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Designing resonance modes of AFM cantilevers and its application for probing of electric properties and operation with ultrasmall oscillation amplitude

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Abstract

Dynamic force microscopy (DFM), distance between the tip and the sample is regulated by maintaining its resonance frequency shift or its oscillation amplitude damping. Owing to a high Q-factor of microfabricated cantilever, weak interaction forces can be easily detected thus atomic or molecular resolution images have been obtained. Moreover, various techniques for probing local electric properties based on electric force detection, such as Kelvin-probe force microscopy (KFM) and scanning capacitance force microscopy (SCFM)[1,2], has been derived from DFM. Sensitivity and lateral resolution for those techniques can be improved by tuning the modulation frequency of an external electric field (modulation frequency: fm) so that the probing frequency (fm for KFM and 3fm for SCFM) matches one of the mechanical resonance frequencies of the cantilever[3].

In general, the first resonance frequency (f1) is utilized for regulating the tip-sample distance in DFM. Thus the lowest available resonance frequency is the second resonance frequency (f2) unless a two-pass (lift) mode is employed. However, since f2 is 6.3 times higher than f1 for rectangular cantilevers, it often becomes higher than the bandwidth of the deflection sensing system utilized in DFM, which is typically less than 1 MHz. Furthermore, effective spring constants at those higher resonance frequencies become quite large and thus not ideal for detecting weak interaction forces. In other words, there is a fixed relationship between the resonance frequency and the effective spring constant for all resonance modes.

In order to overcome such limitations, we have newly designed a novel cantilever structure whose resonance frequency and spring constant at the second resonance mode could be adjusted independently without above-mentioned restrictions. We fabricated one or multiple resonators inside or outside of the main cantilever beam using a focused ion beam milling instrument. We tailored the resonance frequencies and the effective spring constants as optimized by the finite element method calculation and successfully utilized the novel cantilever for KFM and SCFM.

Furthermore, another cantilever design for performing high-resolution DFM imaging was introduced. We fabricated a resonator whose vibration amplitude is much larger than that of a tip on the main cantilever beam. The design helps DFM operation at very small amplitude without sacrificing signal-to-noise ratio of the deflection signal detected on the resonator.

References

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