Photocathode Applications

Photocathodes are surfaces that emit electrons when illuminated with photons due to the photoelectric effect. They are usually a metal or a semiconductor coated with an alkali metal to increase the efficiency by lowering the work function.

Traditionally, photocathodes have been used in high-sensitivity detectors, like night-vision goggles, as well as in electron guns for particle accelerators, with potential extensions into electron beam lithography and scanning electron microscopy. Our group has also been investigating the use of photocathodes for solar energy conversion devices. Such a device would require a very high quantum efficiency (fraction of absorbed photons converted to collected electrons) approaching 100% for reasonable power conversion efficiency, similar to photovoltaics.

Photon-Enhanced Thermionic Emission

We recently proposed a new method of solar energy harvesting which for the first time combines quantum and thermal mechanisms into a single process. The new method, called photon-enhanced thermionic emission (PETE), can potentially overcome the losses inherent to PV while bypassing the challenges faced by traditional thermionics.

Solar photons excite carriers into the conduction band of a p-type semiconductor. These photo-excited carriers rapidly thermalize within the conduction band, and if they encounter the surface with sufficient thermal energy, they can escape into vacuum.

Absorption measurements show the absorptive surface used in photovoltaic applications traditionally use a planar geometry. There is significant room for lowering the work function.

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Theoretical Device Performance

Theoretical PETE conversion efficiency as a function of $J_0$ and concentration of the direct/circum-solar AM1.5 solar spectrum has been calculated. Each photon with energy greater than the bandgap is absorbed and creates one electron/hole pair, while sub-bandgap photons are absorbed as heat. Black body radiation losses and transmissivity, as well as radiative and Auger recombination losses are included. The cathode temperature and electron affinity are chosen to maximize overall efficiency. A PETE device combined with solar thermal could have efficiencies >50%.

Nanostructure Photoemission

Comparison of Negative Electron Affinity (NEA) GaAs Tapered Grating Simulation Results

The photoemission process is best understood through Spicer’s 3-step model which consists of absorption, transport, and emission. However, Spicer’s model only considers a planar geometry, therefore emitted carriers are assumed to escape the surface. If a nanostructured geometry is considered then emitted carriers are no longer guaranteed to escape the surface structure. A 4th step in the photoemission process must be considered which is the probability of escaping after being emitted. We have created a simulation suite to understand the full photoemission process in nanostructures.

Experimental Results

Measurements were performed on p-doped $5 \times 10^{18}$ cm$^{-3}$ GaAs using normally incident unpolarized light. The nanocone and the tapered grating structure, shown in the SEM images to the left, exhibited significantly improved absorptivity across all measured wavelengths. The nanocone and the tapered structure exhibited high quantum efficiency, however they didn’t exceed the planar geometry. One possible route for improvement is to increase the quality of the surface by optimizing the CdS chemistry. Another route for improvement is optimizing the O$_2$ activation procedure. The activation procedure for planar samples is well understood from years of research, whereas nanostructures activate quite differently and are not well understood.

Acknowledgements and Author Affiliations

GCEP

*danriley@stanford.edu,
1Gable Laboratory for Advanced Materials
2Stanford Institute for Materials and Energy Sciences
3Center for Interfacial Engineering for Mechanical Systems at Stanford