BAPVC Annual Project Report

Project Title: Percolating Transparent Metallic Electrodes for Solar Cells
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Summary:
Nanostructured metallic films have the potential to replace metal oxide films as transparent electrodes in optoelectronic devices. An ideal transparent electrode should possess a high, broadband transmittance that is also polarization independent. Using polarization and spectrally resolved photocurrent measurements on model cells with fractal metallic electrodes, the Brongersma group has demonstrated that such electrodes feature a broadband transmission that substantially outperforms square metallic grid electrodes.

Key Accomplishments:
One promising electrode technology that has recently emerged is based on metallic nanostructures arranged in periodic, aperiodic, or random arrays. These high-conductivity metal nanowire arrays can have advantageous electronic and optical properties over conventional (ITO) and alternative (e.g., carbon nanotube meshes and graphene) electrode materials. Unlike conventional electrode materials, for which a lower sheet-resistance typically comes at the expense of a lower optical transmission, nanostructured metal electrodes provide a more desirable trade-off between transmittance and sheet resistance. With recent progress in nanofabrication techniques, large-area, low-cost application of nanostructured metallic electrodes can also be accomplished via nano-imprint, rolling mask, and nanosphere lithography techniques, solution processing or lamination of metallic nanowire meshes, and electrospinning. These methods offer excellent control over the nanostructure size, geometry and in some cases also the spatial arrangement. Moreover, in solar cell technologies, metallic contacts of silver (Ag) and aluminum (Al) are already commonplace, significantly lowering the barrier to the introduction of next-generation nanostructured metallic electrodes.

To achieve an ideal combination of high optical transmittance and low sheet resistance, different nanostructured electrode designs can be considered, starting from simple gratings and grids. In this work, we will first demonstrate that linear gratings exhibit a high yet polarization-dependent transmission while square grids with similar geometrical parameters show a low polarization-independent transmission. To obtain high polarization-independent transmission, other geometries are necessary. To address this need, the Brongersma group demonstrated that nanostructured metallic films with fractal-shaped slits as transparent optical electrodes with high polarization-independent transmission. The proposed fractal slit patterns, known as space-filling curves, efficiently cover the entire surface of the electrode. We experimentally compare the optoelectronic performance of these fractal electrodes by placing them on top of a silicon substrate to form a Schottky barrier detector. The transmission properties in this case can be conveniently assessed through photocurrent measurements (See Fig.1a). With such measurements, we demonstrate that space-filling fractal networks substantially outperform grids and slightly outperform gratings while providing a polarization-independent response. Figures 1b-g show SEM images and the measured photo-responsivity of several electrodes as functions of the illumination wavelength and polarization direction. The work provides valuable guidelines for the design of high-performance, inexpensive aluminum electrodes for use with high-index solar cell materials.

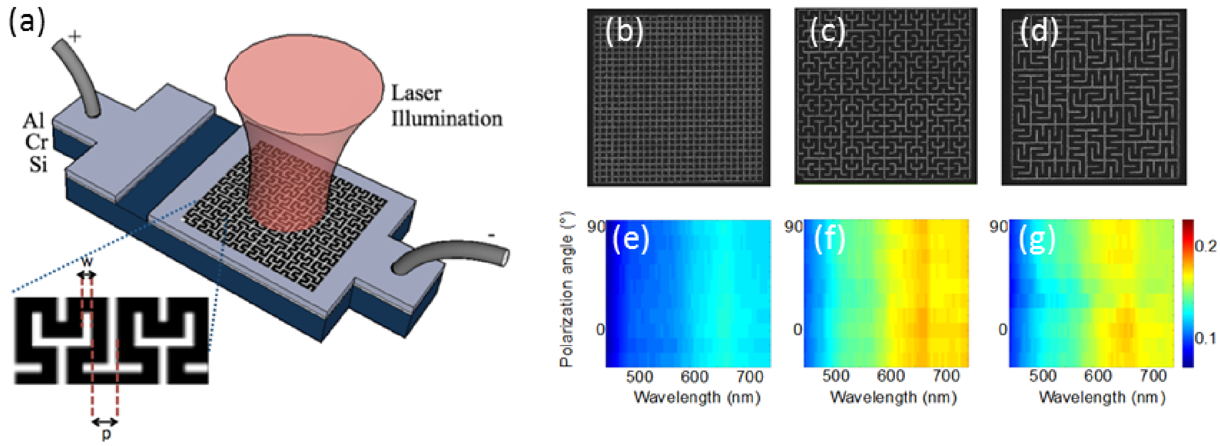

Figure 1. A schematic of the measurement platform where an electrode of a planar Al-Si-Al Schottky detector is patterned with a fractal, metal electrode. The electrode transmits light into the silicon where it generates electron-hole pairs that are extracted as photocurrent. b-c SEM images of Al electrodes patterned with (b) a cross-grid (c) a Hilbert fractal and (d) a Peano fractal. The width of Al nanowires are 100 nm in all electrodes. (e)-(g) Measured photo-responsivity maps (in units of A/W) as functions of the polarization angle and illumination wavelength. Each responsivity map corresponds to the electrode shown above it in the top row. 0° and 90° polarization angles correspond to incident electric field being horizontal or vertical.

Future Work:

The group is currently developing nanostructured metal films with subwavelength wire sizes and spacings as conductive antireflection coatings for light. Currently, a silicon nitride or other high-index layers is required in combination with the metallic grids to facilitate a very high broadband transmissivity into a high index semiconductor layer. We are working on eliminating the need for such a layer, which will allow for the reduction of one material and one processing step. As such, this work is expected to provide a significant cost reduction in the transparent metal electrode fabrication.