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Science Highlights

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Magnetic Switching in Multilayer 'Nanomagnets'

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This study investigated the magnetization reversal processes that take place in arrays of lithographically-patterned magnetic bars. Each bar is 70 nm x 550 nm in dimensions, and is made from a NiFe 6nm/ Cu 3 nm/ Co 4 nm multilayer stack. Arrays of these nanomagnets were characterized using a combination of magnetic force microscopy (MFM), alternating gradient magnetometry (AGM), and scattering experiments using synchrotron radiation. Both magnetic layers (i.e. the Co and the NiFe) form single-domain states at remanence and switch abruptly, but the collective magnetization reversal of the array shows a wide distribution of switching fields due to variability between the elements. Elementally-specific hysteresis loops obtained from synchrotron scattering experiments enable the separate reversal of the Ni, Fe and Co to be followed.

The magnetic properties of lithographically-defined multilayered magnetic solids are of considerable interest for the development of high-density magnetoresistive random access memory (MRAM) devices. The nanoscale bar-shaped magnets used as memory cells in MRAMs are composed of at least two magnetic layers sandwiching a non-magnetic insulating or metallic spacer. Future high-density MRAM devices will require layered magnetic structures with thicknesses below a few tens of nanometers and in-plane dimensions in the sub-100nm regime. Within these structures, the individual magnetic layers are magnetized parallel to their length, and their switching field depends on their dimensions and compositions. Additionally, the magnetic layers interact by both exchange and magnetostatic coupling, which modifies the switching field and stabilizes specific remanent states.

In this work, we first used MFM to show that individual Co/Cu/NiFe sandwich nanomagnets could be magnetized into four distinct states, labelled A-D in **Figure 1**. For comparison, AGM measurements, measured on a piece of the array containing ~10^9 nanomagnets, show the structures switching from state A to B to D as the field is swept from +1000 Oe to −1000 Oe. As the field sweeps from −1000 Oe to +1000 Oe the structures switch from state D to C to A (**Figure 1**). Minor loops (shown as solid points) allow the switching field of the NiFe layers, and the interaction field (i.e. the field that the Co exerts on the NiFe) to be measured. In this sample the Co hard layers reverse over a range of fields centered at 410 Oe. The interaction field was 60 Oe and the switching field of the NiFe layers was 125 Oe.

In addition, utilizing modulated circularly polarized soft x-rays from the X-13A beamline, both reflectivity and magnetic circular dichroism (MCD) patterns were measured for these arrays. The magnetic parameters deduced from elementally-specific hysteresis loops, obtained from the difference signal close to the L_3 absorption edge of the Co and Ni present in the sample, agreed well with those measured by AGM. In the data of **Figure 2** the reversal of the Ni and Fe occurs at identical fields, as expected, while the Co reverses at a higher field. The Ni and Fe loops are both offset from zero by 40 Oe, as a result of the interaction field. All three elements show a distribution of switching fields consistent with AGM data. The average coercive field for the Ni was 120 Oe and for the Co was 410 Oe, which is similar to the results obtained from AGM. These experiments show that synchrotron measurements provide a valuable measurement of magnetization reversal, even in buried layers, and can be used to track the behavior of complex multilayered magnetic structures.

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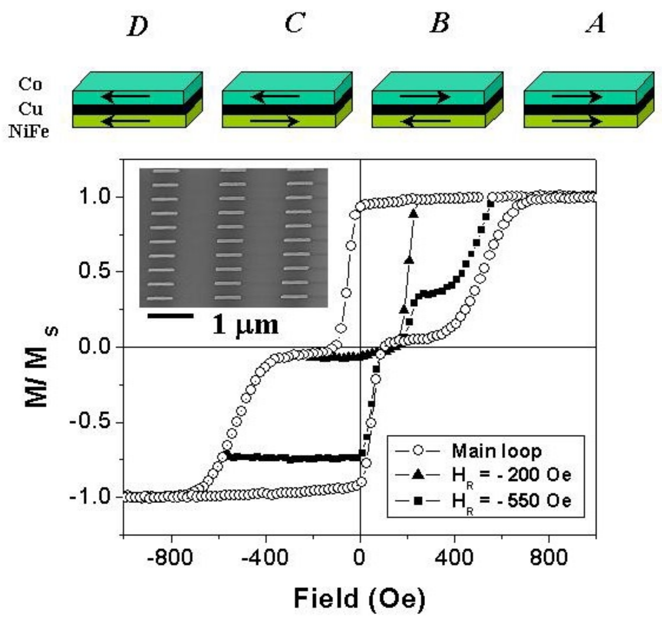

Figure 1. *Room temperature hysteresis loops and minor loop measurements of a 70 x 550 nm² NiFe/Cu/Co PSV nanomagnet array. The reversing fields of the minor loops are -200 Oe (full triangles) and -550 Oe (full squares), respectively. The inset shows a scanning electron micrography of the sample. A schematic representation of the four possible orientations of the magnetization of both magnetic layers is also depicted.*

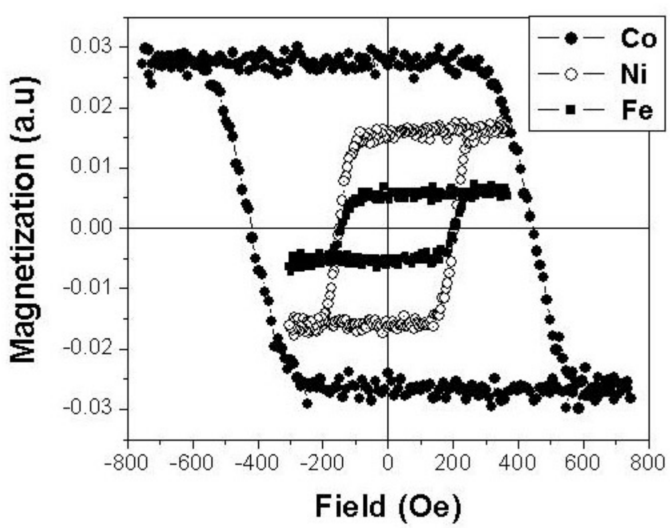

Figure 2. *Elementally-specific hysteresis loops, deduced from magnetic circular dichroismmeasurements, on an array of 70 x 180 nm² NiFe/Cu/Co PSV nanomagnets.*