BAPVC Annual Project Report

Project Title: Thin Si HIT Cells With High Performance Metasurfaces Light Trapping and Passivation

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Summary of Key Accomplishments:

To realize the ambitious goal of superior HIT cell performance in thin (< 50 micron) cells relative to conventional HIT cells, advanced light trapping and state-of-the-art passivation are required of high lifetime materials. To this end, we have in the last year characterized 1) reflectance of high aspect ratio, high lifetime Si structures defined by dry etching, and report what is to our knowledge a **<u>new world-record low angle/spectrum averaged reflectance for Si of R = 0.45 %</u>** from λ = 400-950 nm and 0-50 degree incidence angle 2) and bulk recombination lifetime in the few-100s microsecond range for dry etched and passivated surfaces and passivated 15 micron tall wires and 3) few-microsecond range bulk recombination lifetime for high-aspect ratio (70 micron tall) passivated wires fully removed from their substrate, under peel-off conditions representative of a Si cell mechanical liftoff process.

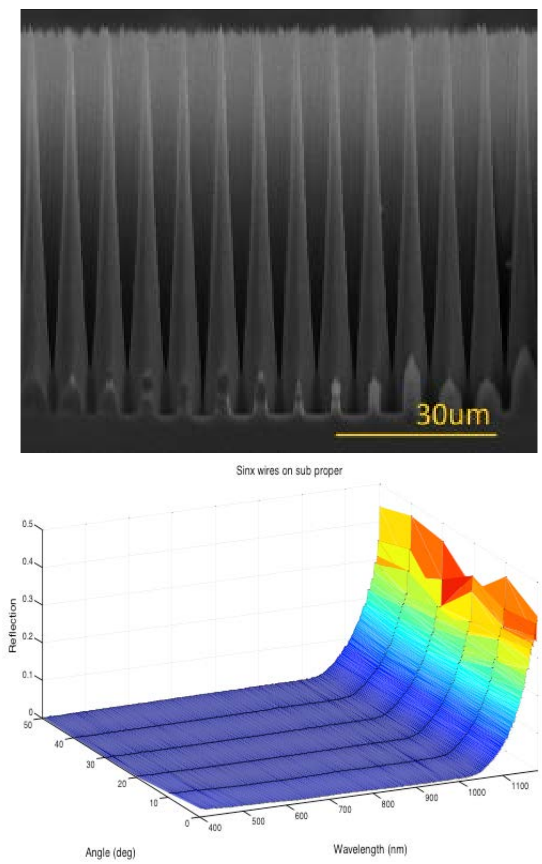

Fig. 1. High aspect ratio crystalline Si microwires fabricated by inductively couple reactive ion etching (above) and reflectance (below). These structures exhibited a world record low spectrum and angle integrated reflectance of 0.45% (400-950 nm wavelength; 0-50 degrees.)

Crystalline silicon is the predominant photovoltaic cell technology and HIT cells hold the current Si record cell efficiency of 25.6% under non concentrating conditions. The maximum efficiency for Si cells is ~29% given by Shockley–Queisser limit, implying there is still room for improvement in efficiency. To approach this limit, we need to achieve 1) extremely low surface reflectivity 2) light trapping at or near the ray-optic limit in Si absorbers with planar equivalent thickness <40 microns 3) very high bulk minority carrier lifetime and very low surface recombination velocity at surfaces. We report here results for a high bulk lifetime microwire absorber morphology, and discuss surface reflectance, bulk lifetime and surface passivation.

Silicon microwire arrays are highly efficient light absorbers with an enhanced near infrared absorption allowing their overall sunlight absorption to approach the ray optic light trapping absorption limit with low areal packing fractions. Previously we have synthesized silicon microwires via vapor-liquid-solid CVD processes employing metal catalysts, and found that the metal catalyst contaminates crystalline silicon absorber and limiting the lifetime in these microwires (~20ns).

