BAPVC Annual Project Report

Project Title: Ultra high efficiency thin film multi-junction solar cell
PI: James S. Harris
E-mail: jharris@stanford.edu

Summary:

The Harris group proposed to develop significantly higher efficiency thin film c-Si based solar cells by combining multi-junctions and advanced nano-scale light management concepts in ultra-thin film devices that lend themselves to very large scale, low cost manufacturing. In the past year, they developed nanostructured solar cell modeling, epitaxial growth and fabrication. A nanostructured GaAs solar cell demonstrated improved Jsc, Voc, fill factor and efficiency. A dielectric nano-structure was designed and fabricated on c-Si thin film which demonstrated broadband and wide angle anti-reflection. They also collaborated with Solexel Inc. to apply this nanopatterning approach to commercial thin film c-Si cells.

Key Accomplishments:

A 'nanowindow' solar cell (Fig 1a, b) was developed that combines a nanostructured window layer with a planar absorber/junction. In addition to carrier confinement and higher lateral conductance of a conventional window layer, this nanostructured window layer serves as a broadband, angle-independent antireflection layer, thus eliminating the need for multi-layer antireflection coatings commonly used for GaAs solar cells. We demonstrate for the first time that both the optical and electrical properties in a nanostructured solar cell are simultaneously enhanced. This AlGaAs/GaAs nanostructured window solar cell achieved an energy conversion efficiency, η = 17.0%, J_{sc} = 24.4 mA/cm^2, V_{oc} = 0.982 V, and FF = 71% at room temperature shown in Fig. 1c. This is compared to efficiencies of less than 5% for previously reported nanostructured GaAs solar cells due to degraded V_{oc} and FF. Fig. 1d shows the bandgap-voltage offset ($E_g - qV_{oc}$) for a number of published nanostructured solar cells with absorbers of c-Si, GaAs, CdTe and a-Si against their bandgap E_g. Our nanostructured window solar cell has a band gap offset with only 0.438 V. In another AlGaAs/GaAs nanostructured window cell, we achieved a V_{oc} of 1.003 V, only 0.417 V lower than the GaAs bandgap, though the overall efficiency was 16.3%, slightly lower than the cell in Fig. 1c. The small band gap-voltage offset reflects a low non-radiative recombination loss in our AlGaAs/GaAs nanostructured window solar cells. By optimizing doping levels and growth conditions, V_{oc} and efficiency for a nanostructured window solar cell can compete with the very best planar solar cells. They also successfully peeled off 160nm thick nanostructured GaAs thin films with XeF_2 etching the Ge sacrificial layer. These peeled off nanostructured thin films show absorption enhancement over the whole spectrum from 350 nm to 900 nm indicating substantial light-trapping. The overall number of photons absorbed by this nanostructured thin film increased by 100% compared to a similar planar control film. On the device side, they fabricated a thin film GaAs solar cell with a 400 nm thick active region, which is only tenth of the thickness of the conventional thin film GaAs solar cell.

A nanoscale textured window structure with dielectric material on a high quality planar PN junction was modeled and fabricated. This nanostructured dielectric layer can passive the semiconductor surface, thus suppress surface recombination which limits the efficiency of typical nanostructured solar cells. Meanwhile, this dialectic structure with wide a bandgap

