Attonewton Sensitivity Magnet-Tipped Cantilevers and Sample Preparation for Single-Electron Spin Detection

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Primary CNF Tools Used: JEOL JBX-6300FS electron-beam lithography system, CVC SC4500 e-gun evaporation system, Oxford PlasmaLab 80+

Abstract:

Magnetic resonance force microscopy (MRFM) is a technique that increases sensitivity and resolution of magnetic resonance imaging beyond that achieved by traditional inductively-detected methods by using a nanomagnet-tipped cantilever as an attonewton-sensitivity force detector. In this report, we detail progress on magnet fabrication and sample preparation at the Cornell NanoScale Science and Technology Facility (CNF) that will enable single electron spin detection via MRFM.

Research Summary:

The Marohn group aims to use MRFM to image three-dimensional structures of biomolecular complexes that are hard to determine using techniques such as x-ray crystallography and cryo-electron microscopy. Achieving the signal-to-noise necessary to detect a single electron requires a nanomagnet with a large field-gradient to maximize the force and force-gradient between sample spins and the cantilever tip. The magnet-tipped cantilever fabrication protocol established by Longenecker separates the cantilever and magnet fabrication processes by depositing magnets first onto patterned chips instead of directly onto the cantilever (magnet-on-chip design) [1]. The fabricated magnet chip is then lifted-off from the wafer and attached to the cantilever with Omniprobe using a dual beam FEI Strata 400 STEM FIB system available at the Cornell Center for Materials Research (CCMR). The batch-serial process prevents the magnet from undergoing extreme conditions during the chemical etching process of the cantilever fabrication, reducing magnet damages. Magnet-tipped cantilevers produced this way have demonstrated record-high field gradients of 5 mT/nm [1], enabling many advances in detection and imaging.

In the past year work done at the CNF focused primarily on reproducing the fabrication protocol for cobalt-tipped cantilevers. The process involves 4-step e-beam lithography patterning on the JEOL JBX-6300FS electron-beam lithography system — alignment marks layout, chip structure, magnetic and under-etch patterning. The alignment and cobalt depositions were achieved with a CVC SC4500 e-gun evaporation system. The chip patterning and under-etch patterning were done in an Oxford PlasmaLab 80+ for silicon etching. The resulting magnet chips are shown in Figures 1 and 2.

The process allows for a 200 to 250 nm magnet overhang at the edge of the cantilever tip. The overhanging magnet design reduces surface noise caused by electrostatic interactions between fluctuating charges in the sample and the relatively large silicon surface of the cantilever tip. Reducing surface noise by increasing this silicon tip-sample separation is crucial to achieving the signal-to-noise necessary or detection and imaging. We are currently in the process of finishing a new batch of magnet-tipped cantilevers at the CCMR by attaching fabricated cobalt magnets onto previously prepared cantilevers.

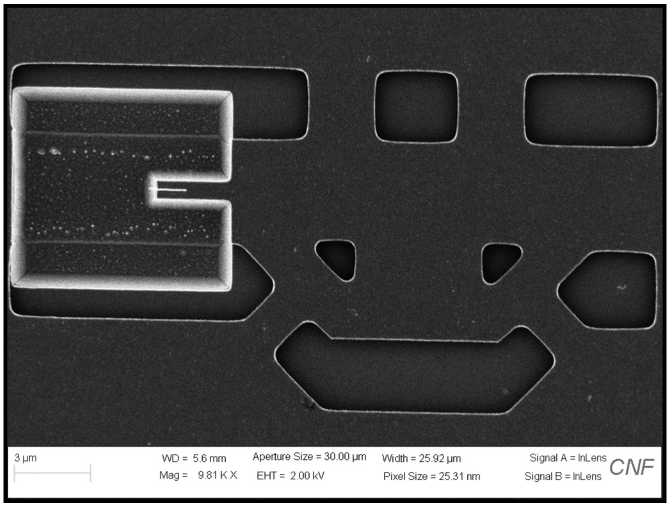

Figure 1: Magnet-on-chip design with an e-beam patterned cobalt. This specific pattern has a magnet of ~ 1 µm in length, 80 nm in width and 200 nm in thickness. The overhang is ~ 230 nm.

