Fabricating a Magnetic Scanning Probe Microscope Tip

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Abstract:

Electron spin in a quantum dot is an attractive candidate for spintronics and quantum information processing (QIP). However, the ability to controllably manipulate spin in quantum dot systems remains a challenge. One option is to use low temperature scanning probe microscopy (SPM) with a magnetic tip to influence spins in such systems. We present a method to fabricate a magnetic tip on an atomic force microscope (AFM) cantilever for use in a low temperature SPM. The method produces a fine samarium-cobalt (SmCo) tip that can generate a perturbative magnetic field to be applied to the sample when the tip is brought into proximity with a quantum dot.

Introduction:

In conventional electronics, information is stored by charge [1], however, limits of lithographic processes are being reached and heat dissipation within integrated circuits is a problem. One alternative avenue that is being explored for computing is spintronics [2]. Information contained in electron spin current could move faster than information in conventional current, since only the spin of the electron would move rather than the electrons themselves [3]. Advantages of manipulating spin and spintronics technology, in comparison to conventional electronics, would be to greatly reduce heat in devices, decrease electric power consumption, and increase data processing speed.

We developed a procedure for fabricating a magnetic atomic force microscope (AFM) tip that can be used in the low temperature SPM used in the Westervelt lab at Harvard University. This microscope runs at liquid He-4 and He-3 temperatures, and has a magnet that can apply an external magnetic field of 7 Tesla to the sample and tip, therefore it is key that the tip be resistant to demagnetization. To manipulate spin, the tip should be 2-3 μm high and have a diameter of no more than 100 nm that will be used to apply a localized magnetic field to quantum dots with 50 nm diameter.

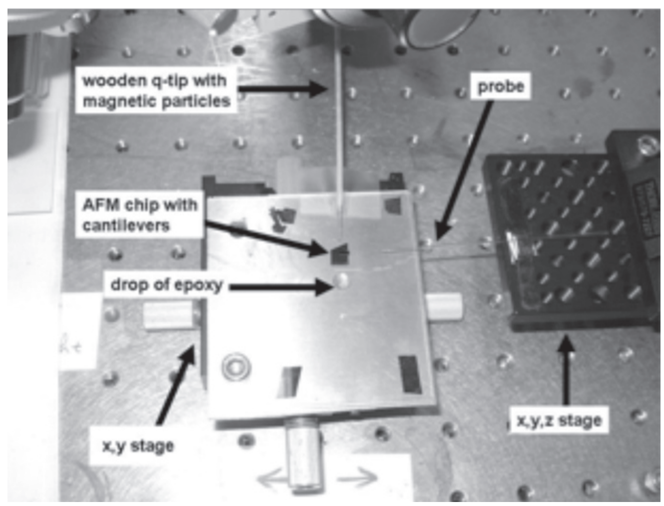

Figure 1: Stage setup used to transfer a magnetic particle onto a cantilever on an AFM chip.

Materials and Processes:

The external magnetic field that can be applied in the SPM is 7T, thus the tip must be very resistant to demagnetization making SmCo an ideal choice for the tip material [4]. The cantilevers used are 250-350 μm long and 30 μm wide. We find and place on the cantilever particles that are 2-5 μm in width and at least 2 μm high. To create particles of this size we file a SmCo magnet then crush the filings with a mortar and pestle making a magnetic powder. Examination of this powder showed that particle sizes were appropriate for placement on the cantilever. Transferring a magnetic particle onto a cantilever is accomplished by making a probe using a glass capillary that is 6 inches long and 1 mm in diameter; the capillary is placed in a micropipette puller that produces a probe with a 10 μm diameter tip. Transferring a magnetic particle also requires an appropriate stage setup. This is carried out by using x,y and x,y,z stages. The probe is placed on the x,y,z stage that moves at a 5μm precision. All other materials go on an x,y stage (see Figure 1).

The epoxy used in this project is EPO-TEK 35ND which is appropriate for low temperature applications and will not shatter when exposed to the focused ion beam (FIB), discussed later in this report.

