

Chapter 13

Nanoparticle Scattering, Absorption, and Interface Effects for Surface Plasmon Enhanced Thin Silicon Solar Cells: Theory, Past Findings, and Future Directions

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ABSTRACT

Recently, surface plasmons have been employed in a variety of methods to increase the efficiency of solar cells. Surface plasmons are oscillations of electrons that arise from surface effects of light interaction with materials that have appreciable free carrier densities; their resonance is confined to a region that depends on the dielectric response of the medium. It has been observed that noble metals exhibit this resonance within visible- near IR range, making them an attractive candidate for silicon solar cells whose primary absorption bands are in this region. Research in silicon-based plasmonic solar cells has utilized the high scattering cross section and favorable angular distributions of noble metal nanoparticle-scattered radiation to increase absorption of thin silicon devices, which are normally weakly absorbing for photons of energy below 2 eV. The interaction is subject to interface effects, interferences of scattered and incident radiation, and the dielectric nature of the embedding medium or surface. In addition, perturbations caused by the longitudinal field of the metal nanoparticle may theoretically enhance the direct interband transitions of free carriers near the particle surface, further enhancing the photocurrent. This latter possibility has yet to be fully explored experimentally in crystalline silicon photovoltaics.

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INTRODUCTION

Thin Film Crystalline Silicon Solar Cells

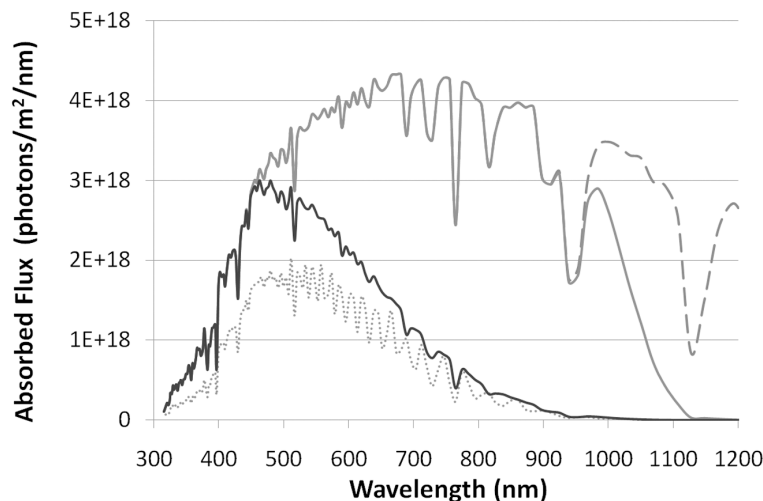
Silicon is the second most abundant material in the earth's crust. It accounts for the vast majority of electronic devices and lies at the heart of the computer industry. Despite its being abundant, environmentally benign, and at this point in our scientific evolution precisely grown and engineered, it is—to put it somewhat poetically—not particularly fond of our sun's offerings. Its absorption coefficient in much of the solar spectrum is so weak that crystalline substrates 300 micrometers thick are required to adequately absorb the bulk of photons whose energy is greater than or equal to its bandgap. Though a thickness less than third of a millimeter may seem nominal by everyday standards, it has in fact proven to be a central factor compromising the adoption of silicon photovoltaics. Semiconductors of direct bandgap materials require thicknesses of a few micrometers, expediting their production and

reducing their costs. As is seen in Figure 1, 300 μm of silicon with an adequate anti-reflective coating will absorb 90% of above bandgap photons, while a 2 μm c-Si film with no front or rear reflection absorbs only one third; for a film on a glass substrate without any anti-reflective coatings, that number drops to barely about one fifth.¹ Yet the long-term benefits of silicon cannot be understated: it is inexhaustible and nontoxic. For this reason, much of silicon-based photovoltaic research now focuses on methods of increased absorption and light trapping within silicon itself, so that thin crystalline silicon solar cells, less than a few micrometers thick, may attain efficiencies as high as bulk wafers.

Plasmonic Modes in Metal Nanoparticles

One path to achieving this is by harnessing plasmonic modes in metal nanostructures. The interaction of light with confined electron gases can lead to numerous remarkable phenomena, which due to dielectric-metal boundaries are ab-

Figure 1. Absorbed photon flux for 300 μm (upper solid line) and 2 μm (lower solid line) thick c-Si wafers, assuming no reflection on the front or rear of the cell. Also shown is the absorbed flux for a 2 μm c-Si film with no antireflective coatings situated upon on a glass substrate (dotted line), and the incident AM1.5 solar flux (dashed line).



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