# Ultrathin $Cu(In,Ga)Se_2$ solar cells with reflective back contacts

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$Cu(In,Ga)Se_2$ (CIGS) solar cells are conventionally grown on a glass substrate covered with molybdenum (Mo). Mo was chosen because it is a refractory material that forms an Ohmic contact with the CIGS thanks to the creation of a thin $MoSe_2$ interface layer. However, it presents a low optical reflectance and high surface recombination. The use of alternative back contact materials is currently under investigation in several groups including ours.[1] A highly reflective back contact should fulfill stringent requirements: it should be able: (i) to sustain CIGS deposition temperatures of at least 500°C with no morphological change or elements diffusion, (ii) to provide high optical reflectance, and (iii) to form an Ohmic contact with CIGS. We recently demonstrated that silver mirrors encapsulated with transparent conducting oxides (TCO) appear as a promising candidate.[2,3]

In this work, we design and characterize 500 nm thick CIGS solar cells with Ohmic and highly reflective back contacts (RBC) compatible with the direct deposition of CIGS at 500°C. Our RBC architecture includes a highly reflective silver mirror encapsulated in ZnO:Al layers for thermal stability, and a top layer of $In_2O_3$:Sn (ITO) for back contact Ohmicity. The EDX/STEM maps of complete cells demonstrate that the Ag mirror of the RBC is efficiently encapsulated in the oxide layers. Besides, they show that the detrimental reaction between CIGS and ITO can be mitigated by adding a 3 nm thick $Al_2O_3$ layer on top of ITO and by decreasing the co-evaporation temperature of CIGS from 550°C to 500°C. The lower temperature also improves the compositional grading of Ga toward the CIGS back interface, leading to increased open circuit voltage and fill factor. The best ultrathin CIGS solar cell on a RBC exhibits an efficiency of 13.5% with a short-circuit current density of 28.9 $mA/cm^2$ (Figure), which are respectively 1.0% absolute and 2.6 $mA/cm^2$ more than the best reference cell on Mo.[4] In the framework of the EU project ARCIGS-M, we are currently focus to transfer this technology to industry (SOLIBRO and Midsummer) as a reduction in the CIGS absorber thickness (≤ 500 nm) reduces the use of scarce elements (indium) and greatly increases the production throughput.

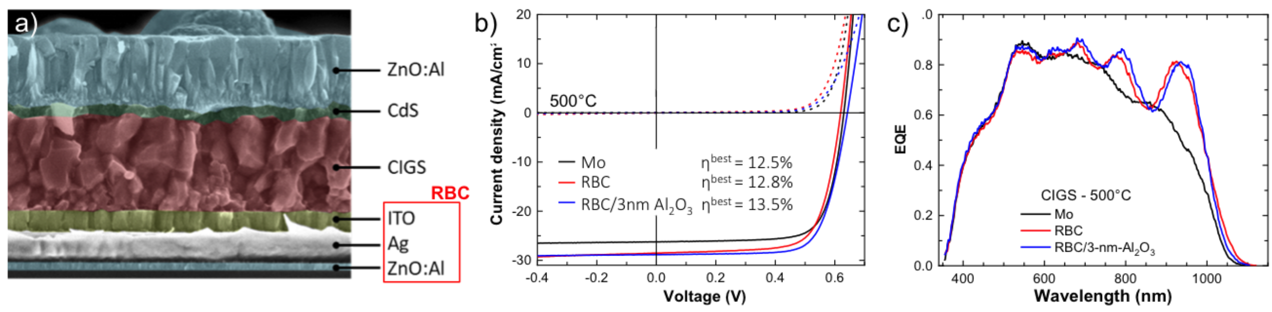


**Figure – a)** SEM cross-section of 500 nm-thick CIGS layer co-evaporated on Mo at 500°C; **b)** IV and **c)** EQE of best ultrathin solar cells co-evaporated at 500°C with back contacts made of Mo (black), RBC (red) and RBC covered with a 3 nm-thick Al2O3 layer (blue).

[1] 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 633, 202 (2016).
[2] Gouillart, et al., "Development of reflective back contacts for high-efficiency ultrathin $Cu(In,Ga)Se_2$ solar cells", Thin Solid Films 672, 1 (2019).
[3] Gouillart et al., "Reflective back contacts for ultrathin $Cu(In,Ga)Se_2$-based solar cells", accepted in IEEE Journal of Photovoltaics
[4] Gouillart et al., "Surface engineering for ultrathin Cu(In,Ga)Se2 solar cells on reflective back contacts", in preparation