Integration of Batch-Fabricated Overhanging Magnetic Nanorods on Attonewton-Sensitivity Silicon Cantilevers

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Abstract:
In this project, we batch-fabricate nickel nanorods overhanging the leading edge of attonewton-sensitivity silicon cantilevers to employ in high-sensitivity magnetic resonance force microscopy (MRFM) experiments. Previously we have demonstrated that overhanging nanorods minimize dissipation at small tip-sample separations, which is critical for our work since sub-5 nm tip-sample separations are needed for optimal sensitivity. However, the yield for intact magnets has remained low due to fundamental process incompatibilities in our forty-two step process. In this report, we’ll discuss our recent work to introduce barrier layers into the fabrication process and reduce the number of processing steps after magnet deposition.

Summary of Research:
Mechanical detection of magnetic resonance opens up exciting possibilities for characterizing soft materials and biomolecules with elemental specificity at nanometer-scale, and potentially atomic-scale, resolution [1]. Achieving atomic resolution requires using cantilevers with a low minimum detectable force at small tip-sample separations and fabricating magnetic tips with only a few nanometers of damage at the leading edge. We address these challenges by: 1) fabricating cantilevers with overhanging magnetic tips, 2) protecting the nanomagnet leading edge by atomic layer deposited (ALD) alumina, 3) characterizing the extent and chemical mechanism of damage by nanometer-resolution electron energy loss spectroscopy (EELS), and 4) developing an alternative approach to serially combine blank attonewton-sensitivity cantilevers with small batch-fabricated Si chips with integrated overhanging magnets.

For high-sensitivity MRFM measurements, sub-5 nm separations between the leading edge of the magnet and the sample spin are needed. Previously, Hickman et al. determined that by fabricating magnets that overhang the leading edge of the silicon cantilevers, the dissipation, or force experienced by the cantilever, remains below the threshold $F_{\text{min}} = 10$ aN down to 3 nm tip-sample separations, and that $F_{\text{min}}$ is negligible above tip-sample separations of 10 nm, as shown by the open circles in Figure 1 [2]. Additionally, our data is compared to the minimum detectable force experienced by the cantilever used in the most sensitive MRFM experiment to date, shown as the filled circle and square in Figure 1; in the aforementioned experiment a single copy of the tobacco mosaic virus was imaged with 4 nm resolution [1].

Recently, we have worked to improve our nickel nanorod-tipped cantilever yield. We determined that high-heat processing steps, which exceeded the temperatures of formation of nickel silicide and nickel oxide, caused extensive damage to almost all magnets during processing. By EELS analysis we determined that even intact magnets had at least 20 nm of nickel oxide damage at the leading edge after processing, as shown in Figures 2 and 3. In order to mitigate this problem, we introduced interdiffusion barrier layers into the process. A thin sacrificial ALD alumina layer was deposited over the nanomagnets during processing, which significantly reduced the formation of nickel oxide at the exposed magnet surfaces, and tantalum was deposited under the nickel magnets, which prevented nickel silicide formation at the nickel-silicon interface. With introduction
of the barrier layers, magnet-tipped cantilever yield improved dramatically; however, frequency-shift cantilever magnetometry conducted on these nanomagnets indicated that magnetization was extremely low after processing. Further optimization of this process is still needed.

We also are currently developing a new fabrication process to batch-fabricate 3 μm wide, 20 μm long silicon chips with integrated overhanging magnets that we will serially attach to blank cantilevers using focused ion beam (FIB) manipulation. This approach will reduce the number of processing steps after magnet deposition from thirty to five, as well as reduce the heat experienced by the magnets to less than that for the temperature of formation of nickel silicide.

In this process, suspended silicon chips are fabricated by first etching slits in the silicon device layer, followed by underetching the buried oxide layer to release the chips. The magnets are then evaporated by electron gun evaporation and the silicon under the magnet is underetched by a reactive ion plasma etch.

References: