



SCIENTIFIC REPORT

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Objective

Photovoltaics (PV) technology is currently enjoying substantial growth and investment. Although there are many approaches to photovoltaic cell design and fabrication, the key performance metric is the cost per watt of PV-generated electricity, which motivates a reduction in material utilization facilitated by enhanced optical absorption. To date, little systematic thought has been given to the question of how plasmon excitation and light localization might be exploited to advantage in photovoltaics. Using insights derived from the other phenomena studied in the plasmonics field, we outline approaches to dramatically modify the light absorption in thin film solar cells. In particular, the ability of plasmonic structures to localize light at subwavelength dimensions is synergistic with use of ultrathin thin film absorbers, as well as quantum well, quantum dot, and potentially molecular photovoltaic absorber materials.

Conventionally, it is thought that photovoltaic absorbers must be optically “thick” to enable nearly complete light absorption and photocarrier current collection. Typically these absorbers are semiconductors with thicknesses several times the optical absorption length and it is several micrometers for direct bandgap compound semiconductors. Furthermore, high-efficiency cells must have minority carrier diffusion lengths several times the material thickness. Thus solar cell design and material synthesis considerations are strongly dictated by this simple optical thickness requirement.

In conventional cell designs, efficiencies of nanometer thickness cells are strongly limited by decreased absorption, carrier excitation, and photocurrent generation, and so new strategies for enhanced absorption and light trapping are desirable. Conventional light trapping schemes use wavelength-scale surface texturing on the front or back of the cell to enhance light absorption. These features, often several micrometers high, are too large to be used with extremely thin films, since the total film thickness is smaller than the surface roughness.

Surface plasmon polaritons (SPPs) are collective oscillations of free electrons at the boundary of a metal and a nonconducting dielectric or semiconductor material. These modes are highly localized at the metal surface and can propagate for several micrometers with minimal loss, but the metal film must be nanostructured because the momentum mismatch between photons propagating in dielectric media and SPPs prohibits their direct excitation by incident light.

Coupling to SPPs results in absorption in a mode volume that is small relative to the exponential absorption profiles that occur in conventional bulk semiconductors. Enhanced absorption thus increases the solar cell's photocarrier injection level and has the potential to achieve performance resembling that of a concentrator cell in which increasing the carrier injection level increases the open circuit voltage.

Purpose of the visit

This visit aims at fabricating a high efficiency organic photovoltaic cell using Ag nanoparticles prepared by the pulse-current electrodeposition. That method is a kind of simple and quick solution process that can control the density and size of metal nanoparticles on conductive substrates at room temperature, to improve the power conversion efficiency as the result of the enhanced optical absorption of incident photon within the active layer.

Work carried out during the visit

Ag nanoparticles were deposited on ITO glass substrates by pulse current electrodeposition, carried out using an aqueous solution of 10 mM AgNO₃ and 50 mM H₂SO₄ at room temperature. For the electrodeposition of Ag nanoparticles, an ITO glass substrate, a Pt wire, and Ag/AgCl were used as the working, counter, and reference electrodes, respectively.

The fabrication of solar cells containing electrodeposited Ag nanoparticles starts with spin coating of PEDOT:PSS followed by drying at 120 °C for 10 min. The PEDOT:PSS layer acts as hole transporting layer and, simultaneously, can restrict direct contact between metal nanoparticles and an active layer, leading to quenching of generated excitons. Here, because localized surface plasmon resonance is an evanescent wave that decays exponentially with distance from the metal surface, thickness of PEDOT:PSS was controlled to ~20 nm, considering the size of Ag nanoparticles (~13 nm). A solution of 30 mg MEH-PPV and 15 mg PCBM in 2 ml of chlorobenzene was then spin coated on top of the PEDOT:PSS layer, forming the active layer with a thickness of ~80 nm, and subsequently annealed at 110 °C for 10 min. Finally, calcium (8 nm) and aluminum (100 nm) were thermally evaporated onto the MEH-PPV/PCBM active layer in a vacuum at $\sim 10^{-6}$ torr with a shadow mask.

We measured the photocurrent density-voltage characteristics. The enhanced photocurrent attributed to the increased excitation generation was observed in the incident photon to current conversion efficiency spectra (*in press*).

Conclusion

The results have been preparing and will be published soon. And also will be presented in an international conference.

Future collaboration aims at realizing a high efficiency organic photovoltaic cell using other metal nanoscale features with other semiconductor materials in a multijunction device.