Low temperature magnetization reversal in patterned nanoislands of $SrRuO_3$ studied using attoAFMI

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Understanding the dynamics of magnetization reversal in materials is key to assessing their potential for magnetic storage. Most studies thus far concentrated on the room temperature behavior of 3d itinerant soft ferromagnets and their alloys which offer the highest potential for commercial application; however, these materials only represent a narrow range of relevant parameters. Livnat Landau and co-workers from the group of Lior Klein (Bar-Ilan University, Ramat-Gan, Israel) explored the other end of the parameter range. Using the attoAFM I they studied the low temperature magnetization reversal properties of $SrRuO_3$ [1].

$SrRuO_3$ is an extremely hard itinerant ferromagnet with a $T_c \approx 150\,K$. In this compound the magnetostatic energy is much smaller than the magnetocristalline anisotropy energy; therefore, the latter dominates its magnetic behavior.

In order to understand the dynamics of the magnetization reversal, Livnat Landau and co-workers patterned hundreds of $SrRuO_3$ thin film nanoislands with varying sizes and shapes. The 10 nm films were grown by James W. Reiner (group of M. R. Beasley, Stanford University, CA, USA) on $SrTiO_3$ substrate using reactive electron beam evaporation [2]. The patterning was performed at Bar-Ilan University by using high resolution e-beam lithography and Ar^+ irradiation for etching out the nanoislands. The side of these square islands range between 50 and 500 nm. A typical set of these islands can be seen on Figure 1.

To observe the magnetization reversal at low temperature the samples were cooled down to the target temperature 4 K and fully magnetized by applying 5 T perpendicular to the film. Prior to each low temperature magnetic force microscopy (LT-MFM) measurement a magnetic field between 0.5 and 3.5 T was applied in the opposite direction, then set back to zero. To minimize the interaction between the magnetic tip and the sample, the tip was kept at least 100 nm from the surface. At this distance the magnetic field exerted by the magnetic coating of the tip is about 500 Oe based on numerical calculations. This value is almost two orders of magnitude smaller than the lowest nucleation field (2 T) at 4 K.

Figure 2 shows the result of a typical LT-MFM scan. It is visible from the figure that not all the islands flip at the same field. Counting hundreds of nanoislands, the group found that the minimum field for full reversal is as high as 3.5 T. This field is very close to the theoretical upper limit predicted by the Stoner-Wohlfarth model. That calculation, taken into the account the angle of the easy axes relative to the normal of the film, gave 3.8 T.

On Figure 2 it is also visible that some nanoislands are partially reversed. The partially reversed islands may allow the determination of an upper bound for the nucleation volume; however, it does not exclude the possibility that the nucleation volume is actually much smaller. By carefully analyzing the statistics and evolution of the partially reversed islands the group also found that from the islands partially reversed at 2 T only 30% were fully reversed at 3 T and the remaining 70% required the full 3.5 T to reach full reversal. This indicates extremely strong domain wall pinning that prevents easy domain growth.

To summarize, the group prepared a series of $SrRuO_3$ nanoislads to study their magnetization reversal using low temperature magnetic force microscopy. Using the attoAFM I they not only determined the reversal field, but by imaging individual domains they were able to follow the magnetization reversal process and domain wall pinning, as well.

References

[1] L. Landau, J. W. Reiner, and L. Klein, *J. Appl. Phys.* **111**, 07B901 (2012).
[2] A. F. Marshall, L. Klein, J. S. Dodge, C. H. Ahn, J. W. Reiner, L. Mieville, L. Antagonazza, A. Kapitulnik, T. H. Geballe, and M. R. Beasley, *J. Appl. Phys.* **85**, 4131 (1999).

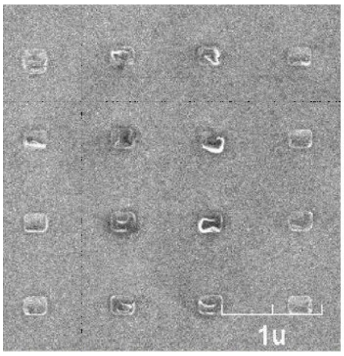

Figure 1: *SEM image of a typical set of 150 nm x 200 nm $SrRuO_3$ nanoislands.*

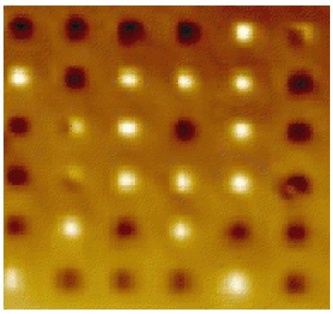

Figure 2: *LT-MFM image of a set of nanoislands. These were first fully magnetized (white islands) and then partly reverted by applying 3 T (black islands).*