Bandgap Imaging for Tandem Cells Based on Standard Luminescence Imagery

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Perovskite-silicon tandem cells already demonstrated a much more efficient photovoltaic energy conversion than single junction commercial products. However, it is still a major challenge to produce an homogeneous and stable perovskite stack ready for upscaling and ageing proof tests. In this context, a new bandgap imaging method is developed to help with locating and understanding defects. This method simply requires a non spectral luminescence camera (robust, sensitive, fast) with the addition of three different optical filters. The resulting images allow to solve a semi-physical model that finally provides the photovoltaic bandgap and the spectral luminescence peak width. Then, this bandgap map helps discriminating defects located in the bulk or in the transport layers, while the peak width map reveals the bandgap defect density. Together, both maps help understanding limiting factors in the bulk, including the case of ionic segregation within halide perovskites.

The semi-physical model uses Rau's luminescence definition based on black body emission, external quantum efficiency (EQE) and a voltage dependence [1]. Only the EQE depends on the sample, its low energy range is modelled with a sigmoid function [2]. Consequently, the resulting solutions are directly comparable to many other studies using this same modelling, in addition to overcoming inaccuracies already highlighted by Chen et al.[3] when using for example gaussian fits. Three photoluminescence (PL) images are measured under constant illumination with different filters placed on the optical path. As PL signal is not stable in time and spatially (mostly due to ion migration), we developed a crucial pixel-by-pixel dynamic correction that decorrelates stability and bandgap issues. Two ratios of the three measured PL images are compared to our modelling (Figure 1 – f) to determine the bandgap wavelength and spectral peak width, respectively λ_G and λ_S.

An example of measurement is represented on Figure 1. The stack of the tested sample is shown on Figure 1 – a, its PL image on Figure 1 – e and the resulting λ_G and λ_S images on Figure 1 – b,d, respectively. Three circular defects around the central busbar can be observed, where the spectral width map λ_S shows more bandgap defects on the edges, while the bandgap map λ_G shows a slight red shift within the circles, and PL image shows additional gradients that most probably do not originate in the bulk but in the transport layers. This 2D information helps figuring where ionic segregation could occur, and how to further investigate with SEM and X-ray diffraction. In addition, the method was validated by comparing certain regions of the map (red squares on Figure 1 – b) to spectrometer measurements (Figure 1 – c). Both results correlate well in homogeneous regions (1 to 2 nm difference), with, however, slightly more dispersion in defect zones. Overall, we observe the same trends, which confirms that this new harmless and contactless technique brings interesting insight and will be used to further investigate the specifics of halide perovskite tandems.

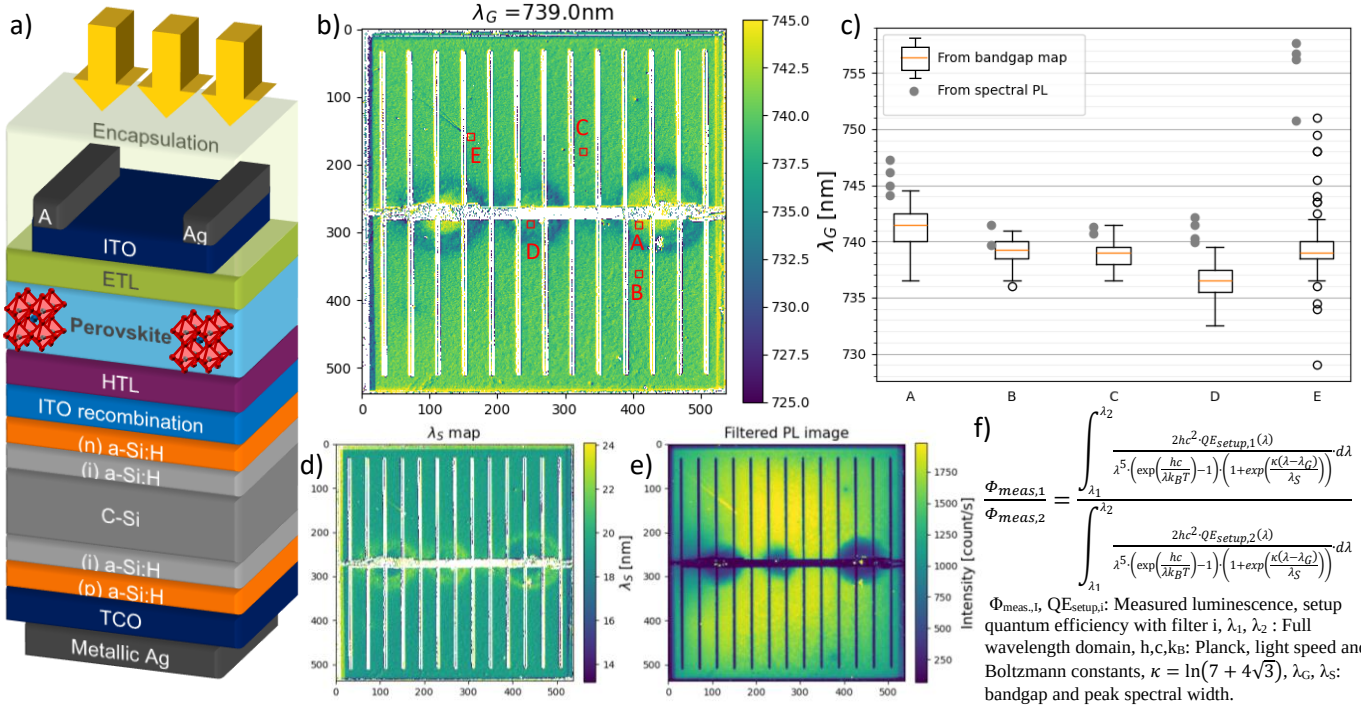

Figure 1– a) Perovskite/silicon tandem stack, b) perovskite top-cell bandgap map, c) bandgap map extractions compared to spectrometer measurements, d) perovskite top-cell bandgap width and e) regular PL image, f) semi-physical model

[1] U. Rau, « Reciprocity relation between photovoltaic quantum efficiency and electroluminescent emission of solar cells », Phys. Rev. B - Condens. Matter Mater. Phys., vol. 76, no 8, 2007, doi: 10.1103/PhysRevB.76.085303.
[2] O. Almora, C. I. Cabrera, J. Garcia-Cerrillo, T. Kirchartz, U. Rau, et C. J. Brabec, « Quantifying the Absorption Onset in the Quantum Efficiency of Emerging Photovoltaic Devices », Adv. Energy Mater., vol. 11, no 16, 2021, doi: 10.1002/aenm.202100022.
[3] B. Chen et al., « Imaging Spatial Variations of Optical Bandgaps in Perovskite Solar Cells », Adv. Energy Mater., vol. 9, no 7, p. 1802790, 2019, doi: 10.1002/aenm.201802790.