On-Chip Studies of Nanomagnets

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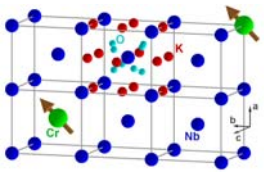
ABSTRACT:

This research is on the quantum effects of magnetic molecules coupled to resonant cavities. Particularly, this research is concerned with the ability to measure the magnetic field produced by a small collection of identical magnetic molecules. This technique could potentially be used for quantum computation using magnetic molecules as the quantum bit. Additionally, this technique could also be used for EPR (Electron Paramagnetic Resonance) type measurements of very small crystal samples.

This area of research focuses on quantum spin dynamics of magnetic molecules are on solid state samples. Measurements will be performed in a dilution refrigerator capable of reaching temperatures less than 10mK. Low temperatures are necessary to eliminate thermal noise allowing for quantum properties to be studied.

MAGNETIC MOLECULES:

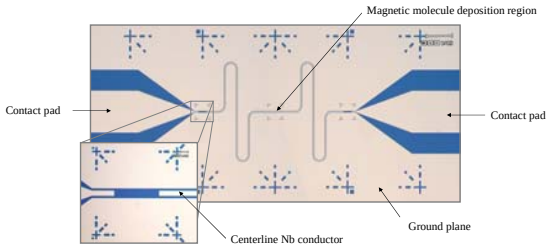
Magnetic molecules are a class of magnetic materials. These materials broaden the properties typically associated with magnets, which include low density, transparency, electrical insulation, and low-temperature fabrication.



Above images shows a rendering of the crystal structure to be grown on the resonant cavity.

RESONANT CAVITY:

Resonant cavities have many applications. One that is being studied at the Maglab is concerned with coupling the cavity to magnetic molecules to allow for quantum state readout. The device is fabricated at the MARTECH from a silicon wafer and a low temperature superconductor (Niobium) using a combination of photolithography and e-beam lithography along with a sputtering system for Nb deposition.



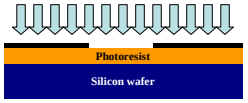
PURPOSE:

If small deposits of molecules in a particular area of the resonate cavity are used, this will allow for magnetic measurements, at low temperatures, of the net magnetic moment. To do this, both molecule adhesion and removal must be controllable. A crystal structure will be used to dilute the magnetic molecules. The crystals will be grown at 5ºC from a mother liquor solution (K_3Nb0_8) containing K_3Cr0_4. Crystals are an attractive method for diluting magnetic molecules due to the ease of reproducibility.

FABRICATION PROCESS AT THE CENTER FOR MATERIALS AND RESEARCH AND TECHNOLOGY (MARTECH)

A silicon wafer is first immersed in acetone and isopropanol and cleaned with a sonicator. It is then coated with photoresist.

Entire wafer is exposed to UV light through a mask. This allows for the transfer of a mask pattern to the photoresist.



Photoresist is then developed removing the exposed region.

Entire sample is coated with a thin layer of Niobium or SiO_2 to prevent the mother liquor from penetrating the photoresist and allow for easy removal of the unwanted crystals.

The entire sample is coated with the mother liquor and then placed in a refrigerator @ 5ºC for 24-48 hours to allow the crystals to grow.

Upon crystal formation, the sample is washed in acetone and isopropanol to remove the unexposed photoresist leaving crystals in the exposed regions of the photoresist.

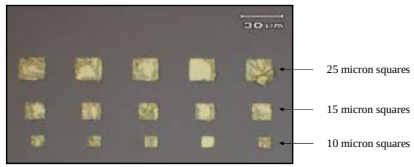
CLEAN ROOM FACILITIES:

On the left it is the photography machine. When designing the devices, photolithography is used, which is very similar to the process used in a dark room for photography. This process allows for the transfer of a micron scale mask shape to a silicon wafer. This process consists of: wafer cleaning, photoresist coating, mask alignment, exposure with UV light, development and soft baking. Additionally, e-beam lithography can be used similarly to photolithography to achieve sub-micron feature sizes.

To the right is the sputtering machine. The sputtering system is used to deposit very pure thin films on substrates. Film thickness can range from several nanometers to several hundred nanometers.

RESULTS:

After the fabrication process is completed, crystals are grown in selected regions. Below shows crystal structures formed on Nb films ranging from 10-25 micron squares. For each size there is about an 80% success rate for achieving crystal formation in the desired region.



CONCLUSION:

The ability to grow crystals in a small, well-defined area is one step closer to using a superconducting resonator to study the quantum properties of molecular magnets. In this case, cromium.

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