Thermal Diffusivity of Free-Standing Silicon Membranes Measured with Laser-Induced Transient Grating Technique

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The thickness dependence of the thermal conductivity of thin membranes is a classical size effect in phonon-mediated thermal transport. Most experimental data available to date have been obtained by contact methods on supported silicon films and a large scatter in the data is observed, particularly in the film thickness range >100 nm. We will report non-contract all-optical measurements on free-standing membranes covering thickness range ~30-400 nm. Single crystal Si membranes were fabricated by backside etching of silicon-on-insulator wafers. In the laser-induced transient thermal grating technique, absorption of crossed laser pulses in a sample sets up a sinusoidal temperature profile monitored via diffraction of a probe laser beam. Optical heterodyne detection enhances the signal level and simplifies the interpretation of the data. The contribution of photoexcited carriers to the signal is well separated from the thermal dynamics due to the much higher diffusion coefficient for the carriers. Thermal diffusivity is proportional to the exponential decay rate of the signal with the proportionality factor determined solely by the period of the thermal grating which is measured with high accuracy. We will also present an analytical equation describing the onset of the size effect which yields an inverse square root dependence of the reduction in the thermal conductivity on the film thickness. Experimental results will be compared with our analytical theory as well as with numerical results obtained by other authors.

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