2D Modeling of InGaP/GaAs/InGaAs Four-Junction Solar Cell

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***Abstract* — Two-dimensional (2D) modeling is reported for InGaP/GaAs/InGaAs four-junction solar cell with tunnel junctions. The cell basic physical properties were demonstrated. The simulated results indicate one-sun efficiency about 40.1% with short-circuit current density as 126.63 A/m^2 and open-circuit voltage as 3.69V. High efficiency up to 45.9% under 100 sun illumination could be achieved.**

I. Introduction

There has been increasing interest to enhance solar cell efficiency by adopting multiple-junction (MJ) structure with tunnel junctions. Significant progress has been made with InGaP/GaAs/Ge and InGaP/GaAs/ InGaAs metamorphic triple junction solar cells [1-3]. Further enhancement of the efficiency is usually realized by adding another sub junction to explore the full solar spectrum range, for example, by tailoring the third cell and the fourth sub-cells with absorbers with bandgap 1.0 and 0.7 eV [3], respectively. Whereas various materials have been proposed for this purpose, tailoring metamorphic InGaAs into 1.1 eV and 0.7 eV absorbers is also a possible choice at least for theoretical evaluation of the four-junction (4J) cell performance. In this work, we present 4J solar cell modeling based on the InGaP/GaAs/InGaAs material system by using a drift-diffusion model based simulator [4].

II. 4J Cell Structure and Modeling Details

The schematic 4J solar cell is displayed in Fig 1. The four junctions each corresponds to InGaP, GaAs, InGaAs and InGaAs materials with bandgap as 1.89, 1.42, 1.13 and 0.7 eV, respectively. Three heavily-doped thin tunnel junctions are utilized to connect the 4 sub-junctions. Solar.AM15 global spectrum is utilized for the cell performance evaluation as well as for the multiple sun No simulation, whereas the normalized spectral responses are simulated under constant power intensity with respect to various wavelengths. The influence from preceding junction(s) is taken into consideration when simulating the spectral responses as well as the current matching consideration. For simplicity, we have assumed a perfect front anti-reflection with power transmission efficiency of 99% for the solar light illumination.

III. modeling Results

The band diagram at equilibrium is shown in Fig. 2 for the simulated 4J cell with tunnel junctions. The relative optical generation is shown in Fig. 3. To achieve current-matching among all the sub-junctions, the fourth junction turns out to have thicker absorber than the other three sub-junction absorbers.

The I-V curves with current matching among 4 sub-junctions are shown in Fig 4. The simulated results indicate one-sun efficiency about 40.1% with short-circuit current density, Isc, as 126.63 A/m^2 and open-circuit voltage, Voc, as 3.69V. The performance under multiple-sun concentration has also been simulated and results are presented in Fig. 5. The fill factor and cell efficiency both increase initially with concentration sun No. At around 100 sun illumination, the cell efficiency can be as high as 45.9%, reaching an optimum. After that optimal point, both fill factor and the efficiency will decrease with concentration sun No. The reduction of the efficiency and the fill factor at high concentration sun number is due to the enhanced limiting effect of the series resistance [1,5]. The maximal efficiency point is therefore relevant to the front contact pad separation distance which actually affects the series resistance [5].

The normalized spectral responses are shown in Fig. 6, which indicate the wavelength ranges where each sub junction contributes to the cell power output. The junctions below the top cell are apparently affected by the preceding junctions. More optimized work on the cell design with fine bandgap tailing as well as the accurate index file compilation are still needed for the cell optimization design. Consideration to utilize other materials for the third and the fourth sub-junctions is also under consideration.

IV. Conclusion

2D modeling of for InGaP/GaAs/InGaAs 4J solar cell with tunnel junctions has been presented. The simulated results indicate one-sun efficiency about 40.1% with Isc as 126.63 A/m^2 and Voc as 3.69V. High efficiency up to 45.9% under 100 sun illumination could be achieved.

