Understanding Carrier Lifetimes in Hyperdoped Silicon Solar Cells

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Introduction

Intermediate band photovoltaics exhibit increased solar cell efficiency by broadening the range of light absorbed. The incoming light excites the electrons (charge carriers) into the conduction band where the cell is most conductive and charge may be extracted.

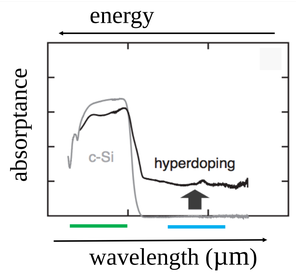


Figure 1: Comparison of the absorptance spectrum for crystalline silicon before and after hyperdoping[1]

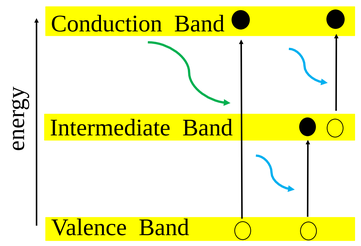


Figure 2: Schematic of photoexcitation of intermediate band photovoltaic

One way to create an intermediate band material is via **hyperdoping**, in which a high concentration of an element i.e. gold is added to silicon.

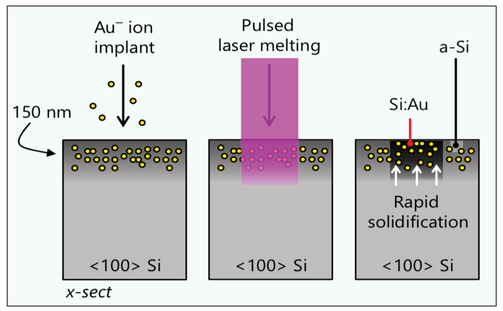


Figure 3: The hyperdoping process for gold (Au) into crystalline silicon[2]

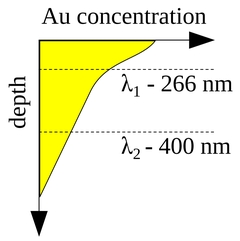


Figure 4: Concentration profile with corresponding absorption depths of excitation pulse

After excitation, free electrons not collected fast enough may relax back down, recombining with the holes they left. The **carrier lifetime** of a cell refers to the duration of time between excitation and recombination. Hyperdoping increases absorption, but decreases carrier lifetime. Finding a compromise between the two will achieve the greatest efficiency.

[1] adapted from Sher *et al.*, MRS Bulletin, 36, 439, (2011)

[2] adapted from Mailoa *et al.*, Nature Communications, 5, 3011, (2014)

Experiment

We probe the number of electrons that are excited to monitor photoconductivity. We do this by detecting the THz signal through the sample at different points in time after the arrival of the excitation pulse.

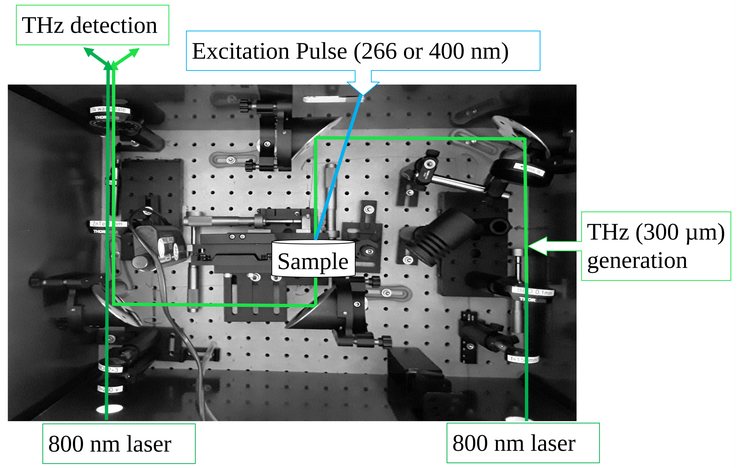
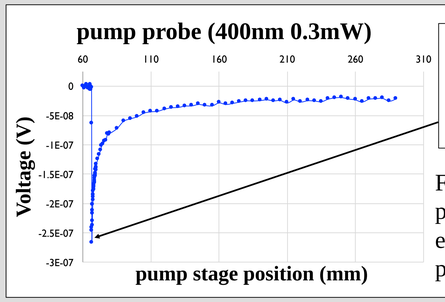


Figure 5: Annotated photo of experimental pump-probe setup inside zero humidity sample box.

