Ultrafast response time as a clue to study heat transfer in nanostructured materials

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Abstract

Thermionic energy conversion (TEC) refers to the process of extracting energy from a heated cathode material that ejects electrons, which can be captured by a colder anode material to then drive current across a load. While traditional TEC devices have often been bulky, recent advances in nanostructured materials promise to open this technology for broader applications. For instance, an array of vertically aligned carbon nanotubes, referred to as a carbon nanotube forest (CNTF), exhibits anomalous heat localization: a localized region of the CNTF can be heated to over 2000 K on illumination with relatively low intensities of light (~10 W/cm^2), in a phenomenon dubbed the Heat Trap[1]. This extreme heat localization allows for a more compact version of a TEC device than is typically seen in conventional metal based cathodes. However, realizing practical TEC efficiency depends on understanding energy transfer dynamics responsible for the Heat Trap effect[2]. Fortunately, energy transfer channels in materials carry a key identifying signature, namely their relevant time scale[3]. In this work, I describe recent results from observing the Heat Trap effect on stimulation by an ultrafast pulsed laser, where the laser pulses are separated by a time period τ that was varied from as short as 1 pico-second to as long as 1 micro-second. The results show an enhancement combined with a red-shift of the localized heating with a characteristic timescale of at most 100 pico-seconds, which is suggestive of thermalisation through electron-phonon scattering. A major source of inefficiency in TEC devices is the space charge effect caused by Coulomb repulsion of electrons. Fast dynamics in a CNTF cathode based TEC make time-varying mode operation possible, which offers a potential route to mitigating space charge. If confirmed, the results of this study will thus provide insights into designing and optimizing nanopatterned materials as cathode materials in next-generation TEC devices and applications.

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[2] M Chang, *et al.*, Phys Rev B, **98**, 155422, 2018
[3] RR Alfano, Orlando:Academic Press Inc, 1984