Transport efficiency mapping in multijunction solar cells by luminescence measurement

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Multijunction solar cells (MJSC) are currently the devices offering the largest conversion efficiencies of the solar radiation (above 45%). Among the different strategies to improve their characteristics, one would be to operate them at higher sunlight concentrations (current standards are from 500 to 1000). Nevertheless, the maximum achievable concentration is limited by the various series resistances of the cells: window layer sheet resistance, metal / semiconductor resistance, tunnel junctions…

To investigate the underlying mechanisms, we introduce a new characterization method, allowing to access transport efficiency maps through processing of luminescence images. Such a method is significantly faster than what could be done with a Light Beam Induced Current setup, and brings additional information compared to the widely used electroluminescence emission measurements in MJSC.

The method is based on following reciprocity relation:

$$f_t(x,y) = \frac{\delta I_T}{\delta I_{x,y}} = \frac{\delta V_{x,y}}{\delta V_T}$$

f_t is the transport efficiency at a position (x,y), defined as the ratio of the collected current at the terminal δI_T to the current $\delta I_L(x,y)$ generated at the surface position (x,y). The reciprocity relation states that this ratio is equal to the ratio of $\delta V(x,y)$, the junction voltage variation at (x,y), to δV_T the junction voltage variation at the terminal. Since the luminescence emission depends exponentially on the voltage, f_t can be measured by differentiating two luminescence images for a slight increase of the terminal voltage, according to:

$$f_t(x,y) = \frac{d\ln(\Phi(E,x,y,\theta))}{d(qV_T/kT)}$$

This method was theoretically suggested (1) for single junction cells, and experimentally verified (2). Nevertheless, its application for MJSC is much more challenging, and would allow us to access highly relevant information.

We verified experimentally this relation by probing lattice matched triple junction InGaP / Ga(In)As / Ge. The electroluminescence signal is recorded by a silicon CCD camera from pco. To separately record the luminescence from the InGaP and Ga(In)As subcells, a short pass 750 nm and long pass 850 nm filters are used, respectively. The luminescence from the Ge subcell is not observed. At an applied voltage of 3.2 volt, for a current of 5.01 A/cm² (corresponding to the short circuit current that would be produced under 716 suns), transport efficiency maps have been determined. In Figure 1 are represented the transport profiles along an axis perpendicular to the metal grid.

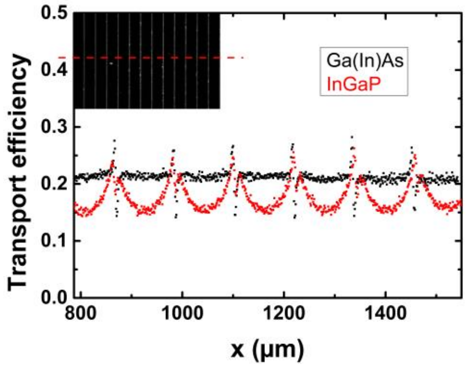

Figure 1 Transport efficiency profiles in the InGaP and Ga(In)As subcells. In inset is a picture of the cell surface. The red dashed line indicate the axis for the profiles.

The data presented in Figure 1 correspond to the theoretical expectation, which validates the reciprocity relation for MJSC. Moreover, we clearly evidence the different behavior in terms of collection probability of the top and middle cells. In the top cell, the collection is much reduced in between two electrical contacts due to the window layer sheet resistance. However, the middle cell collection is rather homogeneous. This is ascribed to the efficient lateral conduction of the tunnel junction between the InGaP and the Ga(In)As subcells. In the future, we will carry out these experiments on different multijunction cells architectures, such as lattice matched ones and wafer bonded cells.

(1) J. Wong et al, PRB 2012 (2) A. Delamarre et al, IEEE JPV 2016