Development of high temperature Si-based tunnel recombination junction for tandem solar cells applications

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Thanks to an established industry, high efficiencies and an adapted band gap energy, silicon solar cells seem to be a good candidate for the bottom-cell of tandem devices. In this work, we focus on high temperature Si-based layers (HTSi) as they seem particularly well suited for both crystalline silicon surface passivation (coupled with tunnel SiO_x layers) and efficient tunnel recombination junctions (TRJ) fabrication [1]. Indeed, the HTSi layers are strongly doped and do not require TCOs to ensure sufficient lateral conductivity like their low temperature processed counterparts. On top of that, solar cells featuring HTSi layers show good temperature stability and so, are potentially compatible with high temperature processed top-cells. We investigated thin PECV(Plasma Enhanced Chemical Vapour)-Deposited Si layers annealed at different temperatures to be used in a TRJ stack but as a hydrogenation step for the passivation of the bottom-cell too.

In order to get boron doped poly-Si layers that would benefit from a hydrogenation step we studied symmetrical samples (poly-Si $(p^+)/SiO_x/c\text{-}Si(n)/SiO_x/poly\text{-}Si(p^+)$) in which the active HTSi layers were deposited via LPCVD (Low Pressure Chemical Vapour Deposition), ex situ doped by PIII (Plasma Ion Immersion Implantation) and furnace annealed at 875°C for 30 minutes. To assess the compatibility of the poly-Si with hydrogenation we measured the implied Voc (iVoc) by PCD (PhotoConductance Decay) of the samples as annealed and after the deposition of an H rich SiN layer by PECVD. After investigation of several processing parameters, we noticed that the implantation acceleration voltage drives the response to hydrogenation. It was shown that for our 15nm thick poly-Si layer the implantation acceleration voltage must stay below 2kV in order to get a good response to hydrogenation. Otherwise, the implantation leads to the creation of defects in the bulk that turn to recombination centres after H rich SiN deposition.

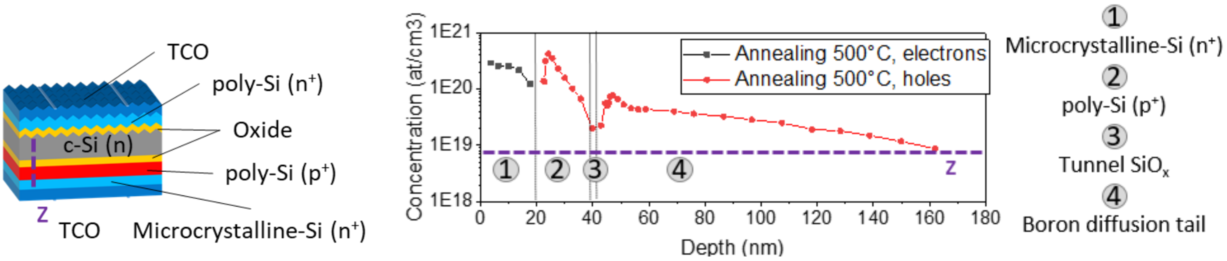

Figure 1 ECV caracterisation of the TRJ

We then investigated the fabrication of TRJ consisting in two phosphorus- and boron-doped HTSi layers. To do so, we deposited by PECVD an in situ phosphorus doped microcrystalline silicon layer on the boron doped poly-Si previously developed. The TRJ was integrated at the rear side of a complete solar cell and, comparing with reference cells (without TRJ at the back); we were able to see its impact on the cells characteristics (Voc, Isc, FF and Efficiency). ECV characterisation (Figure 1) of our TRJ shows that the junction fulfil the two main requirements for a working Esaki like diode[2] [3]: strongly doped layers and a thin space charge region. Our TRJ only induced a FF drop compared to the reference that can be recovered with an annealing at 400°C of the fully metalized cells, which tends to confirm that the TRJ is functional and well activated.

The integration of those layers as the TRJ in a Perovskite on Silicon tandem structure resulted in a functioning device featuring efficiencies up to 19.1% for the champion cell. On top of that, the keys for further optimization have been identified.

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[2] L. Esaki, 'New Phenomenon in Narrow Germanium p − n Junctions', *Phys. Rev.*, vol. 109, no. 2, pp. 603–604, Jan. 1958, doi: 10.1103/PhysRev.109.603.

[3] R. Peibst *et al.*, 'From PERC to Tandem: POLO- and p+/n+ Poly-Si Tunneling Junction as Interface Between Bottom and Top Cell', *IEEE J. Photovolt.*, vol. 9, no. 1, pp. 49–54, Jan. 2019, doi: 10.1109/JPHOTOV.2018.2876999.