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Semi-buried silica microbeads in silicone to reduce reflection losses in concentrator photovoltaics – from modeling to field validation

Maxime DARNON[1,2], Arnaud RITOU[2], Philippe St-PIERRE[2], Gavin FORCADE[3], Joël KINFACK[2], Olivier DELLEA[4], Karin HINZER[3], Gwenaelle HAMON[2]

[1] Laboratoire Hubert Curien, UMR 5516, Université Jean Monnet, Saint Etienne, France
[2] Laboratoire Nanotechnologies Nanosystèmes, IRL 3463, Institut Interdisciplinaire d'Innovations Technologiques, CNRS, U. de Sherbrooke, INSA Lyon, Centrale Lyon, U. Grenoble Alpes
[3]SunLab, Université d'Ottawa, Canada
[4] Université Grenoble Alpes – CEA, Liten, DTNM, F-38054, Grenoble, France

Light reflection on solar cells is a source of losses that reduces the output current produced by solar panels. Among various anti-reflective coating approaches, surface microstructuring leading to a moth-eye-like structure offers the advantage of minimizing reflection across a broad angular and spectral range[1]. In this study, we report on the application of silica microbeads as a surface microstructuring technique for solar cells embedded in concentrator photovoltaic modules.

First, modeling based on rigorous coupled wave analysis and transfer matrix methods was used to evaluate the anti-reflective capability of silica microbeads partially buried in silicone (polydimethylsiloxane - PDMS).[2] Compared to reference solar cells, a gain in current of approximately 2.5% was obtained for 1 µm-diameter silica beads 25% buried in PDMS.

Next, we developed a process that enables the controlled assembly of silica microbeads onto solar cells and applied it to commercial multijunction high efficiency solar cells. The silica microbeads were first assembled on a temporary plastic foil using a Langmuir-Blodgett self-assembly process [3]. The beads were then protected in a water-soluble film. Subsequently, the foil was cut to fit the solar cell's active surface, and the film of protected beads was peeled from the temporary plastic and positioned on top of the solar cell, which had been previously coated with PDMS. The protective film was then dissolved in water, leaving the bare silica beads on top of the solar cell. The PDMS curing step was split into two steps: one precure step performed before the transfer of the film of microbeads and one final cure step after the protective film had dissolved. By varying the ratio of curing time between the precure and final cure steps, it was possible to control the submergence of the beads (*i.e.*, the ratio between the penetration depth and the bead diameter) to be between 10% and 30%.[2] We applied this process to commercial solar cells (see figure 1) and characterized their external quantum efficiency in the lab. From these measurements, and considering an AM1.5D solar spectrum (900 W/m²), we calculated a gain of 2.6% in current, consistent with expectations from the modeling.

Finally, we integrated the solar cells into a test concentrator photovoltaic module and installed the module on a 2-axis solar tracker in the solar park of Université de Sherbrooke.[4] The test module includes 250× plano-convex BK7 lenses from Thorlabs for light concentration. Due to local weather and practical considerations, the operating conditions corresponding to concentrator standard operating conditions (CSOC) were only achieved after approximately one year of operation in the field. A current of 192 and 196 mA was obtained on two cells with microbeads, corresponding to a gain of 12% to 14% compared to a reference cell in the same module. This surprisingly high gain in current indicates that under real operating conditions (i.e., in the field with higher cell temperatures than in the lab, and under a BK7 solar cell that filters out UV light and leads to a broad angular distribution), the benefit of using a broad spectral and angular anti-reflective coating is enhanced. For the best cell, we measured a module efficiency of 29.7% after one year of operation, which also confirms that the surface microstructuring method proposed here not only improves light collection but is durable enough to sustain a full year in the field, even in the harsh weather conditions of Quebec (-30°C during winter nights, +30°C during summer).

Using semi-buried silica microbeads in PDMS as a broad angular and spectral anti-reflective coating thus appears especially beneficial for concentrator photovoltaic applications. The process proposed here is scalable and could be applied to other photovoltaic panels or other applications where broad-spectrum anti-reflective coatings are desired.

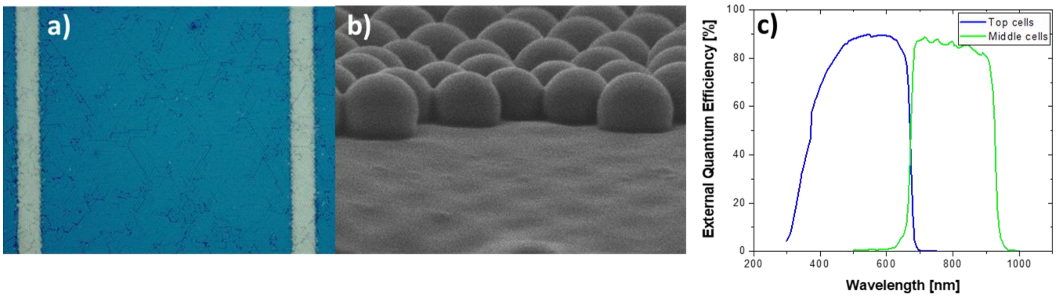

Figure 1 (a) Optical microscope of a solar cell coated with microbeads. The yellowish parts correspond to the fingers of the metallic front electrode. (b) SEM picture of 500 nm-diameter silica nanobeads semiburried (20%) in PDMS. (c) External quantum efficiency of the top and middle sub-cells of a multijunction solar cell coated with semi-buried (25%) 1µm-diameter silica bead.

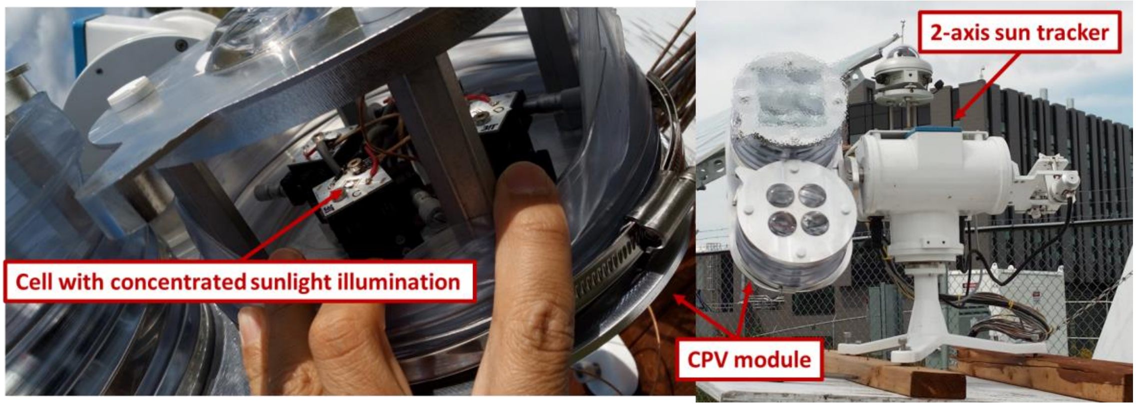

Figure 2 Pictures of the CPV module embedding micro-beads coated solar cells. The CPV module insmounted on a 2-axis tracker in the solar park of Université de Sherbrooke. A closeup view of the (open) CPV module on the left shows one cell under intense sunlight illumination.

References:

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Mots clés : photovoltaïque, photovoltaïque à concentration, micro billes, Langmuir blodgett