Platform for High-efficiency Silicon Heterojunction Solar Cells

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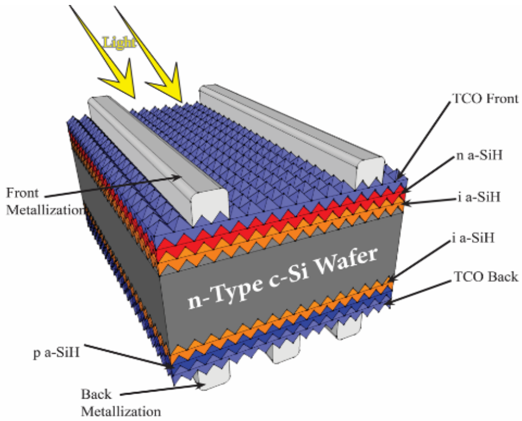
CSEM has set up a complete platform for the fabrication and the characterization of silicon heterojunction solar cells. Innovative and industry-relevant solutions are developed for the improvement of all cell processing steps, aiming for high conversion efficiencies at competitive costs. The technological topics covered at CSEM include wafer bulk quality improvements, wafer texturing and cleaning by wet-chemistry, PECVD depositions of ultra-thin passivating and contacting layers, PVD depositions of low-cost and/or high-mobility transparent conductive oxides, advanced cell metallization and interconnection processes and various characterization techniques. Efficiencies up to 23.44% have been demonstrated following the developments conducted in the frame of the FP7 European project HERCULES.

Silicon heterojunction (SHJ) solar cells present the decisive advantages to combine a high efficiency (potential for modules with >21% conversion efficiency) with limited number of production steps (pre-requisite for keeping reduced fabrication costs). The technology further exhibits a low temperature coefficient (<−0.3%/ºC) as well as a high bifaciality (>90%), triggering high energy yield for bifacial SHJ modules in the field. Thanks to its symmetric structure and to the high level of surface passivation, the SHJ bifacial cell architecture is also the most suited for thin wafers integration. Calculations show that, with SHJ solar cells, the average levelized costs of energy could be below 4 €cts/kWh in sunny countries [1]. Since the PV-center creation in 2013, a strong emphasis is therefore set in CSEM on the development of a complete, performant and flexible platform covering all aspects of production and characterization of SHJ solar cells, from as-cut wafers to finished devices optimized for module integration. This technological platform allows CSEM conducting advanced R&D projects to develop new processes, materials, production and metrology equipment, as well as advanced concepts for improved performance and/or reduced production costs; and also to provide services and small batch production for its customers.

SHJ solar cells implement carrier-selective contacts with high surface passivation formed on crystalline silicon wafer with the deposition of hydrogenated amorphous silicon (a-Si:H) and transparent conductive oxide (TCO) layers. These hetero-contacts are demonstrations of so-called passivating contacts, enabling for its key advantage: increased operating voltages. The intrinsic a-Si:H layers deposited on the wafer surfaces provide excellent chemical passivation, yielding minority carrier lifetime approaching the theoretical limits: as a demonstration, carrier lifetime >50 ms could be achieved with a-Si:H layers deposited at CSEM on 500 µm thick wafers with a resistivity of 20 kOhm·cm. Such carrier lifetime is among the highest values ever reported to our knowledge for silicon with contactable passivation layers. Then, doped a-Si:H layers allow for the selective collection of one type of carriers while blocking the other type, with p-type doped layer acting as hole selective contact, and n-type doped layer as electron selective contact. In 2016, an advanced process for the intrinsic a-Si:H layer was developed on CSEM platform, to maximize passivation properties for complete in/ip SHJ cell precursor stacks while keeping a minimum thickness of about 4 nm for the intrinsic a-Si:H layer. This triggered an improvement of the electrical performance of the developed SHJ cells, with fill factor values up to 81.8% achieved for front emitter SHJ cells. Using Ag printed metallization and indium tin oxide (ITO) and aluminum-doped zinc oxide (AZO) for the front and rear TCO layers, SHJ cells with an efficiency up to 23.44% were then demonstrated on CSEM SHJ solar cell platform.



EFFICIENCY	VOC	JSC	FF
23.63 %	726.4 mV	40.15 mA/cm2	81.03 %

Figure 1: Schematic representation of the symmetrical structure of bifacial silicon heterojunction solar cell. Table detailing performance of the record SHJ devices fabricated in CSEM platform.

At wafer level, special additives were developed to enable low reflectivity after texturing (<9% at 740 nm), while processes for the management of the silicon bulk and surface qualities were developed, yielding improved carrier lifetime of the produced SHJ precursors. Management of front and back optical losses were conducted, by minimizing the a-Si:H thickness, implementing high mobility TCO (with >100 cm^2/V·s), using fine-line printing (<40 µm wide fingers) and adapting the cell with the integration of dielectric layers into advanced architectures at the front and at the rear of the solar cells. The conducted developments combined with the conducted investigations of advanced functional thin films produced by PECVD, PVD and ALD define the development roadmap towards >24% efficiency for such SHJ solar cells.

Some of the developments conducted on the CSEM SHJ cell platform are further presented in 2016 CSEM technological reports: implementation of AZO to replace ITO, integration of CSEM SHJ cells into world record tandem III-V/Si solar cells, implementation of silicon hetero-contacts in an all back-contacted cell structure, as well as developments of alternative metallization and interconnection technologies for SHJ solar cells.

[1] A. Descoeudres, *et al.*, Energy Procedia, 77, 508 (2015).