HETONAN: High efficiency tandem solar cells based on III-V nanowires on silicon

1- Relevance of the Project strategy

In the past 10 years, the photovoltaic (PV) industry has drastically reduced the fabrication cost of modules, from 4 $ down to less than 0.6 $ per Watt-peak[1]. This latter value tends to stabilize. As a consequence, the module represents in 2013 only 22% of the final cost of a rooftop installation[2]. It means that further cost reduction for PV installation mainly relies on better module efficiency in order to increase the power delivered per m². For main-stream photovoltaics based on crystalline Si, the efficiency, which lies today between 20% for high quality commercial modules and 25.6% for laboratory prototypes, cannot exceed the fundamental Shockley-Queisser limit of 30%. To reach a higher efficiency, alternative technological approaches have been proposed.

One of the enabling technologies is based on multi-junction solar cells, coupling several materials and band-gaps to optimize absorption of the solar spectra. They have achieved the highest efficiencies of any PV technology with a record of 44.7% under concentrated sunlight (297 Suns) using quadruple solar cell designs, based on wafer bonding[3]. Each subcell type converts a certain range wavelength of the solar spectrum: short wave radiation, medium wave radiation or infrared. They are connected in series using tunnel junctions. But their large deployment is hindered by expensive processes and substrates (Ge or III-V).

It is possible to reach high conversion efficiency (30%) at a cost compatible with terrestrial applications by combining "a top cell" of high-bandgap energy (1.7 eV) with a Si "bottom cell". It raises the thermodynamic efficiency limit from 30% to 39%[4] (for a planar device under 1 sun illumination). The direct growth of planar III-V films on Si substrate is difficult to implement due to the strong lattice mismatches (except for GaP) and the formation of antiphase boundaries (growth of polar materials on non-polar Si). This prevents obtaining high quality III-V planar films. To overcome these limitations, we propose to use a concept mixing III-V nanowires (NWs) technology for the top cell and a standard Si bottom cell.

Semiconductor NWs have recently emerged as very promising candidates for a new generation of PV devices[5]. Thanks to the strain accommodation by the free lateral surface and the small footprint on the substrate, NWs can be grown with a high structural quality on mismatched substrates. Moreover, NW arrays have very attractive optical properties: low optical reflectance and strong capability for efficient light trapping leading to an increased absorption in comparison to thin films. Therefore, III-V NWs are ideal candidates to build a tandem cell combining them with a planar Si cell.

The project targets the fabrication of such hybrid tandem cells and should lead to a good compromise between high conversion efficiency and reduced production cost. In-depth studies combining theoretical modeling, material growth, processing and characterization in an active feedback loop will be performed. The technological approach we propose is innovative and falls within the strategies developed by the European PV community: development of high efficient devices. It is in-line with "DEFI 2 – ENERGIE PROPRE, SURE ET EFFICACE" and fits with 2 axes: "axe 2 : Captage des énergies renouvelables et récupération des énergies de l'environnement » and with "axe 1 : Exploration de concepts en rupture". Indeed, it targets the proof-of-concept of a new photovoltaic technology based on III-V nanowires and planar Si, which does not exist today. On one hand, it will produce novel PV devices combining high-efficiency and moderate-cost routes, on the other hand, this multidisciplinary research will generate fundamental knowledge and will contribute to establish new state-of-the-art in nanomaterial growth and processing technologies. HETONAN will make a significant contribution in terms of local economic competitiveness. We consider that there is a National interest to develop this technology. This objective requires close interaction between specialists of NW growth, PV technology and modeling and characterizations. These areas correspond to the recognized fields of expertise of the partners of this project.

Although the design, growth and processing of NW solar cells are challenging, the demonstration of such devices is feasible over 42 months based on recent progress achieved by the partners, especially in terms of III-V NW growth on Si and understanding of nucleation mechanisms, formation of radial heterostructured NWs and the demonstration of planar tunnel diodes in Si. The objective is to investigate the practical feasibility and to demonstrate the potential of this technology through achievement of promising performance indicators. If the

1 http://pvinsights.com/
2 P. Verlinden et al., 28th EU PVSEC, 2013
3 http://phys.org/news/2013-09-world-solar-cell-efficiency.html
4 R.R. LaPierre, J. Appl. Phys. 110, 014310 (2011); doi: 10.1063/1.3603029
5 R.R. LaPierre et al., Phys. Status Solidi RRL 7, No. 10, 815–830 (2013) / DOI 10.1002/pssr.201307109

targeted proof of concept stage is successful, it will justify further industrial research and development efforts in order to bring the technology to maturity. A careful attention will be paid to any potential patent that could emerge from the project. The strong scientific knowledge gained on NWs tandem solar cells through HETONAN will give a leading stand for the French research community.