation are plotted in Figure 4. Based on these results, it was possible to understand the extent to which the thickness influences the figures of merit. An increase in the current density is observed as the thickness goes from 0.050 µm to 4 µm, as expected, since more photons are absorbed. One should note that, at a thickness around 2.5 µm, the current density saturates. Therefore, a 2.5 µm thick base layer should be chosen, reducing material consumption and letting a small portion of the high energy spectrum be absorbed by the bottom Si sub-cell.

Figure 5 shows the simulated J-V curve and the figures of merit for the GaAs sub-cell with a thickness of 2.55 µm. The results obtained in the performance study of the GaAs cell regarding the base layer thickness are similar to those presented in the work [5-6].

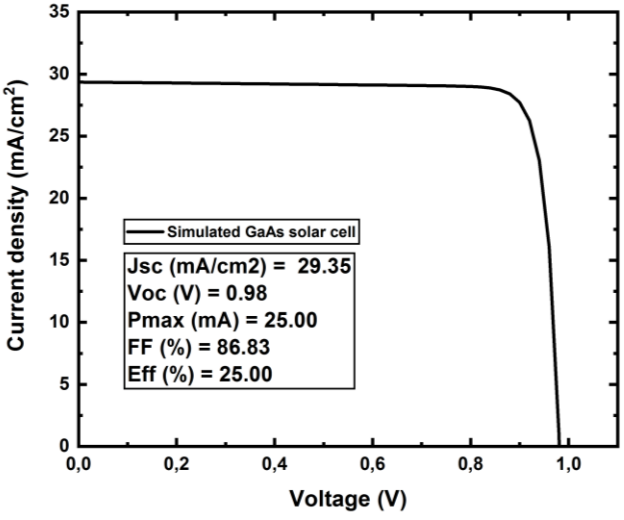

Fig. 3. Simulated J-V curve for a pure GaAs solar cell and its figures of merit.

For future work aiming for a better coupling, simulations will be conducted with different emitter thicknesses and other III-V materials, such as InGaP, which has a higher energy gap than GaAs. The intention to simulate these materials is justified considering a better absorption of higher-energy photons, resulting in a higher J_{sc}. We will also simulate the complete structure, in order to estimate the combined efficiency and compare it with that of the individual Si cell.

IV. Conclusion

GaAs has been investigated as a Si tandem partner for a silicon solar cell. Simulation results indicate that a 2.5 µm thick GaAs *p*-type base layer should be used in the III-V sub-cell in a stacked configuration with Si as the bottom device.

Acknowledgments

This work was partially supported by the Brazilian funding agencies FINEP, FAPERJ, CAPES and CNPq. We would like to acknowledge Professor Izete Zanesco and Adriano Moehlecke for providing the Si solar cells. We would like to acknowledge the creators of the SCAPS software for providing the tool for our theoretical study.

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