Novel strain-free, low-temperature encapsulation approach for perovskite solar cells and panels

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The upcoming generation of photovoltaic (PV) technologies that will support the required energy shift is expected to include perovskite solar cells (PSCs). However, the instability of PSCs is slowing their commercialization. A significative stability assessment has been recently achieved at relevant scale by building a perovskite solar farm [1], whose performances were monitored over more than nine months of real operation. This results remarked the importance to develop suitable encapsulants for this specific PV technology, for which traditional encapsulants proposed for market-established solar cells may fail. Thus, to advance PSC technology, we developed a novel class of encapsulants based on a semi-solid polymeric composite made of low-molecular weight polyisobutylene (PIB) incorporating two-dimensional (2D) flakes of hexagonal boron-nitride (*h*-BN) produced at industrial scale through wet-jet milling exfoliation [2]. While the physical nature of our PIB minimize lamination-induced thermomechanical stresses, *h*-BN flakes, act as physical barriers against environmental agents, including oxygen and moisture, improving the overall barrier properties of the homopolymer PIB along its mechanical and thermal management characteristics. The encapsulation process was carried out at low temperature (between 60 °C and 90 °C) using an industrial laminator. After encapsulation with our PIB:*h*-BN encapsulants, large-area PSCs (1 cm^2 active area) and perovskite solar modules (PSMs) (10 cm^2 active area) (perovskite: $Cs_{0.08}FA_{0.80}MA_{0.12}Pb(I_{0.88}Br_{0.12})_3$) have passed accelerated aging tests, including ISOS-D1 (shelf life storage under ambient conditions), ISOS-D2 (damp heat, >1000 h), ISOS-L1 (light soaking, >1000 h), as well as customized thermal shock (200 cycles with abrupt temperature changes between +85 and -20°C) and humidity freeze (10 cycles with abrupt temperature changes between +85 and -40°C, retaining more than 80% of their initial power conversion efficiency (PCE) [3]. Driven by this excellent results, PSMs have been scaled-up to an active area 150 cm^2 (on a substrate equal to M6 silicon solar cell) and assembled into a perovskite solar panel (PSP) with size 0.11 m^2. Our PSP has been double-side laminated, the front with the transparent homopolymer PIB and the back with the PIB:*h*-BN composite, in order to guarantee a complete sealing of the 4 PSMSs between two glass sheets that also protect the inter-module connections. Our champion PSP has reached a PCE of 13.2%. Currently, two PSPs are being tested outside, while the single modules passed 1000h-ISOS-D2 test.
Lastly, transparent PIB encapsulants has been proposed for the realization of proof-of-concept semi-transparent large-area (active area1 cm^2) PSCs based on wide-bandgap $FaPbBr_3$ perovskite [4]. The encapsulated semi-transparent PSCs reached a PCE of 6.8% with a bifaciality factor (i.e. the ratio between the PCE measured from the back and the PCE measured from the front) as high as 89%, which is similar to the one measured before the encapsulation (92%). Thus, our transparent encapsulant version may find applications for high-PCE perovskite-based tandem systems and building-integrated PVs –PIBVs– (e.g., smart windows, façades and agrivoltaics).

References

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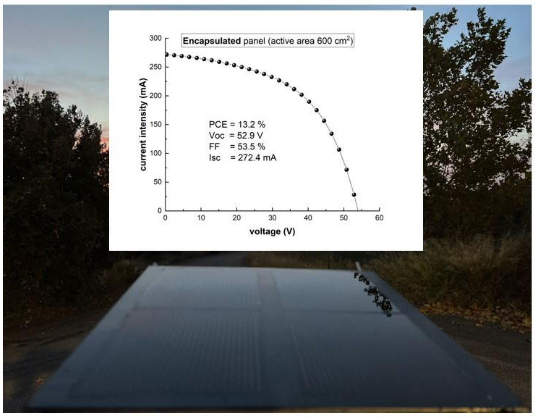
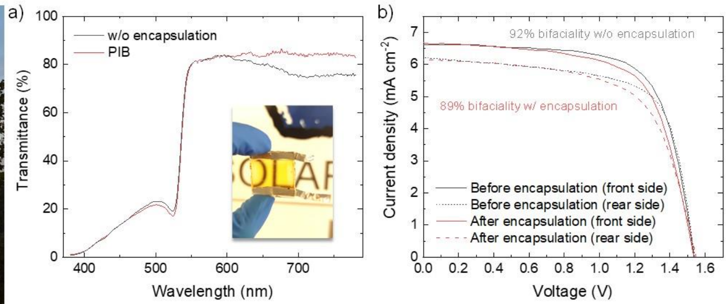
Figures





On left, the I-V characteristic of the encapsulated panel with h-BN. On right: a) UV-Vis transmittance spectra of a transparent PSC before and after encapsulation with PIB. The photograph of the cell is also shown. b) JV curves measured for a representative PSC before and after encapsulation with PIB, for both front and rear side illuminations.

Figure 1: (left) Perovskite Solar Panel laminated (front view) and (right) transmittance and J-V characteristic of a large area semi-transparent solar cell

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