71e Transient Thermal Response of a Nanoscale Multilayered Film

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In state-of-the-art data storage devices an increased emphasis has been laid on achieving higher areal density, which has forced the characteristic length of the devices to nanometer scale. At these scales the sub-continuum effects of ballistic thermal transport and temperature slip at the boundaries become very prominent and energy management plays a crucial role in the operation and reliability of the system. Continuum based Fourier equation is inadequate to describe these phenomena and a more rigorous physics based model, e.g., Boltzmann transport equation (BTE), is required. Since the BTE, based on phase space formulation, is computationally intensive, an alternative model stemmed from BTE, lattice Boltzmann method (LBM), is developed to successfully capture the transient thermal behavior in a sub-continuum domain at a reduced computational cost. A film with alternating materials with different thermal characteristics is chosen to examine the transient thermal profile in the presence of a nanoscale hot-spot. This relatively simple system can provide essential physics of complex data storage systems, e.g., heat assisted magnetic recording (HAMR), patterned media, and phase change media, where thermal effects play a subtle role.

Since LBM is inherently transient, easy to hybridize with other physical models and length scales, and parallel in nature, we have chosen LBM as our simulation tool. For non-equilibrium conditions, the conventional definition of temperature breaks down. Therefore, we assigned an equivalent temperature at which the total equilibrium energy of system is equal to the actual thermal energy. An emphasis has been laid on incorporating accurate boundary conditions, including diffusion and transmission of energy carriers at interfaces, which critically affects the thermal behavior. We extensively studied different length and time scales as well as different boundary conditions. Ghost particles are introduced, all around the real domain of the system, to efficiently simulate boundary effects and are useful in generalizing an isolated domain to an alternating film. Coupled lattice Boltzmann equation for electrons and phonons are solved simultaneously, using multi-grid simulation technique, to simulate metallic solids. LBM used in this work can not only predict the thermal behavior of the sub-continuum system but also provide an estimation of the effective conductivity.

Simulations have been performed on the domains containing a hot-spot and the LBM results are compared with the Fourier equation predictions for different length and time scales. It has been observed that Fourier equation increasingly under-predict the peak temperature rise at the center of the hot-spot as we reduce the system size from the continuum to the sub-continuum domain. When the characteristic length of the system is much greater than the mean free path, Fourier equation can successfully capture the temperature profile. But as the characteristic length is reduced the sub-continuum effect of hot-spot confinement and high temperature rise is captured only by our LBM simulation while Fourier equation fails to achieve so. For an alternating film case, the hot-spot in one domain interfere with the neighboring domains in a complex manner and domain interfaces strongly affect the thermal profile of the system. These phenomena are critical for the design and operation of the alternative data storage systems, such as HAMR and patterned media, by predicting the optimum heating pulse and intensity for the maximum acceptable interference and by accurately modeling the lubricant film's adsorption/desorption, replenishment, and diffusion and head contamination due to the energy transport from the hot-spot. The novel numerical tool developed in this work can successfully simulate complex multiscale systems involving multiple energy carriers with different length and time scales.