Femtosecond laser doping of silicon for photovoltaic devices

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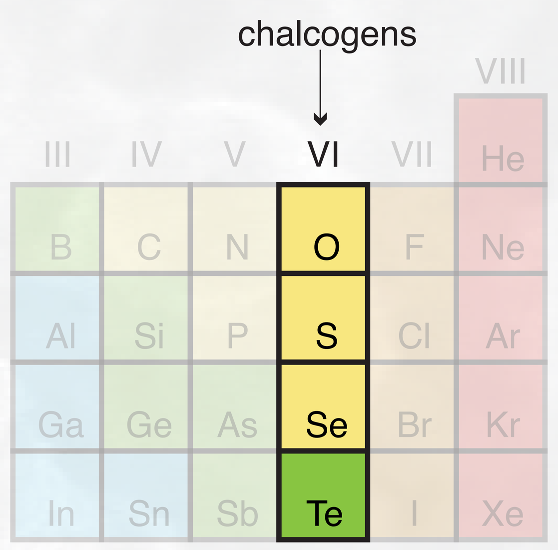
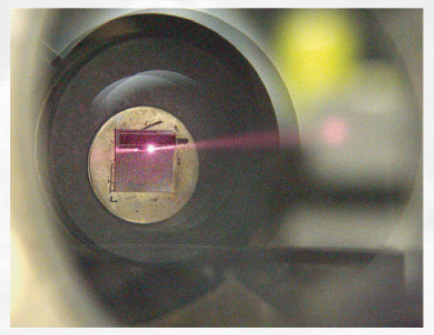
Irradiation and doping

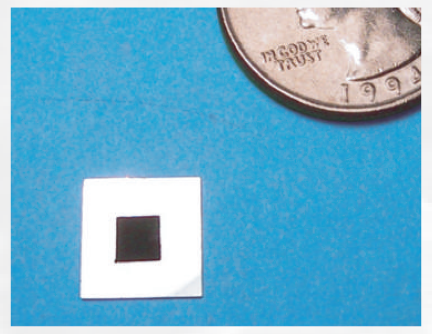
We irradiate a crystalline silicon wafer with femtosecond laser pulses in the presence of a chalcogen-containing gas or film to produce a black surface that is roughened on the microscale.

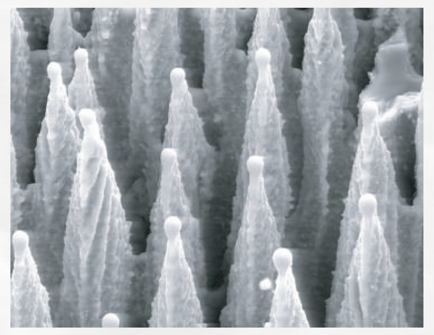
The outer 300 nm of the roughened surface is highly disordered silicon doped with up to 1% of chalcogen.

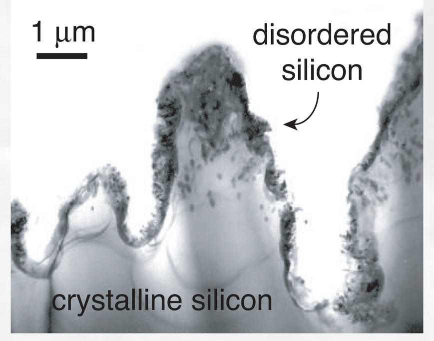


This surface layer has unique optical and electronic properties — such as strong sub-bandgap, infrared absorption — that make it appealing for use in photodetectors and solar cells.



