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Solar upconversion with plasmonic hot carriers

JENNIFER A. DIONNE, Stanford University

Upconversion of sub-bandgap photons is a promising approach to exceed the Shockley-Queisser limit in solar technologies. Placed behind a solar cell, upconverting materials convert lower-energy photons transmitted through the cell to higher-energy above-bandgap photons that can then be absorbed by the cell and contribute to photocurrent. Because the upconverter is electrically isolated from the active cell, it need not be current-matched to the cell, nor will it add mid-gap recombination pathways. Calculations have indicated that single-junction cell efficiencies can exceed 44% upon addition of an upconverter – a significant improvement over the maximum cell efficiency of 30% without an upconverter. However, due to the low quantum efficiencies and narrow absorption bandwidths of existing upconverters, such significant cell improvements have yet to be observed experimentally.

In this presentation, we will describe an entirely new solar upconverting scheme based on hot-carrier injection from a plasmonic absorber to an adjacent semiconductor. The plasmonic system both induces upconversion based on injection of hot-electrons and hot-holes and also enhances light-matter interactions. Low-energy photons incident on a plasmonic particle generate hot electrons and hot holes, which are injected into a semiconducting quantum well and subsequently radiatively recombine. Importantly, the bandgap of the quantum well can be higher than the energy of the incident photon, enabling emission of a higher-energy photon than that absorbed. First, we present analytic calculations showing that efficiencies as high as 25% are possible, significantly higher than existing solid-state upconverters, which are only 2-5% efficient. We also describe how further improvements in the efficiency are possible by employing materials and geometries that allow for more efficient carrier injection. Then, we describe experiments on InGaN/GaN quantum wells decorated with Au disks. On their own, the InGaN/GaN quantum wells do not upconvert. With the addition of the gold disks, strong upconversion is observed. We show how this new upconversion scheme offers spectral tunability across visible and near-infrared frequencies, does not require coherent illumination, is a linear process, and can be broadband.

Contributing authors include Guru Naik and Alex Welch, Stanford University