A novel method for perovskite solar cells failure origin

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To achieve high-performance tandem solar cells, optimizing semi-transparent perovskite solar cells (PSCs) with a p-i-n-type architecture is crusial[1,2]. Using this configuration allows parasitic absorption reduction at the front of the device compared to the n-i-p-type architecture thus, the highest efficiencies are obtained with perovskite cells in p-i-n-type architecture[3]. However, a major drawback of these architectures is the low V_{oc}, resulting from unsuitable n- and p-type interfacial layers, which hinder the optimal functioning of the perovskite layer and promote radiative recombination[4,5]. In fact, among the three major intrinsic stress factors affecting the performance of solar cells, i.e., heat, light, and electric field, the degradation pathways driven by each layer within the stack remains the least investigated. This work emphasizes the role of degraded hole and electron transport layers (HTL and ETL), their respective interfaces with the perovskite, and the limited transport of species or components that dictate the instability of PSCs.

Accelerated aging under continuous illumination was performed under inert atmosphere following the International Summit on Organic Photovoltaic Stability (ISOS) protocols[6]. When light triggers ion and defect migration in perovskite solar cells, it can induce phase segregation, perovskite decomposition and defect formation[7]. As a result, light-induced degradation can lead to damaging changes in organic charge extraction layers, material intermixing at interfaces, and ion exchange between layers in the solar cell[8].

Therefore, to gain a comprehensive understanding of each of these following mechanisms through each layer of the p-i-n architecture, from the hole-transport materials (HTMs), such as NiO_x to the conductive ITO layer, we applied various characterization techniques before (BOL - beginning of life) and after (EOL -end of life) ISOS-L1 aging test, including electrical measurements and in-depth analyses (such as XPS, PL, XRD, SEM, EDX etc.).

We applied on this experiments light soaking accelerated testing as first-level procedure. ISOS-L1 (Laboratory weathering) under inert atmosphere and regulated temperature provide information on the tolerance of each layer exposed to light. After 100h under illumination and restacked from each degraded layer, the "new" devices clearly show different opto-electronical properties. The measured PL line shapes show dissimilar peak positions, peak widths, and are asymmetric in some cases despite originating from identical perovskites (as shown in Figure 2: (a)). The spectra did not only reflect the intrinsic emission of the metal-halide perovskite crystals but were rather influenced by the material optical environment (self-absorption, thin-film cavity effects, different refractive indices)[9]. From the electrical properties results, the first interlayers appeared to be the most stable due to the higher chemical inertness of HTMs to other device components (Figure 2: (b)). Our results suggest that further rational design of new ETMs is necessary to make perovskite solar cells sufficiently stable for the targeted practical applications.

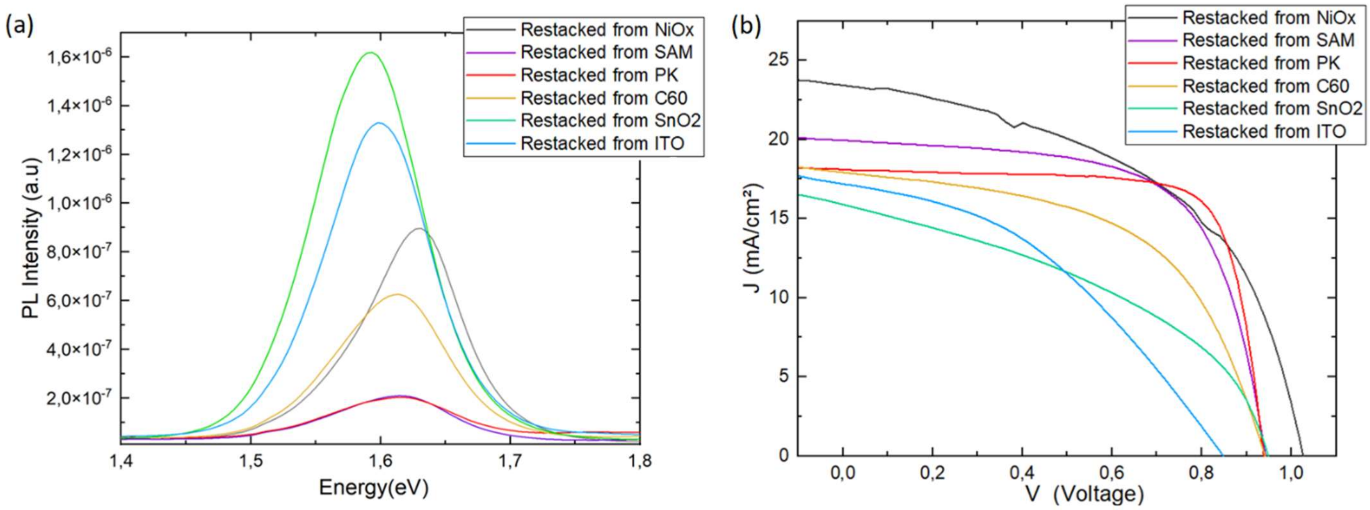

Figure 2: The effect of restacking from degraded layers (a) on photoluminescence spectra line shapes, (b) on current density curves.

References

[1] Lemercier, T., Perrin, L., Berson, S., Flandin, L., & Planes, E. (2021). Innovative PIN-type perovskite solar cells with 17% efficiency: processing and characterization. Materials Advances, 2(24), 7907-7921.

[2] Shen, H., Walter, D., Wu, Y., Fong, K. C., Jacobs, D. A., Duong, T., ... & Catchpole, K. R. (2020). Monolithic perovskite/Si tandem solar cells: pathways to over 30% efficiency. Advanced energy materials, 10(13), 1902840.

[3] Jošt, M., Köhnen, E., Morales-Vilches, A. B., Lipovšek, B., Jäger, K., Macco, B., ... & Albrecht, S. (2018). Textured interfaces in monolithic perovskite/silicon tandem solar cells: advanced light management for improved efficiency and energy yield. Energy & Environmental Science, 11(12), 3511-3523.

[4] Ozerova, V. V., Emelianov, N. A., Frolova, L. A., Fedotov, Y. S., Bredikhin, S. I., Aldoshin, S. M., & Troshin, P. A. (2024). Impact of hole-transport layer materials on the field-induced degradation of pin perovskite solar cells. Sustainable Energy & Fuels, 8(5), 997-1003.

[5] Luo, D., Yang, W., Wang, Z., Sadhanala, A., Hu, Q., Su, R., ... & Zhu, R. (2018). Enhanced photovoltage for inverted planar heterojunction perovskite solar cells. Science, 360(6396), 1442-1446.

[6] Khenkin, M. V., Katz, E. A., Abate, A., Bardizza, G., Berry, J. J., Brabec, C., ... & Lira-Cantu, M. (2020). Consensus statement for stability assessment and reporting for perovskite photovoltaics based on ISOS procedures. Nature Energy, 5(1), 35-49.

[7] Christians, J. A., Schulz, P., Tinkham, J. S., Schloemer, T. H., Harvey, S. P., Tremolet de Villers, B. J., ... & Luther, J. M. (2018). Tailored interfaces of unencapsulated perovskite solar cells for> 1,000 hour operational stability. Nature Energy, 3(1), 68-74.

[8] Lira-Cantú, M. (2017). Perovskite solar cells: Stability lies at interfaces. Nature Energy, 2(7), 1-3.

[9] Goetz, Katelyn P., et al. "Shining light on the photoluminescence properties of metal halide perovskites." Advanced Functional Materials 30.23 (2020): 1910004.