Technology Platform for High-efficiency Silicon Heterojunction Solar Cells and Modules

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CSEM has set up a versatile platform for the fabrication and the characterization of silicon heterojunction solar cells and modules. Innovative and industry-relevant solutions are developed, aiming for high conversion efficiencies at competitive manufacturing costs. The topics covered at CSEM include wafer bulk improvements, wafer texturing and cleaning, depositions of ultra-thin passivating and contacting layers, depositions of low-cost and/or high-mobility transparent conductive oxides, advanced cell metallization and interconnection processes, various characterization techniques, encapsulant assessment and formulation, as well as module design and optimization for maximum performance and reliability.

Silicon heterojunction (SHJ) solar cells present the decisive advantages to combine a high efficiency (potential for modules with >22% 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 passivation, the SHJ bifacial cell architecture is also ideally suited for thin wafers integration.

A strong emphasis is set in CSEM on the development of a complete, performant and flexible platform covering all aspects of production and characterization of SHJ solar cells and modules, from as-cut wafers to optimized modules, including several testing structures to assess particular materials and processes impact on performance and reliability. A focus is set at the interface between cell and module, for which a cross-disciplinary R&D team has been established in 2019. This cell to module technological platform allows CSEM to conduct advanced R&D projects to develop new processes, materials, production and metrology equipment, as well as advanced concepts for improved performance, reliability and/or reduced production costs; and also to provide services and small batch production for its customers.

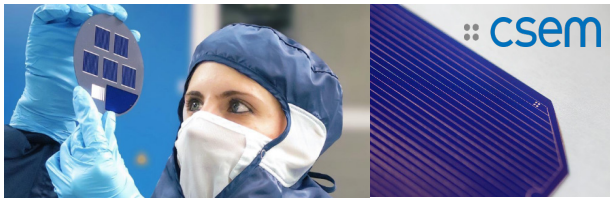

Figure 1: Illustration of test structures used to first achieve 24.2% certified efficiency on 4 cm² solar cells early 2019 using all CSEM processes, transferred to industrial silicon wafers.

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. Following proper silicon wafer specifications combined with a-Si:H and TCO process developments, CSEM could demonstrate in 2019 >750 mV of implied VOC on both commercial n-type and p-type Cz wafers, demonstrating the key asset of the SHJ technology. CSEM developed a complete set of testing structures at cell and module levels, enabling to perform detailed performance losses analysis, accounting for edge effects, passivation, series resistance breakdown, optical analysis, cell to module losses following varying metallization and interconnection schemes, and isolation of key contributions to losses. This enabled for continuous improvement of CSEM baseline SHJ solar cells, enabling to achieve in 2019 up to 24.4% efficiency for a 220 cm² cell on a n-type Cz wafer, and up to 23.6% efficiency for a 220 cm² cell on a p-type Cz wafer, using a busbarless printed metallization grid.

Table 1: Summary of high-efficiency SHJ solar cells developed on CSEM flexible R&D platform.

Metallization	Grid	Cell area	Voc	Jsc	FF	Eff.
Cu plating	4 BBs	Full 6''	742	39.4	81.7	**23.9**
Cu plating	4 BBs	221 cm²	741	39.6	83.2	**24.3**
Ag printed	BB-less	Full 6''	740	39.5	82.1	**24.0**
Ag printed	BB-less	221 cm²	738	39.9	83.0	**24.4**

CSEM developed to maturity a copper plating process enabling to achieve high performance and high reliability. This enables to achieve 24.3% efficiency on a CSEM SHJ solar cell with a 4 busbars metallization design. An efficiency certified at 24.73% could be achieved using CSEM plated grid on industrial partner cell precursor, for a 4 busbars cell, while reliability could be demonstrated with modules passing 3 times IEC test standards.

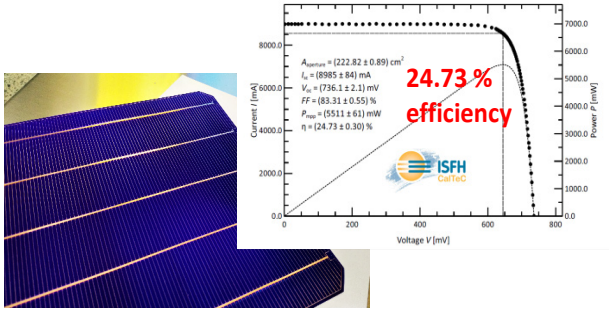

Figure 2: 24.73% certified efficiency demonstrated for a 4 busbars SHJ solar cell using CSEM plated metallization grid.

The solar cells achievements in 2019 are further detailed in [1].

CSEM established materials and processes for optimum integration of SHJ solar cells, providing its own encapsulant formulation, as well as key know-how for multi-wire as well as soldered interconnection approaches.

[1] A. Descoeudres, *et al.*, The versatility of passivating carrier-selective silicon thin films for diverse high-efficiency screen-printed heterojunction-based solar cells, PiP, (2020).