

Nanostructured Metal-Organic Composite Solar Cells

Investigators: Mark Brongersma, Department of Materials Science and Engineering; Peter Peumans and Shanhui Fan, Department of Electrical Engineering, Stanford University

Sponsor: Global Climate and Energy Project

Objective: This project aims at realizing a high efficiency organic photovoltaic cell using metal nanoscale features in a multijunction device. In particular, transparent high-sheet-conductivity nanopatterned metal films will be developed to be used as conductors allowing parallel subcell connection, and metal nanostructures will be embedded in the active layers to enhance the photon absorption and charge separation efficiency.

Background: While the performance of organic photovoltaics has been improving steadily, this technology still faces fundamental limitations in efficiency and stability that need to be overcome for it to be competitive with other solar cells. Innovative cell designs, such as stacked organic/inorganic heterojunctions with embedded nanostructured metal features, may enhance their overall performance. A stack design can increase light absorption efficiency through complementary absorption of separate portions of the solar spectrum by different layers with specifically designed bandgaps. This minimizes thermal losses and increases the overall photon conversion efficiency.

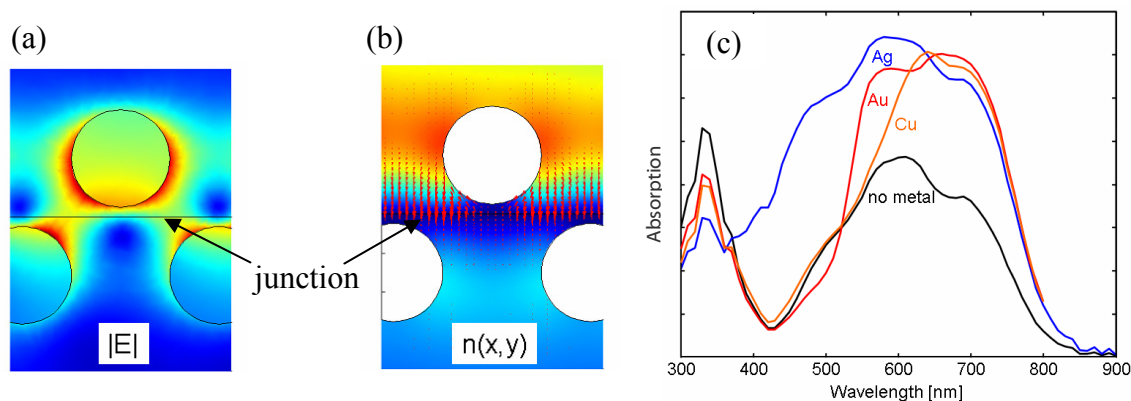


Figure 1: Simulation of a metal nanostructure enhanced organic solar cell. Interaction of an incident electromagnetic wave with metal nanoparticles at the junction between donor (top) and acceptor (bottom) materials leads to resonant effects resulting in an enhanced optical electric field between the particles (Figure 1a). This leads to an increased exciton density at the donor-acceptor junction shown by the red areas in Figure 1b. The absorption enhancement effect for the addition of different metal particles is shown in Figure 1c.

Nanoscale metal structures embedded in organic devices could also potentially be beneficial in improving the light absorption, as well as the charge separation and charge collection processes. When placed at the donor-acceptor interface of an organic heterojunction, electrically isolated metal nanoparticles may enhance photon absorption by concentrating the electromagnetic energy

of incident radiation close to the junction (see Figure 1) and may also assist the exciton energy migration process, leading to enhanced charge separation. Tuning of the spectral properties of the cells may also be achieved through the appropriate choice of metal type and nanostructure shape, size and organization.

In series-connected stacks, the absorption of light by single cells must be carefully designed for photocurrent matching. This constraint makes them intolerant to variations in the illumination spectrum. However, efficient lateral current extraction could be achieved by using high sheet-conductivity nanopatterned metal films that can theoretically transmit 80% of the incident radiation. The upper limit for the transmissivity of these metal junctions is unclear and will be studied in this project. These features would drop the requirement of current matching for multijunction stacks and reduce losses in large-area organic photovoltaics. Various pattern geometries will be explored, such as arrays of nanoscale holes or slits to achieve high radiation transmission through the excitation of sub-wavelength plasmon modes. Geometrical parameters such as the size, spacing, and in-plane symmetry of the nanoscale features will be tuned for optimal light transmission and spectral selectivity.

Approach: This project involves the development of a metal-organic multijunction solar cell through various modeling and experimental activities aimed at understanding the characteristics and operation of nanoscale metal structures embedded in an organic photovoltaic device. In particular the following tasks will be pursued:

- *Large-scale computer simulation of metal nanostructure enhanced solar cells:* Established numerical methods such as Finite-Difference Time-Domain (FDTD), Finite-Element Modeling (FEM), and the Discrete-Dipole Approximation (DDA) will be used to conduct simulation-guided optimizations of optically transparent nanopatterned metal films, and of metal nanoparticles for local optical field enhancement at donor-acceptor junctions and optical tuning. Additional studies will be performed to study the effect of nanoparticles on the exciton diffusion length and the photon upconversion efficiency.

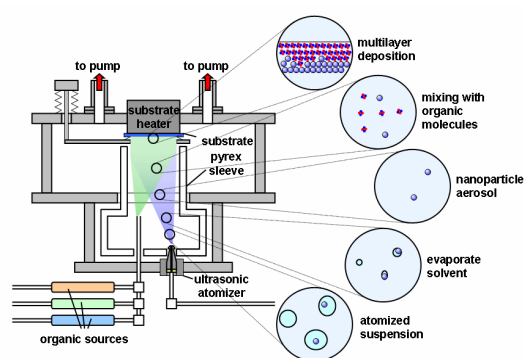


Figure 2: Schematic of the vapor deposition tool. Organic material and insulator-coated metal nanoparticles will be deposited simultaneously in a controlled fashion.

- *Fabrication and characterization of transparent nanopatterned thin metallic films and antenna structures:* Electron Beam Lithography (EBL) and Focused Ion Beam (FIB) milling will be used to fabricate complex nanopatterned metal sheets in a controlled fashion for detailed studies of the

effects of nanoscale geometry on the optical properties. The optical performance of the metal conductors will be investigated with a wide range of techniques including Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), and Scanning Near-field Optical Microscopy (SNOM). A vapor phase deposition tool will be developed to deposit organic and metal nanostructures in a controlled and inexpensive way over large areas (Figure 2). The deposition tool will enable tuning of the shape and the size of the metal nanoparticles and coating with an insulator.

- *Development of demonstration devices:* The performance of the various components of the cells will be tested separately using various demonstration devices, which include: a stacked organic cell using nanopatterned metal films as electrodes; a metal nanostructure-enhanced organic heterojunction; and a stacked, metal nanostructure-enhanced organic solar cell.

- *Cell lifetime investigation:* Cell stability will be studied with an ultrahigh-vacuum characterization chamber, simulated sunlight, and intense laser beams in combination with high temperature.

Contact: Mark Brongersma, brongersma@stanford.edu