Towards III-V nanowires-Si tandem photovoltaic cells

Xiao LI[1a], Marco VETTORI[1b], Andrea CATTONI[2], Céline CHEVALIER[1a],
Philippe REGRENY[1b], Mustapha LEMITI[1a], Michel GENDRY[1b], Alain FAVE[1a]

[1] Institut des Nanotechnologies de Lyon-INL, UMR 5270 CNRS, Université de Lyon,
[a)] INSA de Lyon, 69621 Villeurbanne, France, [b)] Ecole Centrale de Lyon, 69134 Ecully, France,
[2] C2N, UMR 9001 CNRS, Université Paris Sud, Université Paris Saclay, 91460, Marcoussis, France.

Contact e-mail: xiao.li@insa-lyon.fr

Photovoltaics is known as one of the most important renewable energy sources converting solar energy directly into electricity. Benefiting from abundancy, cheapness and environmental sustainability, Si has become an indispensable material in this domain. Since the maximum theoretical efficiency of a single junction Si solar cell is only 29.4% [1], 2-terminal Si based tandem cells are studied to overcome this value by using III-V semiconductors as top cell, so as to achieve optimal bandgap matching between sub-cells [2]. The biggest challenge for III-V films on Si consists in the lattice mismatch, a problem which can be solved by replacing thin films with nanowires (NWs), where mismatch-induced strains can be relaxed on the sidewalls thanks to the small lateral dimension and high surface area of NWs. In our project, a top cell consisting of an ordered array of core-shell GaAs/GaAlAs NWs is fabricated by self-catalyzed vapor-liquid-solid (VLS) molecular beam epitaxy (MBE) on a bottom cell of crystalline Si (Figure 1). Considering the epitaxial nature of the NW growth, it is necessary to employ a Si (111) bottom cell as substrate to ensure a high vertical NW yield [3]. Moreover, a low-resistance p^{++}/n^{++} type tunnel junction must be implemented on the top of the Si (111) bottom cell to electrically connect the two sub-units.

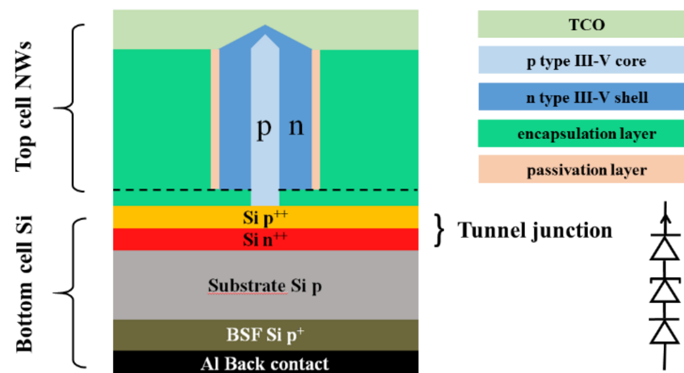

Figure 1 : Schematics of targeted tandem solar cell

In order to introduce a p^{++}/n^{++} tunnel junction in Si (111) substrates, a facile and economical method combining spin-on doping and proximity rapid thermal diffusion (RTD) is used [4]. Boron is used as acceptor and phosphorus as donor. Electrochemical capacitance voltage (ECV) profiler is used to characterize the carrier profiles. The compensation of phosphorus (in the emitter region) with boron atoms is studied carefully in order to realize a thin p^+ doped layer on the surface. The main difficulty is to achieve very high doping concentrations with very sharp doping transitions due to the solid solubility of B in Si is about 4 times lower than that one of P [5]. Every possible influencing factor in the diffusion process is considered to optimize the doping profile, such as heating rate, annealing ambient, annealing temperature and time. One of our typical doping profile is shown in Fig. 2a. The concentration of holes

is higher than 10^{20} cm^{-3} on the surface, while the depth of p^{++} type layer is about 60 nm. p^{++}/n^{++} Si tunnel diodes are made to characterize the electrical properties of the tunnel junction. Moreover, we study the influence of the tunnel structure on the surface recombination of the Si bottom cell and the modification of the doping profiles after the NW growth by MBE in the 550-600°C range.

In order to verify the possibility of obtaining regular arrays of vertical structures, p-GaAs/p-i-n GaAlAs core/shell NWs were grown on Si (111) substrates patterned with SiO_2 masks. The growths were performed by MBE via self-catalyzed VLS mechanism, and promising results were achieved [6][6]. As a matter of fact, we developed a reproducible protocol to obtain high and uniform vertical yields (80-90 %) over patterned areas as large as 0.9 × 0.9 cm^2 (Fig. 2b): such an encouraging outcome constitutes another step forward towards the realization of our NW-based tandem solar cell.

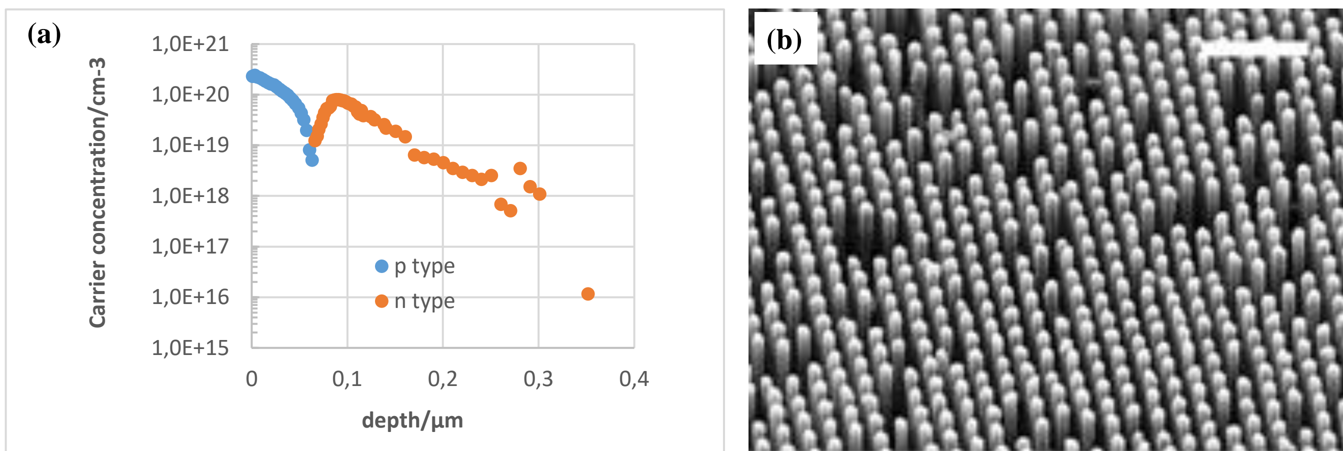

Figure 2: (a) Carrier concentration of a p^{++}/n^{++} type tunnel junction measured by ECV. (b) Ordered array of GaAs/GaAlAs core/shell NWs on Si (111) with high vertical yield (80-90 %); white scale bare corresponding to 2 µm.

Keywords: tandem solar cell, Si tunnel junction, III-V nanowires, VLS-MBE, spin-on doping, patterned substrates, proximity rapid thermal diffusion

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This project is supported by the ANR project Hetonan (ANR-15-CE05-0009).