Plasmonic Enhancement of Solar Cells

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Background

- Thin-film organic photovoltaics (OPVs) are growing in popularly as compared to traditional silicon-based photocells due to their lower costs, comparatively simple fabrication, and ease of integration with numerous flexible substrates over a large area.
- Unfortunately, research in thin-film OPVs is a relatively new field. Low efficiency (the highest reported power conversion efficiency was ~7% at the start of 2011) and stability issues prohibit the technology from widespread industrial and commercial uses.
- The use of plasmonics, which can trap light using various types of nanostructures and periodic nanopatterned arrays, can be employed to control how light behaves at the nanoscale in OPVs. The application of plasmonics is natural considering that one of the limiting factors to efficient thin-film solar cells is the thin optical path through the active layer. Slowed light has a longer optical path, allowing more photons to be absorbed and thus higher electrical efficiencies.

Objective

- Determine the optimal structures (geometry, spacing, etc.) of plasmonic nanostructures in thin-film OPVs to achieve the highest possible power conversion efficiency.

Approach

- Broadband light absorption enhancement is investigated with numerical simulations for an OPV consisting of a blend of poly(3-hexylthiophene) (P3HT) and phenyl-C61-butyric acid methyl ester (PCBM).
- A double plasmonic structure (a top layer of nanodiscs and a bottom nanopatterned array) is investigated using nanostructures fabricated from Ag, Al, and Au.
- Three dimensional finite differential time domain (3DFDTD) electromagnetic simulations using Lumerical's FDTD Solutions software were used to determine the effect of the plasmonic structures on the photocell. The optical absorption of the active layer is determined by calculating the difference between the optical power incident on and transmitted through the OPV.

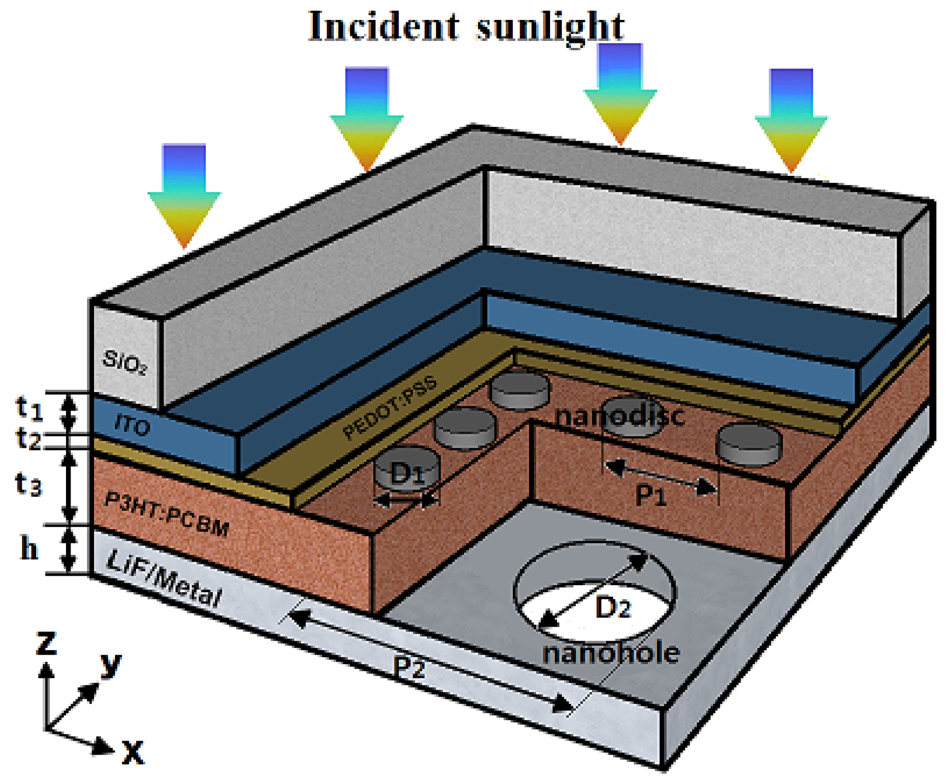


Figure 1: A diagram of our experimental setup: a top layer of SiO_2 (glass), a transparent 50nm-thick indium tin oxide (ITO) anode, a 10nm-thick PEDOT:PSS film into which the top nanodisc array is integrated, the 30nm-thick organic active layer consisting of P3HT and PCBM, and a 1nm LiF layer/80nm back metal film into which the bottom nanopatterned array is present.

- The optimal system is determined by sweeping through various parameters and determining the greatest enhancement.
- The top nanodiscs are studied with a constant period of 100nm and a varying diameter between 10nm and 80nm. The bottom nanohole array is studied by varying the period between 100nm and 400nm while keeping the period/diameter ratio constant at 2.

Results

- Before determining optimal spacing and size, we first determine the optimal materials.

