Development of nanostructured back contacts for high-efficiency ultra-thin CIGS solar cells

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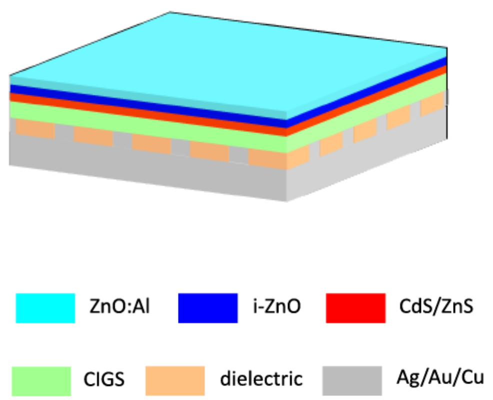
$Cu(In,Ga)Se_2$-based solar cells are currently the most efficient thin-film solar cell technology, with a world record efficiency as high as 22.6% [1]. Indium scarcity and cost issues have driven the need for a drastic reduction of the absorber thickness from 2-3 µm to less than 1 µm. Using conventional architectures with such ultrathin CIGS absorbers would result in a drop of light absorption and an increase of back contact recombination. In the framework of the European project ARCIGS-M, we have been investigating new architectures to improve light trapping and rear passivation in order to achieve 20% efficiency with 500 nm-thick CIGS layers. To reach this goal we have worked simultaneously on 3 main points:

We first investigated a rather simple system, replacing the molybdenum back contact with a transparent conducting oxide (SnO_2:F) and a copper back reflector. We demonstrated an increase of J_{SC} from 21.1 to 25.9 mA/cm² as compared with the standard molybdenum back contact [2]. Even though such solar cells yielded efficiencies up to 11.4% with 450 nm-thick CIGS layers, a copper flat mirror remains insufficient to achieve state-of-the-art short circuit currents in ultrathin CIGS solar cells.

In order to further improve light trapping in ultrathin CIGS devices, we suggest to use nanostructured mirrors composed of a dielectric and a highly reflective metal. We present numerical electromagnetic simulations of complete CIGS solar cells for different CIGS thicknesses and various mirror materials. We demonstrated short-circuit currents of J_{SC} = 36.3 mA/cm^2 (33.6 mA/cm^2) for 200 nm-thick CIGS absorbers with a silver (copper) nanostructured mirror (Figure 1 for silver mirror). In parallel, we have been exploring the use of passivation layers such as Al_2O_3 deposited on molybdenum back contacts. We have developed a large surface area and cost-effective patterning of the passivation layer based on nanoimprint lithography of a sol-gel derived film and wet etching. We will present the first results based on such technological developments combining the nanostructured back contact/mirror with an ohmic contact and a passivation layer.



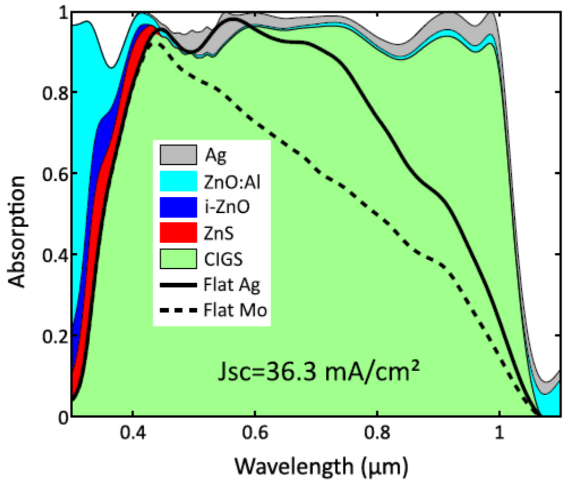


Figure 1. (left): Sketch of a CIGS solar cell with a nanostructured back mirror. The structure is composed of top ZnO:Al (light blue), i-ZnO (blue), ZnS (red), CIGS (green), and a nanostructured mirror (grey) embedded in a dielectric medium (brown). (right): Absorption spectra of the CIGS device (a), calculated for a 150 nm-thick CIGS. Absorption in each layer of the stack is shown (color areas). Absorption in the CIGS layer (green) is compared to results obtained with a flat back contact made of Mo (dotted line) or Ag (continuous line).

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[2] F. Mollica et al., 'Light absorption enhancement in ultra-thin Cu(In,Ga)Se 2 solar cells by substituting the back contact with a transparent conducting oxide based reflector', Thin Solid Films, vol. 633, pp. 202–207, (2017).

[3] J. Goffard et al., 'Light Trapping in Ultrathin CIGS Solar Cells with Nanostructured Back Mirrors', IEEE Journal of Photovoltaics, vol. 7, no. 5, pp. 1433–1441, (2017).