Fabrication of Sub-Micron Lateral Spin Valves

Alayne M. Lawrence
Chemical Engineering, Xavier University of Louisiana

NNIN REU Site: Nanofabrication Center, University of Minnesota-Twin Cities, Minneapolis, MN
NNIN REU Principal Investigator(s): Professor Paul Crowell, Physics, University of Minnesota-Twin Cities
NNIN REU Mentor(s): Michael Erickson, Physics, University of Minnesota-Twin Cities
Contact: alawren1@xula.edu, crowell@physics.umn.edu, erickson@physics.umn.edu

Introduction:

This research project focused on the fabrication of sub-micron lateral spin valves, which are devices consisting of two or more conducting materials that allow us to measure spin injection and relaxation in metallic structures. These spin valves modulate electrical transport depending on the alignment of two magnetic electrodes. In this case, the two magnetic electrodes are separated by a channel of a normal metal, which can be copper, silver or aluminum. One of the major problems with these spin valves is that the resistivity of the normal metal channel, which is grown by evaporation, is dominated by defects. We suspect that if we make these spin valves out of better materials then the spin lifetime will increase. Progress on the fabrication of lateral spin valves of high purity, high conductivity transport channels of copper, aluminum, and silver will be presented.

Experimental Procedure:

Different methods were employed to increase the diffusion length by reducing the resistivity using high purity wires and foils. First, we selected high purity wires and foils on which we intended to deposit ferromagnetic contacts. The aluminum, copper and silver wires used were all approximately 99.99% pure. The aluminum and copper foils were both approximately 99.999% pure and the silver sample used was approximately 99.998% pure. We then measured the residual resistivity ratio of the wires and foils before and after annealing.

Residual Resistivity Ratio:

The measurement we were most concerned with was the residual resistivity ratio (RRR). RRR is measured by the resistance of a sample at room temperature divided by the resistance at a low temperature. At a low temperature, the resistance of an ordinary metal is determined by scattering from defects, while at room temperature the resistivity is dominated by scattering from lattice vibrations. A cleaner sample will therefore have a higher RRR. (See Figure 1.)

Dunk Probe:

At first we were measuring a crude RRR number by measuring the resistance at room temperature and then measuring the resistance at 77K by dunking it into liquid nitrogen. As the measurements progressed, it was clear we needed to examine the temperature dependence of the resistivity below 77K; so in order to do so we decided to use a liquid helium dunk probe to get more accurate data.

The dunk probe works by simply attaching a sample to a large probe and then actually dunking it in a helium Dewar. Figure 2 shows data obtained using the dunk probe.

Annealing:

In order to fabricate better spin valves, we explored improving the properties of the normal metal by annealing. Annealing is a heat treatment that is used to change the grain structure of samples in order to increase the electron transport.

The first anneal was conducted in vacuum. Samples of high purity wires were placed in a quartz tube inside a furnace which was connected to a turbo-molecular pump. Inside the furnace the temperature was brought up to 350°C at a pressure of 4×10^{-6} Torr. After approximately six hours of annealing, we discovered that the RRR did not change significantly and therefore we decided to try annealing in an

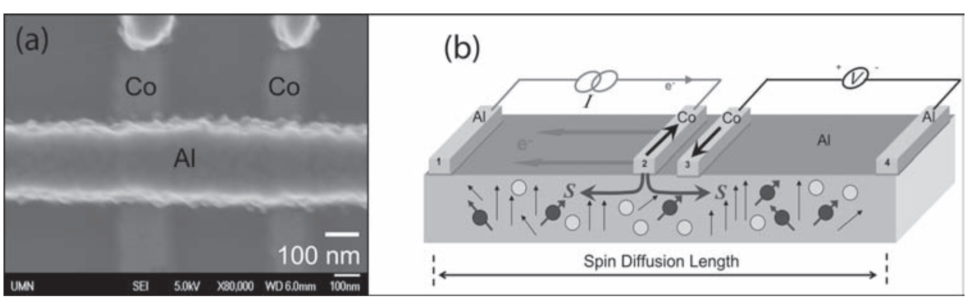

Figure 1: (a) SEM micrograph of a lateral spin valve; (b) Schematic diagram of the device.

oxygen atmosphere. The oxygen annealing was basically conducted in the same manner as the vacuum annealing; the only difference was that a furnace was connected to an oxygen tank instead of a vacuum pump. In addition, a slightly higher temperature of 400°C was used.

Photolithography:

The annealing processes were both done on high purity wires. Eventually we decided to test on high purity foils. Astonishingly, the high purity foils gave RRR's that were significantly larger. We decided to use these foils as the channel for our future spin valves. Since the foil area was very large and the channels for these devices are very small, photolithography was used to etch micron scale wires from foils.

For this process, first the high purity metal foils were mounted on a glass substrate with wax. A thin layer of photoresist (S1818) was then spun followed by a two minute soft bake at 105°C. Second, a wire was mounted onto the foil as a photolithography mask and the same resist was spun again and baked. Third, after the second soft bake was done the sample sat under an ultraviolet light for two minutes in order to keep only the small wire that we wanted. The wire was removed then the resist was developed and a wet etch was done through the metal foils so that a wire was created.

Results and Conclusions:

A comparison of the RRR's amongst different samples suggests that we can improve the transport properties of high purity metal foils. The ability to fabricate spin valves from these materials may lead to better understanding of the role of defects and grain structure on spin relaxation. Additionally SEM micrographs suggest that we may have been able to change the grain structure of metals through annealing. With this knowledge we will be able to go forth and make spin valves out of high purity materials in hope of increasing the spin lifetime. In addition, this work may serve to ultimately develop a new process to deposit ferromagnetic contacts on a single crystal wire.

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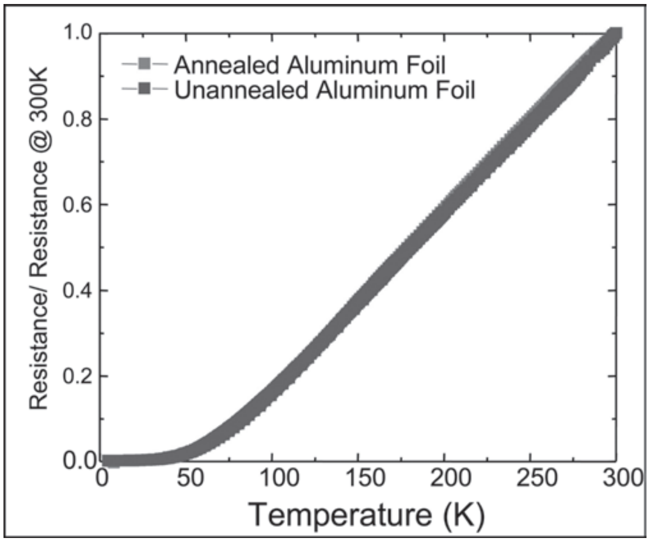

Figure 2: Typical resistivity data for an Al foil.

Sample	Unannealed	Vacuum Annealed	Oxygen Annealed
Aluminum Wire	10.554	11.455	16.203
Copper Wire	7.114	7.635	7.843
Silver Wire	5.129	5.54	5.222
	Unannealed	Annealed	
Aluminum Foil	840	1090	
Copper Foil	271	563	
Silver Foil	25	32	

Figure 3: Table of all RRR measurements.