Thermal Imaging of Carbon Nanotubes by Electron Thermal Microscopy

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The resolution of optical methods traditionally employed for thermal imaging is limited by the wavelength of the radiation, emitted or reflected. Scanning probe methods have better spatial resolution but are inherently slow because the probe needs to attain equilibrium at each point of the sample during scanning. The limitations of these techniques are circumvented by a novel thermal imaging technique, called electron thermal microscopy (EThM), that relies on a solid-liquid phase transition of sub-100 nm indium islands for thermometry. This phase transition at the point of interest can be captured at video rate in a transmission electron microscope (TEM), giving a binary map of temperature above and below this fixed point. This real-time, in-situ method of mapping temperatures can be utilized to extract important thermal parameters. For example, in my work at Maryland, I employed EThM to measure the thermal contact resistance \( R_c \) of Carbon Nanotubes (CNTs) and demonstrated how this \( R_c \) value could be controlled by altering the area of overlap between the CNT and the substrate beneath. Additionally, EThM is particularly useful in understanding the modes of heat transfer in a CNT under high bias. We observed that under high bias the hot electrons, instead of coupling to the phonon system of the CNT, dissipate their energy directly into the substrate. This observation can be explained by invoking the concept of remote electron phonon scattering, where the hot electrons in CNT couple to the optical phonons of the substrate. While this concept of remote electron-phonon scattering has been used to explain low temperature electrical conductivity measurements, this is the first observation in which this phenomenon is believed to be the primary mode of heat dissipation.