MAR16-2015-003816

Abstract for an Invited Paper
for the MAR16 Meeting of
the American Physical Society

Plasmonic Nanomaterials for Optical-to-Electrical Energy Conversion

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High-quality semiconductor solids have been the dominant photovoltaic materials platform for decades. Although several alternative approaches have been proposed, e.g. dye-sensitized cells or polymeric solids, none compete in terms of cost and conversion efficiency, the crucial benchmarks for industrial scale implementation. However, semiconductors suffer from several fundamental limitations relating to the microscopic mechanism of power conversion that preclude them, even theoretically, from achieving conversion efficiency at the Carnot limit of 95%. Indeed, the fundamentally different tasks of semiconductors in photovoltaic devices, both as optical absorbers, and separately, for electron-hole pair separation and collection, often demand opposing trade-offs in materials optimization. Alternatively, recent advances in subwavelength metal optics, e.g. nanophotonics, metamaterials, and plasmonics, provide several new examples where nanostructured metals perform the separate tasks of absorption and charge separation necessary for photovoltaic power conversion. Nanostructured metals are extremely efficient broadband absorbers of radiation, with tailorable optical properties throughout the visible and infrared spectrum. It is traditionally assumed that the lack of a band gap and consequent fast electronic relaxation (fs) and short mean free path (100 nm) hinders efficient carrier collection. However, new phenomena resulting from the remarkable energy concentration and nanoscale collection geometry afforded by plasmonic systems suggest new strategies may be possible that use all metal structures. In this talk, I will describe two ongoing studies in our laboratory that exemplify opportunities for metal-based optical energy conversion: (1) Excitation with circularly polarized illumination can induce strong, persistent electrical drift currents in resonant metal nanostructures via the inverse faraday effect. (2) Plasmonic absorption in metal nanostructures provides an entirely new mechanism for generating electrochemical potential from photons. This behavior is termed a 'plasmoelectric effect' (*Science, 2014*).