Guidelines for enhancing solar cells using surface plasmon polaritons

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(Phys.org) —Researchers from the NIST Center for Nanoscale Science and Technology (CNST) have established guidelines for using surface plasmon polaritons (SPPs) to improve absorption in both photovoltaic or photoelectrochemical cells used for energy conversion. In both types of photocells, SPPs (electromagnetic waves that travel along a metal-semiconductor interface) have the potential to increase the amount of light absorbed in the active material layer, improving the overall efficiency of light collection in solar energy devices.

The researchers have laid out a framework for calculating the maximum achievable efficiency for any arbitrary material of known permittivity (a measure of how an electric field affects a semiconducting or dielectric medium). In SPP-enabled photocells, a metal, such as gold, that supports SPPs is coated with a semiconductor, such as silicon, gallium arsenide, or titanium dioxide. Light absorption in the semiconductor material is expected to increase when SPPs concentrate the electromagnetic field at the interface between the metal and the semiconductor.

Building on the calculations of Shockley and Queisser (1961), which set a thermodynamic limit to the efficiency of a solar cell, the researchers incorporated solutions for Maxwell's equations, a set of equations that form the foundation of classical electrodynamics, to describe SPPs at the interface between a metal and semiconductor. They were able to derive analytical expressions for the maximum achievable efficiency for photocells that incorporate SPPs.

The team showed that the enhancement depends on the optical properties of the semiconductor material and cannot exceed the thermodynamic limit. They showed that photocells based on cadmium telluride, organic polymer blends, and other materials with small positive real permittivity and large positive imaginary permittivity hold particular promise for improving absorption with SPPs. On the other hand, semiconductors like silicon, gallium arsenide, hematite, and titanium dioxide have inherent optical limitations owing to permittivities that result in a significant fraction of the power of the incoming light being lost in the metal and dissipated as heat.

The researchers believe that their findings will guide the design of future energy devices. Their results will allow researchers to predict whether light trapping strategies will be improved by incorporating SPPs formed by different materials and device geometries.

More information: Design considerations for enhancing absorption in semiconductors on metals through surface plasmon polaritons, C. D. Bohn, A. Agrawal, Y. Lee, C. J. Choi, M. S. Davis, P. M. Haney, H. J. Lezec, and V. A. Szalai, *Physical Chemistry Chemical Physics* 16, 6084–6091 (2014).

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