# Nanomagnetism in Complex Magnetic Materials and Devices

*NSF NIRT Grant ECS0303774*

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In this NIRT program, we are focused on the development of oxide and chalcogenide magnetic materials that provides the foundation for a new series of magnetic spin-based devices. These devices will shed light on (1) a fundamental issue in magnetism that has yet to be completely understood- i.e., the nature of magnetism at boundaries of magnetic materials and (2) the technological viability of spin-based devices for memory and logic applications. These spin-based devices are those in which one, two or three dimensions are at the nanometer length scale and where nanoscale control of the surfaces and interfaces is crucial.

## OBJECTIVES, METHODS & FIELDS OF IMPACT

The main research objective of the proposed program is to develop novel complex materials that will lead to an understanding of the role of surfaces and interfaces in spin polarized structures where one, two or three dimensions are at the nanometer length scale and where nanoscale control of the surfaces and interfaces is crucial. Our approach is the following:

- (i) the development of novel bulk oxide and chalcogenides with structurally and chemically tunable properties (Stacy/Suzuki)
- (ii) the development of these complex materials in thin film form (Moodera/Suzuki)
- (iii) the fabrication of nanoscale spin device structures (Moodera/Suzuki)
- (iv) local electronic and magnetic characterization of the complex surfaces and interfaces by X-ray Magnetic Circular Dichroism and X-ray Resonance Resonant Magnetic Scattering (Idzerda) and transmission electron microscopy and electron energy loss spectroscopy (Suzuki)
- (v) electronic transport and magnetic characterization of spin device structures including inelastic tunneling spectroscopy (Moodera/Suzuki)
- (vi) theoretical modeling of the electronic, magnetic and transport behavior of the spin device structures (Butler).

Together these efforts will effectively address the role of surfaces and interfaces in spin polarized structures and individually these efforts will have significant impact in solid state chemistry, materials science and device physics and engineering. This integrated approach brings together the complementary expertise of the five PI's that is essential in addressing the main challenges in magnetism and spin sensitive research.

The second objective of the proposed program is (i) to develop educational opportunities for undergraduate and graduate students and (ii) to develop an apprenticeship program based on magnetoelectronics and a supplemental engineering module for an existing inquiry based learning program for high school students. These programs will enhance existing outreach efforts at the University of Alabama, UC Berkeley, MIT and Montana State University. The undergraduate and graduate students will be particularly prepared for a career in any magnetics-related field and will be generally prepared for a science career in materials science and engineering, physics or chemistry.

## NOTABLE RESULTS

Through the development of novel complex oxide and chalcogenide materials, we have been able to probe spin-based phenomena in heterostructures where the interface quality can be controlled.

EuO is a novel magnetic semiconductor that, used as a tunnel barrier, filters the spins of the tunnel current between two non-magnetic electrodes in the tunneling process. EuO selectively allows only spin-up electrons to tunnel, thereby creating a spin-polarized current of electrons. As a result, a current of highly spin-polarized electrons is created (Figure 1). The observations of 30% spin polarization in EuO junctions (Figure 2) and of up to 25% junction magnetoresistance in magnetic junctions with paramagnetic insulating tunnel barriers are testament to the importance of interface control at the nanometer length scale in such spin-based devices.

We have also calculated the electronic density of states and have estimated the conductivity for a new type of spin valve using novel oxide materials. The magnetic layers of the proposed spin valve would be made from $CrO_2$ which is the only known oxide ferromagnet. The spacer layer would be made from $RuO_2$. We have estimated that the electronic conductivity of a spin-valve with parallel magnetic moments for $CrO_2$ could be 96% of that of pure $CrO_2$. The conductance of the spin-valve with the $CrO_2$ moments oppositely aligned would theoretically be zero, at low temperature, although a small current would be made possible by higher order effects due to finite temperature effects.

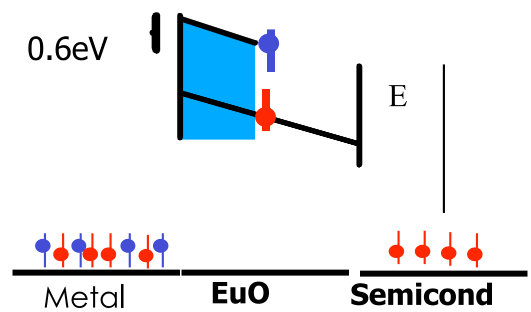



Figure 1. EuO tunnel barrier showing spin filter effect.

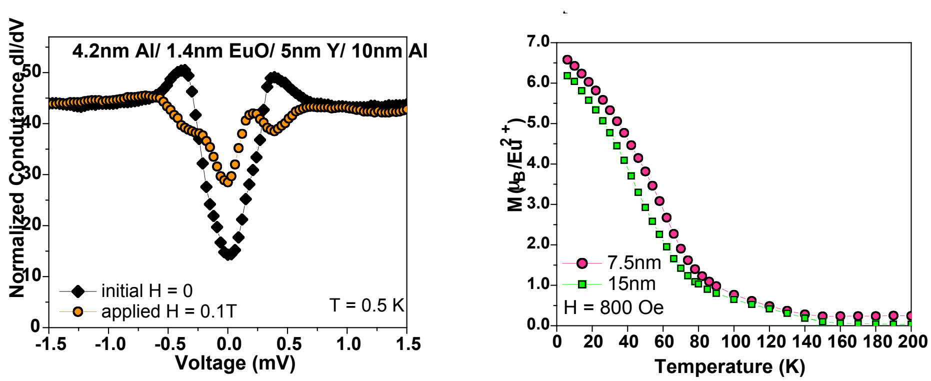
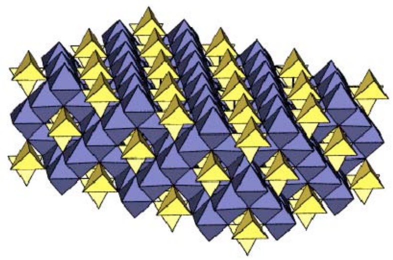



Figure 2. Magnetization (above) of ultrathin EuO films and the conductance of junctions with EuO that may act as spin filters.

We have also focused on a family of complex chalcogenide spinel materials that have, up until now, been largely ignored for their spin-polarized functionality. We have developed ferromagnetic $CuCr_2Se_4$ compounds in bulk and thin film form in conjunction with band structure calculations. Theoretical calculations suggest that this material is a promising candidate for electrodes of junction devices.



(a)

(b)

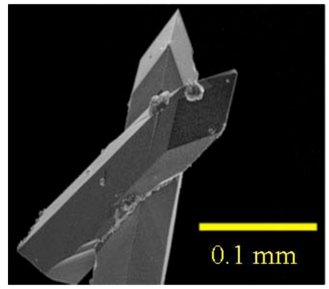



Figure 3. (a) Spinel crystal structure of complex chalcogenide CuCr2Se4 and (b) a photograph of a single crystal sample.

We have been successful in developing processes for the synthesis of bulk single crystal, bulk polycrystalline pellet and thin films of $CuCr_2Se_4$. Structural and magnetic characterization of bulk and thin film samples have shown good crystallinty and long range magnetic order.