References

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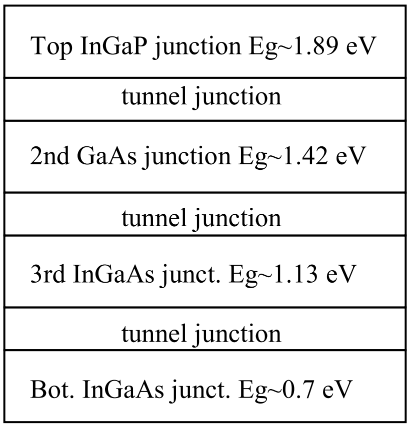

Fig. 1. Schematic 4J solar cell structure.

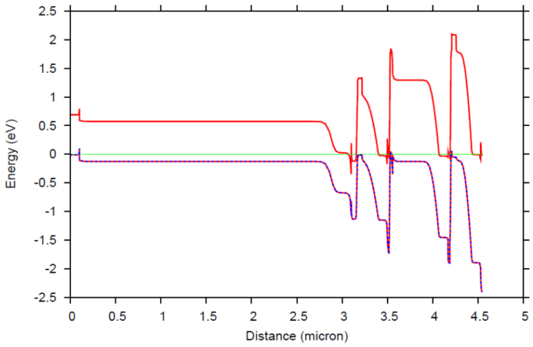

Fig. 2. Equilibrium band diagram showing 4J cell with tunnel junctions.

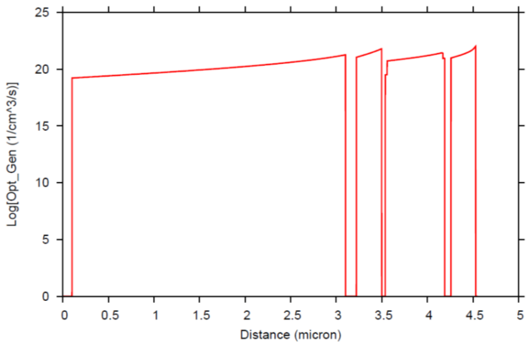

Fig. 3. Optic generation for the 4J cell simulated.

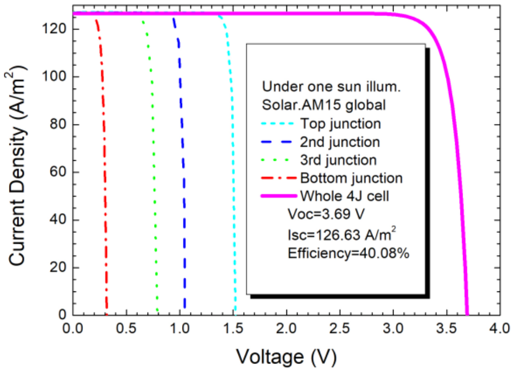

Fig. 4. I-V curves showing also the current matching achieved among the four sub-junctions.

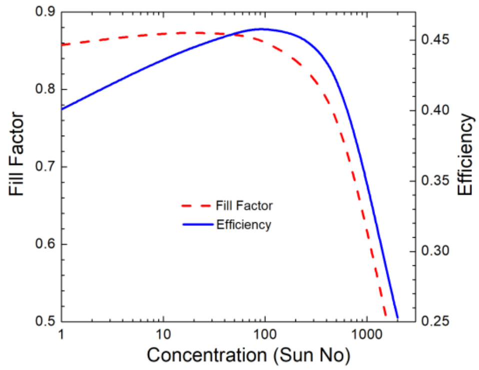

Fig. 5. Fill factor and efficiency versus concentration sun No.

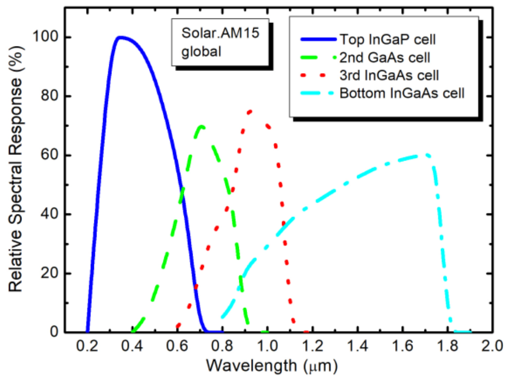

Fig. 6. Normalized spectral responses.