Spin Manipulation of Antiferromagnetic Devices

Alice Perrin
Physics, The College of William and Mary

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY
NNIN REU Principal Investigator: Dr. Daniel Ralph, Physics, Cornell University
NNIN REU Mentor: Gregory Stiehl, Physics, Cornell University
Contact: aeperrin@email.wm.edu, dcr14@cornell.edu, gms263@cornell.edu

Abstract:

Antiferromagnets (AF), the most common type of magnetically ordered material, exhibit a zero net magnetic moment below a specific temperature, called the Néel temperature, which renders them unresponsive to manipulation by magnetic fields [1]. Previous works have manipulated AF moments indirectly by way of the exchange spring effect, where a magnetic field is used to manipulate a ferromagnet exchange coupled to an AF [2]. Our recent work focused on reproducing this method of AF manipulation through observing tunneling anisotropic magnetoresistance (TAMR) in antiferromagnetic devices in which the antiferromagnet is interfaced with a tunnel junction. The TAMR effect is a change in the resistance through the AF/tunnel junction barrier due to the rotation of the AF moments. Our finished devices exhibited TAMR, thus demonstrating the successful manipulation of the AF magnetic moments through exchange coupling. Future work will introduce magnetocrystalline strain on the devices as another means with which to manipulate the moments.

Introduction:

A better understanding of the dynamics of AF magnetic moments could lead to antiferromagnetic components in magnetic memory storage and a broader range of materials available for use in electronics [1]. Antiferromagnets used as spin torque driven resonators would also allow for further study in the terahertz frequency range. However, because antiferromagnets cannot be manipulated by magnetic fields, other methods must be explored in order to study them. One means of manipulating the AF moments is to interface the antiferromagnet with a ferromagnet. Below the blocking temperature there is an exchange coupling effect, and each AF moment is pinned to a corresponding ferromagnetic moment. In a magnetic field, the AF moments resist the rotation of the ferromagnetic moments until it becomes energetically advantageous for the coupled moments to rotate. However, the AF moments rotate non-uniformly, experiencing a winding effect, seen in Figure 1.

We observed the tunneling anisotropic magnetoresistance effect (TAMR) in order to confirm the success of the exchange coupling. TAMR is an effect in which we see a change in the resistance of a device comprising a tunnel junction interfaced with an antiferromagnet, where the antiferromagnet acts as a single magnetic electrode [3]. This change in resistance occurs because the density of states at the interface changes as the AF moments rotate. As the density of states decreases, less electrons will be able to tunnel through the junction, and there will therefore be a higher resistance through the device.

Fabrication:

We began fabrication of our devices by sputtering a stack of materials onto a 200 micron silicon wafer in a magnetic field. From the substrate upward, the stack was made up of: Ta(5)/Ru(10)/Ta(5)/NiFe(0-10)/IrMn(3)/MgO(2-3)/Ta(3)/Ru(10) where the number after each layer is its thickness in nanometers. The bottom layers of Ta/Ru/Ta made up the bottom electrode of our devices. The next layers contained a NiFe ferromagnetic layer, antiferromagnetic IrMn, a MgO tunnel junction, and a top electrode of Ta/Ru. The finished devices allowed us to pass a current through a pillar containing the ferromagnet, antiferromagnet, and tunnel junction in order to measure the resistance of the stack. These

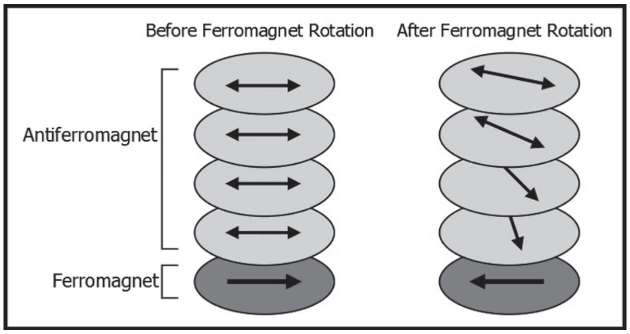

Figure 1: When exchange-coupled, the rotation of the antiferromagnetic moments is non-uniform.

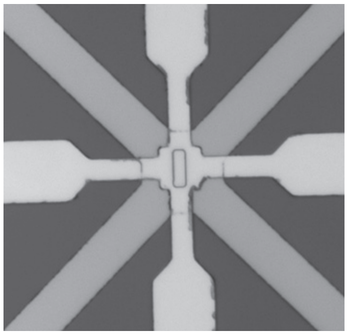

Figure 2: A top view of a finished device with a 3 by 9 µm pillar.

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pillars ranged in surface area (as seen from the top) from 1 × ½ μm to 10 × 5 μm to allow us to examine the role of the area on the TAMR effect.

Results and Conclusions:

We gathered data from devices with layers NiFe(10)/IrMn(3)/MgO(2.5) nm, cooling them to temperatures ranging from 2.2K to 50K. We measured the resistance of the devices versus the magnetic field, which swept over a range large enough to induce moment rotation in the coupled ferromagnet and antiferromagnet. In Figure 3, we can see two clear steady resistance states where the slope of the data is near zero. The device switched between these states at ± 500 Oe depending on whether the field was sweeping negatively or positively, due to the drag caused by the antiferromagnet moments resisting rotation. This, along with the two resistance states, provides qualitative evidence of TAMR in our devices and therefore demonstrates successful manipulation of the AF moments through exchange coupling.

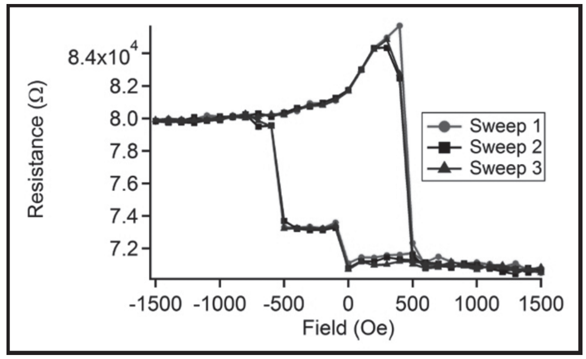

Figure 3: A hysteresis curve demonstrating stable resistance states around 70 kΩ and 80 kΩ, indicative that AF moment rotation has occurred.

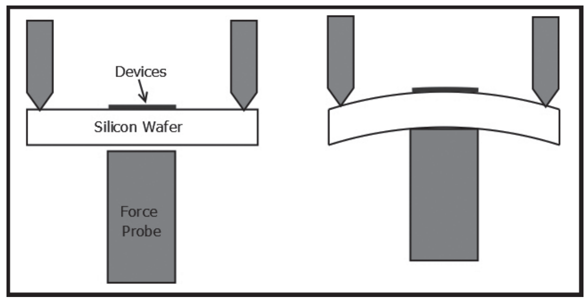

Figure 4: The wafers can be laterally manipulated by a three point strain induction system.

Future Work:

Future work on this project will incorporate the use of strain as an addition means of manipulating the AF moments by altering the magnetocrystalline anisotropy of the antiferromagnet. This will redefine the rotation angles at which the energy of the moments are at a minima, allowing for a method of manipulating the moments directly. Our method of inducing strain on the devices can be seen in Figure 4. Strain will be explored as both a supplement to and a replacement for exchange coupling as a means to manipulate the AF moments.

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