Frequency and Damping Noises of a Mechanical Oscillator with Optomechanically Modified Effective Quality Factor

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The quality factor (Q) of an oscillating force sensor is a critical parameter for characterizing the noises that affect the measurement in frequency modulation atomic force microscopy (FM-AFM). Both the thermal and displacement sensor noise affect the frequency noise, with their impact depending on the cantilever's Q-value in different environments [1].

The effective Q factor refers to the quality factor of a mechanical resonator as modified by external control, such as optomechanical feedback or active feedback damping. The effective Q factor can be tuned by applying external force or feedback. This tunability enables us to optimize the resonator's response for specific measurements. However, the influence of the effective Q factor on frequency noise remains not fully understood. While theoretical models suggest that both thermal and displacement sensor noise contributions to frequency noise depend on Q, systematic experimental studies of frequency noise across a wide range of effective Q values are still lacking.

To achieve this, we employed optomechanical excitation using two different lasers (excitation and detection lasers). We established a Fabry-Perot cavity by positioning an optical fiber close to the cantilever, enabling both detection and excitation lasers to reflect back into the fiber. In this configuration, the excitation force depends on the optical intensity on the cantilever, which depends on the cantilever's position due to optical interference. The resulting position-dependent optical force acts as a spring whose spring constant is determined by the slope of the interferogram pattern (optical intensity vs cavity length relations). Also, any time delay between the optical forces and the cantilever's position introduces damping, thereby tuning the effective Q.

We implemented this method in a low-temperature AFM setup with two laser sources: a 1310 nm laser for excitation and a 1550 nm for detection. The effective Q was tuned by varying the average intensity of the 1310 nm laser, without changing the cavity length. We carefully measured the frequency shift and dissipation noise density spectra for different effective Q values. Our results demonstrated that these noises are independent of the effective Q factor.

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References

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