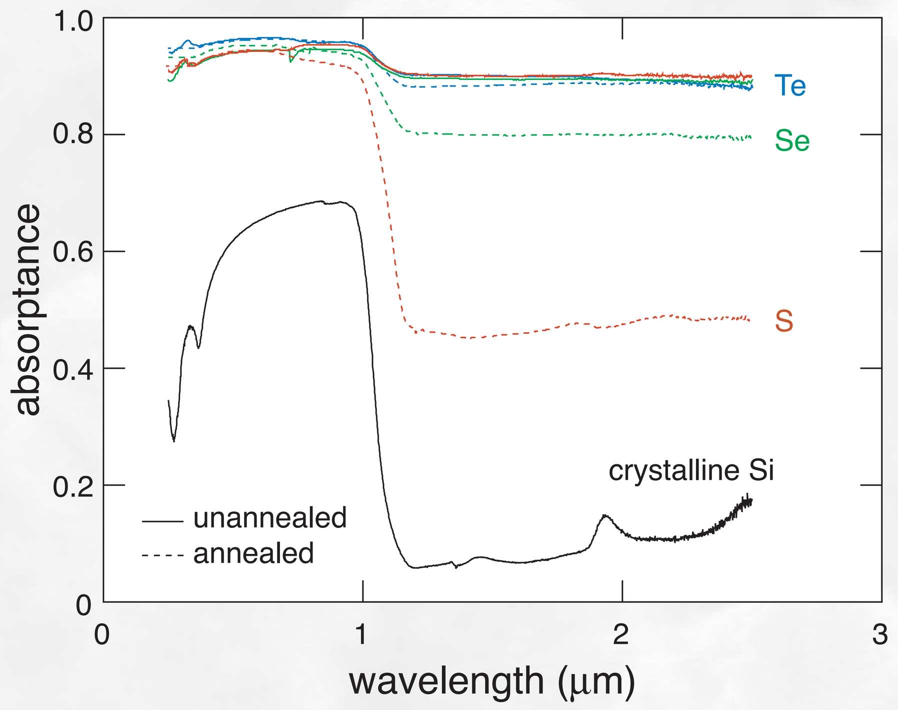


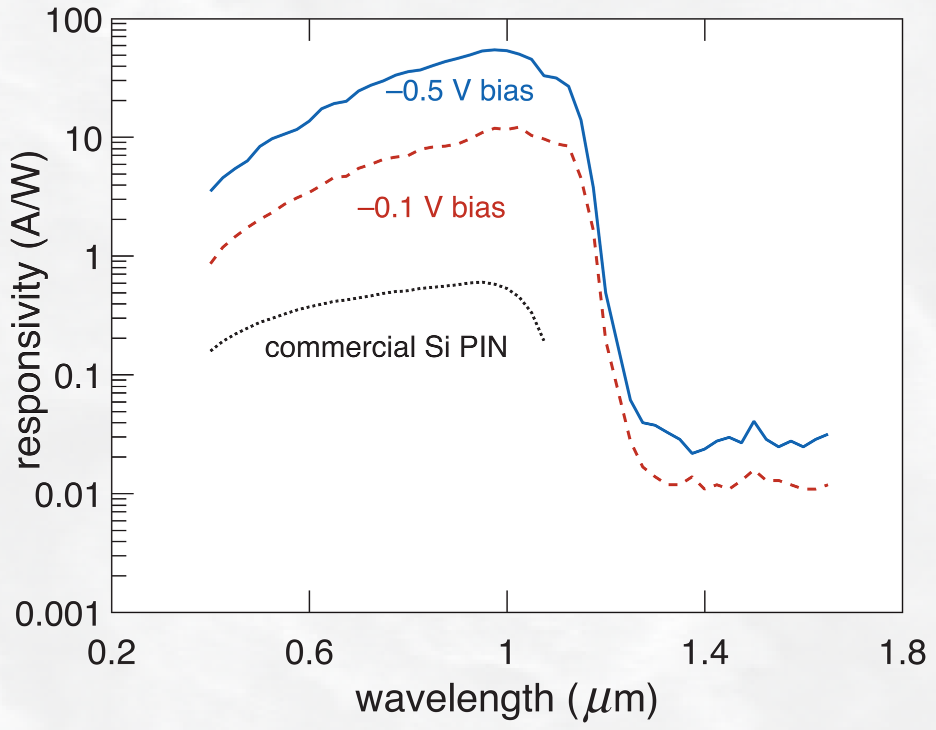


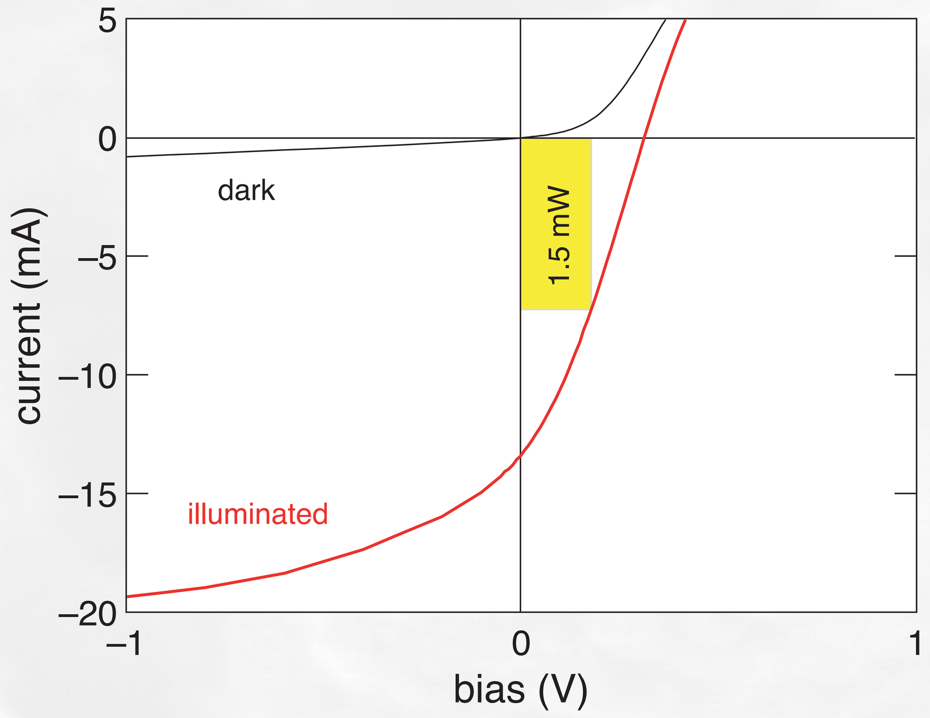


Sub-band gap devices

After laser-doping with chalcogens, silicon exhibits strong optical absorption at wavelengths corresponding to photon energies less than the band gap. The absorption is connected with the production of mobile electron-hole pairs, even at near-infrared wavelengths. We have fabricated photodetectors exhibiting large gain in the visible region of the spectrum and significant response at infrared regions of the spectrum.