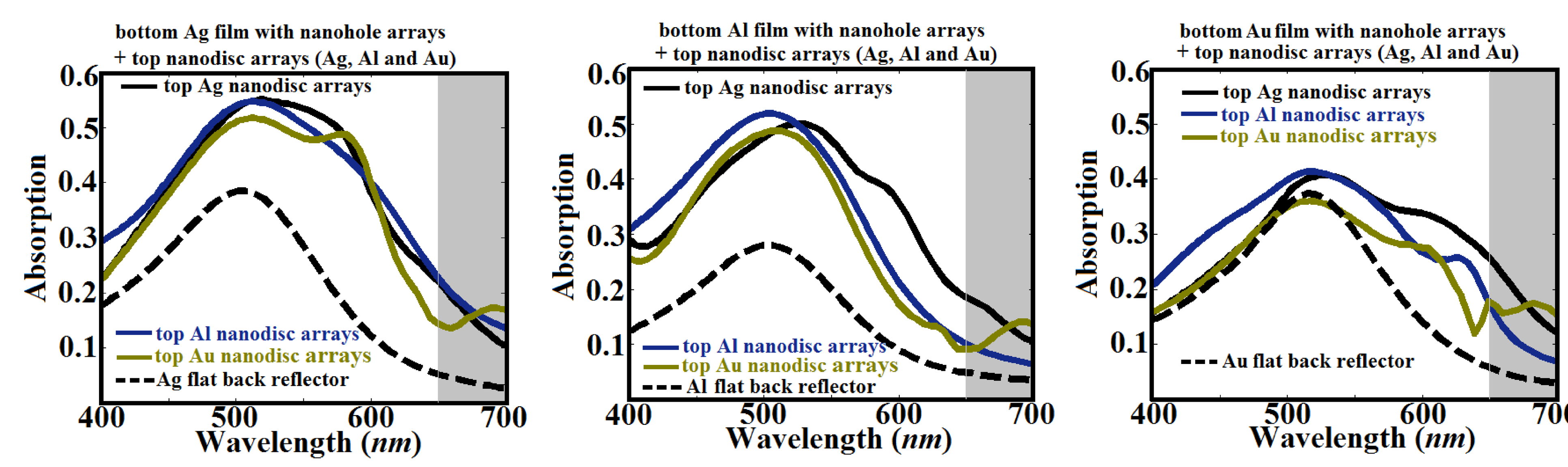


Figure 2: Three charts showing absorption at various wave lengths of an Ag film (left), Al film (center), and Au film (right) using optimized parameters.

- Either an Ag or Al film with an Ag nanodisc array are determined to be the optimal combination of materials. However there are experimental issues with using Ag as the bottom cathode, so an Al film with Ag nanodiscs are investigated further.

