Nanoprobe investigation of perovskite III-V-nanowires multi-junction solar cells

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Metal halide perovskites (MHP) and III-V nanowires (NWs) have been widely investigated for photovoltaic applications. The MHP exhibit excellent optoelectronic properties, which, together with the tunable bandgap and the simplicity of the fabrication, make them a promising candidate as the top absorber in multi-junction solar cells. NWs can enable the use of expensive III-V semiconductors due to the reduced material consumption, and strain relaxation in the vertical direction allows for fabrication on lattice-mismatched substrates. Furthermore, their strong optical confinement due to optical resonant modes results in enhanced light absorption, beyond the footprint of the NWs.
This study aims to investigate the light propagation and fabrication challenges of a multijunction solar cell, featuring III-V NWs in the bottom cell and MHP in the top cell.

To model the optical response of the multi-junction solar cell, we use the finite element solver JCMwave. The absorptance results serve as the upper limit for the external quantum efficiency, under the assumption that all absorbed photons contribute to the resultant current density.
First, the bottom cell is modelled to highlight the impact in reflectance of the ITO top contact. The reflectance is minimized, varying ITO thickness, while considering resistivity constraints when scaling down its thickness. The multi-junction solar cell is modelled in different configurations. In the 3-terminal structure, where the electrical contacts are independent, the total current generated by both the top and bottom cells is maximized

at the cost of equal voltage of the cells. In contrast, in the 2-terminal counterpart, the absorptance is optimised to obtain current matching and the voltage is considered to add up between the two different structures. Offering evidence of the reflectance reduction by employing nanostructures. The simulations provide an understanding of the material choices.

Based on the modelling results, a perovskite-compatible processing scheme to fabricate the tandem structure is developed. Starting from the InP substrate, gold catalyst particles are deposited via Talbot Displacement lithography, followed by InP NWs grown in a horizontal flow metal organic vapor phase epitaxy (MOVPE) reactor. They are then processed into solar cells, defining device areas, sized 800 μm x 800 μm.

The perovskite top cell was built on top of the ITO layer, covering the bottom cell device area, and serving as a recombination layer. A hydrophobic self-assembly monolayer improves the selectivity of the perovskite deposition in the designed device areas. Then $MAPbBr_3$ and CuSCN (HTL) are spin-coated, while ITO is sputtered as a top contact. On this stack, the photo-resist is patterned to allow for ITO removal outside the device areas, then it is stripped by PGMEA solvent.

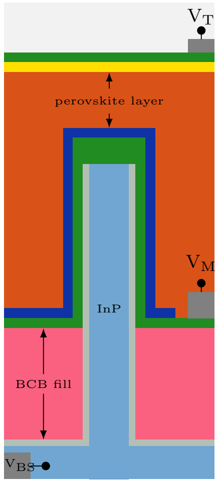

Figure: Schematic of the multi-junction solar cell.

The resulting multi-junction solar cell is characterised inside a scanning electron microscope using electron beam-induced current (EBIC) measurements. This technique can probe the electrostatic potential over the structure, highlighting the junctions, furthermore, in the same setup, the electrons' source can be used to obtain the I/V characteristic. Contact is made via a tungsten nanoprobe, pressed against the ITO to ensure contact with the perovskite layer.

The results show that voltage adds up between the $MAPbBr_3$ top cell and the InP NWs bottom cell, but the short circuit current and the fill factor are poor. However, in this first attempt, EBIC measurements allow us to identify the challenges within the chosen materials, paving the way for further investigations to improve the fabrication processes.

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