Selective-area growth of III-V nanowire arrays on Si and their application for tandem solar cells

C. Tong,[1,2] A. Delamarre,[1] R. De Lépinau,[1,2] A. Scaccabarozzi,[1] F. Oehler,[1] J.-C. Harmand,[1] S. Collin,[1,2] A. Cattoni[1,2]
[1] Centre de Nanosciences et de Nanotechnologies (C2N), CNRS, Université Paris-Saclay
[2] Institut Photovoltaïque d'Île-de-France (IPVF), Palaiseau, France

The photovoltaic market is dominated by crystalline silicon (Si) solar cells with a record efficiency of 26.7% approaching the detailed balance limit. Tandem solar cells combining a III-V semiconductor top cell with a Si bottom cell are currently one of the most studied routes to exceed 30% efficiency. Tandem solar cells fabricated with direct bonding hold the current state of the art (35.9%, [1]), but this technology is not industrially viable due to the high cost of processing and III-V substrates. Direct epitaxy of III-V on Si, using a metamorphic graded buffer to accommodate the different lattice constants and thermal expansion coefficients, remains a challenge (25.9%, [1]).

The possibility of growing high quality III-V nanowires (NWs) on mismatched substrates represents an elegant way of fabricating a III-V on Si tandem solar cell, avoiding both the use of expensive III-V substrates and the difficult integration of III-V on Si. While III-V NWs on a Si tandem cell can theoretically exceed 33% efficiency [2], convincing proof of concept remains elusive with only modest efficiency (11.1%, [3]), mainly limited by the V_{OC} and FF of the III-V NW-based top cell.

In this work, we present a robust selective-area growth method for GaAs-based NWs on p-Si(111) substrates by molecular beam epitaxy, leading to very high NW vertical yields (close to 100%). Using this method, a Ga-catalysed p-GaP(stem)/p-GaAs(core)/i-GaAs (shell)/n-InGaP(shell) radial hetero-junction NW solar cell was fabricated and characterized. Optoelectrical characterization of encapsulated and contacted NWs yielded devices with an efficiency of 3.68%, and a state-of-the-art V_{OC} for NW arrays on Si of 0.65 V (Figure a, b). The high intrinsic quality of the NWs has been confirmed by hyperspectral imaging with a quasi-Fermi level splitting of 0.84 eV obtained under a 1 sun illumination (maximum achievable V_{OC}), indicating that the NW cell performances are limited rather by contacts resistance losses (Figure c). One-dimensional SCAPS simulations suggest the presence of a high n-InGaP/ITO contact resistance [4]. This problem has to be ascribed to the relatively low doping concentration of the III-V NWs doped with amphoteric Si, and we demonstrate that Te-doped III-V NWs can achieve higher doping concentrations [5]. A new generation of axial p-GaP/p-GaAs/n-GaAsP hetero-junction NW solar cell is under fabrication with an improved n-III-V/ITO contact resistance. The latest results will be presented together with a comparison between radial vs axial hetero-junction NW solar cells.

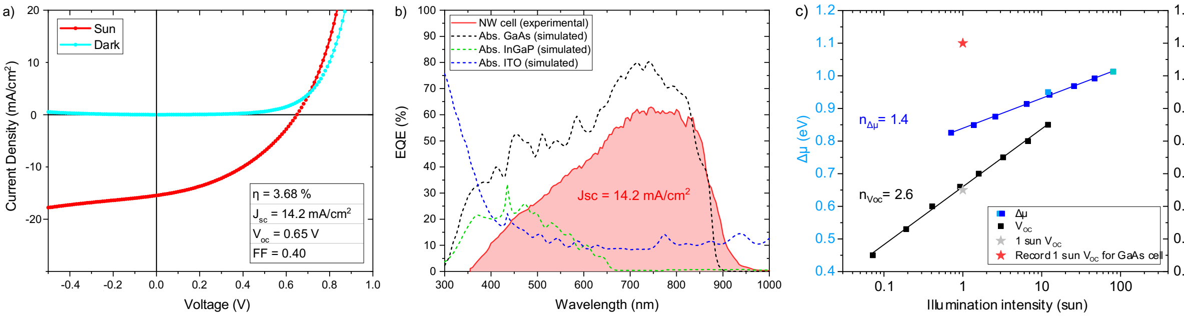

Figure - **(a)** JV curves in the dark (blue) and under a 1 SUN (red), **(b)** EQE of the GaAs/GaInP NW solar cell (red) and simulated absorptions for GaAs, GaInP and ITO (dashed). **(c)** Evolution of the quasi-Fermi level splitting (Δμ, blue) and the open-circuit voltage (V_{OC}, black) with illumination intensity [4]. The record V_{OC} for planar GaAs cell (red star) corresponds to the one obtained by Alta Devices.

[1] M.A. Green et al., « Solar cell efficiency tables », Prog. Photovolt. Res. Appl. 29, 657 (2021).

[2] R.R. LaPierre, « Theoretical conversion efficiency of a two-junction III-V nanowire on Si solar cell », J. of Appl. Phys. 110, 014310 (2011).

[3] Yao M. et al., « Tandem Solar Cells Using GaAs Nanowires on Si: Design, Fabrication, and Observation of Voltage Addition », Nano Letters 15, 7217 (2015).

[4] C. Tong et al., « GaAs/GaInP nanowire solar cell on Si with state-of-the-art Voc and quasi-Fermi level splitting », Nanoscale 2022, DOI: 10.1039/d2nr02652j

[5] C. Tong et al., « Cathodoluminescence mapping of electron concentration in MBE-grown GaAs:Te nanowires », Nanotechnology 33, 185704 (2022).