We calculate the normalized decay in photoconductivity over time from the data and fit the curve to find lifetime.



Peak signal occurs when THz arrives at same time as excitation pulse

Figure 6: Graph of raw data from a pump-probe scan with 400 nm excitation pulse pumping at 0.3 mW power.

However, in hyperdoped silicon samples, we find a bi-exponential decay that gives us two lifetimes: a fast and slow decay. We hypothesized that recombination processes in the cell may be affected by the uneven concentration profile created in the doping process that forces a pile-up of Au atoms near the surface. (Figure 4) In order to test this, we collected pump probe scans for a set of samples at two different excitation wavelengths, 400 nm and 266 nm, corresponding to two different absorption depths. We hoped to show faster decay when 266 nm excited closer to the surface pile-up.

Results

Data was collected for 12 Si:Au samples with varying processing conditions and surface passivation. All 12 samples show a clear difference in fast decay between 266nm verses 400nm light.

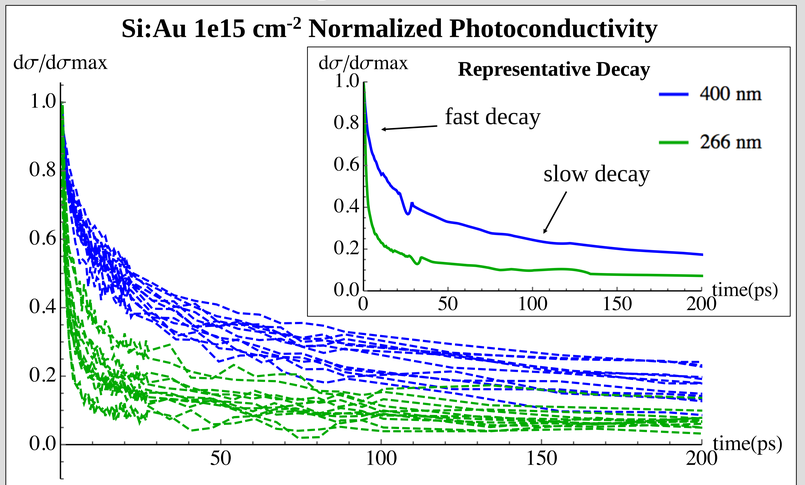
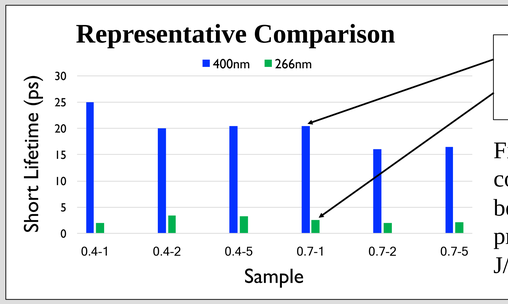


Figure 7: Graph of decay in photoconductivity over time for all 12 samples at 400nm and 266nm with representative inset graph.

After fitting the decay, we found that the short lifetime was roughly a magnitude faster at 266nm light (~ 2-3 ps) compared to 400nm (~ 20 ps). This confirms our hypothesis that the concentrated pile-up of Au atoms effects recombination processes in the material.



400nm ~ 20 ps
266 nm ~ 3 ps

Figure 8: Bar graph comparing short lifetime between samples of varying processing fluences (0.4, 0.7 J/cm^2) and # of shots (1, 2, 5)

Conclusion and Future Work

To improve decay, we must better understand how to counter this effect:

- Surface etching to remove 'pile-up'
- A MATLab simulation of decay dynamics based on different concentration profiles from
  - Varied melting speeds and temperatures
  - Varied doping elements