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 of the open circuit voltage in nanophotonic cells, a theoretical design that is able to reach the light trapping limit for current in ultra-thin crystalline silicon cells, and a collaboration with Yi Cui's group that demonstrated the theoretical prediction of the ultra-thin crystalline silicon cells.

Key Accomplishments:

The short circuit current of the solar cell is fundamentally determined by the absorption of solar photons. Enhancing the absorption is of crucial importance especially in ultra-thin cells. The result from this project (Figure 1) has shown that the use of front and back surface nanocone array provides a viable strategy to reach the theoretical limit in ultra-thin cells. The key idea is the design the structure to simultaneously achieve effective anti-reflection and light trapping, exploiting the geometrical degrees of freedom that are inherent in nanocone array. In collaboration with Yi Cui's group at Stanford, the theoretical design of such nanocone concepts has been experimentally demonstrated in ultra-thin crystalline silicon cells. Experiments showed significant enhancement of short-circuit current in this design compared with other designs.

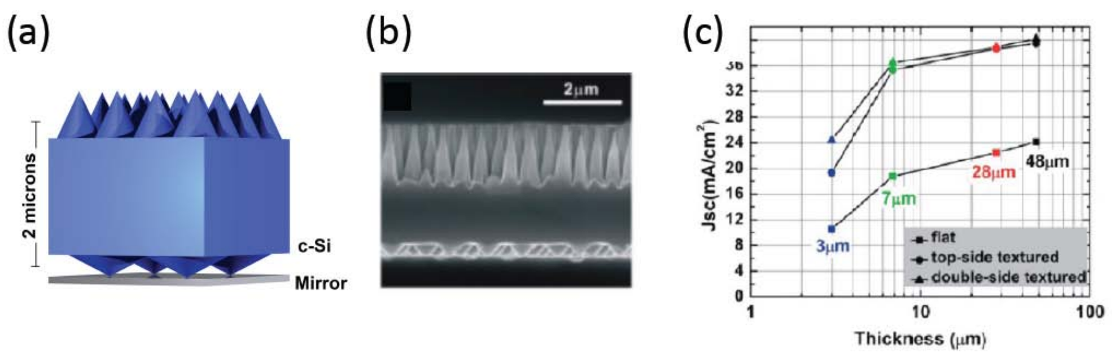

Figure 1. (a) Theoretical design of a nanocone ultra-thin crystalline silicon cell that is capable of reaching the light trapping limit. The cones on the front surface are used for anti-reflection. The cones on the back surface are used for light trapping. (b) Experimentally fabricated nanocone crystalline silicon cell. (c) The double-sided nanocone structure shows large enhancement of short-circuit current, as compared with other strategies.

The open circuit voltage of the solar cell is fundamentally determined by detailed balance. For radiative cell, the open circuit voltage is controlled by the thermal radiation of the cell. A key insight developed in this project is that the thermal radiation from a solar cell peaks at the solar cell semiconductor band edge. Consequently, by influencing only the absorption property of the spectral region immediately above the semiconductor band gap, one can control the open circuit voltage of solar cells through nanophotonic design. And moreover, since the short circuit current is controlled by the entire spectral region above the band gap, one has independent control of the current and the voltage through nanophotonic design. As an illustration of this concept, a GaAs thin film cell has been designed with open circuit voltage significantly above the bulk cells (Figure 2).

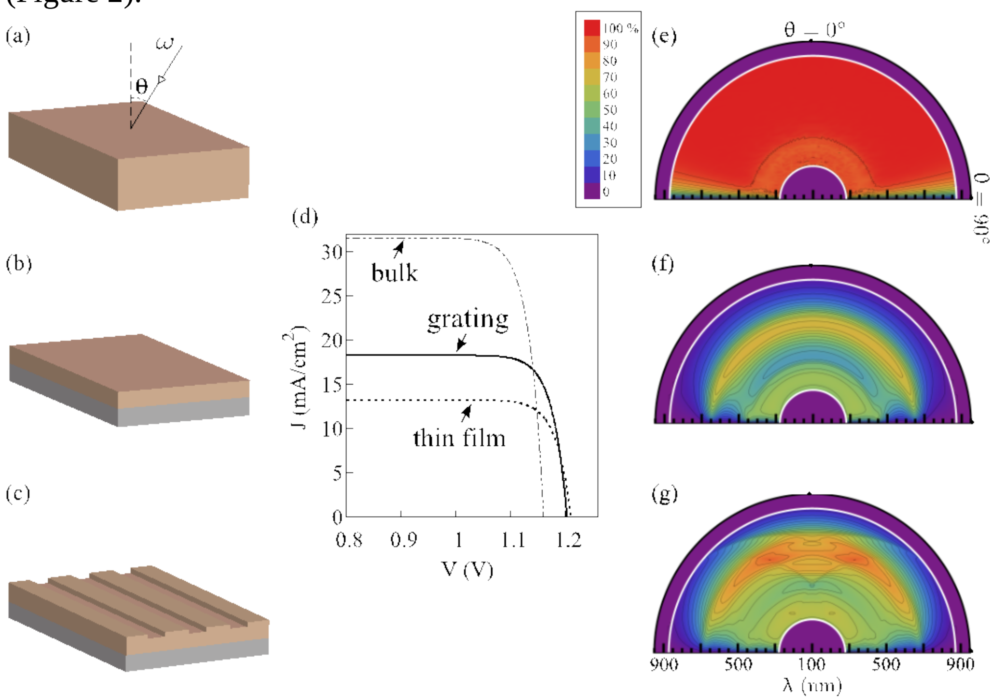

Figure 2. Detailed balance analysis of nanophotonic solar cells. (a)-(c) Structures considered. (a) Bulk GaAs cell. (b) A thin film GaAs cell with a thickness of 44nm. (c) A thin cell with grating introduced. (d) I-V characteristics of the three cells shown in (a)-(c) calculated by detailed balance analysis. The thin film cell has significantly enhanced open circuit voltage but greatly reduced current. The grating on a thin cell preserves the voltage enhancement and enhances its current. (e)-(g) Absorption properties as a function of angle and wavelength for the three cells. The white line indicates the position in wavelength of the GaAs bandgap. The suppression of absorption immediately above the bandgap is responsible for the open circuit voltage improvement of nanophotonic cells.

Future Work:

Efforts are underway to continue to understand the current and voltage behavior in nanophotonic solar cells. A specific effort is to understanding the carrier distribution in nanophotonic silicon cells, and to contrast the voltage behavior of silicon cell with cells where the recombination is dominated by radiation. Other efforts include the understanding the open circuit voltages in the context of nanowire cells through detailed balance analysis.