Nanostructured Solar Cells Have Improved Charge Collection and Self-Cleaning Properties

Zhu et al. report on the use of "nanodome" solar cells to simultaneously improve optical absorption and enhance surface cleanliness. The resulting structures have power conversion efficiencies of 5.9%.

There has been almost continuous research on improving photovoltaic efficiency through optical designs which enhance collection efficiency. A fair amount of this research has centered on three-dimensional structures fabricated through etch (e.g. grooves in Si), or conformal growth that result in improved collection efficiency through multiple reflections. Zhu et al. have extended this approach to the nanoscale, allowing for enhanced optics leading to improved absorption, superhydrophobic functionality of the surface, and perhaps critically, enhanced charge collection in a potentially promising PV absorber material which lacks extended electronic states.

The authors make a clear and logical argument for their approach, implementing their design on a-Si:H. This material is a highly efficient optical absorber due to the direct 1.8 eV transition between nearly-localized states, requiring roughly 1% of the film thickness of cast silicon for effective light absorption. This characteristic is of importance in the economics of PV, as it results in significantly reduced raw material costs. Unfortunately, these nearly localized states in a-Si:H deleteriously affect charge transport properties, resulting in a short carrier diffusion length of a few hundred nanometers. Further, as this material is mostly amorphous, there are Stabler- Wronski defects with long-term behavior that adversely affect performance. There are reports these effects are diminished at film (absorber) thicknesses below several hundred nanometers. The authors seek to address these issues through fabrication of conformal "nanodome" p-i-n PV cells: a 300 nm active layer of a-Si:H, fabricated using "nanocone" quartz substrates as a template.

The authors describe the fabrication process in detail. The initial template is formed by using monodispersed SiO_2 particles assembled into closed pack layers on a quartz substrate. This template is subsequently plasma etched using standard oxide etch chemistry, resulting in "nanocones" on the substrate. This is followed by the fabrication of the p-i-n "nanodomes" through PECVD deposition of a-Si:H. It is not apparent what developments would be required to make this fabrication technique scalable, resulting in large-scale PV cells based on these structures.

The authors' data demonstrates a 25% improvement, resulting in cells with 5.9% conversion efficiency. This improvement is mostly the result of an efficient and relatively flat absorbance between 400 nm and 800 nm in these nanostructured cells, with 94% absorption. Further, the design is such that this high absorption efficiency persists for radiation incident over a large angular range. These improved optics result in a short circuit current that is near the theoretical value imposed by the band gap of the material. The benefits of the shorter charge collection paths in these nanostructured cells on charge collection efficiency, and how it is manifested in power conversion efficiency will require more work to quantify completely.

Another interesting advantage of these structures is that they have superhydrophobic properties, and may potentially have suffer less from performance degradation over time due to dirt accumulation on the surface of the PV cell than conventional cells. The authors demonstrate enhanced “self-cleaning” properties through surface chemical treatment that introduce hydrophobic molecules.