Interfaces optimization for high-efficiency fully scalable semi-transparent p-i-n perovskite solar cells

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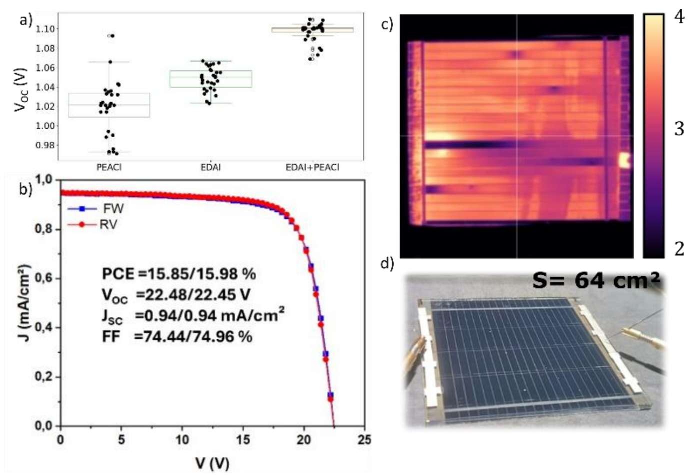
Perovskite solar cells (PSC) have reached higher or comparable efficiencies than their silicon counterparts within less than 15 years (NREL. Best Research-Cell Efficiency Chart.). Yet, high power conversion efficiencies (PCE) are complicated to maintain when upscaling the fabrication process, which involves depositing perovskite in open-air conditions, using only scalable deposition techniques such as slot-die coating and vacuum deposition techniques, and using lower cost materials (Zhao et al., Nano Energy, 128, 2024).

Another aspect that has long prevented PSC commercialization is the degradation of their performance over time, which has led the community to gradually shift towards the p-i-n (inversed) architecture, known to be intrinsically more stable. At IPVF, we have developed an expertise in the deposition of perovskite open-air using slot-die coating for application in silicon/perovskite tandems, recognized as a strategic avenue for PSC to reach the market (Erkan Aydin et al., Science 383, 2024). In the last years we successfully transferred this knowledge to the semi-transparent p-i-n architecture by depositing perovskite on a NiOx hole transport layer (HTL), and by using C60 and SnO_2 as n-type contact layers. Interface optimization has been key to reach high PCE (18.7%) with this architecture.

I will show how using a mix of Phenethylammonium chloride (PEACl) and ethylene di-amine iodide (EDAI) (Liu et al., Adv. Mater. 36, 2024) we have been able to fully supress quasi-fermi level splitting (QFLS) losses attributed to the perovskite/C60 interface and to achieve +100 mV in V_{OC} with a double cation perovskite (**Figure a**). This passivation strategy was developed and studied using spin-coating in open-air conditions as a tool, and characterized using SEM, XRD, hyperspectral imaging (photoluminescence) and EQE measurements. Remarkable PCE gains (+ 2.5% in average) could be achieved over thanks to an improvement of all J-V parameters (J_{SC}, V_{OC}, FF).

Slot-die coating was then used to deposit EDAI/PEACl, with the aim to propose a high-efficiency 100% upscalable stack. Optimizing deposition parameters as well as EDAI/PEACl ink composition allowed to exceed performance achieved by spin coating. Finally, we report semi-transparent 64 cm^2 modules with >15% PCE achieved with a fully scalable process (**Figure b, c and d**).



a) V_{OC} data of 0.09 cm^2 cells showing the conjoin effect of PEACl and EDAI b) J-V curves c) PL emission map obtained by hyperspectral imaging d) photo - of the champion module (64cm^2)