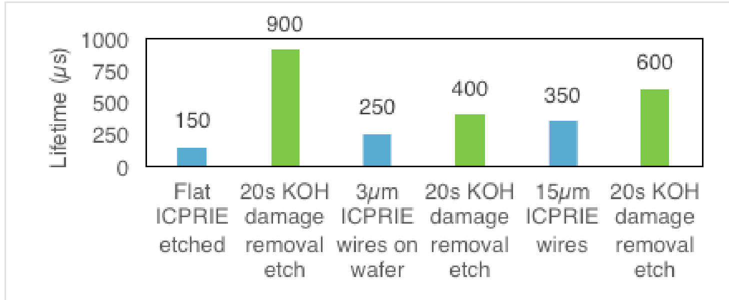

Fig. 2 Minority carrier lifetime inferred from microwave photoconductive decay measurement for dry etching and subsequent chemical etching of Si with 1 msec as-received wafer bulk lifetime. KOH etching recovers the measured lifetime of flat and 15 micron tall wires to 900 and 600 microseconds, respectively.

In our current work we have explored microwire synthesis via dry etching. Specifically we have used cryogenic inductively coupled plasma reactive ion etching of high (>1 msec) bulk lifetime wafers as an alternative process for making silicon microwires. By choosing the dry etching conditions to be primarily chemical, the surface damage can be minimized. Chemical etching following the dry etching for ~20s in 30% KOH at 80^{o}C has been demonstrated to remove the surface damage and aid in recovering the lifetime as illustrated in Fig. 2.

Higher aspect ratio (70 micron tall) microwires defined on ICPRIE-etched Si wafers were fabricated in other experiments, and then removed from the substrate, and subsequently passivated by several types of chemical treatments. These included passivation of substrate-removed wires in iodine/ethanol, 2% HF/water, 49% HF/water and 1:1: HCl/water. The lifetimes of etched wafers and microwires collected separately in a vial under various passivation ambients as given in Fig. 3 below. A maximum lifetime of 1.9 microseconds is observed in Silicon microwires (15 μm diameter, 70 μm tall) passivated in 1:1 HCl solution after damage removal on front and back surfaces. This corresponds to a diffusion length of ~75 micron in the microwires.

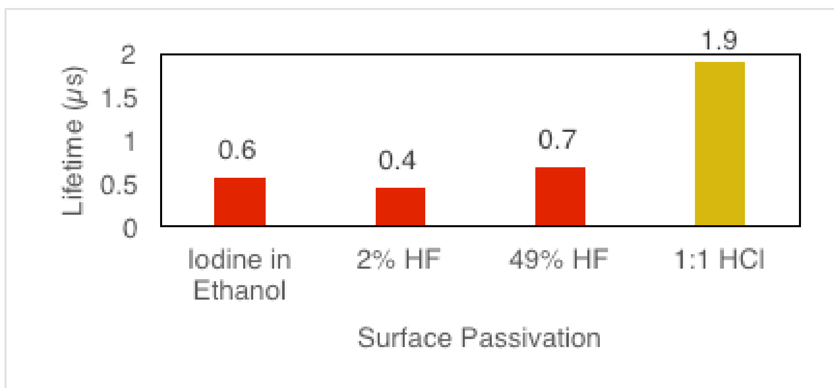

Fig. 3 Minority carrier lifetime inferred from microwave photoconductive decay measurement for dry etching and subsequent chemical passivation of Si removed from bulk wafer substrate. Passivation in 1:1: HCl/water afer KOH etching recovers the measured lifetime of 70 micron tall wires to 1.9 microseconds, corresponding to a 75 micron diffusion length.

Future Work:

We plan to integrate the findings with results of the work from Brongersma and Bowden to develop a process for a thin light-trapping HIT cell with record photocurrent density for absorber layer equivalent thicknesses less than 50 microns. Specifically we will characterize quantitatively the spectral absorption and photocurrent spectral response (preliminary measurements already completed), and will work to 1) integrate our microwire absorber layer structures with the Arizona State a-Si:H growth process and 2) combine insights with the Stanford group about metasurface light trapping for chemically passivated Si structures.