Ultrathin Diamond NEMS Cantilevers with Enhanced Frequency Stability for High-Sensitivity Mass Sensing

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Ultrathin single-crystal diamond (SCD) nanoelectromechanical systems (NEMS) are highly attractive for precision sensing because they combine nanoscale dimensions with exceptional mechanical robustness, low dissipation, and high thermal stability. Here, we investigate the frequency stability and detectable mass limit of a 50-nm-thick, 60-μm-long SCD cantilever fabricated by a smart-cut-assisted thinning strategy, with emphasis on the benefits of the second mode resonance operation.

The ultrathin diamond cantilever maintains high crystalline quality and exhibits resonance behavior consistent with the Euler–Bernoulli beam model, confirming excellent structural integrity at extreme thickness scaling. Frequency fluctuations were measured in a closed-loop tracking configuration with a bandwidth of 1 Hz, and the stability was quantified using Allan deviation. The sampling rate was fixed at 500 Sa/s. Time-domain measurements over 60 s show stable resonance responses for both the fundamental and second mode. As shown in **Figure 1**, the Allan deviation demonstrates a clear improvement in frequency stability in the second mode, with the minimum value decreases from 4.89×10^{-6} for the fundamental mode to 1.45×10^{-6}.

This improved frequency stability directly enhances the detectable mass limit. Based on the mass-sensing relation, the minimum detectable mass improves from 6.16×10^{-19} kg in the fundamental mode to 1.83×10^{-19} kg in the second mode, showing more than a threefold enhancement. The improved frequency stability of the second mode arises from its higher resonance frequency, which reduces the relative impact of thermally induced frequency fluctuations. These results demonstrate that second-order mode operation is an effective route toward unreliable and ultrasensitive diamond NEMS for next-generation nanomechanical sensing.

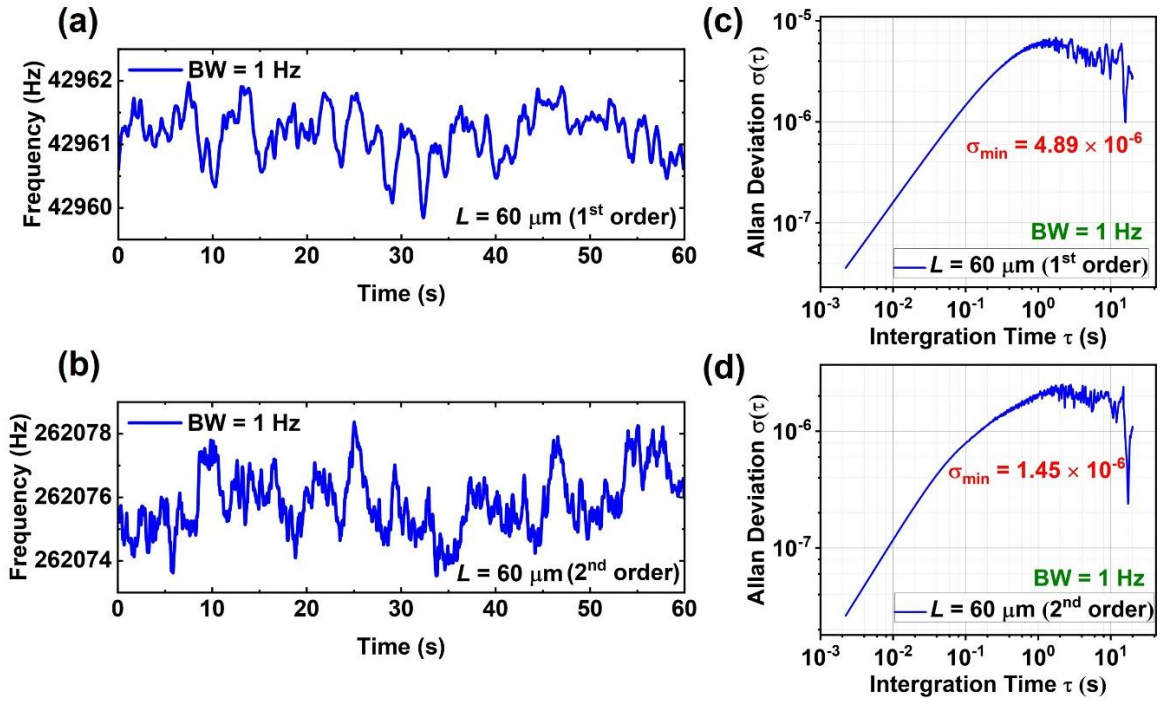


Figure 1. Frequency-stability characterization of a 50-nm-thick, 60-μm-long SCD NEMS cantilever measured at a bandwidth of 1 Hz. Time-domain resonance-frequency fluctuation of (a) the fundamental mode and (b) the second mode over 60 s. (c) Allan deviation of the fundamental mode, showing a minimum value of 4.89×10^{-6}. (d) Allan deviation of the second mode, showing an improved minimum value of 1.45×10^{-6}. The improved frequency stability of the second mode leads to a lower detectable mass limit than that of the fundamental mode.