BAPVC Annual Project Report

Project Title: Theory and Simulation of Photon Management in Nanostructured Solar Cells

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Summary:

This project aims to elucidate the fundamental physics that governs the current and voltage behaviors in nanostructured solar cells, and to develop strategy for enhancing solar cell efficiency thorough photon management. The key accomplishments in this period include a detailed balance analysis that elucidates the influence of optical physics on the voltage behavior of nanowire solar cells.

Key Accomplishments:

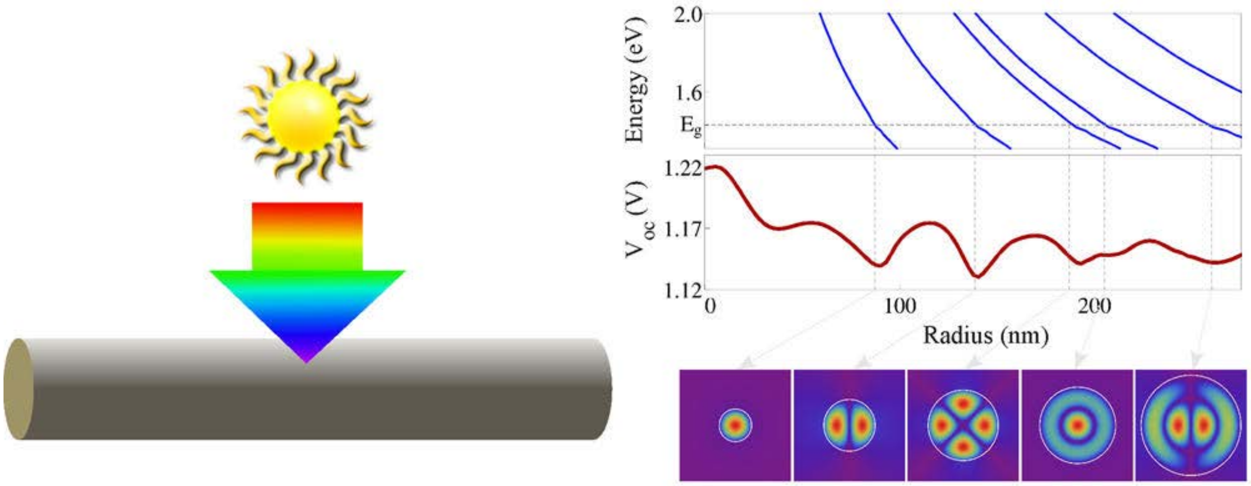

Figure 1. Left panel: Schematic of a GaAs nanowire solar cell. Right Panel: Top graph shows the resonance energy in the nanowire as a function of the radius, with the field patterm of these resonances exhibited in the botoom graph. The middle graph shows the open circuit voltage as a function of radius. The voltage drops each time the energy of the resonance cross the band gap of the semiconductor.

Semiconductor nanowire-based solar cells have been shown to be promising candidates for third-generation photovoltaics. Compared with traditional thin-film solar cells, the advantage of the nanowire cells include easily scalable manufacturing, lower cost, efficient charge separation, and tunable optical absorption. From the optical physics point of view, the nanowire geometry is interesting in that it supports a variety of optical resonances each with a spectral peak location that directly depends on the wire's diameter. In particular, a properly designed nanowire can support optical resonances with an absorption cross-section that is many times larger over the nanowire's geometrical cross-section. Accordingly, there has been a strong interest in engineering the location of these optical resonances of the nanowire in order to enhance its optical absorption and therefore its short-circuit current performance. However, in order to understand the fundamental limiting performance of a nanowire solar cell, these studies on the nanowire's output current behavior need to be complemented with a better understanding of the nanowire's intrinsic voltage behavior.

We present a detailed balance analysis of current density−voltage modeling of a single-nanowire solar cell. Our analysis takes into account intrinsic material nonidealities in order to determine the theoretical efficiency limit of the single-nanowire solar cell. The analysis only requires the nanowire's absorption cross-section over all angles, which can be readily calculated analytically. We show that the behavior of both the current and voltage is due to coherent effects that arise from resonances of the nanowire. In addition, we elucidate the physics of open-circuit voltage enhancement over bulk cells in nanowires, by showing that the enhancement is related to the removal of resonances in the immediate spectral vicinity above the bandgap.

This work has been published in Nano Letters. (S. Sandhu, Z. Yu and S. Fan, Nano Letters 14, 1011, 2014).

Future Work:

We are in the process of extending the detailed-balance analysis, as described above, towards the understanding of nanophotonic silicon cells. Here, the efforts in particular will be focused on elucidating the impact of various intrinsic non-radiative recombination mechanisms, including the Auger recombination, and the surface recombination on the performance of nanophotonic silicon cells.