Above 30% Efficiency Tandem Solar Cells using Silicon Heterojunction Bottom Cell

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The CSEM PV-center and the National Renewable Energy Laboratory (NREL, USA) have jointly fabricated more than 30% efficient tandem solar cells using silicon bottom cells. This result sets a benchmark in the development of such silicon based tandem cells, approach followed by many groups worldwide to surpass the theoretical limit of silicon single-junction solar cells. The top cell was made of either GaInP or GaAs and fabricated by NREL, while the bottom cells were silicon heterojunction solar cells fully manufactured in CSEM fabrication platform. Special focus was set on optimizing the silicon cell for application in such tandem configuration. The top and bottom cells were mechanically stacked in 4-terminals tandem devices, and world record certified efficiencies of respectively 30.45% and 30.63% were achieved for GaInP/SHJ and for GaAs/SHJ tandem cells.

Within the next years the conversion efficiency of Silicon single-junction solar cells will converge towards its practical limit between 26% and 27% under one-sun operation. This performance limit can then be overcome by adding one or more cells with bandgap energy larger than 1.1 eV to the silicon cell. Thereby, short-wavelength photons are converted in the higher-bandgap top cells, reducing thermalisation losses in the solar cell and leading to the generation of an additional voltage. Simulations, based on the detailed balance limit, have shown that dual-junction cells with Si bottom cells can achieve theoretical efficiencies over 45%. The optimum top cell must feature a bandgap energy in the range of 1.6 to 1.8 eV and a high external radiative efficiency. In this context, large efforts are set worldwide in the development of such tandem solar cells using a silicon bottom cell, and in particular at CSEM to prepare the next generation solar cells.

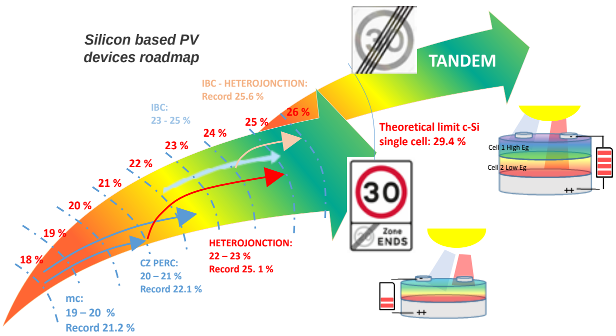

Figure 1: Schematic representation of silicon based PV devices roadmap for enhanced efficiency, with potential to overcome the 30% efficiency limit with tandem cells structures.

The Silicon heterojunction solar cells (SHJ) developed at CSEM are well suited for integration in tandem cells. SHJ cells have passivating contacts enabling for its key advantage of high operating voltages, and further provide excellent response in the long wavelength range, contributing to record 1-sun efficiencies (up to 23.44% achieved on CSEM fabrication platform). A challenge for SHJ cells remains the parasitic light absorption in the thin a-Si:H and TCO films especially for short wavelengths at the front side of the cell. The integration of a SHJ cell in a tandem device therefore cancels this intrinsic limitation of SHJ cells: excellent conversion of short-wavelength radiations up to typically about 700 nm is realized in the top cell and efficient conversion of the longer-wavelength radiations is achieved in the SHJ bottom cell. To demonstrate the potential of such tandem solar cells structures implementing a SHJ bottom cell, two different structures were tested in collaboration with NREL and EPFL. The CSEM SHJ bottom cells were combined with top cells fabricated by NREL, either a rear-hetero-junction GaInP top cell or a GaAs top cell. The fabricated top and bottom cells were then mechanically stacked to form 4-terminals III-V/Si tandem cells, with each of the sub-cell being operated independently at its own maximum power point.

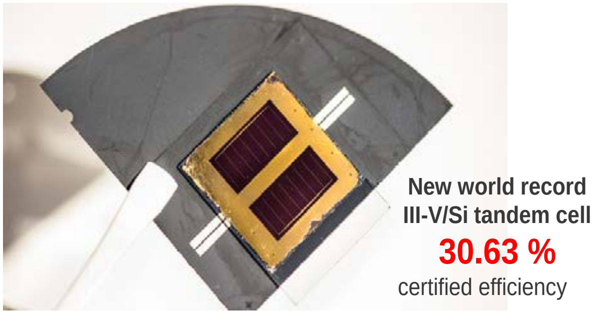

Figure 2: Picture of 1 cm² III-V/Si tandem cells mechanically stacked, demonstrating up to 30.63% record efficiency.

Main electrical characteristics of the devices are summarized in Table 1. The accurate analysis of the cumulative tandem cell efficiency requires the bottom cell JV-curve to be measured while the top cell is kept at its maximum power point. Under these conditions, resulting cumulative tandem cells efficiencies of 30.45% and of 30.63% are achieved.

Table 1: Characteristic parameters of the NREL certified JV-curves of the GaInP/SHJ and GaAs/SHJ tandem cells fabricated.

	V_{OC} [mV]	J_{SC} [mA/cm²]	FF [%]	cell efficiency [%]	tandem cell efficiency [%]
GaInP/Si tandem, A= 1.005 cm²					
GaInP top cell	1448.3	15.30	85.1	18.83	30.45
Si bottom cell	691.9	21.49	78.2	11.62	
GaAs/Si tandem, A= 1.006 cm²					
GaAs top cell	1090.9	28.98	81.5	25.61	30.63
Si bottom cell	669.1	9.53	78.8	5.02	

To the best of our knowledge, these are the III-V/Si multi-junction solar cells with the highest one-sun efficiency ever reported. This efficiency exceeds the theoretical efficiency limit (29.4%) and the record experimental efficiency value (26.33%) of a Si single-junction, 1-sun solar cell and is also higher than the record efficiency 1-sun GaAs device (28.8%). It is also close to the record 1-sun efficiency for dual-junction solar cells of 31.1%, which was achieved with monolithic GaInP/GaAs devices. It therefore demonstrates the high potential of such tandem solar cells using SHJ bottom cell. This work opens the route for testing/developing new processes, materials and concepts enabling to further boost, establish PV as performant energy source.

• NREL, USA