Cumulative effects of confinement and scattering for an efficient photocurrent in ultra-thin solar cells

Yann Claveau[a], Fabienne Michelini[a], Marc Bescond[a] and Nicolas Cavassilas[a]
a. Aix Marseille Université, CNRS, Université de Toulon, IM2NP UMR 7334, 13397, Marseille, France

With the emergence of nano-structures in optoelectronics it becomes crucial to understand the charge transport properties of such devices. Given the nanoscale, a satisfying model should fully take into account quantum behaviors, such as confinement and scattering, but also a great variety of external perturbations, such as magnetic or electric fields. In particular, the recent development of nanoscale solar cells leads to an urgent need of reliable theoretical support[1] for experiments. Size downscaling of devices below the mean free path of generated carriers will indeed reduce the cost but deep understanding of the physics is nevertheless required to reach the highest solar cell efficiencies.

In such quantum structures, the electronic transport is quasi-ballistic and the thermalization, which is one of the principal cause of the Shockley-Queisser limit[2], could be then strongly reduced. However their efficiency remains far below bulk materials with 10 to 13% for ultra-thin materials compare to 20 to 30% for bulk materials[3]. In order to improve their performances, the light-management for a more efficient photon absorption[4, 5] has to be completed by a better extraction of charge carriers.[6]

Using the non-equilibrium perturbation theory, we theoretically investigate impacts of quantum confinement on photocurrent in ultra-thin solar cells (Fig. 1). We show that the direction distribution of the electron velocity is discretized. This permits to optimize the efficiency of the photocurrent by fostering the electron propagation in the transport direction (Fig. 2). As we shall see it can be done by confining the absorber. In that case, electron-phonon scattering, that is especially strong, act as an electron guide and the consequence is a better efficiency with scattering. These results cannot be captured through semi-classical approaches usually adopted to describe thicker structures in which the thermalization of carriers is total.

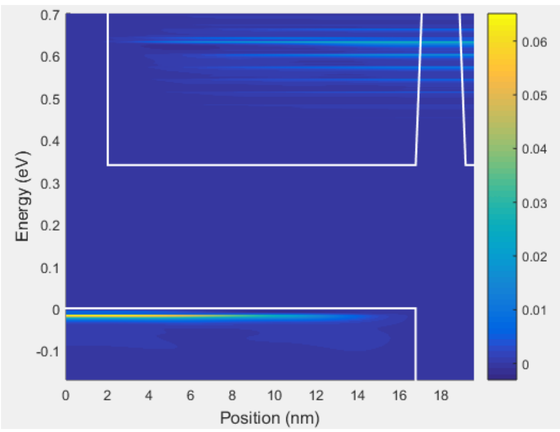

FIG. 1. Current spectra (arb. unit) of a 15 nm InAs solar cell with perfectly selective contacts: closed for minority carriers and fully open for majority carriers with a tunnel barrier (2 nm thick and 0.5 eV height) in the conduction band between the absorber and the contact.

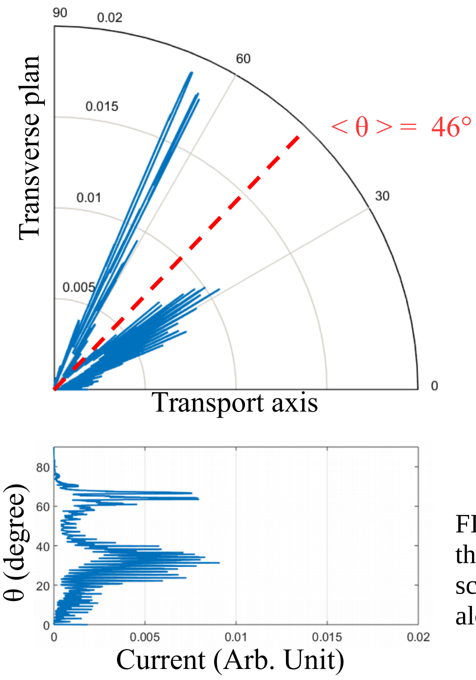

FIG. 2. Angular distribution of the current with electron-phonon scattering. Electrons are focused along the transport axis

[1] N. Cavassilas, F. Michelini, and M. Bescond, J. of Renewable and Sustainable Energy 6, 011203 (2014)

[2] W. Shockley and H. J. Queisser, J. Appl. Phys. 32, 510 (1961).

[3] R. F. Service, Science 339, 263 (2013)

[4] N. Vandamme, H. L. Chen, A. Gaucher, B. Behaghel,A. Lematre, A. Cattoni, C. Dupuis, N. Bardou, J. F. Guillemoles, and S. Collin, IEEE J. of Photovoltaics 5, 565 (2015).

[5] W. Yang, J. Becker, S. Liu, Y.-S. Kuo, J.-J. Li, B. Landini, K. Campman,and Y. H. Zhang, J. Appl. Phys. 115 (2014),

[6] N. Cavassilas, C. Gelly, F. Michelini, and M. Bescond, IEEE J. of Photovoltaics 5, 1621 (2015).