Mass-loaded Cantilevers with Suppressed Higher-order Modes for Magnetic Resonance Force Microscopy

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Magnetic resonance force microscopy (MRFM) [1] uses an ultra-sensitive cantilever to detect magnetic resonance in small ensembles of spins (either nuclear spins or electron spins). The technique requires the detection of a very small (attonewton) oscillating magnetic force exerted on a magnetic tip by the spins in the sample [2, 3]. An RF magnetic field is used to manipulate the spin orientation at a rate that matches the kHz resonance frequency of the cantilever.

In order to extend this technique to single-spin sensitivity, the magnetic tip must generate a large magnetic gradient (e.g., several gauss per angstrom) in order to create a measurable force. Previous experimental and theoretical studies have shown, however, that sub-angstrom thermal vibration noise in the upper modes of the cantilever, in combination with the large gradient, creates enough magnetic noise to destabilize the spin.

To overcome this problem, the MHz-frequency thermo-mechanical noise of the cantilever must be suppressed. For detection of electron spins, the frequency range that is most important is in the range of 10 to 20 MHz, corresponding to the Rabi frequency of the spin. In this frequency range, vibration noise of only a few milli-angstroms can be detrimental.

Amongst various methods for suppressing the high order mode noise [4], this work focuses on mass-loaded cantilevers (Fig. 1). Finite-element analysis of such cantilevers reveals that they will have significantly lower noise spectral density at MHz frequencies. This type of design can be engineered to have large gaps in the mode spectrum (Fig. 2).

Fabricating such dual-thickness cantilevers poses special challenges. Unlike previous single-thickness cantilevers [2], the present design calls for a very thin "hinge" section (0.1 μm thick) coupled to a considerably thicker "mass" (2 μm thick). To minimize dissipation, the cantilever has to be made of single-crystal silicon, with surfaces that are as clean and defect-free as possible. The thickness of each section needs to be highly uniform as well. We have chosen to use the oxidation-thinned silicon device layer of an SOI wafer to form the hinge, and selective silicon epitaxy to form the mass. In addition, to reduce clamping losses and ensure a high quality factor, a separate epitaxial layer was used to stiffen the support region near the base of the cantilever. We are investigating cantilever performance at both room and low temperatures.

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[2] "Attonewton force detection using ultrathin silicon cantilevers," T.D. Stowe, K. Yasumura, T.W. Kenny, D. Botkin, K. Wago, and D. Rugar, *Appl. Phys. Lett.,* 71 (2), pp. 288-90, 1997.
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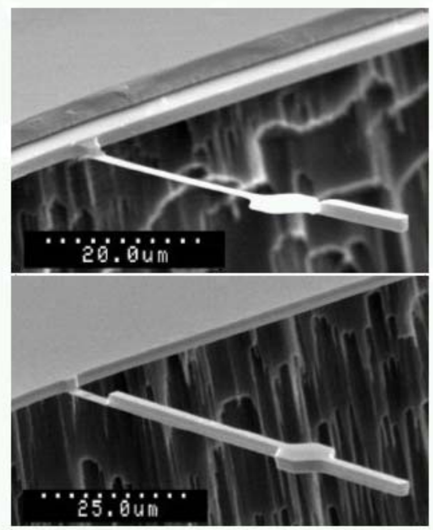

Fig. 1: Mass-loaded cantilevers with 0.1 μm thick hinge and 2 μm thick mass. Two different designs are shown, with different mass sizes. The paddles are used for laser interferometry.

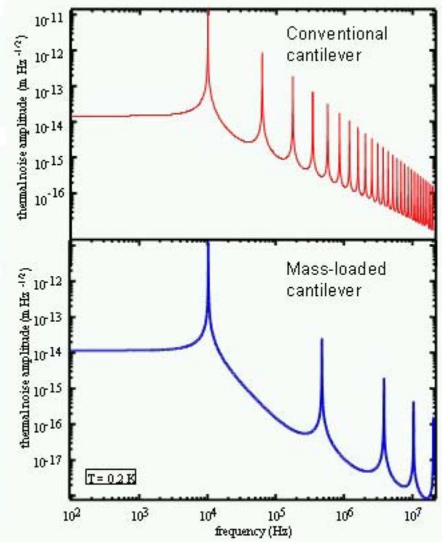

Fig. 2: Theoretical thermal noise spectra of (a) conventional, (b) mass-loaded cantilevers [note large spectral mode gaps in (b)].