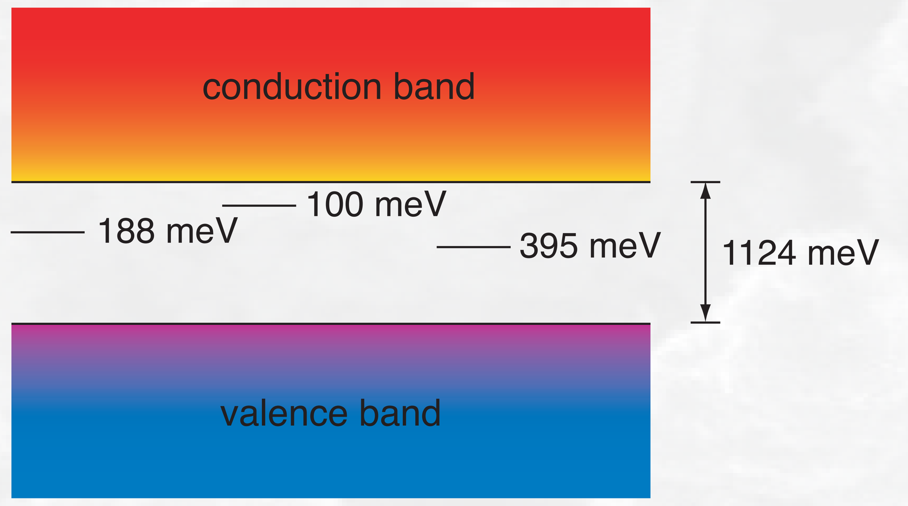




We have also fabricated proof-of-principle solar cells. Under AM1.5 irradiance, the cells demonstrate 2% energy conversion efficiency. Our design – a single heterojunction diffusion-dominated device – was not optimal, and yielded low efficiency.

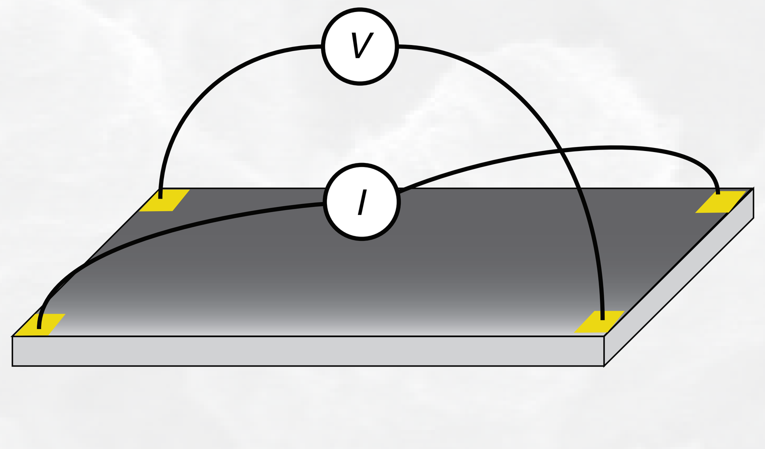
Energy states of the dopants

Sub-bandgap absorption often arises from optically active impurity states or bands within the band gap. Many such states have been observed for sulfur in silicon. We would like to know which, if any, of these states are formed by femtosecond laser doping.

