Sample Preparation for Single-Electron Spin Detection

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Primary CNF Tools Used: CVC SC4500 e-gun evaporation system

Chemistry

Abstract:

Magnetic resonance force microscopy (MRFM) is a scanning probe microscopy technique that aims to achieve high force sensitivity and sub-nanometer resolution of magnetic spins through spatially resolved magnetic resonance. This report discusses a recent study on methods of preparing MRFM samples at the Cornell NanoScale Science and Technology Facility (CNF) that will improve sample preparation techniques and progress us towards the goal of single electron detection and imaging in an MRFM microscope.

Summary of Research:

In MRFM, nuclear magnetic resonance or electron spin resonance are detected as a force or force gradient on the tip of a microscopic cantilever. The Marohn group prepares attonewton-sensitivity nanomagnet-tipped cantilevers using a method previously developed at the CNF.

In recent test experiments, the sample is a 200 nm thick layer of polystyrene doped with an electron radical spin probe, 4-amino-TEMPO. This polystyrene sample is spin-coated on a coplanar waveguide (10 mm by 2 mm by 0.5 mm). A 12 nm gold film is then deposited on top of the polystyrene by electron-beam vapor deposition and wire-bonded to the ground plane.

It has been shown that with the gold film, surface non-contact friction from the sample can be sufficiently reduced to achieve signal to noise ratio necessary for single electron detection. However, comparing recent measurements of them MRFM-ESR signal to numerical simulations suggests the existence of a 20 nm layer at the top of the sample in which the 4-amino-TEMPO does not contribute to the signal.

Bulk ESR measurements suggest the reduction in signal may be due to sample damage induced by e-beam vapor deposition of the gold layer.

In this study we investigated an alternative hypothesis, that magnetic field fluctuations from the metal film reduced the spin-lattice relaxation time T1 of electron radical spins to a degree that made them undetectable via MRFM.

Thermal motion of electrons in materials produce small magnetic fields. Near the surface of conductive materials such as metals, these charge fluctuations can produce enough magnetic field fluctuations at the electron Larmor frequency to produce electron relaxation. In their 2018 paper, Ariyaratne, et al., develop equations to quantify this relaxation effect and use the T1 relaxation of nitrogen-vacancy (NV) centers as a detector of conductivity in metal films (85 nm thick Ti, Al and Ag films) [1]. The induced relaxation rate is proportional to the conductivity of the metal thin film and related to the distance between the targeted spin and the metal film.

The work done at the CNF allows us to predict the effect of our 12 nm gold film on the MRFM sample. The test sample was a 200 nm polystyrene film spin-coated on a silicon chip identical in size to our coplanar waveguide. A 12 nm gold film was deposited on top of the polystyrene film with the CVC SC4500 e-gun evaporation system at the CNF. The resulting samples were wired bonded and the resistivity of the gold film was measured using Quantum Design 14T "Blue" Physical Property Measurement System (PPMS) at the Cornell Center for Materials Research (CCMR). The resistivity was profiled at 4.2 K and 10^{-5} Torr, conditions closely resembling MRFM operating conditions. The preliminary data shows a resistivity of 116 nΩ-m for the 12 nm gold film on polymer, suggesting that the relaxation rate of electron spins in the polystyrene sample due to the gold film would be minimal.

We expect to further explore the behavior of metal films with different parameters with the help of CNF in the coming year. This information will help us to improve sample design and how best to reduce noise due to sample dielectric fluctuations without reducing our ability to detect sample spins.

References:

[1] Ariyaratne, A. et al.; Nat Commun, 2018, 9, 2406.