Photon-Enhanced Thermionic Emission

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Existing Solar Technology

Intrinsic inefficiencies in solar energy technologies limit their ability to produce clean, inexpensive electricity on a global scale. Photovoltaics use photons to generate electron-hole pairs in a semiconductor. These photons must have at least as much energy as the semiconductor’s bandgap to be absorbed and converted into current, but any energy above the bandgap is lost as heat.

Photovoltaics have dramatically improved the overall conversion efficiency; a 20% efficient photovoltaic topping cycle could increase the performance of a solar thermal system by 60%. However, photovoltaic efficiencies plummet at high temperatures needed for such a system.

Solar Spectrum

Combining these two technologies into a poly cyclic system, with a thermal engine running off the waste heat of a photovoltaic, could dramatically improve the overall conversion efficiency; a 20% efficient photovoltaic topping cycle could increase the performance of a solar thermal system by 60%. However, photovoltaic efficiencies plummet at high temperatures needed for such a system.

Photovoltaic

Solar Thermal

Photon-Enhanced Thermionic Emission (PETE) Process

When a material is heated, electrons with high kinetic energy can escape into vacuum. This process, thermionic emission, can be used to directly generate electricity from heat. Thermionic emission for energy conversion faces challenges such as very high operating temperatures, low output voltages, and space charge-limited currents.

PETE Device

A PETE device consists of a semiconducting cathode and a metal anode separated by a small vacuum gap, both having low work functions to allow significant emission from the cathode and to minimize thermalization losses in the anode. Heat from thermalization and absorptive losses is used to thermionically emit carriers, and is also used by a thermal cycle attached to the anode. The cathode surface may nanostructured to enhance light absorption and electron emission.

Experimental Evidence

We measured the temperature dependent electron emission of excited GaN with an electron affinity of roughly 0.3-0.4 eV. The energy distribution curves (EDCs) have the characteristic shape of thermally emitted electrons, and the distribution widths broaden with temperature.

The emission current was measured as the sample temperature was varied. The yield more than doubled for 350 nm illumination. Measurements on a negative electron affinity sample have a negative correlation with temperature. This is because electrons do not need to overcome an additional barrier at the surface, so the dominant temperature effect is reduction in diffusion length.

Comprehensive Process Simulation

Nanomaterials offer multiple avenues to develop an efficient PETE device. We are developing a suite of integrated simulation tools to study electron emission from nanomaterials.

1. Light Absorption

Light absorption in nanostructures is modeled using Fourier Modal Method. The absorption data is then sent to the electron dynamics simulation.

2. Electron Dynamics

Electron dynamics are modeled using a Monte Carlo simulation that incorporates the full band structure. The position and trajectory data is sent to the emission ballistics simulation.

3. Emission Ballistics

Electron emission ballistics are calculated using Simion. The quantum yield of the sample is determined from the combined results of these three models.

Experimental Capabilities

- Time-resolved spectroscopy with high intensity (~1000 suns) optical excitation
- Electron collection and energy analysis
- Sample temperature control
- Surface coating deposition including Cs, Ba, and Sr
- Surface Analysis: AES, UPS/XPS, LEED

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