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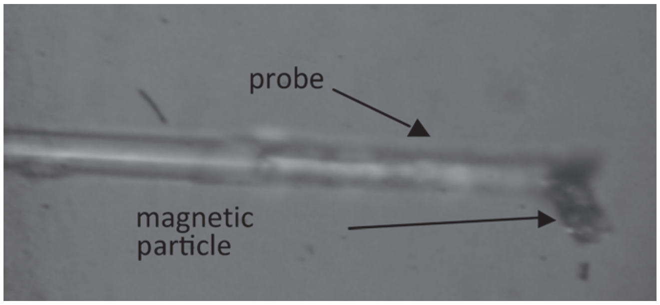

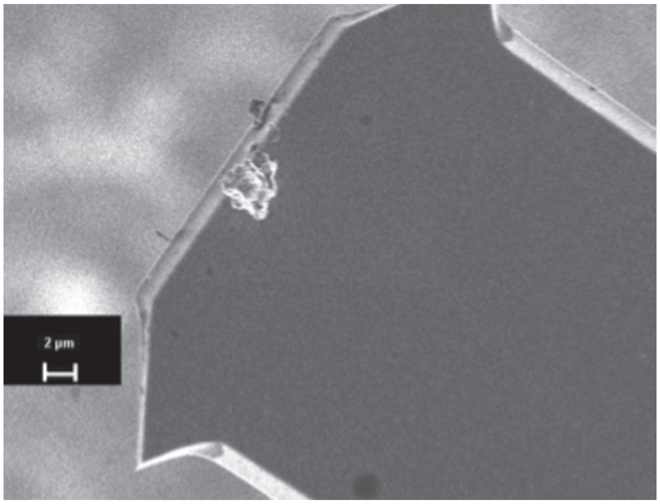

Figure 2, top: A glass probe transferring
a magnetic particle onto a cantilever.

Figure 3, bottom: A magnetic particle about
3 µm across glued to the tip of a cantilever.

Working under a light microscope at 50x resolution, the probe is gently dipped into a drop of epoxy then repositioned to make contact with the cantilever leaving a small drop of epoxy. We attach a new probe to the x,y,z stage and focus on the wooden q-tip with the magnetic particles. The x,y stage is adjusted until a single magnetic particle is located on the q-tip. Taking advantage of Van der Waals forces, we remove a small magnetic particle from the q-tip by contacting the probe to a magnetic particle (see Figure 2) [5]; we select particles 2-5μm in width and height (see Figure 3). Before the epoxy dries we place the attached particle 3/8 inch under a sintered ferrite ceramic magnet; this magnetic field repositions the particle on the cantilever so that poles are perpendicular to the cantilever. Twenty-four hours later samples are inspected with the light microscope to see if magnetic particles have repositioned and have a pole facing up. Samples are viewed in the scanning electron microscope (SEM) to verify there is only one magnetic particle on the cantilever. Appropriate samples are selected for the FIB; the FIB accelerates ions toward the sample and removes atoms in a process called milling.

For this project we milled SmCo which is a heavier material than the silicon cantilever where it sat, so we had to be careful not to inadvertently mill the cantilever. Also important, is that the FIB images with ions, which can potentially damage our sample, so we image at a low current of 10 pA and search for positions to begin milling. The ideal position for milling is when our view is perpendicular to the cantilever. With the object of interest in sight we adjust milling current to 150-180 pA and mill for approximately 60 seconds. These specifications worked well for fabricating a magnetic tip with tip diameter less than 100 nm (see Figure 4).

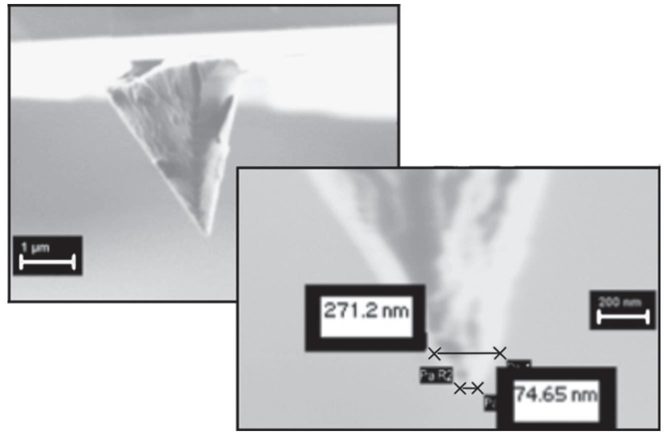

Figure 4: A SmCo magnetic particle milled into a tip.

Conclusions:

We have presented the techniques used to fabricate a magnetic SPM tip that could be used to manipulate spin in quantum dot systems. By following this procedure one can repeat this process and successfully fabricate a magnetic tip for future applications.

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