Progress towards High-efficiency Perovskite/Silicon Tandem Devices

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In the framework of the European Horizon 2020 project CHEOPS (low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells) and the Swiss SNF BRIDGE Program, CSEM has been working towards the realization of high-efficiency perovskite/silicon tandem cells, with a focus on the use of inorganic hole and electron collection layers. With devices exceeding 25%, and most processes compatible with production technologies, CSEM places itself at the forefront of research in that promising and highly competitive development area.

On top of the promise of high efficiency (as high as 23.7% for single junction devices [1]) at reduced costs, perovskite-based devices have gained a lot of traction to be used in a multi-junction configuration. There, the high-bandgap perovskite (PK) absorber is stacked on top of a lower bandgap absorber (*e.g.*, c-Si, CIGS or a low bandgap PK). By minimizing photo-generated carrier thermalization losses, multi-junction devices allow to overcome the theoretical Auger efficiency limit of single junction Si-based devices. This is of particular interest in an industrial landscape where c-Si PV manufacturers are beginning to look towards future technologies to continue to push their efficiencies even higher and to further lower system costs. CHEOPS and the BRIDGE Power project aims at tackling the difficult task of developing 2-terminal PK/Si tandem cells approaching the symbolic limit of 30% efficiency.

To that end, CSEM developed the different building blocks required for efficient tandem devices. In a first part, CSEM was charged with optimizing the single junction PK solar cells, as well as upscaling its deposition and processing to large area minimodules with record efficiencies [2]. This included the development of charge transport layers (CTLs) by industry relevant techniques. Specifically, CSEM designed NiOx layers by low-temperature sputtering deposition as a hole transport material, as well as low-temperature ALD SnO_2 as an electron transport layer. The latter can be deposited without damaging the underlying sensitive PK and makes it possible to sputter the front TCO without suffering from sputter damage. Moreover, this achieved the desired goal of having fully inorganic CTLs, which is a condition for an improved thermal and air stability of the device.

Implementing these developments on a silicon heterojunction bottom cell with a polished front led to a best result of 24% using a standard ITO front contact. In addition, CSEM developed a more transparent conductive contact by low-power sputtering. This let more light pass into the bottom cell, allowing for higher current. Moreover, the low-power sputtering limits the sputter damage, leading to higher Voc. All in all, an efficiency of 25.4% (Figure 1) was achieved, surpassing the highest published PK/Si tandem efficiency to date. It is noteworthy that said published efficiency is also the result of a collaboration between EPFL-PVlab and CSEM that led to the highest published and certified efficiency (25.2%) using a textured Si subcell for improved optical properties [3].

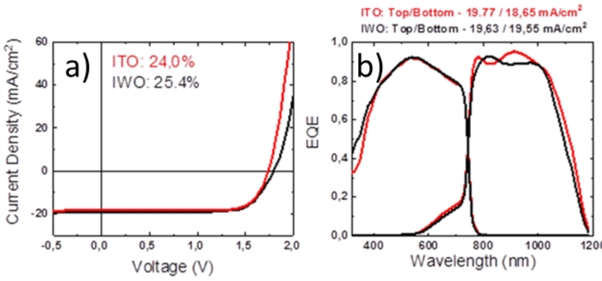

Figure 1: a) IV curve of hero cells comparing the difference between standard ITO and an optimized transparent electrode on small area cells (1.43 cm²) b) Comparison of EQE of devices upon improving the top TCO transparency. Note that this is the highest reported photocurrent values for flat perovskite-silicon tandems.

Building on the know-how in terms of both high-efficiency tandem design and upscaling, CSEM was then able to produce record efficiency large area (57.4 cm²) tandem of 24.3% (Figure 2). Such demonstrator cell features industrial front metallization schemes. This was made possible thanks to CSEM's expertise in low-temperature silver paste screen printing.

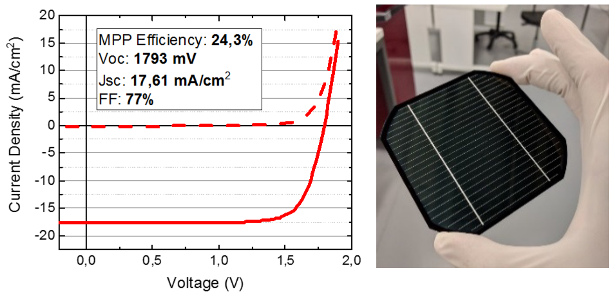

Figure 2: (left) IV curve of large area demonstrator tandem with screen-printed metallization at an aperture area of 57.4; (right) Photograph of large area demonstrator cell.

These recent developments position CSEM as a frontrunner in the PK/Si tandem research community, attracting the attention of traditional PV manufacturers.

[1] NREL, "NREL Efficiency Chart," 14 December 2018. [Online]. Available: https://www.nrel.gov/pv/assets/pdfs/pv-efficiency-chart.20181214.pdf. [Accessed 17 December 2018].

[2] A. Walter, S.-J. Moon, B. A. Kamino, L. Lofgren, D. Sacchetto, F. Matteocci, B. Taheri, J. Bailat, A. Di Carlo, C. Ballif, S. Nicolay, "Closing the cell-to-module efficiency gap: A fully laser scribed perovskite minimodule with 16% steady-state aperture area efficiency", IEEE Journal of Photovoltaics, vol. 8, no. 1, pp. 151-155, Jan. 2018.

[3] B. A. Kamino, B. Paviet-Salomon, S.-J. Moon, N. Badel, J. Levrat, G. Christmann, A. Walter, A. Faes, L. Ding, J. J. Diaz Leon, A. Paracchino, M. Despeisse, C. Ballif, S. Nicolay, "Low Temperature Screen-Print Metallization for the Scale Up of 2-Terminal Perovskite-Silicon Tandems ", submitted, 2018.