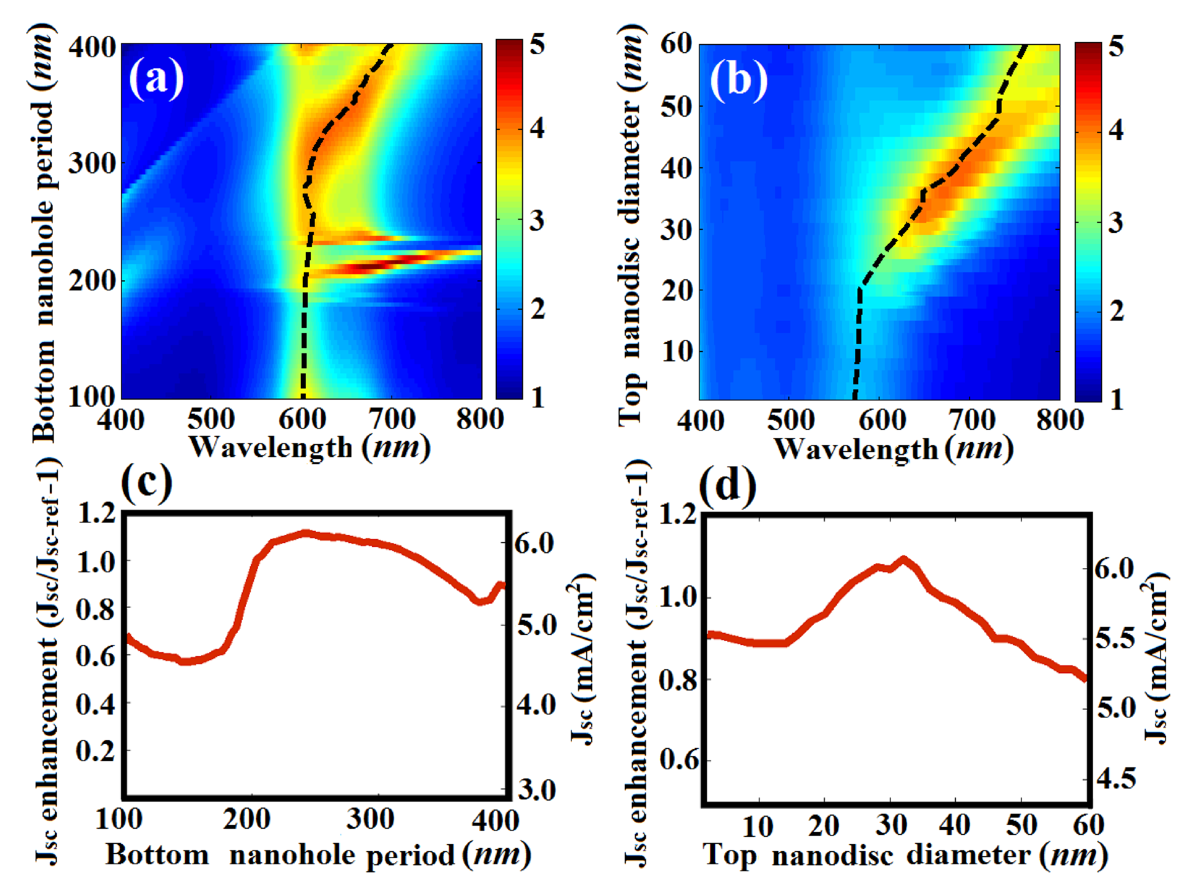
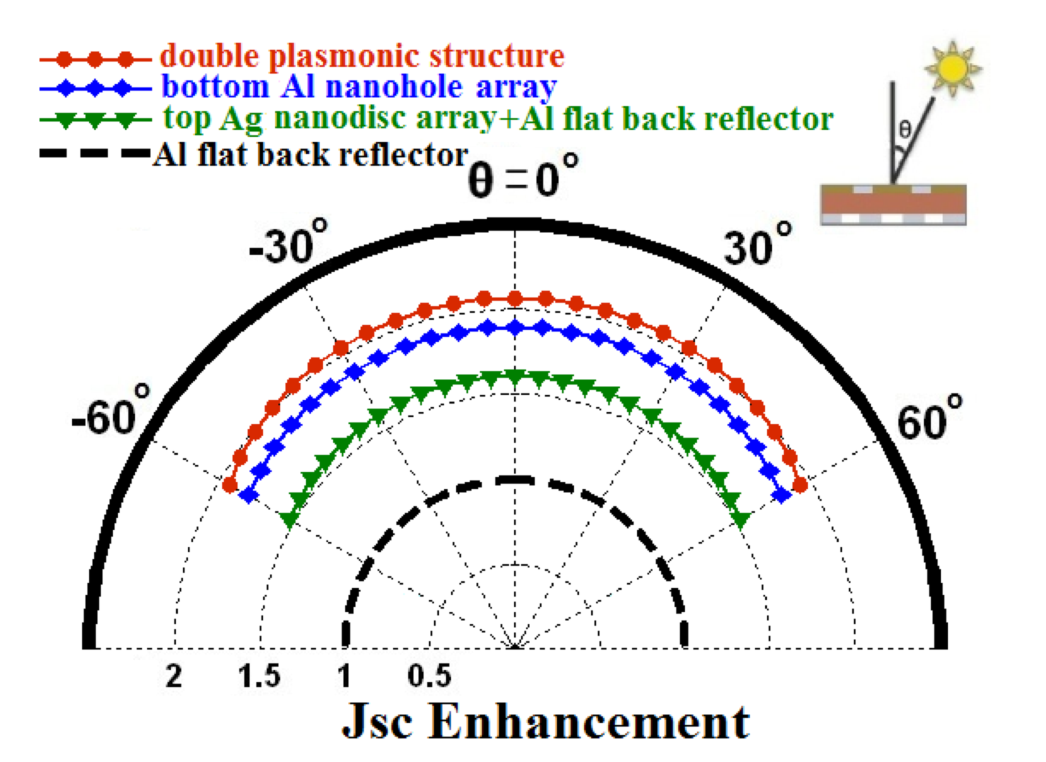


Figure 3: 2D maps showing the absorption enhancement as a function of bottom nanohole period/top nanodisc diameter and wavelength of incident light, along with the corresponding short circuit current density (J_{SC}) as a function of period/diameter.

- Simulations suggest that enhancement is near a maximum over a broad range of periods (200-330nm) and diameters (*25-35nm*), indicating a tolerance when fabricating photovoltaics.

Figure 4: J_{SC} as a function of angle of incidence of the incident light for the double plasmonic structure photovoltaic (using the optimized parameters D1=30nm, P1=100nm, D2=130nm, P2=260nm) , photovoltaics with only one plasmonic structure, and a photovoltaic with no plasmonic structures.



Conclusion

- The use of plasmonics to enhance the performance of organic photovoltaics is a feasible option for improving their efficiencies.
- A double plasmonic structure, as opposed to a single structure, allows a larger enhancement to be achieved due to coupling between the surface plasmon polariton modes excited by each structure individually.
- A broadband, polarization-insensitive, and wide-angle enhancement is shown using 3DFDTD simulations.

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