Carrier extraction optimization in record V_{oc} GaAs/GaInP nanowires on Si for tandem solar cells

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Direct growth of high structural quality III-V nanowires (NWs) on mismatched substrates such as Si, represents an elegant way to fabricate a III-V on Si tandem solar cell avoiding both the use of expensive III-V substrates and the difficult integration of III-V semiconductors on Si [1]. In principle, III-V NW based top cells with an optimal bandgap at 1.7 eV can be directly grown on a Si bottom cell and efficiencies exceeding 33% at AM1.5G have been predicted for such architecture [2]. The success of this strategy relies on the precise control of the NWs growth on Si(111), their crystal structure, doping, junction formation, passivation, and opportune contacts. At present, state-of-the-art NW solar cells are based on gold catalysed axial GaAs homo-junctions grown on GaAs(111)B by MOCVD with an efficiency of 15.3% [3]. Ga-catalysed GaAs NW solar cells directly grown on Si(111) stays behind, with efficiencies of 7.74% for axial homo-junction [4] and 4.1% for radial homo-junctions [5], mainly limited by relatively poor V_{OC} (<0.39 V) and FF (<0.4).

In this work, we fabricate and characterize the top cell consisting of Ga-catalysed n-InGaP(shell)/p-GaAs(core)/p-GaP(stem) NW radial heterojunctions grown by Molecular Beam Epitaxy onto inactive p-type Si(111) substrates (inset Fig. 1.b). The fabrication steps will be presented and the several challenges relating to it addressed. The optimization of key processing steps ensures a perfect selective growth and high yield of vertical NWs (100% reached recently! See Fig. 1.a). Optoelectrical characterization of encapsulated and contacted NWs yielded heterojunction devices with an efficiency of 3.7%, along with a V_{OC} of 0.65 V (Figure 1.b), higher than the reported state-of-the-art GaAs NW core-shell junctions [5]. The high intrinsic quality of the NWs has been confirmed by hyperspectral imaging with a quasi-Fermi level splitting of 0.88 eV obtained under 1 sun illumination (maximum achievable V_{OC}), indicating that the NW cell performances are limited rather by contacts resistance losses. At the front contact, electron extraction is hindered by insufficient carrier concentration in the NW n-type shell due to the amphoteric nature of the Si dopant. A cathodoluminescence study on tellurium as a promising alternative to Si dopant will be presented (Fig. 1.c). At the back contact, hole extraction is impacted by the carrier concentration in the p-GaP stem, introduced in the NWs to catalyse their vertical growth. One-dimensional SCAPS simulations on the effect of GaP doping on the magnitude of the barrier for hole extraction in the NW cell will also be presented (Fig. 1.d), along with a cathodoluminescence study aimed at quantifying the hole concentration in the p-GaP stem.

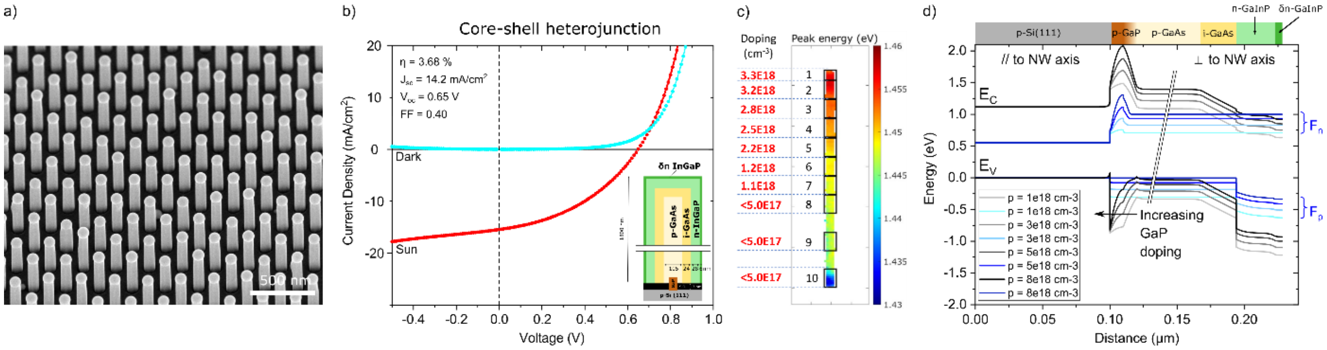

Figure a) As-grown p-GaAs(core)/p-GaP(stem) with 100% vertical yield. **b)** JV-characteristics (dark and under AM1.5G) of the radial heterojunction NW cell (architecture shown in inset). **c)** CL peak energy map of a single Te-doped GaAs NW with associated electron concentrations. **d)** Band diagrams obtained from 1D SCAPS simulations under AM1.5G and V_{MPP} bias for different GaP stem doping concentrations.

References

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