Domain Wall Track in a Praseodymium Strontium Manganite Oxide Nanobridge

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Abstract and Introduction:

Research into spintronics has led to many discoveries that are unexpected and exotic. Some of these discoveries have already been implemented as electronic devices, most prominently as computer hard drives, read heads, and magnetic random access memories, yet there is still much more to be uncovered and understood [1,2]. The anomalous magnetoresistance of magnetic domain walls discovered in strained manganite films cannot yet be fully explained and it was our goal to discover the nature of this phenomenon [3].

This study looked into the fabrication and testing of constricted nanobridges made of manganite thin films that exhibit low-field magnetoresistance [4]. Two different methods of fabrication were implemented. The first method used electron beam lithography (EBL) and the second used focused ion beam (FIB) milling. The nanobridges were made in varying dimensions, with the goal of restricting the number of magnetic domains present so that its effects dominated the behavior of the devices.

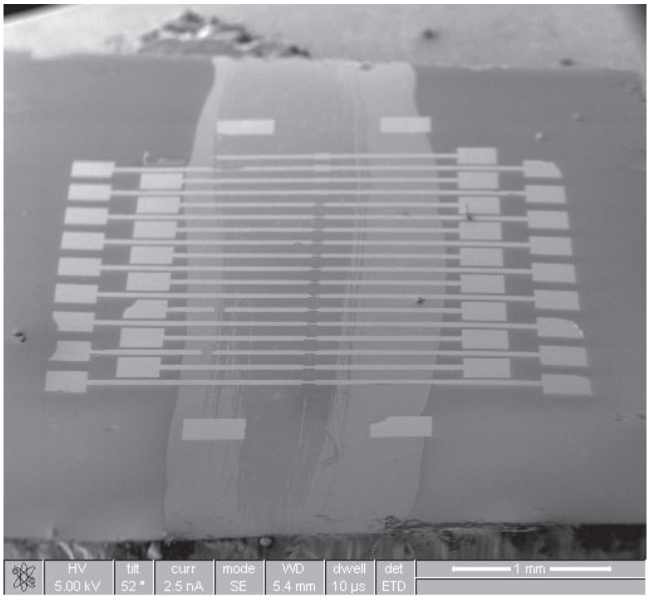

Figure 1: SEM image of revised pattern with gold leads across manganite film.

Experimental Procedure:

Fabrication began with a lanthanum aluminum oxide (LAO) substrate with 50 nm of praseodymium strontium manganite oxide (PSMO) deposited using pulsed laser deposition [5]. We then evaporated 200 nm of gold (Au) and used standard photolithography techniques with a negative photoresist to prepare the sample for ion milling. The FIB removed the Au and manganite film where the photoresist was not protecting it. In later samples, the design was changed so that the fabrication of the bridge would not require a second, more difficult removal of the Au. In the revised design, the manganite oxide film underwent standard photolithography and FIB to leave a single long strip. Then, through use of the negative photoresist, Au lines were evaporated perpendicular to the film strip (Figure 1).

To make the nanobridge, two trenches were etched in line with each other, leaving a gap of ~ 100 nm in between the end of one trench and the beginning of the other. The gap would then bridge the two sides of the film/Au. In etching the trenches, two different methods were explored. In both cases the trenches were etched parallel to the Au leads and perpendicular to the film strip. The first technique used EBL in conjunction with reactive ion etching and the second used FIB. The beam used in the EBL had a minimum width of ~ 30 nm, while the FIB beam had a minimum of ~ 7 nm.

Results and Conclusions:

Fabrication using EBL and FIB each presented unique advantages and disadvantages. In EBL, sample viewing was made possible through the use of a scanning electron microscope (SEM). However, looking directly at the sample would damage the photoresist, and therefore we could only view the corners of the sample and use its dimensions to calculate the correct location for the bridges to be etched. In this method, it was important to make sure the measurements of the device dimensions were accurate so that the bridges were etched in between the Au leads and on the film.

Due to computer integration, it was easy to create multiple bridges on a single device. In contrast, while performing FIB, we could use the SEM to directly view the location where the nanobridge needed to be placed; however, there was a minimum magnification requirement that forced us to make multiple runs to create a single bridge. It was also necessary to make each bridge individually.

The most important factor in the fabrication process was how short the bridge length was, or how narrow the etched trenches could be made. Using the smallest beam width in EBL, the narrowest trench we made was ~ 100 nm. However, with the FIB, we were able to obtain a trench width of ~ 40 nm (Figure 2).

