Semi-empirical approach for modelling the optical properties of semitransparent perovskite solar cells for tandem applications

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4-terminal tandem has been built in our lab combining semitransparent (Cs,MA,FA)Pb(Br,I)$_3$ triple cation perovskite solar cell (PSC) with a commercially-available Al-BSF silicon solar cell [1]. Their efficiency reaches 22.3% (+3.8% in comparison with the PCE of the silicon cell). To further improve the efficiency, parasitic optical losses have to be minimized, mainly in the near infrared region (NIR) in order to keep a high efficiency for the silicon bottom cell.

Optical characterizations and modelling help to identify the origin of losses in the perovskite cell. Most of the time, optical modelling is based on path light simulation with the Transfer Matrix Method (TMM), which uses the optical indices n and k and the thickness of each layer of the stack [2]. Jiang et al. have shown that the optical indices of the materials that composed the PSC can change with the composition and the fabrication process, especially for the perovskite layer [3]. Moreover, to the best of our knowledge, no optical data on triple cation perovskite is available. Thus specific measurements on the materials considered are needed. We report here the optical modeling of our semitransparent PSC.

An iterating process has been used to find correct optical indices n and k for each layer (FTO, TiO_2, Perovskite, Spiro and ITO). First, the thickness of each layer deposited on glass substrate is measured with a profilometer. Combined with ellipsometry measurements, a model for the optical indices of the materials is created with the software DeltaPsi, developed by Horiba Jobin Yvon. Then, optical properties of PSC, such as transmission, reflection and absorption, were modelled using a Matlab code developed by the McGehee group at Standford and based on the TMM [4]. The program leads to the transmission, the absorption and the reflection of the stack. The iterating process continues until the Mean Absolute Error (MAE) is lower than 5% between simulated and experimental datas,

The final values for n and k are consistent with what is published in the literature when available. A very good fit is obtained for absorption, transmission and reflection for the measured tandem cell, as shown in figure 1.A. The fact that the inference figures are really close to each other is an evidence of the correctness of the indices and the thickness of each layer. These results will allow to precisely design the devices, to quickly test the interest of various materials and to predict their impact on the efficiency of the bottom silicon cell and the tandem cell. Optical losses in the PSC are also analyzed. Figure 1.B shows the distribution of the absorption into the PSC between the different layers, it is observed that, NIR absorption is mainly caused by the electrodes (ITO and FTO), spiro and the glass substrate. Furthermore, the air–glass and ITO-air interfaces are responsible of parasitic reflection.

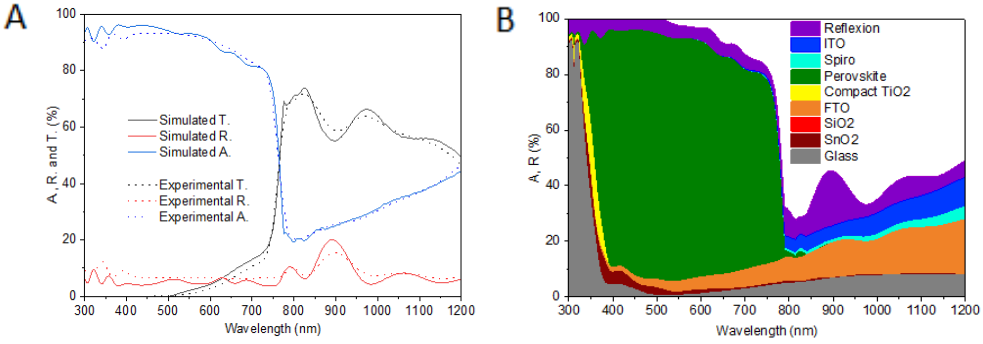

Figure 1:
A. Simulated and experimental data of the transmission, absorption and reflection of the PSC
B. Distribution of the absorption into our PSC between the different layers.

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