Perovskite Upscaling: from Cells to Modules

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CSEM is upscaling perovskite solar cells from lab-scale cells to minimodules. The organic-inorganic perovskite is one of the most promising solar cell materials of recent years with a strong prospect to combine with crystalline silicon solar cells into very high efficiency tandem cells. The up-scaling to larger areas is a requirement for the formation of commercial perovskite/silicon tandem cells. Laser-scribed modules with 11.5% efficiency are demonstrated.

Efficiencies of solar cells based on organo-metallic halide perovskite absorber material have increased at a dramatic rate over the last few years, currently reaching more than 20% efficiency [1]. However, most of the efficiencies reported so far have been obtained on solar cells with small lab-scale areas of less than 0.3 cm^2. Only a handful of studies have addressed the performances of mini-modules based on perovskite and none of them have used laser scribing, an industry standard for thin-film solar cells, to form interconnections.

This project, 'Systems for ultra-high performance photovoltaic energy harvesting' (Synergy), focuses on the up-scaling of perovskite processes and the creation of high efficiency mini-modules through laser scribing.

The overall module design is illustrated schematically in Figure 1, defining active- and dead-area widths as well as the aperture area i.e. the full area of the module including dead areas but without substrate borders and contacts.

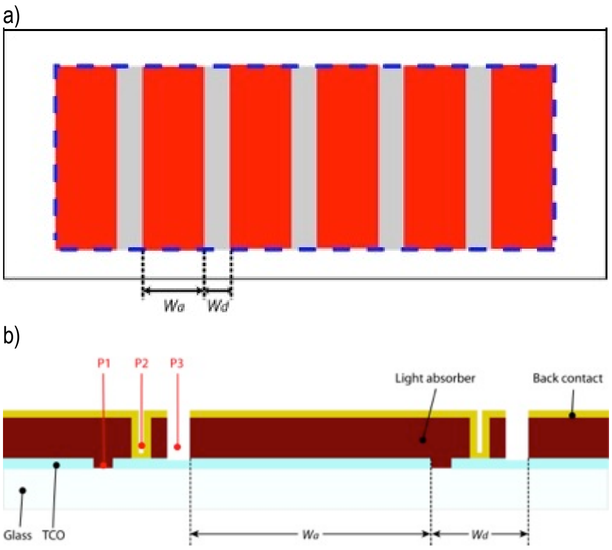

Figure 1: a) Schematic mini-module illustrating the width of activ (W_a) and dead (W_d) areas, as well as the aperture area (dashed blue line). b) Module cross section defining the scribes P1-P3 and the active- and dead-area.

Initial attempts on 6 cm^2 large mini-modules produced a modest aperture area efficiency of 5.5%, owing to a highly resistive contact between adjacent segments [2]. Still, this was to the best of our knowledge the world's first fully laser scribed perovskite mini-module, and the 16% dead-area fraction was the lowest reported value until then.

A set of measures were taken to improve module efficiency and increase module area.

- The P2 line processing is crucial for the inter-segment conduction and investigations pointed to residues of the highly resistive TiO_2 scaffold layer still present after laser scribing. The use of a thinner scaffold layer (150 nm instead of the original 300 nm) led to a P2 scribe free from residue and a module with drastically decreased resistance values.
- A change of anti-solvent led to improved perovskite homogeneity through spin-coating and the module size was doubled to 12 cm^2.
- Optimizations of the laser scribing process enabled denser scribing and dead-area ratios of less than 10%.

Altogether, these developments have allowed us to demonstrate a perovskite mini-module with 11.5% aperture area efficiency, the 2nd highest globally reported value at the time of presentation at EUPVSEC 2015. The main performance data of the mini-module are summarized in Table 1.

Table 1: Performance of optimized perovskite mini-module with voltage and current values given per module segment for easy comparison with the reference cell.

	Area (cm^2)	**Eff. (%)**	**V_{oc}/seg. (mV)**	**J_{sc}/seg. (mA/cm^2)**	**FF (%)**
module	10.9 (active area)	12.6			
	12 (aperture area)	11.5	1087	14.4	73.4
Ref.	0.49	15.5	1014	20.1	75.9

The module voltage (V_{oc}) and fill factor (FF) are close to, or even better, than the value of the reference cell while the current density (J_{sc}) is still comparatively low. Current is lost not only in the scribed dead-area but a delamination of the back-contact layer has also been observed, further reducing the current collecting area. Our development focus at present on back-contact adhesion and the transition from metallic to transparent back-contact layers in order to enable the formation of four-terminal perovskite/silicon tandem cells.

CSEM thanks Nano-Tera.ch, the Swiss Federal Office for Energy and Swiss Solar Connect for the funding of this work.

[1] S.I. Seok, *et al.*, Science, 2015, 1234-1237

[2] S.-J. Moon, *et al.*, JPV, 5, 2015, 1087-1092