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# Nanoscale Thermal Transport Across a Semiconductor Heterostructure Interface

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The rapid growth of manufacturing and application of nanomaterials in devices, together with the ever-increasing need to achieve a denser circuit integration at higher operating speeds/frequencies in electronics, have led to more aggressive thermal conditions in nano-devices, which must be adequately dealt with for the further improvement of the device performance in terms of speed and function. To meet this urgent need for the thermal management issues requires a thorough understanding and controlling of the thermal transport at the nanometer scales [1, 2].

In contrast to thermal conduction inside a homogeneous bulk medium, the heat transport in nano-structures is drastically altered in several important aspects, displaying the unique characteristics of locally non-thermal equilibrium and highly non-steady thermal conduction. When the device dimension reduces to nm scales, comparable to the wavelengths and mean-free-paths of electrons and phonons, the heat conduction will change from diffusive to ballistic thermal transport. Due to the much reduced scattering of heat carriers (electrons and/or phonons), a thorough thermal equilibrium between electrons and phonons, and among different phonon modes is usually hard to reach and maintain. Consequently, thermal relaxation among sub-systems is concurrent with thermal transport, resulting far from equilibrium situation and requiring much more sophisticated model, far beyond the conventional bulk Fourier heat diffusion equation, to treat this non-equilibrium heat conduction. In the extreme case, the definitions of subsystem temperatures (Te or Tl) in nonequilibrium nanoscale systems become fundamental issues. In addition, microchip running at GHz or faster frequencies can create a highly non-steady heating of semiconductor heterojunction with high peak heating power and large transient temperature gradient. Under these conditions, both local temperature and interfacial thermal current are fast changing on ns and faster timescale, thus cannot be adequately treated with conventional steady or quasi-steady thermal conduction. Furthermore, interfaces act as a thermal barrier, significantly decreasing the heat conduction. At present, dynamics of non-steady interfacial thermal transport on nanoscales is an active research area, aimed at improving the thermal management for better device performance and functionality as well as gaining in-depth understanding of the dynamics in nanomaterials.

Here, we report our preliminary results on probing thermal transport across a GaAs/AlGaAs interface. The temperature imbalance across the interface was created by ultrafast heating of the top GaAs nano-film with fs laser pulses and kinetics of interface thermal transport was monitored using time-resolved Reflection High Energy Electron Diffraction. The experimental results were numerically modeled with diffusive heat equations. The extracted thermal boundary conductance (TBC) were found to increase with increasing temperature imbalance across the interface. The TBC's agree well with the Diffuse Mismatch Model in the diffusive transport region, but show evidence of further increasing at temperatures higher than Debye temperature, opening up questions about the mechanisms governing heat transfer across interfaces under highly non-equilibrium conditions.

References

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