

Air Damping Effect on Quality-Factor in High-Order Resonance Modes of Single-Crystal Diamond Microcantilevers



National Institute for Materials Science ¹, China University of Geosciences (Beijing) ²

°(DC) Guo Chen ^{1,2}, Zilong Zhang ¹, Keyun Gu ¹, Liwen Sang ¹, Satoshi Koizumi ¹, Yasuo Koide ¹,

Zhaohui Huang ², and Meiyong Liao ¹

E-mail: meiyong.liao@nims.go.jp

Single-crystal diamond (SCD) for micro/nanoelectromechanical systems (MEMS/NEMS) has attracted a lot of interest because of their numerous outstanding properties, such as the highest Young's modulus, the highest thermal conductivity, and low intrinsic dissipation. ¹⁻³ Resonant cantilevers with high-frequency and high-quality (Q) factor hold great promise for high-sensitivity and high-resolution sensors. ⁴ Under practical use, resonators are always operated in atmospheric air, and this environment significantly impacts their Q -factor in comparison to vacuum conditions. ⁵ For MEMS cantilevers, air damping is very pronounced, particularly in the fundamental resonance mode. ⁶ However, the resonant behavior in high-order modes of SCD cantilevers against pressures has not been reported yet.

In this work, we fabricated diamond cantilevers ⁷ and investigated the effect of gas atmosphere on Q -factor in high-order resonance of SCD MEMS cantilevers. As shown in **Fig.1**, the Q -factors of a 120 μm long SCD microcantilever in three different resonance modes (1st, 2nd, and 3rd), are plotted as a function of the ambient pressure varied from high vacuum (10^{-4} Pa) to atmospheric pressure (10^5 Pa). The inset demonstrates the relative stability of the resonance frequency (f) versus gas pressure for all the three modes. The Q -factor of the high-order modes is found to be nearly constant up to pressures between 10^{-4} to 10^0 Pa and then decreases to less than 1,000 in 10^3 Pa, similar to the fundamental mode. Compared to the high-order modes, the first mode has higher Q -factors in vacuum (intrinsic regime). Nevertheless, the high-order modes in the molecular and viscous flow regimes ($P > 10^1$ Pa) exhibit higher Q -factors than the fundamental mode. Hence, in low-vacuum and atmospheric environments, the high-order resonance modes provide a profound sensitivity improvement for MEMS sensing devices, attributed to the much higher fQ product.

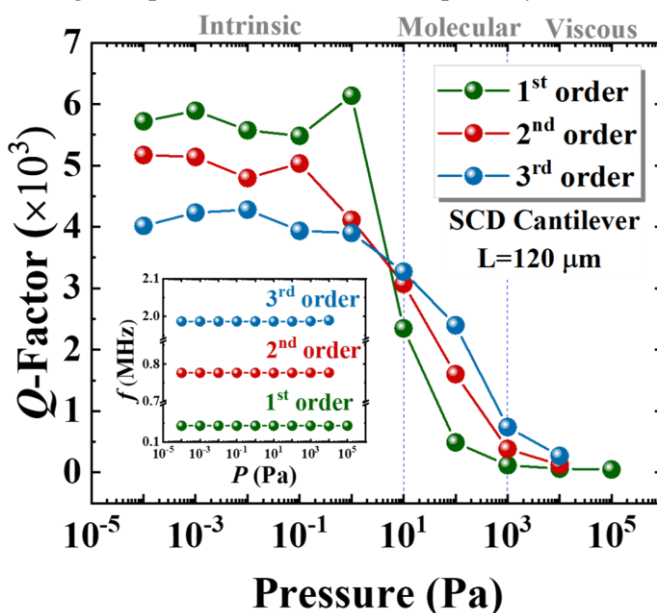


Fig. 1. Pressure dependence of Q -factor and resonance frequency (inset) of a 120 μm -length SCD microcantilever in the first three vibrations orders. The range of pressures is divided into intrinsic, molecular flow, and viscous flow regimes for gas damping of a cantilever.

References

1. G. Chen, et.al, *Diam. Relat. Mater.* 138, 110240 (2023).
2. G. Chen, et.al, *Proc. TRANSDUCERS 2023*, pp. 2185-2188 (2023).
3. Z. Zhang, et.al, *Adv. Funct. Mater.* 2300805 (2023).
4. H. Sun, et.al, *Adv. Quantum. Technol.* 2300189 (2023).
5. Y. Chen, et.al, *Diam. Relat. Mater.* 129, 109340 (2022).
6. M. Li, et.al, *Nat. Nanotechnol.* 2(2), pp.114-120, (2007).
7. M. Liao, et.al, *Adv. Mat.* 22, 5393 (2010).