Nanowires for tandem junction solar cells.

Magnus T Borgström

Solid state Physics, Lund University, Lund, Sweden
Email:magnus.borgstrom@ftf.lth.se, web site: http://www.nano.lth.se/; www.ftf.lth.se

Semiconducting nanowires have been recognized as promising materials for high-performance electronics and optics where optical and electrical properties can be tuned individually, where the nanowires due to excellent light absorbing properties [1] have been suggested for future high efficiency solar cells [2, 3]. Especially, the geometrical shape of the nanowires offers excellent light absorption. Using nanowires covering only about 12 % of the surface, record efficiencies of VLS grown nanowires has been reported for InP nanowires of 13.8 % and for GaAs nanowires of 15.3%, and recently 17.8 % efficiency was reported for etched out top down fabricated nanowires.

In order to further optimize the performance of nanowire photovoltaics (PV), and integrate them on Si in a tandem junction configuration, nanowires with dimensions corresponding to optimal light harvesting capability are necessary. We developed nano imprint lithography for patterning of catalytic metal particles with a diameter of 200 nm in a hexagonal pitch of 500 nm, for which synthesis was redeveloped since the metal particles were found to move during annealing, destroying pattern fidelity before nucleation. We found that a pre anneal and nucleation step was necessary to keep the particles in place during high temperature annealing to remove surface oxides. We intend to transfer these grown nanowires to a Si platform (existing PV), either by direct growth on Si PV, or by nanowire peel off in polymer, followed by transfer and electrical contacting, or by aerotaxy and alignment for transfer to Si.

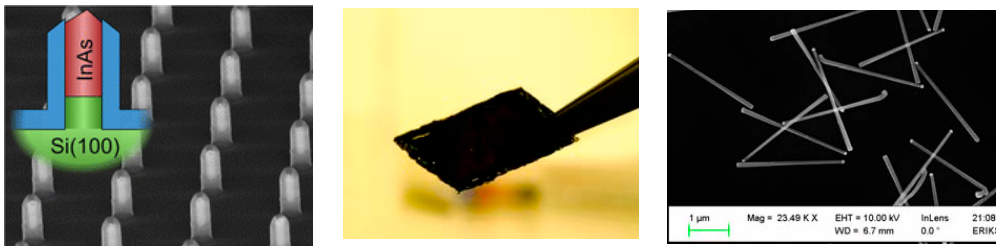

Figure 1) Three approaches for III-V nanowire –Si tandem junction formation. Left: direct growth on Silicon by template assisted selective area growth (IBM) Middle: Nanowire growth, peel off in polymer and transfer to Silicon. (Lund) Right: Aerotaxy, nanowire alignment and transfer to Silicon. (Solvoltaics, Lund)

The optimal band gap in combination with Silicon is about 1.7 eV, where we identify GaInP and GaAsP as materials for development of nanowire pn junctions by doping, the heart in a solar cell. Therefore, we investigated the effect of p doping on the GaInP nanowire growth dynamics [5]. A study of n type doping was carried out in parallel, which is still ongoing work. In order the effect on growth dynamics in situ we used optical reflectometry to determine the nanowire growth rate in real time by use of a bar coded nanowire structure. Due to the bar code, a time stamp is given and high-resolution transmission electron microscopy was used to verify the reflectometry data and energy dispersive x-ray spectroscopy in TEM was used to determine the materials composition in the nanowires. we show that the doping results in a smaller nanowire diameter, a more predominant zincblende crystal structure, a more Ga-rich composition and an increased axial growth rate. We attribute these effects to changes in seed particle wetting angle and increased TMGa pyrolysis efficiency upon introducing diethylzinc. We were unable to make electrically transparent contacts to lowly doped p type GaInP, and no back gate

response was observed to highly doped GaInP, indicating degenerate doping levels. Therefore, we demonstrate degenerate p-doping levels in $In_xGa_{1-x}P$ nanowires by the realization of an Esaki tunnel diode.

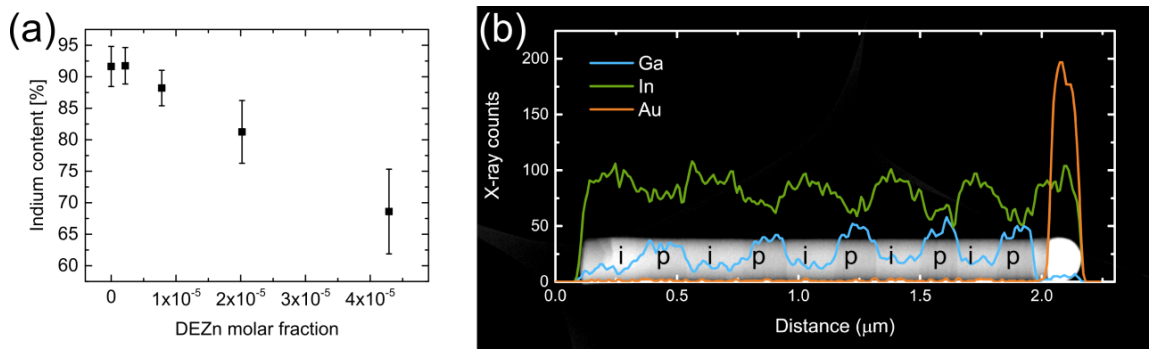

Figure 2) Composition changes to more Ga-rich $In_xGa_{1-x}P$ nanowires when adding DEZn. (a) Composition extracted from x-ray diffraction (XRD) from an ensemble of homogeneously doped $In_xGa_{1-x}P$ nanowires, at different DEZn molar fractions. Error bars indicate full-width-at-half-maximum of the XRD-peak. (b) Energy dispersive x-ray spectroscopy scan of a barcoded $In_xGa_{1-x}P$ nanowire. The nanowire composition changes in a reversible fashion to more Ga-rich when growing in the presence of DEZn.

In the long term, we intend to surpass the two junction architecture for even higher predicted efficiencies by more accurate matching to the solar spectrum by use of three and four junction geometry. A critical component working as a transparent contact between junctions is the Esaki tunneling diode. We fabricated and characterized NW tunnel diodes using the $InP/Ga_{0.3}In_{0.7}P$ material system which has a type I band alignment where the band gaps are given by 1.35 eV and 1.70 eV respectively. This bandgap combination is predicted to be suitable for a tandem solar cell, offering a maximum efficiency of 35.5% [7]. Both forward (i.e. InP (bottom) / GaInP (top)) and inverse (i.e. GaInP (bottom) / InP (top)) configurations were grown and characterized with purpose of comparing their relative benefits and promise for incorporation as active parts in tandem solar cells. From these investigations we demonstrate working tunnel diodes independent of doping polarity in the $InP/Ga_{0.3}In_{0.7}P$ material system. Note that for the inverse geometry, the nanowire peel-off and transfer technique is essential since it will allow to turn the peeled off nanowires upside down, letting the high band gap material be on top of the low band gap material for selective light harvesting. The peel-off still shows challenges, as the nanowires tend to tilt in the polymers used, either when drying the polymer, or when dissolving it in a solvent for subsequent contacting. I will discuss some of the ideas we have on how to stabilize the process.

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