This one benefit alone made focused ion beam milling the preferred fabrication method. However, the FIB process was also superior to that of EBL because it was faster and less expensive.

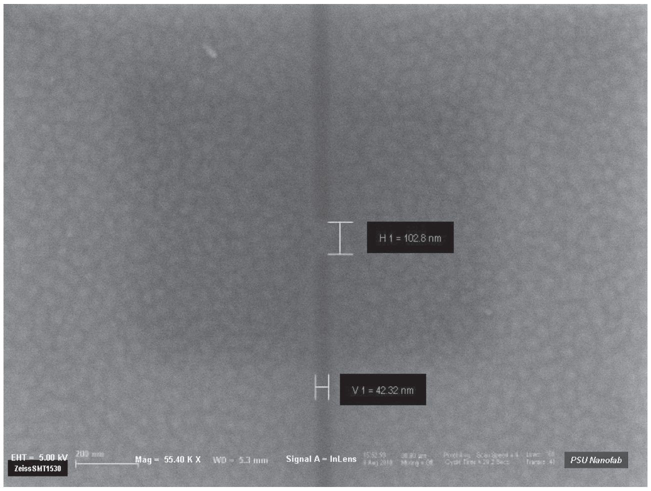

Figure 2: Field emitting SEM of nanobridge fabricated using focused ion beam milling.

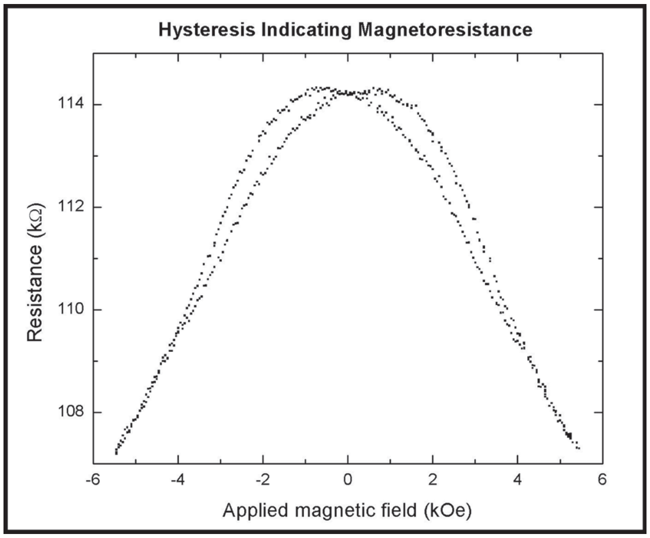

Figure 3: Evidence of magnetoresistance with noticeable hysteresis.

In testing a device made using the FIB, we were able to find signs of magnetoresistance (Figure 3). This was important because it meant the process was effective in limiting the number of magnetic domains present in the bridge, exposing the phenomena believed to create the low-field magnetoresistance to future measurements.

We concluded that the focused ion beam milling technique was better than the electron beam lithography process for our purposes of fabricating a nanobridge in manganite film. The combined benefits of shorter bridge length, faster fabrication, and lower cost made it the superior choice.

Future Work:

In the future, we will deposit a thinner layer of PSMO film of higher quality, narrowing the 50 nm thickness to ~ 12 nm. We hope to make the trench even narrower; having a thinner film will aid in this endeavor. In the new setup, a metal strip connecting the sides of the bridge to the gold leads should help prevent the measurement of resistance in the film outside the bridge.

And most importantly, in the future we will examine the nature of the anomalously large low-field magnetoresistance.

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References:

[1] Wolf, S. A., Awschalom, D. D., Buhrman, R.A., Daughton, J. M., von Molnar, S., Roukes, M.L., Chtchelkanova, A.Y., and Treger, D.M., "Spintronics: A Spin-Based Electronics Vision for the Future", Science, 294, 2001.

[2] Das Sarma, S., Fabian, J., Hu, X., and Zutic, I., "Spin Electronics and Spin Computation, Solid State Community", 119, 2001.

[3] Wang, H. S., Li, Q., Liu, K., Chien, C. L., "Low-field magnetoresistance anisotropy in ultrathin PSMO films grown on different substrates", Applied Physics Letters, 74, 1999.

[4] Hu, Y., Li, Q., "Strain-Induced Magneto-Transport Properties of Manganite Thin Films", PhD Thesis Paper, Penn State University.

[5] Chrisey, D. B., and Hubler G. K., "Pulsed Laser Deposition of Thin Films", Wiley-Interscience, New York, 1994.