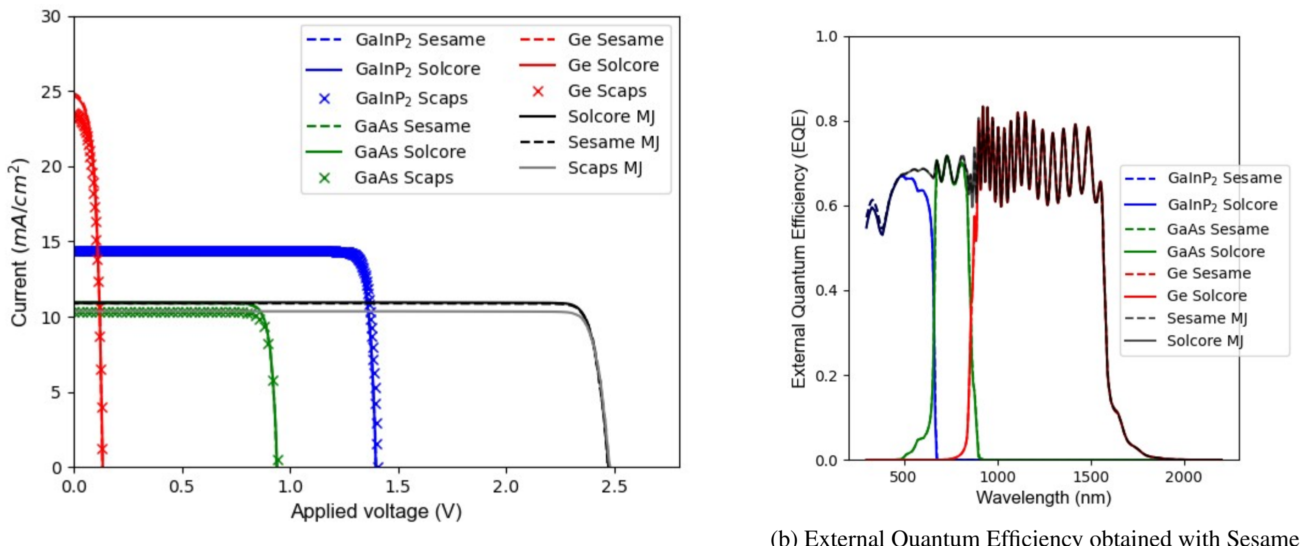
Simulating III-V multi-junction solar cells for space applications: Performance insights and design challenges using open source software

Antoine Fées[1,2], Inès Revol[1], Rodolphe Vaillon[1], Pablo Caron[2], Thierry Nuns[2], Guilhem Almuneau[1]
[1]LAAS-CNRS, Université de Toulouse, CNRS, Toulouse, France
[2]Office National d'Etudes et de Recherches Aérospatiales (Onera), Toulouse, France

III-V multi-junction (MJ) solar cells for space applications primarily use the $GaInP_2$–GaAs–Ge monolithic architecture, achieving up to ~35% power conversion efficiency [1]. Recent advances in four or more junction cells necessitate precise control of current-matching conditions to optimize Beginning of Life (BOL) efficiency. Additionally, space radiation from protons and electrons alters the short-circuit currents of subcells, reducing efficiency over time [2]. Therefore, reliable numerical prediction tools are essential to assess radiation impact and ensure optimal performance until the End of Life (EOL) [3].

To optimize cell efficiency, it's crucial to tailor optics, proton and electron radiation impact behavior, and subcell parameters like thickness and non-radiative lifetimes through numerical simulations [4]. Simulations also provide insights into cell physics by extracting parameters from experimental I(V) and external quantum efficiency (EQE) curves. Most simulation software (e.g. Silvaco, Sentaurus, Nextnano, PC1D, SCAPS...) rely on solving the Poisson-Drift-Diffusion system of equations with efficient numerical computational methods and can then serve both for radiation hardness diagnosis and as a predictive tool to design new cells [5].

In this study, we use, assess, and compare two recent Python-based open-source Poisson-Drift-Diffusion solvers, Solcore [6] and Sesame [7], to model the current-voltage response (fig. 1a) and EQE (fig. 1b) of a multi-junction solar cell. Optics are handled using a Python-based Transfer Matrix Method (TMM) engine [8]. We also compare these simulation results with those from the standard simulator SCAPS [9], discuss the differences between the software and possible improvements (e.g. handling the tunnel junctions) for simulating space multi-junction solar cells.



(a) Current-voltage response obtained with Sesame, Scaps and Solcore

(b) External Quantum Efficiency obtained with Sesame and Solcore

Figure 1: Example of Poisson-Drift-Diffusion simulation results for a $GaInP_2$–GaAs–Ge MJSC for space applications. Are plotted the individual contributions of the subcells and the MJ structure total I(V) curve and EQE.

Acknowledgment
This work was funded by the French Occitanie region under a grant of the key challenge PV-STAR. (PhotoVoltaic in non-STandARd conditions).

[1] Verduci, R., et al., *Adv. Energy Mat.* **12(29)**, 2200125 (2022)
[2] Raya-Armenta, J.M., et al., *Sol. Energy Mater. Sol. Cells* **233**, 111379 (2021)
[3] Sato, S. I., et al., *Sol. Energy Mater. Sol. Cells* **93(6-7)**, 768-773 (2009)
[4] Leem, J. W., et al., *J. Korean Phys.* **64**, 1561-1565 (2014)
[5] Piprek, J. (Ed.), Handbook of Optoelectronic Device Modeling and Simulation: Lasers, Modulators, Photodetectors, Solar Cells, and Numerical Methods, Vol. 2. CRC Press (2017)
[6] Alonso-Alvarez, D., et al., *J. Comput. Electron.* **17**, 1099-1123 (2018)
[7] Gaury, B., et al., *Sol. Energy Mater. Sol. Cells* **198**, 53-62 (2019)
[8] Byrnes, S. J., *arXiv*, 1603.02720 (2016)
[9] Verschraegen, J., Burgelman, M., *Thin Solid Films* **515(15)**), 6276-6279 (2007)