Fractal heat diffusion in nanoscale devices and subdiffraction limit thermal imaging

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As device sizes shrink and frequency of operation increases, localized heating happens at a length scale comparable to that of a large number of ballistic phonons. The transition between reversible energy transport and irreversible thermal diffusion is investigated using various formalisms ranging from Fourier theory and Boltzmann transport, to generalized random walk and fractional diffusion equation. We describe some of the recent experimental studies of quasi ballistic heat conduction using femtosecond laser pump-probe technique as well as thermoreflectance imaging. We show that Lévy random walk and superdiffusion can describe heat propagation in thin film semiconductor alloys better than the normal Brownian diffusion. We show that fractal dimension of the random walk could be quite robust in the presence of scattering by nanostructures. Full-field transient thermoreflectance thermal imaging with 50 nanoseconds time resolution is used to study the temperature profile in GaN power transistors and nanoheater samples. Preliminary results on sub-diffraction limit thermal imaging using image deconvolution are presented. Depending on the signal-to-noise ratio, spatial resolution down to 100nm is achieved. Evidence of hydrodynamic heat transport in Silicon and InGaAs thin films will be discussed.