On the determination of power losses in perovskite-based solar modules:
the method of purposely-introduced defects

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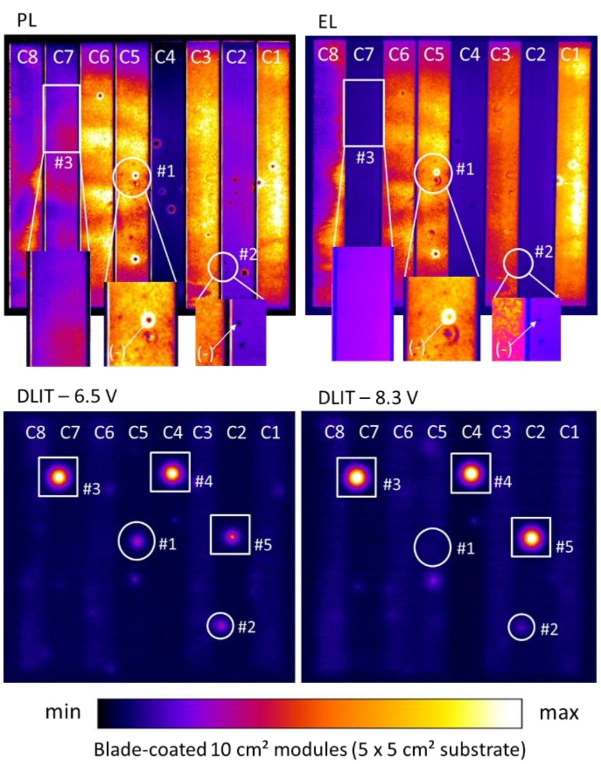
Perovskite solar cells are a promising thin-film technology because of their relatively low cost and easy fabrication compared to other already mature solar cell (i.e. Si, CIGS, CdTe). Although the photovoltaic conversion efficiency (PCE) of small laboratory cells (current record is 25.5% [1]) is rapidly approaching the maximum thermodynamic limit (best cells have passed 80% of this limit), the efforts to up-scale perovskites often yield heterogeneities in devices dramatically reducing their PCE. The causes of such heterogeneities may include particle conglomerates, wrinkled structures, compositional heterogeneity and pinholes [2]. Pinholes are quite common and most unfavorable because they can act as Ohmic or non-Ohmic shunting pathways. Thus, the development of strategies to determine the origin of pinholes is essential to optimize the fabrication process for efficient large-area solar cells and modules.



To this end, we use a set of imaging techniques of photoluminescence (PL), electroluminescence (EL) and dark lock-in thermography (DLIT) to identify heterogeneities in Dr. Blade deposited 5 x5 cm² perovskite solar modules consisting of 8 serially connected cells. As the signals emitted by the device (luminescence and thermal dissipation) stem from complex phenomena because of a multilayer structure, and the correct interpretation of the images and defects within them is not straightforward, we develop the method of purposely-introduced defects based on small-area (0.33 cm^2) perovskite single solar cells. In this method, the defects in form of lack of a certain layer (SnO_2, perovskite or PTAA) were deliberately introduced into the devices. Comparing the signal intensities from defective and non-defective areas leads to a unique signature for each kind of defect (lacking layer), which further allowed us to build the defects catalogue. We thus tested this defects catalogue for more than ten Dr. Blade deposited perovskite modules (one representative module is shown in Fig. 1). It turned out that several modules likely contain pinholes in the perovskite layer, which act as localized areas of strong power dissipation (i.e. defect #2). TEM / EDX analysis is currently underway to further confirm this and shed light on the origin of other types of defects (i.e. #3, #4 and #5).

Fig. 1 - Imaging of a 5 x 5 cm² device. PL: photoluminescence. EL: electroluminescence. DLIT: dark lock-in thermography. C1-C8 correspond to eight different cells, electrically connected in series to form a module. Several types of defects were identified.

[1] Best Research-Cell Efficiency Chart (2021); https://www.nrel.gov/pv/cell-efficiency.html

[2] Schubert, M., at al., *Adv. Energy Mater.*, 2020, 10, 26, 1904001