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Ultrathin Single-Crystal Diamond NEMS Cantilevers for High-Sensitivity Nanomechanical Sensing

T. Nanocarbons II: from synthesis to advanced applications

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Abstract

Ultrathin nanoelectromechanical system (NEMS) resonators are essential for achieving ultimate force and mass sensitivity, yet fabricating mechanically robust devices with nanometer-scale thickness and low dissipation remains a major challenge. In particular, conventional semiconductor materials suffer from enhanced surface-related losses when scaled to the nanoscale, while two-dimensional (2D) materials, despite their atomic thickness, face limitations in reproducibility, controllability, and quality (Q) factors. These challenges motivate the search for an ultrathin NEMS platform that combines nanoscale dimensions with high mechanical stability and scalability.

Here, we report a smart-cut-assisted thinning strategy that enables the reliable batch fabrication of ultrathin single-crystal diamond (SCD) NEMS cantilevers with thicknesses down to 50 nm, representing the thinnest SCD NEMS cantilevers reported to date. The fabricated devices exhibit well-controlled geometries and preserve high crystalline integrity, leading to resonance frequencies that closely follow Euler–Bernoulli beam theory over a wide frequency range from 10 kHz to 3 MHz. Despite their extreme aspect ratios, the ultrathin diamond cantilevers maintain high mechanical performance, with quality factors on the order of $\sim 5 \times 10^4$ at room temperature.

Benefiting from diamond's ultralow intrinsic dissipation, absence of native oxide, and superior thermal conductivity, the resonators demonstrate excellent thermal robustness. The quality factor remains above 6×10^3 at temperatures as high as 773 K, accompanied by a low temperature coefficient of frequency of approximately -10 ppm/K. Owing to the combination of reduced mass and high Q-factors, the devices achieve a force sensitivity of $\sim 10^{-17}$ N/Hz^{1/2} and a mass resolution down to 5.89×10^{-20} kg when operated in higher-order modes, approaching the performance of carbon

nanotube-based resonators while offering far superior robustness and manufacturability.

These results establish ultrathin single-crystal diamond as a highly promising NEMS material platform that bridges the gap between conventional MEMS materials and 2D nanomechanical systems. The demonstrated fabrication strategy and device performance open a viable pathway toward scalable, high-sensitivity, and thermally stable nanomechanical sensors for applications in force spectroscopy, mass detection, and operation in harsh environments.

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