THEOS THEORY AND SIMULATION OF MATERIALS

MARVEL NATIONAL CENTRE OF COMPETENCE IN RESEARCH

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Nanoscale reversible energy transport and irreversible thermal transport

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Abstract: 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, hyperbolic heat equation, Boltzmann transport, Shastry formalism 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. We show that truncated 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 ErAs embedded nanoparticles when their concentration increases by two orders of magnitude, reducing the bulk thermal conductivity of InGaAlAs by a factor of three. Full-field transient thermoreflectance thermal imaging with submicron spatial and 50 nanoseconds time resolution is used to study the temperature profile in nanoheater samples. Preliminary results on sub-diffraction limit thermal imaging with 100nm resolution will be presented. While ultrafast heat transport in alloys can be explained well using latest Lévy random walk models, some open questions about the role of normal scattering and hydrodynamic heat transport in non-alloy semiconductors (e.g. widely used silicon!) will be described. Quasi-ballistic effects have important implications in thermal management of high power electronic and optoelectronic devices and the design of nanostructured thermoelectric materials.

Ali Shakouri is the Mary Jo and Robert L. Kirk Director of the Birck Nanotechnology Center and a Professor of Electrical and Computer Engineering at Purdue University. He received his Engineering degree from Telecom Paris, France in 1990 and Ph.D. from California Institute of Technology in 1995. His current research is on nanoscale heat and current transport in semiconductor devices, high resolution thermal imaging and waste heat recovery systems. He is also working on a new interdisciplinary sustainability curriculum in collaboration with colleagues in engineering and social sciences. He received the Packard Fellowship in Science and Engineering in 1999, the NSF Career award in 2000 and the Thermi Award in 2014.