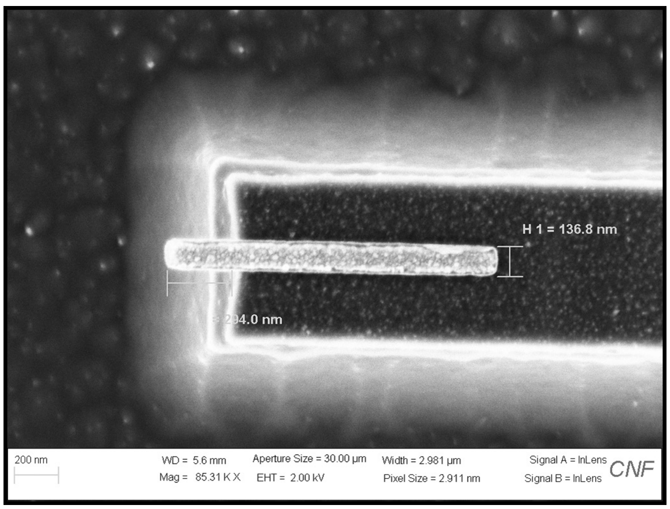

Figure 2: Cobalt magnet overhanging at the edge of the chip design. The magnet patterned is ~ 1.2 µm long, 136 nm wide and 200 nm thick. The overhang is 294 nm.

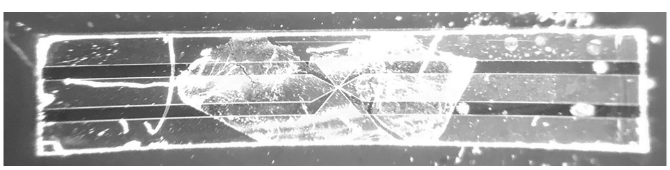

Figure 3: Multilayer graphene deposited on top of a coplanar waveguide spin-coated with a 200 nm thick polystyrene film. See full color version on pages xxviii-xxix.

To reduce surface noise for MRFM detection, the sample is coated with 12 nm gold film by e-gun deposition and wire-bonded to the ground plane to reduce surface charge accumulation. However, recent experiments suggest the e-gun deposition damages our nitroxide spin probes up to 20 nm in depth. One experimental approach is to use multilayer graphene as a replacement for gold due to its high electrical conductivity and mild conditions for transfer [2].

The substrate for growing multilayer graphene is a silicon wafer (290 nm oxide layer) with a 300 nm nickel film. The nickel film is deposited by the CVC SC4500 e-gun evaporation system at the CNF at a rate of 4 angstrom/s. The graphene is then chemical vapor deposited at 900°C using the furnace from McEuen group (Department of Physics, Cornell University). The multilayer graphene is removed from the substrate and onto the surface of a water bath by a nickel etching process and directly scooped up onto a coplanar waveguide covered in a spin-coated sample. The resulting graphene-coated waveguide is shown in Figure 3. The properties of the graphene are characterized by an Asylum-MFP3D-Bio-AFM-SPM and a Renishaw InVia Confocal Raman microscope at the CCMR and the surface noise is then analyzed in our MRFM microscope.

We have yet to demonstrate surface noise comparable to e-gun deposited gold although more testing is needed. In addition, we are looking forward to further improving our magnet-tipped cantilever fabrication process in terms of increasing yield and reducing magnet damage to increase the sensitivity and resolution of our MRFM microscope.

References:

[1] Longenecker, et al. ACS Nano 2012, 6 (11), 9637-9645.

[2] Jo, G., et al. Nanotechnology, 2010, 21, 175201.