Development of Highly Conductive Transparent Materials for PV Applications

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In the framework of the CTI project TACOS, CSEM develops highly transparent and conductive electrode materials for PV applications.

In collaboration with the Meyer Burger group, CSEM develops electrode materials for the Silicon heterojunction technology (HJT). The high efficiency achieved with HJT solar cells rely on high quality n-type crystalline silicon wafer and on high quality surface passivation by amorphous silicon thin film for low bulk and surface recombination. In order to collect the generated photocurrent, a combination of a front transparent conductive oxide (TCO) electrode and silver printed fingers is used.

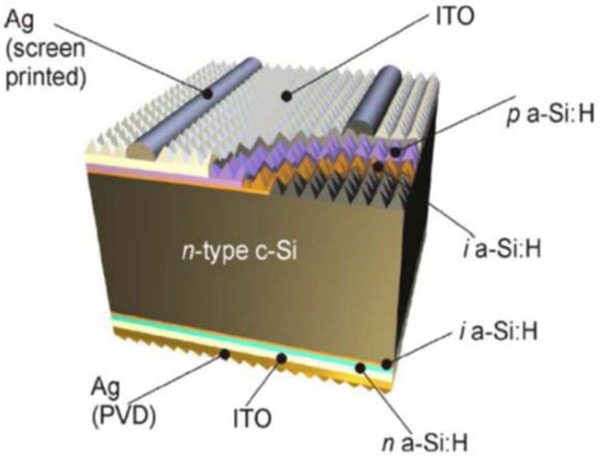

Figure 1: Schematic representation of a silicon heterojunction solar cell.

The front TCO for HJT solar cells has to fulfill the following criteria:

- Low sheet resistance in order to minimize the electrical losses during the lateral transport of the current
- Low absorbance in order to minimize the optical losses
- Ability to form a good ohmic contact with both the a-Si doped layer and the silver fingers
- TCO thickness determined in order to form a quarter wavelength anti-reflection layer

For TCO in general, a lower sheet resistance can be obtained by either increasing the TCO thickness, the carrier density or the carrier mobility. However, in the case of HJT solar cells, the optimum TCO thickness is determined by the anti-reflection condition while carrier concentration should be kept low to minimize the infrared parasitic absorbance of the TCO. Therefore the carrier mobility is the main TCO parameter that can be increased in order to fulfill all the imposed criteria on the front TCO.

Actually, sputtered indium tin oxide (ITO) is the most standard TCO used for HJT solar cell production. Among other materials, CSEM is evaluating sputtering of high indium content TCO such as pure In_2O_3 doped with hydrogen (IO:H) or still In_2O_3 with trace amount of tungsten (IWO) or Cerium (ICO:H), as well as indium free TCO such as aluminum doped zinc oxide (AZO). Figure 2 shows the maximum electron mobility achieved for each TCO for a carrier density around 2×10^{20} cm^{-3} and a thickness of 100 nm after annealing at 190°C. In comparison to the standard ITO, higher electron mobilities are obtained for high indium content TCO, while a lower mobility has been obtained for the AZO indium free TCO. With both ICO:H and IO:H, it is possible to reach electron mobilities higher than 100 $cm^2/(V\ s)$, but this necessitates the use of water vapor doping during the material sputtering, which makes the deposition process difficult to control and hence less reproducible.

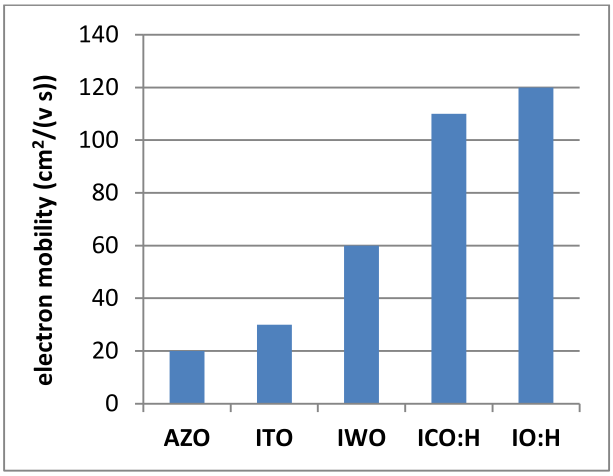

Figure 2: Carrier mobility for different TCO materials for a carrier density around 2 10^{20} cm^{-3} and a thickness of 100 nm after annealing at 190°C.

In terms of HJT solar cell efficiency, an absolute efficiency gain of 0.4% has been obtained with IWO in place of ITO while a reduction of the efficiency has been observed when replacing the ITO by AZO. These results have confirmed the possibility to increase the efficiency of HJT solar cell by using TCO with higher carrier mobility.

In the framework of the TACOS CTI project, CSEM and Meyer Burger also evaluate the industrialization potential of the different TCO for HJT solar cell production. For such evaluation, the final solar cell performance is an important criterion, but the following criteria have also to be taken into account:

- Raw material and sputtering target cost
- Process reproducibility
- Machine complexity
- Process tack time
- High reliability after module implementation

The final goal of the TACOS project is to find the best TCO in order to achieve the lowest cost of electricity production with silicon HJT solar module.

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