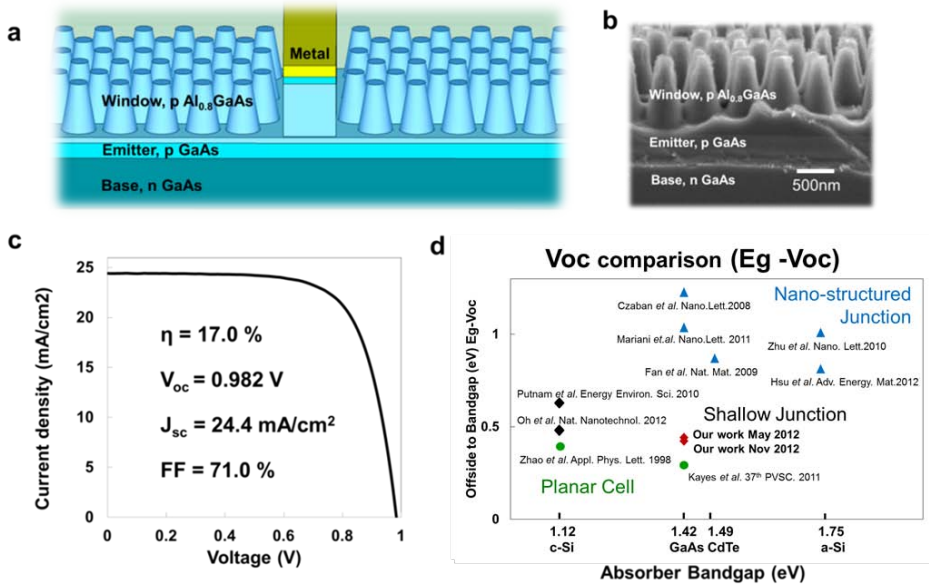

Fig. 1. Overview of an AlGaAs/GaAs nanostructured window solar cell. (a) Schematic of the device structure. (b) SEM cross-section image of the solar cell active region with $Al_{0.8}Ga_{0.2}As$ nanocone window layer. (c) 1 Sun J-V characterizations of the best sample. (d) bandgap-voltage offset (E_g/q - V_{oc}) for several published nanostructured solar cells with absorber materials of c-Si, GaAs, CdTe and a-Si.

material avoids the absorption loss. Specifically, a nanostructured dielectric layer using SiN_x on a Si solar cell is demonstrated in this project (Fig. 2a). A reflection less than 10% over a wide spectral range and incident angle was demonstrated with a 40 µm thick Si thin film (Fig. 2b). A 44% improvement of efficiency has been attained compared with a planar Si cell (Fig. 2c). They also collaborated with Solexel Inc. to apply this nanopatterning on commercial thin film Si cells.

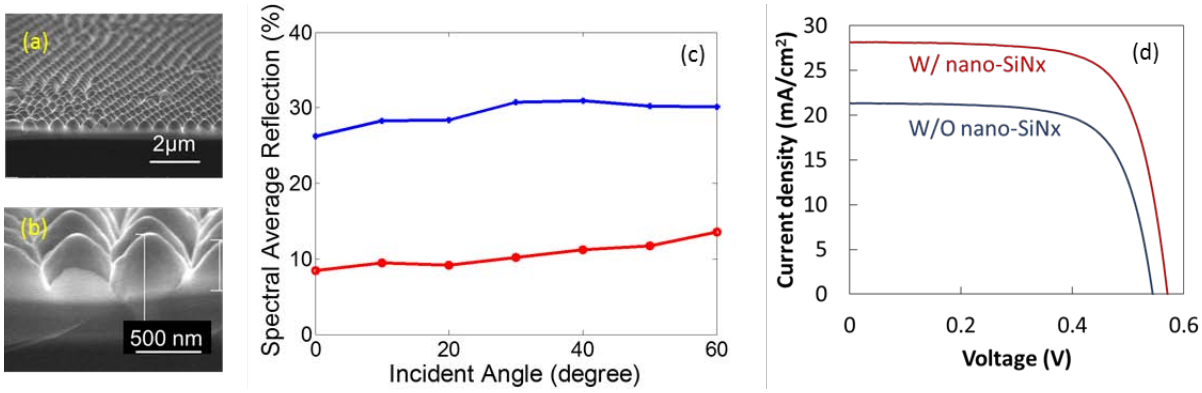

Fig. 2. (a) (b) SEM of fabricated SiN_x nano-dome array. (b) AM 1.5 spectrum weighted reflection over a wide range of incident angle. (c) 1 Sun J-V characterizations of the best sample.

Future Work:

The Harris Group will continue to develop a nanostructured single junction thin film GaAs solar cell with a high short circuit current extraction of over 20mA/cm^2 with an overall energy conversion efficiency of over 18%. They'll also fabricate light trapping nanostructures for Si thin film solar cells and collaborate with Solexel to apply this nanopatterning to commercial cells.