Ultrasensitive Cantilevers for Magnetic Resonance Force Microscopy and Energy-Dissipation Studies

CNF Project # 863-00

Principal Investigator(s): Professor John A. Marohn

Abstract:

Magnetic resonance force microscopy (MRFM) is an emerging technology which uses a force on a magnet-tipped microcantilever to detect magnetic resonance, providing three-dimensional, subsurface imaging of paramagnetic samples [1]. If sufficiently high sensitivities can be reached, this technique could achieve atomic scale imaging, and be used, for example, to read out the structure of large biomolecules or study structure at buried semiconductor interfaces. Two main obstacles impeding progress toward this goal are excessive energy dissipation of unknown origin between the cantilever and sample surface [2], and the lack of a strategy for creating the specialized magnetic tips required for the next generation of MRFM experiments.

We are working to solve both of these problems using the facilities at the Cornell NanoScale Facility. In earlier work at CNF, we were able to create highly force-sensitive cantilevers [3] which were used to detect magnetic resonance in GaAs at unprecedented nuclear MRFM sensitivity [4]. We have since improved the fabrication process and created cantilevers with sharpened, metal-coated tips which were used to study tip-surface energy dissipation. We are also pursuing an advanced magnetic-tip fabrication process for MRFM.

Summary:

Cantilevers are created from the device layer of a silicon-on-insulator wafer using optical lithography. The substrate layer is retained as a handling die, and the oxide layer is sacrificial. First, cantilevers are patterned in photoresist on the device layer using the GCA Autostep 200 stepper. After a tetramethylammonium hydroxide development, the device layer is etched through with an SF$_6$ plasma (PlasmaTherm 72 reactive-ion etcher). The cantilevers are then coated with a layer of SiO$_2$ using plasma-enhanced chemical vapor deposition (GSI) for protection during the backside process. The backside is patterned with contact optical lithography using the EV620, then etched through the oxide layer using the Unaxis 770 Bosch-process deep reactive-ion etcher. Finally cantilevers are released with a buffered HF etch.

In order to probe energy dissipation between the cantilever and a surface, cantilevers are sharpened using mask-offset optical lithography [5], which can be reproducibly automated with the Autostep 200. Non-contact frictional energy loss is measured as the tip approaches various chemically distinct surfaces. Our results indicate that the friction is due to fluctuating electric dipoles in the sample. Furthermore, because of the dependence on the dielectric thickness, we believe that this friction is not a surface effect, but due to fluctuations in the volume of dielectric below the tip.

Next-generation MRFM experiments will require sub-100 nm magnetic tips which protrude from the cantilever along its longest dimension. We are currently developing a process to achieve this, and have some preliminary results at the micron length scale. Rectangular magnets 1 µm x 3 µm x 50 nm thick were fabricated by evaporation and liftoff of Co on [111]-oriented silicon. A SiO$_2$ etch mask was deposited by plasma-enhanced chemical vapor deposition (GSI). Etch holes were patterned using optical lithography, then etched through the SiO$_2$ and ~300 nm deep into the Si using reactive ion etching. After stripping photoresist, the magnets were underetched with a KOH etch. The magnets were released by a HF etch of the SiO$_2$ followed by critical-point drying. The etch holes were positioned with respect to the Si crystal planes such that the magnets could be controllably undercut [6]. The resulting magnets protruded from a ledge, exactly as is needed for future MRFM experiments.

We are currently moving this process to the JEOL 9300 electron beam lithography system to create sub-100 nm protruding tip magnets.

References:

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Figure 1, top right:
A high sensitivity cantilever 4 µm wide, 250 µm long and 0.34 µm thick. The wider portion is used for motion detection by fiber optic interferometry. Inset: The cantilever’s tip.

Figure 2, below right:
Non-contact friction measured over three samples. All measurements were taken at 300K in 1x10^-6 mbar in a custom-built force microscope.

Figure 3, below left:
Micron-scale test of MRFM tip process. A 50 nm thick Co magnet protrudes from a ledge patterned by KOH etching of the 111-oriented substrate.

Figure 1

Figure 2

Figure 3