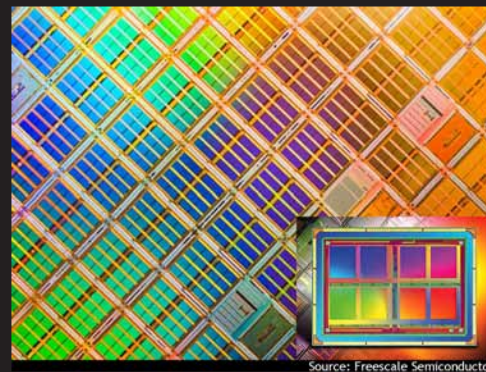
Magnetic Nanostructures for post-CMOS Electronics

Objective

Our goal is to address the metrology of magnetic effects at the nanoscale level. Nanomagnet arrays form the basis for important data storage technologies, notably magnetoresistive random access memory and bit-patterned media for ultra-high density storage devices. Moreover, the semiconductor industry is looking beyond conventional CMOS processing, where current lithography techniques are expected to fail. Although fabrication methods for post-CMOS circuitry have not been established, it is certain that the magnetic components involved will be in the nanometer range. Even though defects are expected to dominate device behavior at this range, the metrology of defect-induced magnetic effects is not available at this scale.

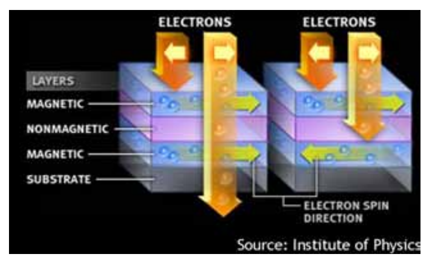


Impact and Customers

- *Magnetoresistive Random Access Memory (MRAM)*
  MRAM chips are fast and energy efficient. However, a broader market for MRAM is hampered by nonuniformity issues resulting from the current manufacturing processes. Our research will address such limitations.

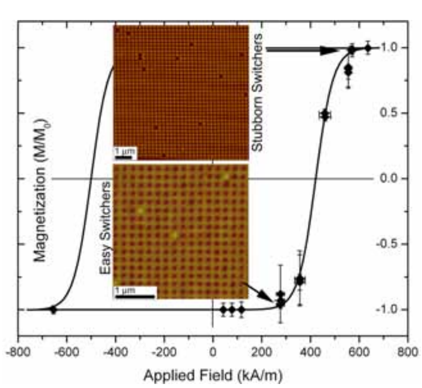
- *Bit-patterned media hard drives*
  Bit-patterned media is the future of ultrahigh density storage. Our research focuses on bit uniformity metrology to enable the identification and quantification of manufacturing problems that limit the deployment of this new platform in next generation hard drives.

- *Post-CMOS electronics*
  Our metrology will underpin the manufacturability of nascent devices using spin-based technologies. The incorporation of nanomagnets is desirable due to their high speed and low power consumption attributes, thus alleviating heat dissipation problems associated with CMOS scaling.



Approach

We focus primarily on arrays of magnetic nanostructures in order to reveal how defects alter the fundamental physics of magnetization reversal processes in the nanometer regime. We have an integrated approach that consists of four interrelated elements. The first element, film edge metrology, addresses the role of the edge on magnetic behavior uniformity in magnetic nanostructures. The second element, magnetooptical nanostructure spectroscopy, is meant to provide fast and precise individual nanostructure "fingerprints". Another element, microscopy, provides quantitative microstructure and defect information that can be correlated with magnetic behavior. Finally, a nanomagnetic modeling element offers an efficient and accurate theoretical predictive tool.



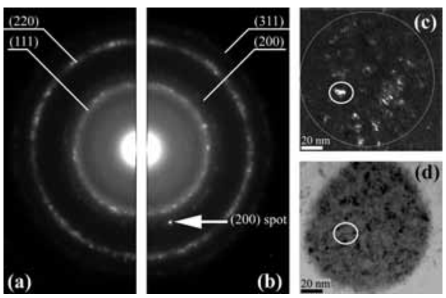
NANOMATERIALS

Accomplishments

Microstructural origin of switching field distribution

We found an important microstructural origin of switching field distribution (SFD) in polycrystalline Co/Pd nanodot arrays. Based on the evidence that grains with in-plane [100] vectors are correlated to dots with small switching fields, we concluded that these grains "trigger" or initiate switching.

