BAPVC Annual Project Report

Project Title: High Efficiency Ultrathin Silicon Solar Cells

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Summary:

The goal is generate high efficiency ultrathin silicon solar cells with understanding of their device physics and developing manufacturing process. The Cui group at Stanford University has reported progress in the production of $< 10\mu m$ monocrystalline silicon at a wafer scale with regular fabrication processability and experimentally demonstrated that with novel nanoscale photon management structures, 3µm-thick Si can absorb 58% of the above bandgap sunlight and 7µm of 86%. They studied the balance between excellent photon absorption and efficient electrical collection in ultrathin monocrystalline-Si solar cells, and demonstrated >80% EQEs at wavelengths from 400 to 800 nm in a sub-10- µm -thick Si solar cell, resulting in 13.7% power conversion efficiency.

Key Accomplishments:

Ultrathin monocrystalline Si cells offer the potential of saving materials, increasing manufacturing throughput, and enabling easy low-weight installation. The Cui group developed wafer-scale free-standing ultrathin monocrystalline Si fabrication with uniform thickness from 10 to sub-2µm by KOH chemical etching (see Fig1 (a,b)). These ultrathin Si exhibits excellent mechanical flexibility and bendability, as shown in Figure.1(d,e). Unexpectedly, these ultrathin Si materials can be cut with scissors like a piece of paper, and they are robust during various regular fabrication processings. To demonstrate their processability in solar cell applications, the Cui group fabricated planar and double-sided nanotextured solar cells on these free-standing ultrathin Si films. Furthermore, they also experimentally demonstrated a large light absorption enhancement by a double-sided surface nanotexture design on the free-standing ultrathin Si films. With the front-side nanocone array designed for broad-band antireflection over the entire usable solar spectrum and the back-side pattern designed for light trapping roughly in the 800−1100 nm wavelength range, light absorption in 3µm thick Si film is largely enhanced with a130%

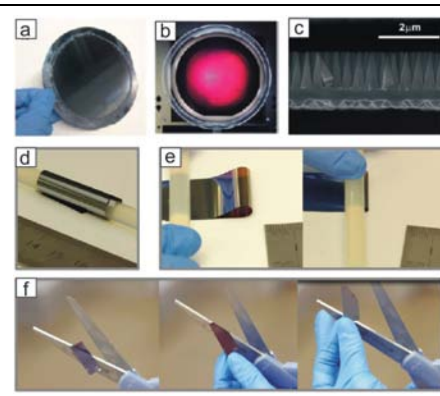

Fig. 1, (a) and (b) 4-in. wafer-size ultrathin Si films illuminated by the white light from the backside. (c) SEM image of the cross sections of a double- sided patterned films.(d) A 3µm thick Si film was wrapped around a plastic rod with diameter of 7 mm. (e) The Si film was folded and then pressed by the plastic rod. The minimum folding radius is around 1 mm. (f) Si cutting process using scissors. Ref[1] increase in Jsc, achieving 58% absorption of the above bandgap sunlight. 7μm thick Si can absorb 86% of the above bandgap sunlight.

Despite the exciting success of nanoscale texturing in light trapping, the power conversion efficiencies of nanostructured Si solar cells, however, remain below 19% for thick devices and below 11% for thin devices. The Cui group fabricated a sub-10-μm-thick Si solar cell with a 13.7% power conversion efficiency which utilizes all-back-contact design to overcome the critical problems of nanostructured devices: Auger and surface recombination. In general, nanostructured solar cells have a highly doped emitter layer at the front, fabricated by high-temperature diffusion processes. Because the diffusion profile of the dopants is dependent on the surface morphology, a nanostructured device tends to have a much deeper junction depth with a higher concentration compared with a planar device. It leads to severe Auger and surface recombination of charge carriers. Another problem of nanostructured Si solar cells is the increased surface area. Considering the fact that the surface recombination becomes more critical to device performance as the absorber becomes thinner, the increased surface area in a thin Si solar cell can lead to a severe decrease of efficiency. The Cui group designed devices with two main advantages: the all-backcontact design and the nanocones. Its all-back-contact design prevented Auger recombination loss near the front (see Fig.2), and its nanocone structure minimized the increase in surface area while enhancing the light absorption significantly. As shown in Fig. 3, it demonstrates over 80% EQEs at wavelengths from 400 to 800 nm.

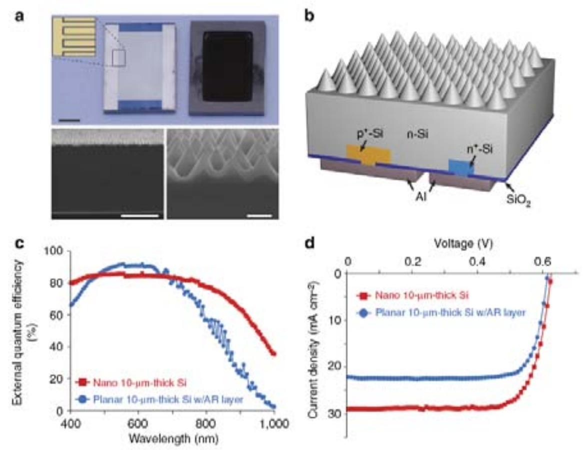

Figure 2. Ultra-thin Si nanocone solar cell. (a) Optical image and SEM cross-sectional views of the 10-μm-thick Si solar cell. (b) Schematic illustration of the device. (c) EQE data of the device and a planar control. (d) J–V characteristics of two devices in c. Ref [2]

Reference:

1. S. Wang, B. Weil, Y. Li, K. X. Wang, E. Garnett, S. Fan, and Y. Cui, "Large-Area Free-Standing Ultrathin Single-Crystal Silicon as Processable Materials," Nano Letters 13(4393)(2013).

2. S. Jeong, M. D. McGehee, and Y. Cui, "All-back-contact ultra-thin silicon nanocone solar cells with 13.7% power conversion efficiency," Nature Communications 4(2950) (2013).

Future Work:

Future work focuses on the push for higher efficiencies in the 10-20μm Si solar cell. This goal can be accomplished via two methods: 1) producing a heterstructured intrinsic thin-layer (HIT) solar cells; 2) good passivation with an oxide layer and careful surface preparation of ultrathin Si solar cells. The goal is to improve the 13.7% efficiency to 17.5%, and then further to over 20%. 3) Develop scalable and low-cost manufacturable process to generate thin Si with low material loss.