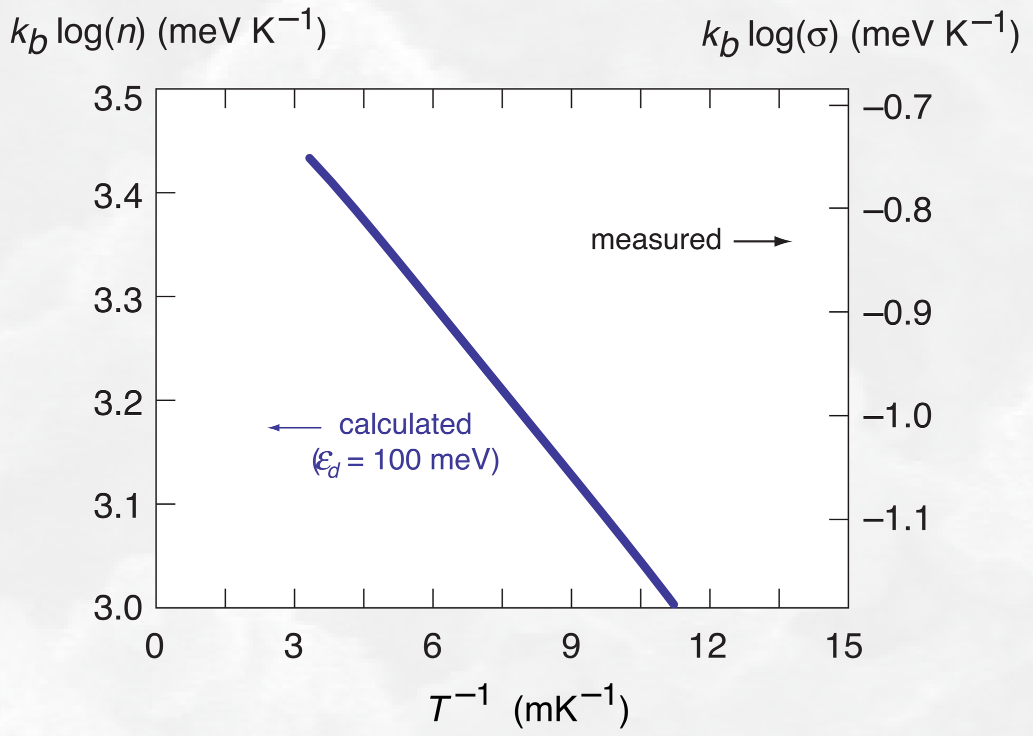


Which donor levels are created?

To identify impurity states, we study the temperature dependence of the electrical properties, such as conductivity in a sulfur-doped sample. We are currently extending this to Hall measurements. The slope of the temperature dependence on an Arrhenius plot identifies the impurity level.



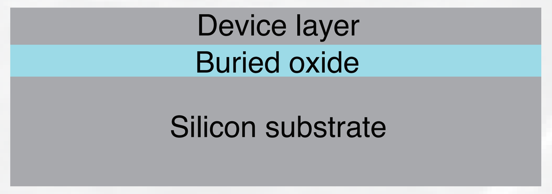
Four-point measurement of resistivity

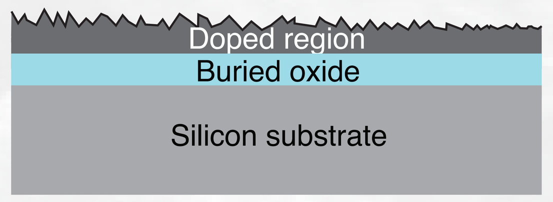


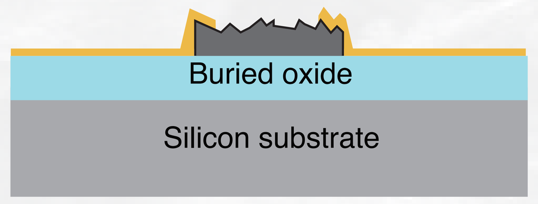
Preliminary measurements are consistent with an impurity band 100 meV below the conduction band edge.

Future work

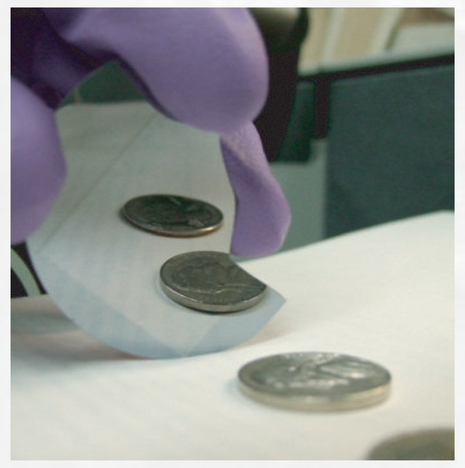
Using silicon-on-insulator (SOI) wafers, we have succeeded in isolating the surface layer. We are currently using this technique to study fs-laser doped silicon's electrical properties and quantify the impurity band's characteristics.



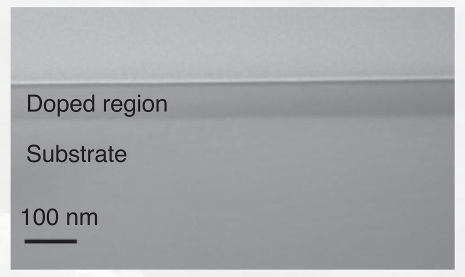




After understanding the size and location of the impurity band, we will incorporate it into the optimal solar cell design.



Additionally, we are invesitigating increasing the diffusion length and lowering the surface recombination velocity. We have discovered methods for avoiding the unusual surface structures associated with femtosecond laser doping and can create both textured and specular surfaces. We are also investigating methods to improve crystallinity through thermal as well as laser processes.



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