Pressure dependence of the quality factor of a micromachined cantilever in rarefied gases

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Abstract

We present a study of the damping behavior of monocrystalline silicon cantilevers in different rarefied gas regimes. Mechanical quality factors Q were analyzed at controlled ambient pressures in the range of 0.01 Pa to 100 Pa. Emphasis was laid on the investigation of the fundamental vibration mode Hence, the test structures were harmonically excited by the Lorentz force acting on the current carrying lead attached to the top surface of the cantilever. The micromachined clamped-free cantilevers featuring a length of 2 mm, a width of 1.5 mm and a thickness of 20 µm, were manufactured in SOI technology. The experimental results were compared with existing theories revealing an underestimate of the damping parameter for the Knudsen range Kn = 0.1 to 10. So far, squeeze-film damping by free molecular flow and kinetic damping were taken into account in damping models for the quasi-molecular regime. However, our measurements indicate that also the ongoing molecular flow around the test structures has to be considered. Hence the damping coefficient has to be calculated with methods of the free molecular aerodynamics. Thus, we used an algorithm based on the random walk model that allows the usage of already available knowledge in the field of Direct Simulation Monte Carlo. With this approach the quality factor of a squeezed-film damped cantilever in the quasi-molecular regime was derived. The results were compared with the most recent stochastic model, where the theoretical predictions and the experimental investigations indicate significant squeezing up to a Knudsen number of 10. In a superposition of both damping mechanisms, kinetic and squeeze-film damping, a satisfactory characterization of the damping behavior of an oscillating cantilever in the quasi-molecular regime with Knudsen numbers in the range of 10 down to 0.02 was achieved.