Development of Indium-free TCOs for Silicon Heterojunction Solar Cells

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In the framework of the H2020 project INREP and the CTI project TACOS, CSEM develops in collaboration with the Meyer Burger Research (MBR) indium free transparent conducting oxides as a replacement for indium tin oxide.

High efficiency silicon heterojunction technology (HJT) solar cells are a very promising solution for the development of clean renewable energy sources. Indeed, this technology holds the highest record efficiency for single junction silicon solar cells (>26%). Furthermore, it is cost competitive thanks to a fabrication process involving a limited number of fabrication steps compared to other wafer based technologies. In this context, CSEM has developed a strong expertise in this technology, and in parallel, the Meyer Burger group is proposing a full platform for silicon HJT solar cell production. Despite its established advantages, it remains necessary to further increase the competitiveness of this technology to promote its adoption within a very conservative industry. With this in mind CSEM has been developing indium-free transparent conducting oxide (TCO) to replace the costly indium tin oxide (ITO) which is currently the standard material used in HJT as front and back electrodes (Figure 1).

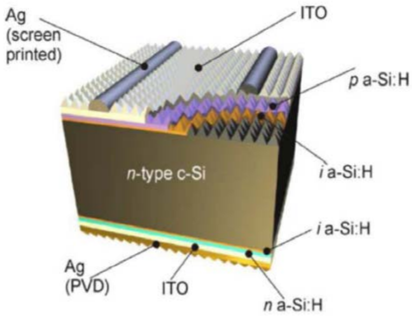

Figure 1: Typical semiconductor HJT solar cell structure.

The chosen alternative for ITO is aluminum-doped zinc oxide (AZO) as it has a high bandgap (3.3 eV), ensuring good transparency and can be doped to high carrier concentrations (~10^{21} cm^{-3}), allowing high conductivity. AZO can be sputtered, therefore targets can be installed into the existing ITO PVD tools. However, the properties of AZO are not on par with ITO: for typical layers used in solar cells the AZO mobility is ~15 $cm^2/(V.s)$ against 30 $cm^2/(V.s)$ for ITO. Hence, to achieve the same sheet resistance a higher carrier concentration is required, thus increasing losses by free carrier absorption. AZO is also more sensitive to residual moisture, which raises concerns about process sensitivity and controllability but also about the reliability of finished devices incorporating these layers. Therefore, CSEM should demonstrate that it is possible to achieve similar cell efficiencies with AZO contacts than with ITO ones and that cells with AZO can be made in a production environment with good reliability.

The design of the solar cells was carefully considered in order to circumvent the intrinsic limitations of AZO with respect to ITO. For example a rear emitter design where the p a-Si is at the back and the n at the front has been chosen. This way wafer conduction helps current spreading thus relaxing conductivity constraints on the AZO. Contacts were initially developed on CSEM cells, and then the process was tested on Meyer Burger 6 inch production cells. Figure 2 shows that replacing ITO by AZO can be done with minimal power conversion efficiency (PCE) losses (-0.2 point).

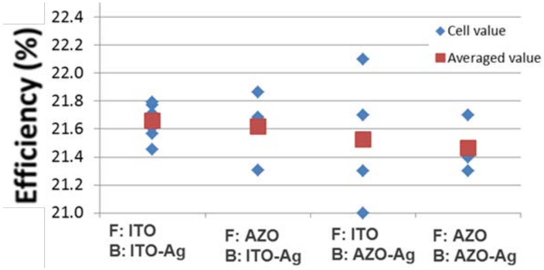

Figure 2: Comparison between AZO and ITO contacts on Meyer Burger HJT solar cells efficiency (F, B: front and back contact).

These very encouraging results were transferred on MBR tools with active support from CSEM, first on a semi-production scale tool and their full scale production scale allowing processing of 42 cells in one go. Initial runs on the large scale tool exhibited efficiencies 0.6 points below ITO reference but more recent results exhibited efficiencies 0.2-0.3 point below references, showing the results obtained at CSEM can be transferred on the production tools. Continuous process improvement is expected to further reduce the gap. Finally the reliability of cells using AZO was assessed and compared to ITO by testing 1 cell mini-modules for damp heat degradation (85°C; 85% humidity). It was observed that there is no significant difference between the two types of cells and the mini modules using AZO cells pass the IEC standard degradation test (<5% relative degradation for 1000 hours).

Figure 3: 16 indium-free cells demo module.

In summary AZO transparent electrodes as replacement for ITO is at a stage close to production with very similar PCEs and reliability and an industrial scale compatible process.

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• Meyer Burger Research