ANR EPCIS project results: CIGS on c-Si Tandem Solar Cell???

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The aim of the ANR EPCIS project was to develop tandem solar cells associating single crystalline silicon bottom cell, with a bandgap of 1.12 eV and CIGS top cell, specially optimized for large bandgap around 1.6-1.7 eV. In particular, our purpose was to grow $Cu(In,Ga)Se_2$ (CIGSe) and $Cu(In,Ga)S_2$ (CIGSu) films under quasi-epitaxial conditions on silicon, through a wide bandgap GaP intermediate layer epitaxially deposited on silicon. The aim of epitaxy on GaP was to improve the CIGS top cell efficiency thanks to a reduction of the structural defects density detrimental for the cell performance, and taking advantage of the better structural and electronic matching than with the commonly-used Mo/Glass substrates. In previous studies, we have shown that we are able to grow epitaxially both the CIGSu and CIGse epitaxially onto a GaP/Si pseudo-substrates [1,2]. Therefore, quasi-epitaxial CIGS-Si tandem solar cells has the potential to emerge as cost competitive for the next generation of PV modules.

In this paper, we present all the significant achievements towards the development of the EPCIS CIGS/Si tandem cell. First, INL has developed the Si bottom subcell in a passivated emitter rear totally diffused (PERT) configuration, and with an all-Si tunnel junction (TJ) on the surface of c-Si ,suitable for the subsequent development of the tandem cell. This TJ is obtained using a Proximity Rapid Thermal Diffusion method [3].

Then epitaxial 50 nm-thin GaP quasi-lattice matched have been successfully grown first, in Institut FOTON Lab, on highly-p-doped silicon substrate and then on the TJ/Si bottom subcell provided by INL. Such intermediate layer has been found to be essential to avoid any delamination effect between the CIGS and the silicon and to obtain an epitaxial relationship between both absorbing layers, limiting the grain boundaries density in CIGS which has been founded to be detrimental in such high bandgap CIGS materials. Moreover, the GaP is expected to act as a selective contact between both subcell, reflecting the electrons photogenerated in the CIGS and allowing the holes to recombine in the TJ.

Finally, both IPVF and IMN have developed CIGSe and CIGSu wide bandgap subcells, the CIGSu alowing to reach much larger gaps than CIGSe but is more exploratory.

The fabrication of Ag-alloyed pure sulfide wide bandgap CIGSu was investigated at IPVF [4], since Ag alloying of CIGS is known to promote grain growth and ultimately cells efficiencies. The absorbers were deposited by sequential evaporation of Cu, Ga, In and Ag layers, followed by a sulfur annealing. A two-step approach was chosen in order to investigate short annealings and/or low temperature annealings, and thus avoid degradation of the bottom silicon solar cell in a monolithic CIGSu/Si stack. All solar cells have a non-toxic Cd-free Zn(O,S) buffer layer completed with ZnO:Al/(Zn,Mg)O window layer.

Then, the CIGSu and CIGSe epitaxial growth on GaP/Si(001) pseudo-substrates has been studied with particular attention to the control of the CIGS/GaP interface [1,2,5]. Concerning the CIGSu top subcell growth performed at IMN, the presence of excess copper in a sulfurized atmosphere induces spontaneous chemical reactions that degrades the GaP layer to form a thin layer of CuGaS2 which keeps the epitaxial relationships with both the silicon and the CIGSu. Forthcoming studies are in progress to investigate the possibility of forming a CuGaS2 layer by adding copper exclusively to GaP, i.e. by consuming the entire GaP layer in order to obtain a thin CuGaS2 layer suitable to obtain a good electrons reflector.

Some AZO/i-ZnO/CdS/CIGSe top subcells deposited at IMN have also been investigated. Fig 1 shows the results obtained under solar AM1.5G illumination, on such CIGSe subcell epitaxially grown onto a GaP/Si conducting substrate in a top-bottom configuration, compared to the same solar cell heterostructure deposited on a conventional Mo/SLG substrate, during the same growth run. While optimization of R_s and R_{sh} values are required to obtain larger FF, small gains in J_{sc} and V_{oc} values are obtained in the GaP/Si case with respect to the Mo/SLG one. Then Fig 2 shows the results under solar AM1.5G illumination on a CIGSe/Si tandem cell structure obtained with all the buildings blocks developed during EPCIS project, in a 2T configuration, compared to the top subcell solar cell deposited on a conventional Mo/SLG substrate, and during the same growth run. The V_{oc} of the top subcell is measured equal to 0.62V while the V_{oc} of the solar tandem cell structure is equal to 1.12V, suggesting that a tandem solar cell has been obtained.

To confirm this result, forthcoming EQE measurements on both the 2 subcells of the tandem cell structure, are scheduled soon.

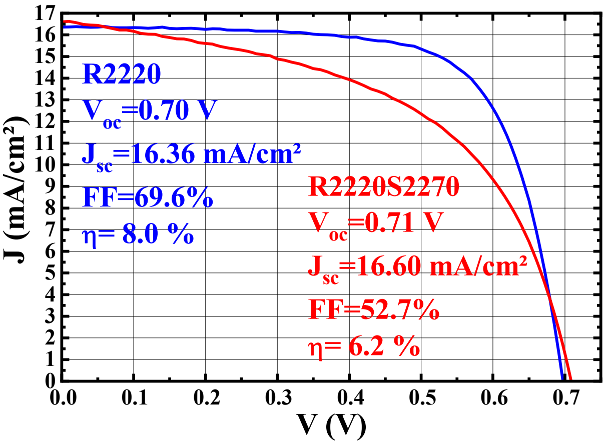

Fig1: L-I-V curves obtained under AM1.5G solar illumination from the CIGSe top subcell, in blue: deposited onto conventional Mo/SLG substrate (R2220 cell), and in red: deposited onto a GaP/Si conducting substrate (R2220S2270 cell)

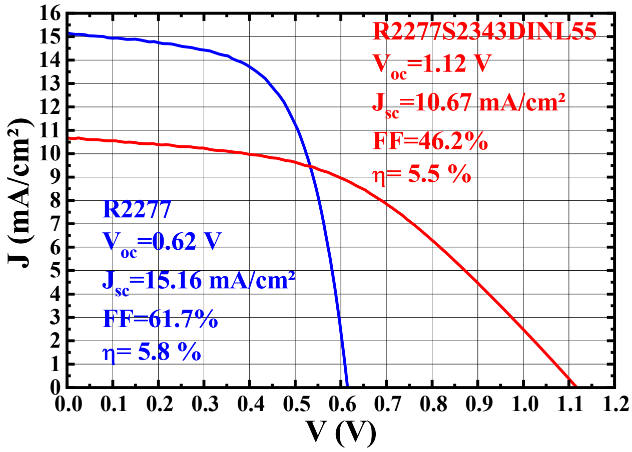

Fig2: L-I-V curves obtained under AM1.5G solar illumination, in blue: from the CIGSe top subcell deposited onto conventional Mo/SLG substrate (R2277 cell), and in red: from the tandem solar cell (R2277S2343INL55 cell).

This work is supported by the French National Research Agency project EPCIS (Grant no. ANR-20-CE05-0038) and the PIA (Grant no. ANR-IEED-002-01), by the French Contrat Plan État-Région and the European Regional Development Fund of Pays de la Loire. The authors acknowledge RENATECH+ (French Network of Major Technology Centers) for technological support, and the CIMEN Electron Microscopy Center in Nantes.

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