Stable Perovskite Solar Modules: strategy and optimization route from n-i-p to p-i-n architecture on rigid & flexible substrate

Luigi Angelo Castriotta[1], Francesco Di Giacomo[1], Fabio Matteocci[1], Luigi Vesce[1], Maurizio Stefanelli[1], Vivek Babu[2], Rosinda Fuentes Pineda[2], Babak Taheri[1], Narges Yaghoobi Nia[1,3], Mahmoud Zendehdel[1], Francesca Brunetti[1], Konrad Wojciechowski[2,4], Aldo Di Carlo[1,3]

1 - Centre for Hybrid and Organic Solar Energy (CHOSE), Department of Electronic Engineering, University of Rome Tor Vergata, Rome, 00133, Italy

2 - Saule Technologies, Duńska 11, Wroclaw, 54-427, Poland

3 - Istituto di Struttura della Materia (ISM-CNR), Via del Fosso del Cavaliere 100, Rome, 00133, Italy

4 - Saule Research Institute, Duńska 11, Wroclaw, 54-427, Poland

Perovskite Technology is advancing at unprecedented levels in the last years, with efficiencies reaching up to 25.7%. These incredible results are obtained at very small area scale (<0.1cm^2), reducing consistently its efficiency when increasing the area, with certified efficiency reaching up to 19.3% on 5x5cm2 substrate area[1]; Module design is needed in order to reduce the impact of the resistivity of the transparent conductive oxide (TCO) on the performance of the system. The introduction of modules consisting of series connected cells brought a huge improvement both on efficiency and fill factor of the device, since the module's output current is that of one subcells, reducing in this way resistive losses. Stability on perovskite technologies is an hot topic nowadays, and very few works shown stability also at module scale. [2]

In this work, we conducted an assessment strategy on design of perovskite modules, in both architecture n-i-p[3] and p-i-n[4], and on both substrate types available in the market, on glass rigid and on pet flexible substrate. By doing so, and by optimizing the interface between perovskite and transporting layers, we were able to reach up to 19.1%[5] and 18.1% efficiency on 5.5x5.5cm^2 substrate area on rigid n-i-p and p-i-n structure, respectively, and 12.1%[6] and 10.5%[7] efficiency on flexible n-i-p and p-i-n structure, respectively. Furthermore, we were able to demonstrate, for the first time, an outstanding light stability of Perovskite Modules over 1000 h. We believe that, by using the best optimized laser parameters, by reducing defects occurring during deposition and by passivating perovskite film, these technologies could exploit in the market and be the main actor in the photovoltaic field.

[1] S. Chen, X. Dai, S. Xu, H. Jiao, L. Zhao, J. Huang, *Science* **2021**, 373, 902.
[2] S. Zhang, R. Guo, H. Zeng, Y. Zhao, X. Liu, S. You, M. Li, L. Luo, M. Lira-Cantu, L. Li, F. Liu, X. Zheng, G. Liao, X. Li, *Energy & Environmental Science* **2022**, 15, 244.
[3] L. A. Castriotta, M. Zendehdel, N. Yaghoobi Nia, E. Leonardi, M. Löffler, B. Paci, A. Generosi, B. Rellinghaus, A. Di Carlo, *Advanced Energy Materials* **2022**, 12, 2103420.
[4] F. Di Giacomo, L. A. Castriotta, F. U. Kosasih, D. Di Girolamo, C. Ducati, A. Di Carlo, *Micromachines* **2020**, 11.
[5] L. Vesce, M. Stefanelli, L. A. Castriotta, A. Hadipour, S. Lammar, B. Yang, J. Suo, T. Aernouts, A. Hagfeldt, A. Di Carlo, *Solar RRL* **2022**, n/a, 2101095.
[6] B. Taheri, F. De Rossi, G. Lucarelli, L. A. Castriotta, A. Di Carlo, T. M. Brown, F. Brunetti, *ACS Applied Energy Materials* **2021**, 4, 4507.
[7] L. A. Castriotta, R. Fuentes Pineda, V. Babu, P. Spinelli, B. Taheri, F. Matteocci, F. Brunetti, K. Wojciechowski, A. Di Carlo, *ACS Applied Materials & Interfaces* **2021**, 13, 29576.