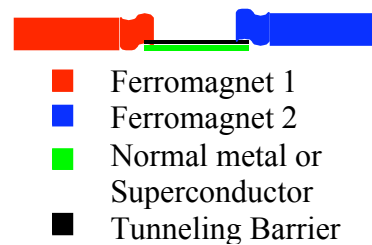


***NIRT Highlight***  
***Spin Transport and Dynamics in Nanoscale Hybrid Structures***  
(NSF NIRT award #0103302)

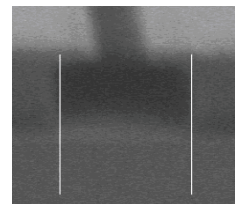
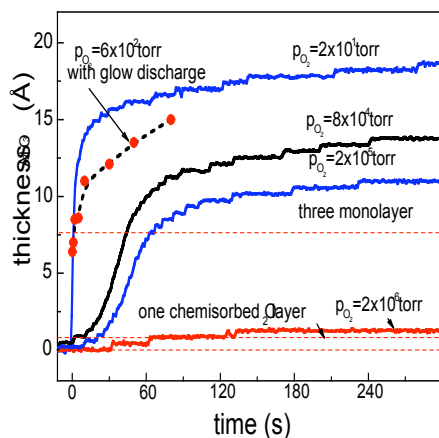
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The objective of this project is to fabricate and characterize nanoscale hybrid junction structures that will reveal new physical aspects of quantum states and dynamic behavior of single electron spins. Several interesting effects have been predicted for spin-dependent transport in ferromagnet (FM)/metal/ferromagnet and FM/superconductor/FM double junctions. The project is aimed to experimentally verify these theoretical predictions. The approach of this study is to combine the recent advances in single-electron transistors and spin tunnel junctions, to fabricate hybrid junction devices using ebeam lithography and shadow evaporation techniques. This work contributes to current research in spintronics community and provides more comprehensive understanding of the spin dynamics to develop innovative spin based nanoelectronic devices.



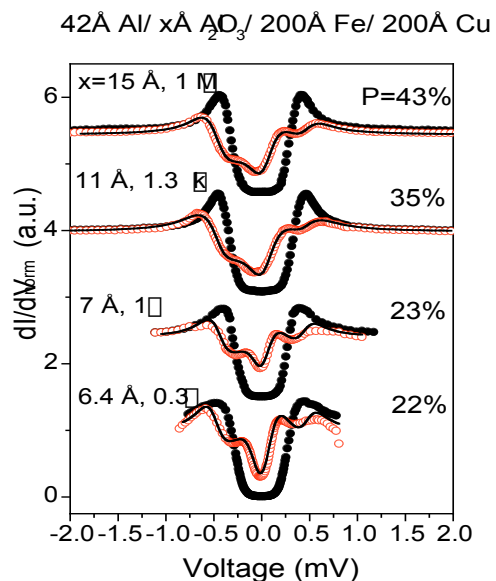
The key points for our device fabrication include: (1) getting large undercut (the ratio between top linewidth and undercut needs to be at least 1:6) using ebeam lithography for successful triple angle evaporation; (2) obtaining high quality oxide barriers between the ferromagnet and the center island.

By exposing a bilayer resist with two different doses, we have successfully obtained a resist mask with top linewidth of about 60 nm and an undercut of about 600 nm (see figure on the right).



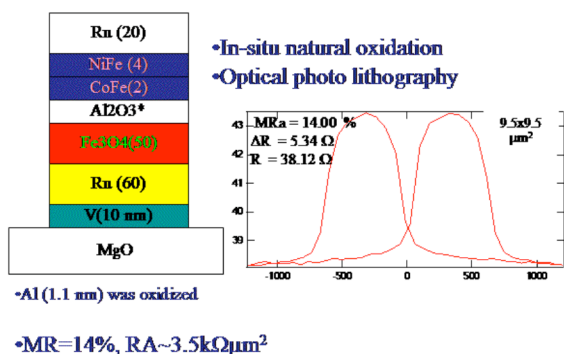
We have also studied the barrier oxidation and the relation between the barrier thickness and spin polarization, and have gained expertise in growing ultra-smooth metal films and very thin oxide layer over the metal film using molecular beam epitaxy. Figure on the left shows the dependence of the oxide thickness on time and oxygen partial pressure. Al is used as the center island in this sample. To measure the spin transport through the device, the barrier resistance should be in the range between 20 kΩ and 500 kΩ, corresponding to the oxide layer thickness of 5–7 Å. Al films grown at room temperature and at 77 K show different smoothness. The low temperature grown Al films are smooth with a roughness of 2-3 Å.

Our studies have shown that barrier thickness, which determines junction resistance, influence the spin polarization considerably. When the barrier resistance changes from  $1 \text{ M}\Omega$  to  $0.3 \text{ }\Omega$ , the spin polarization drastically drops to 22% from 43%. The black curve in the figure on the right indicates the conductance curve of superconducting Al when the external magnetic is zero. At external magnetic fields greater than zero, spin splitting of the density of states of Al occurs and the spin polarized electrons from Fe tunnels through the junction. The red curve in the figure is the conductance measured at 3.3 T.



Another highlight of this project is the fabrication of magnetic tunneling junctions (MTJ) using half metallic materials. Half metallic materials are attractive due to their high spin-polarization (100%), which makes them promising candidates for tunnel junctions and spin injection. Epitaxial growth of  $\text{Fe}_3\text{O}_4$  (magnetite) on MgO single crystal has been reported by many groups, and is predicted to be a half-metal.  $\text{Fe}_3\text{O}_4$  on MgO is known to be semi-hard magnetic material, however its low squareness is detrimental for pinned layer by itself. And a highly conductive underlayer is required for applying  $\text{Fe}_3\text{O}_4$  as an electrode in

magnetic tunnel junctions to avoid non-uniform current distribution. We have successfully grown epitaxial  $\text{Fe}_3\text{O}_4$  films using V/Ru underlayer on an MgO single crystal. This stacks show relatively high squareness (0.66) and  $H_c$  (550 Oe). TMR of 12.6% to 14% and Resistance Area product (RA) of 3 to 3.5  $\text{k}\Omega$  were achieved for almost all junctions. This value is one of the highest TMR using an  $\text{Fe}_3\text{O}_4$  electrode. RA product is almost same for different size of junctions, which indicates that geometrical effect was hardly seen on this MTJ.



Another thrust of this research is to investigate the dynamic characterization of spin lifetime, relaxation and diffusion length when electrons tunnel from a ferromagnetic electrode to a non-magnetic island. The technique we utilize to address this problem is the measurement of DC effects associated with magnetic resonance. This technique affords a simple DC probe of electron polarization strength and relaxation time as a function of position in a thin film. We have designed and fabricated mask sets to measure the position dependence of the DC resonance signal accompanying magnetic resonance in films. Our FMR system has shown the uniform resonance in a variety of magnetic thin films from a relatively thick (30 micron) layer of Ni-Fe-B alloy, several Ni and Ni iron layers, and also Co film about 10 nm thick.