Photonic and heterostructure design for next-era silicon and tandem photovoltaics

Harry A. Atwater

Thomas J. Watson Laboratories of Applied Physics,
California Institute of Technology, Pasadena, California 91125
email: haa@caltech.edu

Abstract

Silicon photovoltaics technology is now the world's largest optoelectronic industry, with a production capacity of >60GW. We discuss photonic and heterostructure design approaches for next-generation silicon photovoltaics that go beyond today's including i) broadband light trapping structures ii) broadband light trapping with non-regular and trapezoidal-shaped nanostructures, photonic crystal superlattices and tapered III-V/Si nanowire arrays ii) heterostructure carrier-selective contacts for high-voltage silicon cells and iii) tandem III-V/Si design approaches.

We describe computational and experimentals effort to design polarization-independent, angle-insensitive, broadband spectral response by direct coupling of incoming light to the resonant modes of subwavelength-scale nanoresonators incorporated into the active layer of thin film crystalline silicon solar cells. Our prototype structure consists of a two-dimensional periodic array of micron-thickness thin film Si nanoresonators. A crossed trapezoidal-shaped Si absorbers is employed with a rectangular cross section in order to excite broadband Mie resonances across the visible spectra to facilitate broadband and polarization-independent light absorption.

We also survey here several different superlattice photonic crystal based designs for <50 micron thick c-Si solar cells, demonstrating that these structures have the ability to increase broadband absorption from λ = 300nm to 1100nm by more than 100% compared to a planar cell with an optimized anti-reflection coating. We show that adding superlattices into photonic crystals introduces new optical modes that contribute to enhanced absorption. The greatest improvements are obtained when combining a superlattice photonic crystal with a randomly textured dielectric coating that improves incoupling into the modes of the absorbing region.

Designs for achieving near-unity broadband light absorption in sparse nanowire arrays, in III-V nanowires on Si substrates are also described. Sparse (<5% fill fraction) nanowire arrays achieve near unity absorption at wire resonant wavelengths due to coupling into 'leaky' radial waveguide modes of individual wires and wire-wire scattering processes.

Further improving the open circuit voltages and efficiency of silicon solar cells also requires the introduction of heterostructure device architectures that serve as carrier-selective contacts. Recent developments have shown that even in Si solar cell technology there is room for tremendous improvement. Using the heterojunction with intrinsic thin layer (HIT) approach up to 25.6 % power conversion efficiency was achieved. This technology uses a-Si as passivation,

window and blocking layer for crystalline Si. We will discuss approaches to use of other materials as wide bandgap carrier-selective contacts.

In particular, we have studies thin GaP selective contacts to Si solar cells. Here we present a band alignment study carried out by X-ray photoelectron spectroscopy using thin layers (2-16nm) of GaP on Si. The valence band offset was determined by core level analysis as well as by fitting valence band spectra of thin film samples as linear combination of pure material spectra. We obtained a valence band offset of 0.24±0.12 eV and which significantly differs from the band offset predicted by the Schottky model (0.89 eV). Kelvin probe and cross sectional Kelvin probe force microscopy measurements showed that significant surface band bending is occurring at the GaP/air interface which sets the obtained valence band offset as an upper boundary. Similar approaches for other heterostructures will be outlined