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:

High V_{oc} absorbers are required for future high-efficiency multi-junction cells, which could be grown as wide bandgap micro/nanopillars. The group investigated the characteristics of high bandgap micron-sized InGaP nanoneedles/pillars directly grown on lattice mismatched silicon substrates, and explored selective area growth for solar cell absorption enhancement. 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 were demonstrated by the group, both record for InP directly grown on Si.

Key Accomplishments:

One way of realizing low cost and high efficiency photovoltaics is to employ high quality III-V nanopillars synthesized on low cost substrates. The group demonstrated 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 an InP nanowire or nanopillar solar cell grown on a foreign substrate, which 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, external quantum efficiency is as high as 400% at 550nm and generally greater than 100% in the visible spectrum, beyond that predicted by Lambert-Beer law is achieved over a broad solar spectrum (Fig.1a). Specifically in the surface normal direction, the field enhancement compensates the reduced of surface exposure area, resulting in a relatively smooth I_{sc} (Fig. 1b). Similarly V_{oc} is relatively insensitive to angle (Fig. 1c) all under 1 sun illumination.

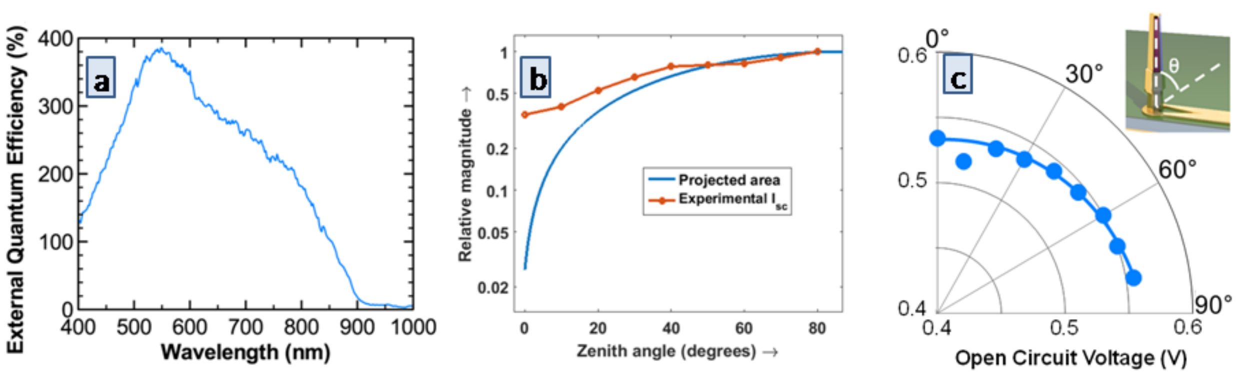

Figure 1. (a) Measured external quantum efficiency top-down illumination of a single InP nanopillar solar cell fabricated on silicon substrate. (b) I_{sc} as a function of incident angle under 1 sun (AM 1.5 G) IV characteristics of InP solar cell. (c) V_{oc} as a function of incidence angle.

It was also demonstrated, for the first time, single crystalline wurtzite InGaP nanoneedles with composition ordering directly grown on silicon substrate. Intense room temperature photoluminescence emission at 1.47 eV indicated the feasibility of employing InGaP needles as an efficient high-bandgap light emitter/absorber. By increasing Ga precursor flow it was possible to reach a wider bandgap of E_g~1.50 eV at room temperature and E_g~1.58 eV at low temperature, for $In_{0.82}Ga_{0.18}P$ intrinsic micropillars on a silicon substrate (Fig.2a-b), regardless of the lattice mismatch constraint, also presenting Fermi-level splitting values larger than 0.95 eV under 1 sun from equivalent V-I characteristic (Fig.2c). Selective area growth of micro/nanopillars on a patterned silicon substrate improved the density from 65% to 95% (Fig.2d), which can be used to enhance the absorption of the nanostructures and future device performances.

Spectral splitting PV, which laterally disperses the solar spectrum onto an array of PV materials with different bandgaps, can offer superior efficiency to tandem multi-junctions by eliminating the current and lattice matching constraints and improving robustness to spectrum variations. The spectral dispersion/splitting optics is realized using a low-cost thin-film diffractive optical element (Fig.3a), designed using computational optimization methods. A sample of the element was fabricated on photoresist, with experimental splitting efficiency shown in Fig. 3b.

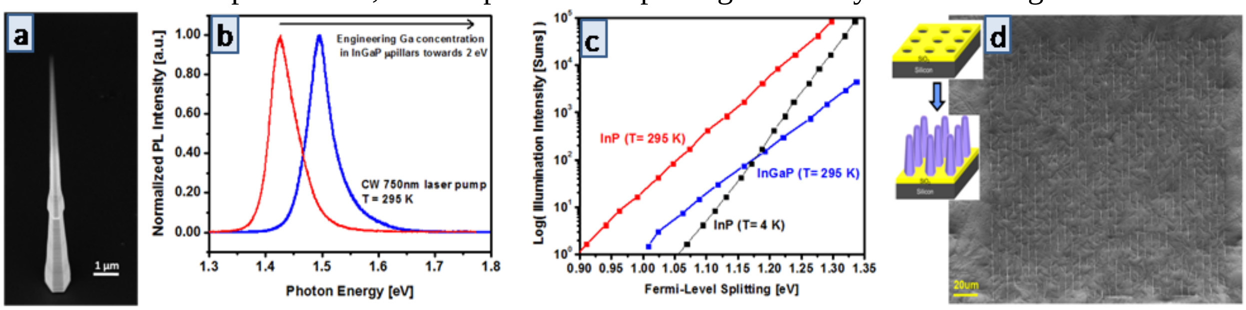

Figure 2. (a) Scanning electron micrograph of a micro-sized $In_{82}Ga_{18}P$ needle. (b) Ga content variation in InGaP towards 2 eV. (c) Comparison between Fermi level splitting from InGaP and InP micro/nanopillars. (d) High yield selective area growth of needles on a patterned silicon substrate.

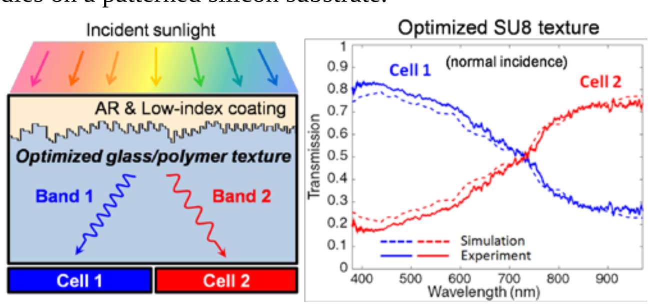

Figure 3. (a) Schematic of spectral splitting optics. (b) Optical efficiency of spectral splitting element fabricated on SU8 photoresist, showing experimental results and simulated performance of the fabricated structure. The transmission coefficient through each cell is normalized to the light passing through the sample.

Future Work:

Aspects to be taken into account in future works: (1) Continue to do growth development to increase Ga content towards 2 eV. (2) Optimize site controlled growth, supported by numerical simulations, to enhance the total absorption of ordered pillar arrays. (3) Study different device designs (p-i-n junctions, layer thicknesses, front-and back surface fields, etc.) (4) Develop high bandgap claddings materials for surface passivation and transparent metal. (5) Investigate spectral splitting designs for a larger cone of solar incidence angles for converting diffuse light. (6) Study higher resolution patterning techniques of dielectric thin films for spectral splitting.