From Bare Material to Complete Tandem Cell: Understanding and Monitoring the Transient Photoluminescence Decay of Perovskite-Based Devices

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Tandem solar cells are among the most promising technologies to surpass the efficiency of single-junction silicon cells, with current records (34.85%)[1] exceeding the Shockley–Queisser limit. To achieve further performance improvements, understanding the recombination processes at each step of the cell fabrication can lead to optimized design and stack architecture. Transient photoluminescence (TrPL) measurements enable the determination of photogenerated charge carrier decay times[2]. These decay times can be interpreted to estimate bulk and interfacial recombination, as well as charge carrier separation or interface charging effects[2].

The goal of this work is to study the impact of each layer of the Perovskite/Silicon tandem device, from the bare perovskite layer on glass or on cSi to the complete tandem cell, with TrPL measurements (Figure 1&2) and establish some references for future characterizations. The impact of passivation was also investigated: for each split, samples passivated with Piperazinium Diiodide (PDI) were fabricated in order to evaluate its influence on recombination dynamics. Initial results show good reproducibility and repeatability. As expected from literature, the addition of a C60 layer on the perovskite significantly reduce the decay times from tens of microseconds to hundreds of nanoseconds. More surprisingly, the PDI passivation, while improving the V_{OC} of complete devices (data not shown here), reduce the observed decay times and alter the shape of the PL decay curves. To better understand these phenomena, another representation of the TrPL data, intruduced by Krückemeier et al.[3] is being examined: the decay time displayed as a function of the time-dependent quasi-Fermi-level splitting, which helps distinguishing between different recombination mechanisms and transient charge transport phenomena. Modeling approaches are also being explored to support the complex analysis of the data. In addition, other passivation pathways are currently being studied.

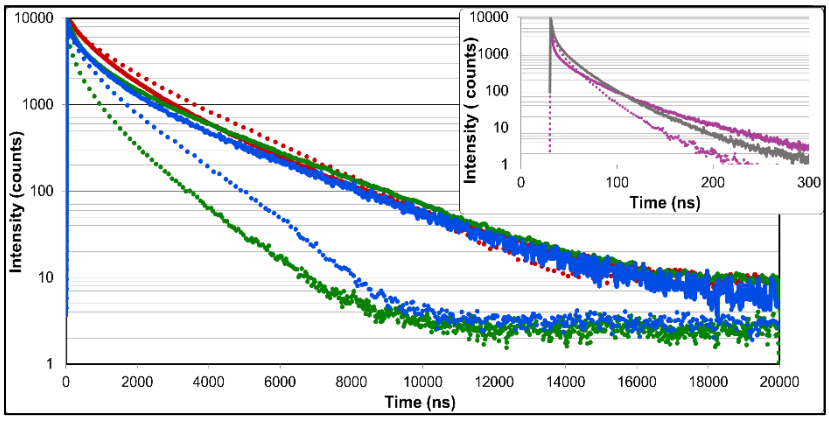

Fig. 1 - TRPL curves showing recombination dynamics across different layer stacks of a perovskite/Si tandem solar cell, with and without PDI passivation. Colours correspond to the outline of each analysed sample in Fig.2.

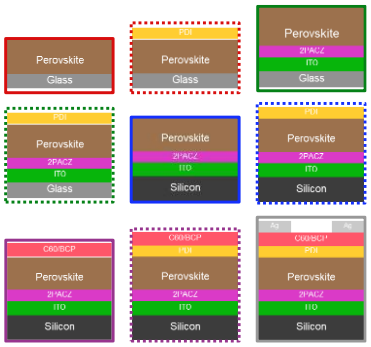

Fig. 2 - Representation of each analysed sample.

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(2) Li, Z.; Liu, A.; Basnet, R.; Black, L. E.; Macdonald, D.; Nguyen, H. T. Applications of Time-Resolved Photoluminescence for Characterizing Silicon Photovoltaic Materials. *Semicond. Sci. Technol.* **2025**, *40* (4), 045015. https://doi.org/10.1088/1361-6641/adc47a.

(3) Krückemeier, L.; Krogmeier, B.; Liu, Z.; Rau, U.; Kirchartz, T. Understanding Transient Photoluminescence in Halide Perovskite Layer Stacks and Solar Cells. *Adv. Energy Mater.* **2021**, *11* (19), 2003489. https://doi.org/10.1002/aenm.202003489.