Abstract:
Magnetic resonance force microscopy (MRFM) is a developing technology in the family of force microscopy techniques. MRFM detects magnetic resonance as a force on a magnet-tipped microcantilever facilitating three-dimensional, chemically specific subsurface imaging at the nanoscale [1]. If sufficiently high sensitivities can be reached, this technique could achieve atomic scale magnetic resonance imaging, and could be used, for example, to read out the structure of large biomolecules or to study buried semiconductor interfaces. An essential step in achieving the required sensitivity is the development of high sensitivity cantilevers with nanoscale magnetic tips. Our work at the CNF has focused on creating 50-200 nm wide nickel and cobalt magnets which extend from the tips of 5 µm wide, 400-1500 µm long single-crystal silicon cantilevers.

Summary:
The purpose for creating overhanging, nanoscale magnets is to maximize the force exerted on the cantilever by each magnetic spin, while minimizing noise in the force signal that arises from non-contact frictional forces between the cantilever and the sample. To achieve single-spin sensitivity the front of the magnet must be within a few nanometers of the sample. Work by our group [2] has found that, within tens of nanometers of sample surfaces, metal has less friction than silicon, that narrow cantilever tips have less friction than wider ones. Thus our cantilever design has the magnet extending past the end of the silicon cantilever, and the very tip of the silicon cantilever is narrowed from 5 µm to 1.

The fabrication process starts with single crystal silicon-on-insulator wafers. Electron-beam lithography with the JEOL-9300FS is used to define the magnets, which are created through thermal deposition of nickel or cobalt and subsequent liftoff. Next, the E-beam lithography is used to define the tip of the cantilever, around the location of the magnets. Isotropic SF₆ plasma etching is used to etch these pits through the device layer of the wafer. This etch also removes the silicon underneath part of the magnet, leaving it overhanging the front edge of the cantilever by approximately 100-200 nm. The cantilever body is defined with the GCA Autostep, and etched. A layer of PECVD oxide is deposited on the front of the wafer to protect the devices during backside processing, and on the reverse of the wafer to serve as an etch mask during the last portion of backside processing. The backside of the wafer is patterned using the EV-620, and etched through to the buried oxide layer by a Bosch etch in the Unaxis 770. The cantilevers are released in buffered hydrofluoric acid etch, followed by critical point drying. The work in the past year has focused on preventing silicide formation. After exhaustive testing, we suspect that silicide formation is causing the degradation of the magnets during the Unaxis backside etch step. Our current work is in modifying the backside etch process to minimize heating of the magnets, by either slowing down the rate of the Bosch etch, or using KOH etching to finish the silicon removal.
References:

Figure 1: SEM of a 400 nm wide, 200 nm thick Ni magnet on the tip of a silicon cantilever, resting on an oxide layer.

Figure 2: SEM showing similar region as that seen in figure 1, after backside processing released the cantilever from the oxide layer.

Figure 3: SEM image showing the entire length of the cantilever, as well as a portion of the base. These cantilevers have frequencies around 2 kHz, and quality factors in the range of 30,000-100,000 in vacuum.