BAPVC Annual Project Report

Project Title: Optimal Integration of Transparent Electrodes and Photon Management

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Summary:

The objective of the project is to continue to develop the understanding of the interplay of transparent electrodes and photon management, and to develop a pathway towards low-loss and light-trapping transparent electrodes for improved overall solar cell efficiency, while eliminating dedicated light-management layers.

Key Accomplishments:

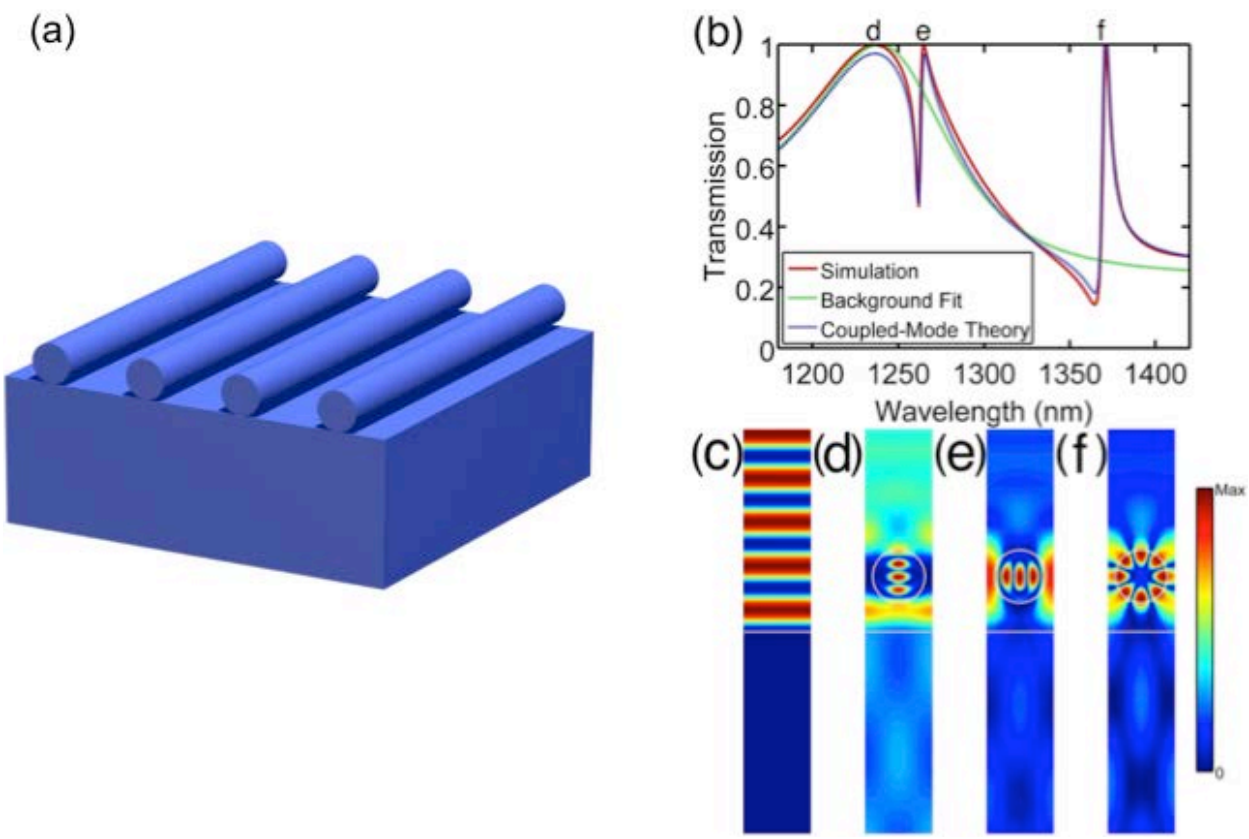

Figure 1. (a) Geometry consisting of resonant nanowires sitting on a substrate. (b) Transmission spectrum for the geometry in (a). (c) Various resonances in the geometry in (a).

Transparent conducting electrodes play critical roles in solar cell technologies . Traditionally, the performance of transparent electrodes is understood in terms of an optical-electrical trade-off in fundamental material properties ; for example increasing the carrier density improves the

electrical conductivity but decreases the optical transparency. We emphasize here, however, that in practical solar cells, the transparent electrode layer is placed in a complex electromagnetic environment involving other device layers. Thus the property of a transparent electrode needs to be understood taking into account the electromagnetic interaction between the electrode and the surrounding layers. This gives rise to a number of opportunities both in terms of loss reduction and in terms of light management capabilities for transparent electrodes.

In this period we undertake a study of the theoretical condition for optical resonances for anti-reflection. The initial study was carried out using dielectric nanowire, but the same physical principle can be generalized to metallic nanowire as well. We introduce the theoretical condition for complete reflection cancellation in this resonant antireflection scheme. Using both general theoretical arguments and analytical temporal coupled-mode theory formalisms, we show that in order to achieve perfect resonant antireflection, the periodicity of the array needs to be smaller than the free-space wavelength of the incident light for normal incidence, and also the resonances in the subwavelength objects need to radiate into air and the dielectric material in a balanced fashion. Our theory is validated using first-principles full-field electromagnetic simulations of structures operating in the infrared wavelength ranges. For solar cell or photodetector applications, resonant antireflection has the potential for providing a low-cost technique for antireflection that does not require nanofabrication into the absorber materials, which may introduce detrimental effects such as additional surface recombination. Our work here provides theoretical guidance for the practical design of such resonant antireflection schemes.

This work has been published in Optica. (K. X. Wang, Z. Yu, S. Sandhu, V. Liu and S. Fan, Optica 1, 388, 2014).

Future Work:

We are in the process of applying the same principle to the study of metallic nanowire as well, with the aim to designing metallic structures that can function as an anti-reflection layer.