

Custom-Made Single-Crystal Silicon Cantilevers for Magnetic Resonance Force Microscopy

CNF Project Number: 2125-12

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Primary CNF Tools Used: JEOL JBX9300FS

Abstract:

We employed e-beam lithography to prepare custom single-crystal silicon attonewton-sensitive microcantilevers for use in magnetic resonance force microscopy measurements. By using a focused-ion beam system to modify the bare cantilevers in a post-fabrication procedure, we can prepare magnet-tipped cantilevers with a variety of magnet shapes, sizes, and materials.

Summary of Research:

Magnetic resonance force microscopy (MRFM) is a scanning-probe technique used to resolve the locations of nuclear and electronic spins using principles of magnetic resonance. To accomplish this, we bring an attonewton-sensitive magnet-tipped microcantilever in proximity to a spin-polarized sample. The sample's polarization is modulated and the resulting changes to the cantilever's vibrational amplitude and frequency are recorded as the signal. A puzzle in recent electron spin resonance (ESR)-MRFM experiments is a factor of 17 in missing signal. This missing signal used to be greater, a factor of 340, and was ameliorated by modified sample preparation procedures [1].

To recover the remaining factor of 17 in signal, we are investigating potential sources of spin-lattice relaxation time (T₁)-shortening in our experiment. This is the focus of our investigation because a sample spin with a T₁ shorter than the oscillation period of our cantilever would not contribute significantly to the observed shift in the cantilever's mechanical resonance frequency.

Two potential sources of induced T₁-shortening are thermal magnetic fluctuations [2] and thermal current fluctuations [3]. Both of these causes can be investigated using blank fabricated cantilevers [4] and post-fabrication FIB-enabled modification [5].

We demonstrated that FIB can be used to attach magnetic particles ranging in size from ~400 nm to ~5 μm to blank cantilevers. The procedure can be used to mill particles to shapes of interest (i.e., cylinders), and to attach various magnetic materials. Significantly, this includes magnetic materials that are electrically insulating, like yttrium iron garnet (YIG). This last point is significant because it will allow us to address the theory that thermal current fluctuations are the cause of signal loss, whereby the degree of T₁ shortening is proportional to the magnet tip's conductivity.

Conclusions and Future Steps:

We have shown that the e-beam lithographically prepared silicon microcantilevers are suitable for post-fabrication modification in a FIB system. Future work may investigate the possibility of batch-fabricating magnet tips out of magnetic materials, such as YIG, so that the procedure can be applied to a more uniform starting point, rather than needing to mill a new shape from a microparticle every time.

References:

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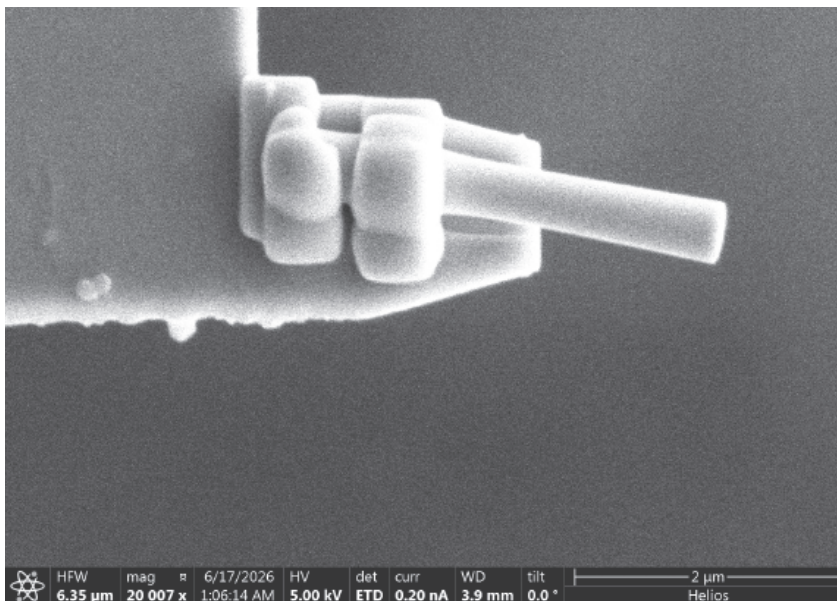


Figure 1: A 3.3 m-long, 480 nm-diameter cylinder of neodymium iron boron, ion-milled from a sphere and electrostatically transferred to the leading edge of a custom-made silicon cantilever. FIB-milled magnet tips affixed to lithographically prepared cantilevers will enable the exploration of different magnet materials and shapes in MRFM experiments.