# High-concentration silver alloying and rubidium fluoride post deposition treatment for high-efficiency CIGS solar cells


**Abstract**

Recent advancements in CIGS solar cells have been achieved by incorporating silver (Ag) to partially replace copper (Cu) in the absorber layers. This addition of Ag facilitates grain growth by lowering the melting temperature of the absorber while maintaining high performance. This study focuses on the impact of Ag alloying of CIGS absorbers (ACIGS), their fabrication, characterization, and Indium-to-Gallium ratio (GGI), to reach bandgaps range from 1.0 eV to 1.7 eV.

ACIGS absorber layers were fabricated on soda-lime glass substrates. Absorber layers with different bandgaps from 1.1 eV to 1.6 eV were fabricated using the ACIGS absorber layers. For Ag-alloyed absorbers, a thin Ag layer was thermally evaporated with varying thickness onto the Mo back contact before absorber deposition. The thickness or percentage of Ag was determined depending on Cu content in the absorber. A three-stage co-evaporation process was employed to fabricate the ACIGS absorbers at a substrate temperature of 550°C. The deposition process was followed by sodium and rubidium alkaline post-treatment.

The [Ga]/([Ga]+[In]) (GGI), copper-to-(gallium plus indium) ratio (CGI) and silver-copper ratio (AAC) as a function of the deposition temperature and the bandgap of the absorbers were determined by X-ray fluorescence (XRF) and their elemental depth profiles were compared using glow discharge optical emission spectroscopy (GDOES) analysis. An evolution in the slope of the gallium profile is clearly observed with the addition of Ag. The increase in crystalline size and grain growth by Ag alloying is observed by XRD (X-ray Diffraction) and scanning electron microscope (SEM) as in Fig 1(a). Efficiency improvements of up to 17.5% were achieved, with a $V_{oc}$ of 687 mV by Ag alloying and further enhancements in $V_{oc}$ to 710 mV were made possible by applying a rubidium fluoride (RbF) post-treatment, which increased the efficiency to 19.8%. The addition of an anti-reflective coating (ARC) led to a final efficiency boost to 20.8% as shown in Fig 1(b). The correlation between the elemental depth profile of the absorbers, the Ag-alloying, varying bandgaps and their impact on the solar cell performances will be discussed.


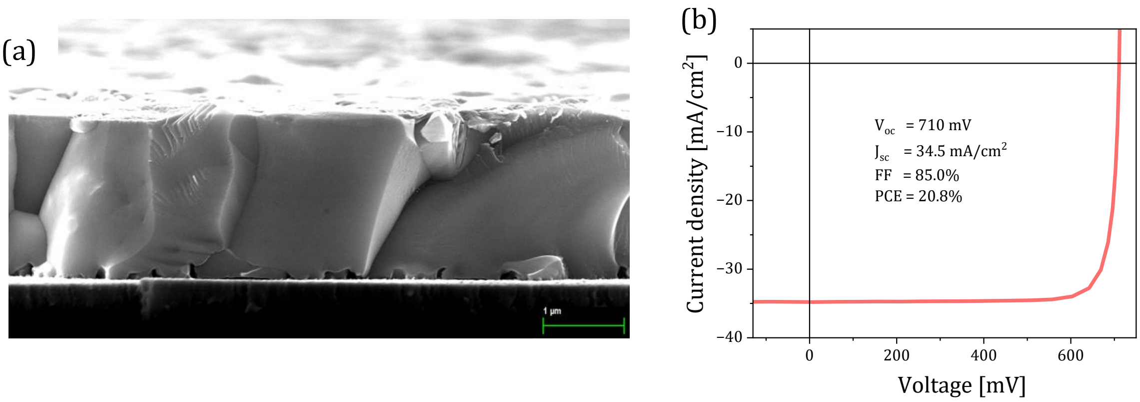


*Figure 1:* (a) SEM images of the full cross-section and (b) Current voltage characteristics of the ACIGS with RbF postdeposition