Thermionic-enhanced near-field thermophotovoltaics

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Abstract

Solid-state heat-to-electrical power converters are thermodynamic engines that use fundamental particles, such as electrons or photons, as working fluids. Virtually all commercially available devices are thermoelectric generators, in which electrons flow through a solid driven by a temperature difference. Thermophotovoltaics and thermionics are highly efficient alternatives relying on the direct emission of photons and electrons. However, the low energy flux carried by the emitted particles significantly limits their generated electrical power density potential. Creating nanoscale vacuum gaps between the emitter and the receiver in thermionic and thermophotovoltaic devices enables a significant enhancement of the electron and photon energy fluxes, respectively, which in turn results in an increase of the generated electrical power density. Here we propose a thermionic-enhanced near-field thermophotovoltaic device that exploits the simultaneous emission of photons and electrons through nanoscale vacuum gaps. We present the theoretical analysis of a device in which photons and electrons travel from a hot LaB_6-coated tungsten emitter to a closely spaced BaF_2-coated InGaAs photovoltaic cell. Photon tunnelling and space charge removal across the nanoscale vacuum gap produce a drastic increase in flux of electrons and photons, and subsequently, of the generated electrical power density. We show that conversion efficiencies and electrical power densities of ~ 30% and ~ 70 W/cm^2 are achievable at 2000 K for a practicable gap distance of 100 nm, and thus greatly enhance the performances of stand-alone near-field thermophotovoltaic devices (~10% and ~10 W/cm^2). A key practical advantage of this nanoscale energy conversion device is the use of grid-less cell designs, eliminating the issue of series resistance and shadowing losses, which are unavoidable in conventional near-field thermophotovoltaic devices.

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