BAPVC Annual Project Report

Project Title: High V_{oc} Solar Absorbers; the Missing Link for High-Efficiency, Spectral-Splitting, Solar Cells

PI: Eli Yablonovitch; **Co-PIs:** Connie Chang-Hasnain and Ming Wu
E-mail: *eliy@eecs.berkeley.edu*

Summary:

For future high-efficiency multi-junction cells, we need high V_{oc} absorbers, which could be grown as wide bandgap nano-needles. We have developed metastable high-quality core-shell nanoneedles/pillars growth of InP and InGaP directly on lattice-mismatched silicon substrates. We demonstrated single InP nanopillar solar cells with a conversion efficiency of 19.6 % and an open circuit voltage of 0.534 V under AM 1.5 G illumination, both record for InP directly grown on Si. We investigated the characteristics of high bandgap micron-sized InGaP needles and explored selective area growth for solar cell absorption enhancement.

Key Accomplishments:

One way of realizing low cost and high efficiency photovoltaic is to employ high quality III-V nanopillars synthesized on low cost substrates. We demonstrate that a single InP nanopillar grown and fabricated on silicon substrate exhibits a record power conversion efficiency of 19.6% and an open circuit voltage (V_{OC}) of 0.534 V under AM 1.5 G illumination. This is the highest efficiency and V_{OC} ever achieved for InP nanowire or nanopillar solar cell grown on a foreign substrate. This high efficiency and V_{OC} can be attributed to high-quality single-crystalline wurtzite-phased InP nanopillars grown using a novel regrowth technique to drastically reduce the dark current by three orders of magnitude. Taking advantage of dielectric antenna effect, optical absorption beyond that predicted by Lambert-Beer law is achieved over a broad solar spectrum between 400~800 nm. Together with cheaper growth substrate, less material usage, high efficiency InP nanopillar solar cell is a promising pathway in making solar energy more affordable than conventional energy sources.

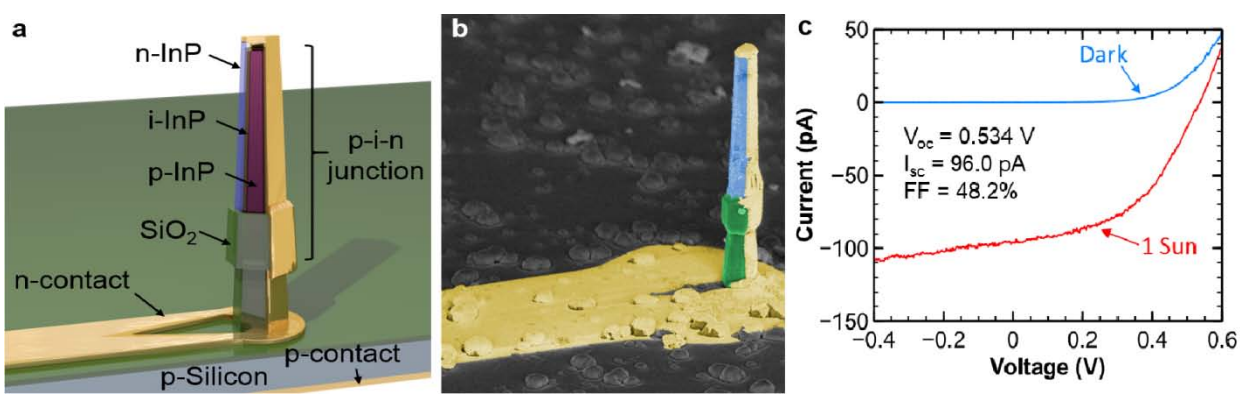

Figure 1. (a) Schematic of a single InP nanopillar solar cell fabricated on silicon substrate. (b) Corresponding scanning electron micrograph. (c) Dark and 1 sun (AM 1.5 G) IV characteristics of InP solar cell.

We also demonstrated, for the first time, single crystalline wurtzite InGaP nanoneedles with composition ordering directly grown on silicon substrate. Intense room temperature

photoluminescence emission indicates the feasibility of employing InGaP needles as an efficient high-bandgap light emitter/absorber. Though the bandgap of InGaP nanoneedle shown here is ~1.47 eV, it is possible to reach a wider bandgap regardless of the lattice mismatch constraint, benefitting from the unconventional stress relaxing mechanism facilitated by the metastable core-shell growth mode. Extraordinarily long carrier lifetimes of 190.9 ns further attested the superior surface quality of these nanoneedles with such high surface-to-volume ratios. They also developed selective area growth of nanoneedles/pillars on a patterned silicon substrate with very high density, which could be used to enhance the absorption of the nanostructures and future device performances.

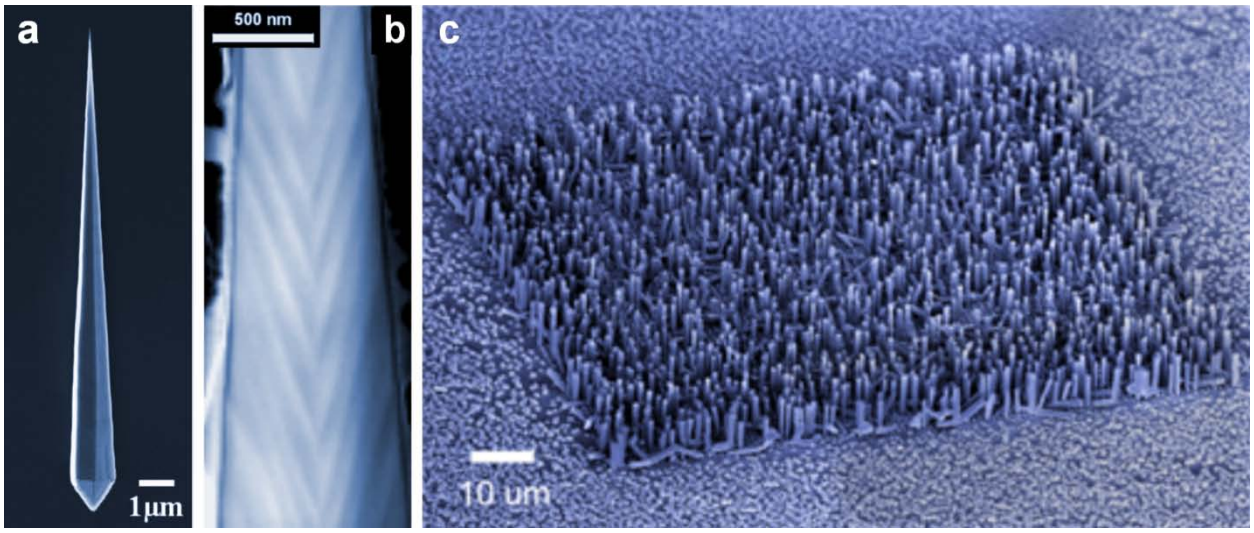

Figure 2. (a) Scanning electron micrograph of a micro-sized InGaP needle. (b) Distinctive V-shape composition ordering observed from this wurtzite-phased InGaP needle. (c) High yield selective area growth of needles on a patterned silicon substrate.

Future Work:

Future work will be focused on the following aspects: (1) Optimize site controlled growth, together with FDTD simulations, to enhance the total absorption of ordered pillar arrays. (2) Study different device designs (p-i-n junctions, layer thicknesses, front-and back surface fields, etc.) (3) Develop high bandgap claddings materials for surface passivation and transparent metal.