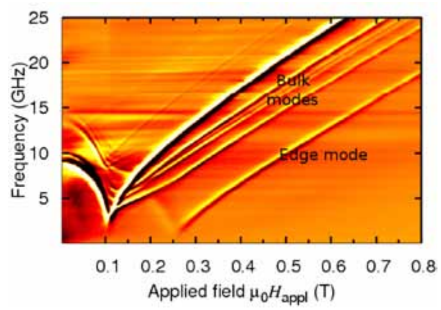
Furthermore, the ease of switching these nanodots is linked to the size of the trigger grains. The extent to which the [001] vector points out of plane may also play a role in reducing the switching field. Control of the microstructure, to eliminate the trigger grain, may be the key to reducing the SFD in Co/Pd nanodot arrays.



Trigger grain causes SFD in Co/Pd nanodots

Thin film edge magnetic properties vary with patterning process conditions

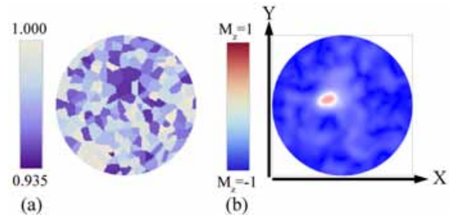
Using ferromagnetic resonance spectroscopy, we were able to separate edge behavior from bulk behavior in Permalloy magnetic nanostripes. We showed that the patterned edges of magnetic films have measurable magnetic characteristics, and that quantitatively, the magnetic properties depend on the etching conditions used to create the edges. These results have important implications for generating nanostructure arrays with uniform properties and for understanding the behavior of magnetic nanodevices.



Measured resonances in nano-stripes

Modeling polycrystallinity in nanomagnets

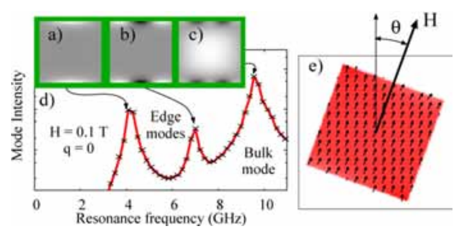
In response to the growing need for a more accurate micromagnetic model to understand switching phenomenon in nanoscale magnets, we developed the capability to model magnetic behavior due to polycrystalline grains using the NIST Object Oriented Micromagnetic Framework (OOMMF). This allows users full flexibility in determining the easy axis orientations and magnetocrystalline anisotropy in each individual grain, as well as the intergranular exchange coupling strength.



Modeling nanograins as a magnetization reversal trigger

Micromagnetics on curved geometries using rectangular cells

We introduced a 3-D compatible correction method for calculating the micromagnetics of arbitrary shaped magnetic elements using regular finite-difference discretization. The correction reuses the magnetostatic code on a finer mesh to compute local anisotropy terms for cells in the neighborhood of the boundary. To validate the correction algorithm, we used an edge mode frequency test, which revealed that grid-induced magnetic behaviors were largely eliminated.



Edge modes test the robustness of correction

Learn More

Robert McMichael (CNST)
Thomas Silva (EEEL)
Justin Shaw (EEEL)
Michael Donahue (ITL)

June W. Lau
(Metallurgy)
(301) 975-5711
june.lau@nist.gov
www.nist.gov/metallurgy

Publications

Lau JW, McMichael RD, Schofield MA and Zhu Y *Correlation of Edge Roughness to Nucleation Field and Nucleation Field Distribution in Patterned Permalloy Elements* J. Appl. Phys., 102: 023916 (2007)

Lau JW, McMichael RD, Chung SH, Rantschler JO, Parekh V and Litvinov D *Microstructural Origin of Switching Field Distribution in Patterned Co/Pd Multilayer Nanodots* Appl. Phys. Lett., 92: 012506 (2008)

Maranville BB, McMichael RD and Abraham DW *Variation of Thin Film Edge Magnetic Properties with Patterning Process Conditions in $Ni_{80}Fe_{20}$ Stripes* Appl. Phys. Lett., 90: 232504 (2007)

Donahue MJ and McMichael RD *Micromagnetics on Curved Geometries Using Rectangular Cells: Error Correction and Analysis* IEEE Transactions on Magnetics, 43: 2878 (2007)