Two-temperature time-fractional model for electron-phonon coupled interfacial thermal transport

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Abstract

This research investigates thermal transport in multi-layer metal-nonmetal thin films under femtosecond laser pulses. In particular, a two-temperature time-fractional (2T-TF) model based on the Caputo fractional derivative is presented, and finite difference method is used to solve the governing heat conduction equations. To validate the results of 2T-TF model, they have been compared to the experimental data and Boltzmann transport equation (BTE) results. The 2T-TF model is demonstrated to be much more accurate than the conventional two-temperature model based on the Fourier's law, while its complexity can be much lower than BTE simulations. Moreover, various forms of thermal resistances can be readily implemented to the 2T-TF model. Notably, our 2T-TF simulations clearly demonstrate the effectiveness of inserting a metallic interlayer with high electron-phonon coupling factor to expedite the electron cooling in the top metallic layer for a metal-nonmetal heterojunction structure, which is applicable in cooling of nano-electronic devices leading to better understanding of thermal process and improvement in thermal design of such devices. The 2T-TF model can serve as a convenient and reliable tool for simulating electron-phonon coupled thermal transport in multilayered systems. This model can be used in laser based thermoreflectance technique to provide accurate measurement of thermophysical properties of different material, for example the thermoelectric materials which are widely used in space applications.