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Reduced Thermal conductivity in Nanostructures and the Intrinsic Limit of the Q-factor in Nano-Mechanical Resonators

As the operation frequency of mechanical resonators enters into the GHz regime, the intrinsic damping mechanism arising from phonon-phonon interactions introduces a fundamental limit in the performance of the resonators, which is usually expressed by the "Q•f" product of the quality factor, Q, and the work frequency, f. Phonon-phonon dissipation depends on the material properties and, therefore, it is important to consider their changes arising from the reduction in feature size. In this context, it is well known that nanoscale materials exhibit a reduction of the thermal conductivity compared to their bulk counterpart, mainly ascribed to the shortening of the phonon mean free path due to diffusive scattering of phonons at the boundaries [1]. Here we report the impact of modified thermal properties on the intrinsic damping mechanism limiting the performance of mechanical resonators.

A silicon nanomembrane can be considered as the simplest example of a nanoscale resonator since it shows a well-identified Lamb mechanical resonance with thickness-tuneable frequency in a range from 10 GHz to 1 THz [1]. The intrinsic mechanical mode absorption is calculated using the Akhieser damping model modified to take into account the size effect on the thermal conductivity [3]. In addition, we suggest the possibility to extract thermal conductivity values from lifetime measurements, which opens the possibility to use the Q-factor as indicative of the thermal conductivity/diffusivity of nano-resonators.

References:

[1] A. M. Marconnet, M. Asheghi and K. E. Goodson, J. Heat Transfer 135, 061601 (2013).
[2] J. Cuffe, O. Ristow, E. Chávez, A. Shchepetov, P.-O. Chapuis, F. Alzina, M. Hettich, M. Prunnila, J. Ahopelto, T. Dekorsy and C. M. Sotomayor Torres, Phys. Rev. Lett. 110, 095503 (2013).
[3] E. Chávez-Ángel, J. S. Reparaz, J. Gomis-Bresco, M. R. Wagner, J. Cuffe, B. Graczykowski, A. Shchepetov, H. Jiang, M. Prunnila, J. Ahopelto, F. Alzina, and C. M. Sotomayor Torres, APL Mater. 2, 012113 (2014).