"Implementing Nanofabricated Architectures in $Cu(In,Ga)Se_2$ Ultrathin Solar Cells"

J.P. Teixeira[1], A.F. Violas[1,2], A.J.N. Oliveira[1,2,3], E. J. Ribeiro[1], X.L. Pinheiro[1,2,4], A. Perdomo[1], B. Tinoco[1], P.A. Fernandes [1,3,5], P.M.P Salomé[1,2]

[1]INL - International Iberian Nanotechnology Laboratory, Avenida Mestre José Veiga, 4715-330 Braga, Portugal
[2] Physics Department of University of Aveiro, 3810-193 Aveiro, Portugal
[3] i3N, Physics Department, University of Aveiro, 3810-193 Aveiro, Portugal
[4]CICECO-Aveiro Institute of Materials, Physics Department, University of Aveiro, 3810-193 Aveiro, Portugal
[5]CIETI, Physics Department, Instituto Superior de Engenharia do Porto, Instituto Politécnico do Porto, 4200-072 Porto, Portugal

jennifer.teixeira@inl.int

From a basic point of view, a solar cell's work principle is governed by two main phenomena, light absorption and carriers' collection. This work will address novel solar cell systems and discuss them to boost the two mentioned phenomena in an ultrathin approach. We present different solar cell designs to meet total light absorption and negligible rear interface recombination in a reduced absorber layer.

From the photovoltaics (PV) market, $(Ag)Cu(In,Ga)Se_2$ (A)CIGS thin film solar cells exhibit a consolidated efficiency [1], high energy yield, and are recyclable while having a good footprint in the European market [2]. Thinning the (A)CIGS layer to a sub-micrometer scale fits a sustainable energy transition – less material and less throughput time. However, cell architecture must be updated through interface passivation and light management schemes to tackle interface recombination and incomplete absorption, respectively [3,4]. Thus, innovative rear interface designs to overcome the challenges of scaling down the (A)CIGS-based absorber are presented and discussed. Different high-performing substrates were designed to embed passivation and/or light management solutions, developed throughout optimized and scalable nanofabrication procedures to be integrated into ultrathin (A)CIGS based solar cells, for conventional rigid, flexible, and bifacial approaches. Both passivation and light management schemes are primarily evaluated via 1D electrical and 3D optical simulations - Poisson and drift-diffusion calculations, and finite-difference time-domain (FDTD), respectively.
For effective passivation, different dielectric materials and nano-contact schemes were tested, while for optimized absorption dielectric and metallic nanostructures were explored for scattering purposes.

The inclusion of dielectric nano-contact schemes on Mo in sub-micrometer (A)CIGS based solar cells allowed for improved open circuit voltage (V_{oc}) concerning non-passivated references. A rear interface passivation scheme based on a SiO_x scheme of 92 % passivated area has been integrated into ultrathin cells with V_{oc} gains over 100 mV compared to baseline cells, compatible with a reduction in the rear surface recombination velocity from 10^7 to 10^3 cms^{-1} [3]. Additionally, the integration of randomly distributed Au nanoparticles under an AlO_x 77 % passivated line contact scheme, allowed for an experimental optoelectronic gain of 3.7 $mA.cm^{-2}$, ascribed to an improved rear reflectance and scattering, along with an improved charge carrier collection and a decrease in the rear surface recombination velocity, demonstrate via 3D optical and 1D electrical simulations [5]. The exploitation of sub-wavelength schemes is addressed by different high-resolution and scalable process-flow(s). The nanofabrication procedures are grounded on nanoimprint lithography (NIL), which might be improved to a simple stamping based procedure. The introduction of those innovative rear interface designs has led to absolute experimental light to power conversion efficiency gains of up to 2 % regarding reference cells.

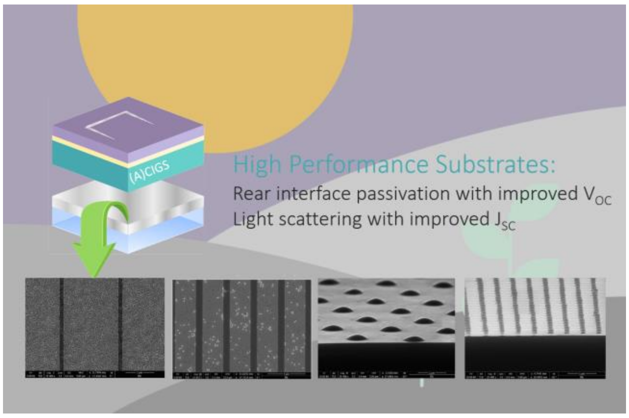

Figure 1. Nanoschemes for passivation and light management strategies developed for (A)CIGS ultrathin solar cells.

References

[1] J. Keller *et al.*, Nat. Energy (2024)
[2] CIGS Thin Film Photovoltaics for EU's prosperity, energy transition and enabling net zero emission target (2021)
[3] A. J. N. Oliveira *et al.*, Adv. Funct. Mater. 33 (2023) 2303188 (2023)
[4] A. J. N. Oliveira *et al.*, Adv. Photonics Res. 3 (2022) 2100190
[5] A. J. N. Oliveira *et al.*, Solar RRL submited