Proceedings of MNHMT09
Micro/Nanoscale Heat and Mass Transfer International Conference
December 18-21, 2009, Shanghai, CHINA

MNHMT2009-18015

NANOSCALE HEAT TRANSFER IN THIN FILMS

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ABSTRACT

Heat transfer in thin films treats phonons as particles in the Boltzmann Transport Equation (BTE). However, phonons only allow slow thermal response. Rapid heat transfer is possible provided films are allowed to promptly emit non-thermal electromagnetic (EM) radiation. Quantum mechanics (QM) used in the response of nanoparticles (NPs) is extended to thin films through the theory of QED induced EM radiation. Here QED stands for quantum electrodynamics. Atoms in thin films are generally under EM confinement at vacuum ultraviolet (VUV) levels that by QM are restricted to zero specific heat, and therefore Joule heat cannot be conserved by an increase in temperature. Instead, conservation proceeds by VUV emission following QED induced up-conversion of low frequency Joule heat to the VUV confinement frequency of the film. The thermal conductivity appears reduced only because the VUV emission is excluded from the heat balance, but if included, the film maintains bulk conductivity.

INTRODUCTION

Classical heat transfer by Fourier heat conduction theory is generally thought not applicable to thin films having thickness smaller than the mean free paths of the phonons that carry heat to the surroundings. Reduced thermal conductivity in experiments is explained by ballistic heat transfer where the phonons are treated as particles in the BTE.

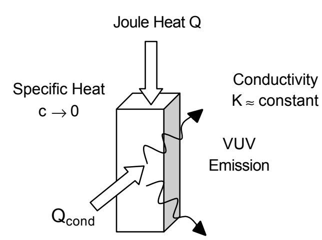
However, thin film heat transfer by the BTE is limited to slow thermal response. The BTE cannot respond at optical frequencies, say by the visible (VIS) emission from quantum dots (QDs) under near infrared (NIR) laser irradiations. The EM confinement of photons in QDs is quasi-bound allowing prompt leakage in the VIS by QED induced radiations not included in the BTE. To wit, the BTE and reduced thermal conductivity is not used in the VIS response of QDs.

In contrast, Joule heat gain in thin films is now conserved by conductive heat loss alone that excludes QED induced radiation losses, and therefore the thermal conductivity appears reduced from that of the bulk when in fact the bulk conductivity is not reduced. QED induced radiations find basis in the fact that atoms in thin films are under EM confinement at VUV levels that by QM are restricted to zero heat capacity levels of thermal kT energy. Here, k is Boltzmann's constant and T is absolute temperature.

Lacking heat capacity, the specific heat of thin films vanishes, and therefore the Joule heat cannot be conserved by an increase in temperature. See www.nanoqed.org Instead, the low frequency Joule heat is conserved by QED inducing up-conversion to the EM confinement frequency of the film that is subsequently balanced by VUV leakage loss. But the VUV leakage beyond the UV-cutoff of standard photomultipliers is usually not observed to be included in the film heat balance.

PRESENTATION

The background of thin film heat transfer is shown to begin over 30 years ago by Kelemen and extended recently by Davitadze et al. in 2002. The problem of reduced thermal conductivity has been shown [1] to originate in the classical heat transfer assumption that specific heat is constant as the film thickness is reduced. The QM size effect is presented to show the atoms in thin film have zero specific heat at the nanoscale with Joule heat conserved by VUV emission.



Zero specific heat means the thermal diffusivity diverges. Conductivity measurements by the Pulse method based on diffusivity are therefore unstable, the stability achieved by inclusion of the substrate in diffusivity measurements.

REFERENCES

[1] T. Prevenslik, "Heat Transfer in Thin Films," Third Int. Conf. on Quantum, Nano and Micro Technologies, ICQNM 2009, February 1-6, Cancun, 2009.

