New architecture and bonding process for III-V//Si tandem solar cells

Phuong-Linh Nguyen[1,2,3], François Chancerel[2,3], Philippe Baranek[1,2], Oliver Hoehn[4], David Lackner[4], Frank Dimroth[4], Marco Faustini[5], Stéphane Collin[2,3], Andrea Cattoni[2,3]

[1] EDF R&D, EFESE, Technologie du Solaire, Palaiseau, France
[2] Institut Photovoltaïque d'Ile-de-France (IPVF), Palaiseau, France
[3] Centre de Nanosciences and Nanotechnologies (C2N), CNRS, University Paris-Saclay, Palaiseau, France
[4] Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany
[5]Laboratoire Chimie de la Matière Condensée de Paris, Sorbonne Université, CNRS, Collège de France, Paris, France

Conventional single-junction solar cells have a theoretical maximum efficiency of 33.7 %. In order to overcome this limit, multi-junction solar cells represent a promising option. The combination of several absorber materials enable a better use of the solar irradiance spectrum. If an ideal material combination is selected, a two-terminal (2-T) tandem solar cell can reach an efficiency of 42.7% under one sun illumination. In this field, research on III-V//Si tandem solar cell attracts more and more attention. A state-of-the-art efficiency of 34.1% has been demonstrated by Fraunhofer ISE with 3-junctions, 2-T tandem fabricated by direct wafer bonding of III-V on Si [1, 2]. The main drawbacks of this technology are its cost and its scalability into an industrial process.

In this project, we are developing an industrially scalable and low-cost method to bond the III-V top solar cell on the silicon bottom cell using transparent conductive layers (TCLs). The proposed architecture (shown in Fig. (a)) is based on a III-V on Si tandem solar cell. Electromagnetic simulations show current matching (19.5 mA/cm^2) equivalent to a III-V on Si tandem using direct wafer bonding. Moreover, thanks to the presence of low refractive index TCLs ($n \leq 1.5$), our design allows the photon recycling effect in the top cell. Numerical calculations demonstrate that this effect leads to an absolute efficiency enhancement up to 0.8 % as compared to the direct bonding architecture (see Fig. (b)), resulting in an efficiency of 37.2%.

We have developed the transparent and conductive sol-gel derived and hybrid materials used for the different TCLs. Electrical contact between TCLs and the two sub-cells is ohmic with low contact resistivities, resulting in a total voltage loss of only few mV. We also developed a bonding process based on a conductive polymer and compatible with the TCLs, III-V and TOPCon Si solar cells. The bonding is performed in air, it does not require any wafer polishing and it is robust versus particle contamination. First prototypes of TOPCon Si solar cells bonded on glass (see Fig. (c)) showed no visible defects or edge defects and high stability, also against different organic solvents. The development of the complete III-V on TOPCon Si tandem solar cells is currently in progress.

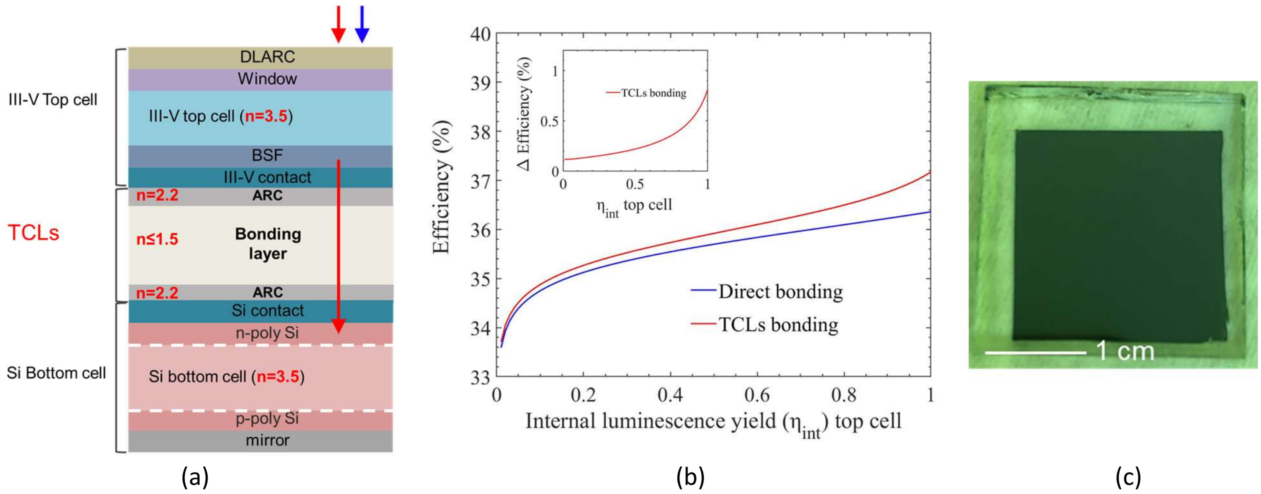

Figure. (a) Architecture of the optimized tandem using TCLs bonding (b) Efficiency enhancement with TCLs bonding compared to direct bonding architecture (c) Photo of a TOPCon Si solar cell bonded on glass using a conductive polymer.

[1] L. David *et al., Two-Terminal Direct Wafer Bonded GaInP/AlGaAs//Si Triple-Junction Solar Cell with AM1.5g Efficiency of 34.1%*, Solar RRL **2000210** (2020)
[2] R. Cariou *et al.*, *III–V-on-silicon solar cells reaching 33% photoconversion efficiency in two-terminal configuration*, Nature Energy **3**, no. 4, pp. 326–333 (2018)