Magnetic Imaging

Objective

Our goal is to develop a real-time magnetic domain imaging system and apply it to technologically important systems, including data-storage and permanent magnets with increased energy products, in order to test and publicize its unique capabilities. In this project we will develop methods to visualize magnetization reversal processes to explain the mechanism and ramifications of exchange interaction on the remagnetization processes in composite magnetic materials comprised of species with dissimilar bulk magnetic characteristics.


Magneto-Optical Indicator Film System

METALS

Impact and Customers

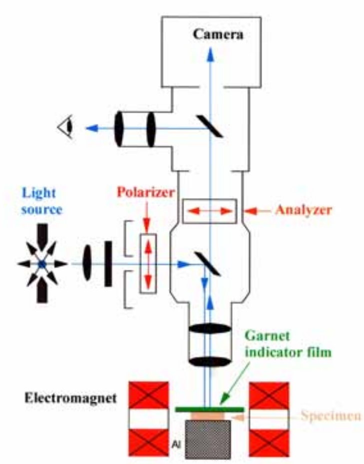
- In collaboration with the Russian Academy of Sciences (Moscow), the advanced Magneto-Optic Indicator Film technique (MOIF) was developed to image magnetic spins and domain structures in real time. Other collaborators include the Johns Hopkins University and Chang Won University (S. Korea).
- The technique is now used in many laboratories around the world for imaging flux penetration in superconductors; for high T_C superconductors, it is the "method of choice." Acceptance by manufacturers of miniature magnetic devices such as the newer generation of magnetic read heads and field sensors has been slower due to unavailability of enough imaging films.
- Using the MOIF technique we have been able to make several unique and technologically important measurements, including the findings that the remagnetization behavior can "differ" for different sides of the hysteresis loop in technologically-important "exchange-biased" films, and proving magnetic spin rotation in magnetic "exchange springs."

Approach

Advanced magnetic devices and storage media will rely on ultra-thin ferromagnetic films; since such films are quasi two-dimensional magnets, they can have strong perpendicular magnetic anisotropy (PMA). Optimization of future materials, including improved yields, requires the ability to measure film interactions. The advanced magneto-optical indicator film (MOIF) technique is a particularly appropriate tool to obtain such information.

This technique uses a Bi-substituted yttrium iron garnet film with in-plane anisotropy, placed on top of a specimen to be analyzed. This enables the observation of the magnetic stray fields above the specimen through the magneto-optical double Faraday effect of the garnet film. This optical image of the stray magnetic fields is observed by polarized light optical microscopy. A digital difference technique is used for quantitative analysis of the magneto-optical images.

MOIF Microscope Configuration



Advantages of the MOIF method:

- Real time visualization of magnetization dynamics.
- Any magnetic material can be investigated, and only magnetic information is observed.
- Quantitative
- Observations over a wide temperature range.
- It is simple in operation, and inexpensive to construct.

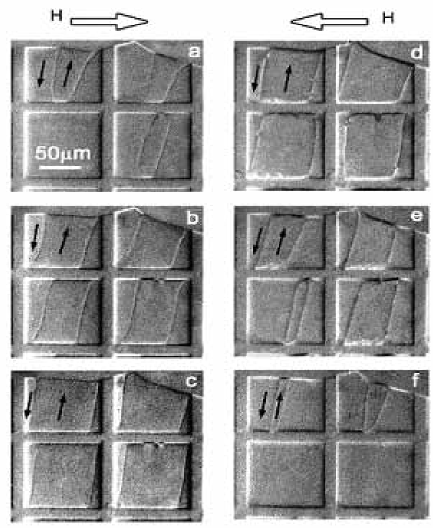
Accomplishments

Developing new magnetic materials for magnetic storage devices requires a deep understanding of the remagnetization processes. To help the industry in such an important task, NIST is using the advanced Magneto-Optical Imaging technique to study magnetization reversal processes in magnetic materials with perpendicular magnetic anisotropy, such as artificial nanostructures consisting of two or more materials with drastically different magnetic characteristics. This study by the Magneto-Optical Indicator Film technique (MOIF) provided visualization of the magnetization reversal in a bilayer consisting of a continuous 30 nm thick $Ni_{77}Fe_{14}Mo_5Cu_4$ soft ferromagnetic (FM) film covered by a 10 nm-thick, patterned square grid (110 μm wide squares with 10 μm wide grid strips) of antiferromagnetic (AFM) FeMn.

We have discovered that the antiferromagnet not only changes the properties of the FM regions immediately underneath it, but despite the large pattern period, also drastically affects the remagnetization behavior in the adjacent uncovered parts of the ferromagnet. Specifically, we demonstrated pattern-controlled nucleation of domain walls and an overall asymmetry in the reversal behavior of the uncovered FM film when the polarity of the in-plane field is reversed. These data show an unexpectedly long-range lateral influence on thin-film magnetization reversal by a rectangular array of FeMn pinning films.

We consider these results to be a major advance in understanding the remagnetization processes of patterned magnetic media, and we expect that our results will be used by the recording industry to develop magnetic materials for practical applications in perpendicular magnetic recording, and by scientists to understand the nature of the exchange interactions at the interface between a ferromagnet and an antiferromagnet.

This program is important because ultra-thin patterned ferromagnetic films, especially those with strong perpendicular magnetic anisotropy (PMS), are candidates for use by the magnetic recording industry to achieve very high density storage. Therefore, it is crucial that the industry know the distance to which magnetic exchange bias effects between a FM and an AFM extend in the ferromagnet; conventional wisdom would not have led to expectations of tens of micrometers as the extent of the effect.



MOIF image shows the asymmetry of the domain structure dynamics during magnetization reversals in opposite directions.

Forward branch of the hysteresis loop:
(a) $\mu_o H=1.32$ mT, (b) $\mu_o H=1.38$ mT, (c) $\mu_o H=1.62$ mT.

Backward branch:
(d) $\mu_o H=0$, (e) $\mu_o H=-0.84$ mT, (f) $\mu_o H=-0.88$ mT.

Learn More

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Publications

Kabanov YP, Nikitenko VI, Egelhoff, Jr. WF, Shapiro A and Shull R *In-plane Bias in a Patterned Ferromagnetic/Antiferromagnetic Bilayer* Phys.Rev. B, (2008 in press)

Iunin YL, Kabanov YP, Nikitento VI, Cheng XM, Clarke D, Tretiakov OA, Tchernyshyov O, Shapiro AJ, Shull RD and Chien CL *Asymmetric Domain Nucleation and Unusual Magnetization Reversal in Ultrathin Co films with Perpendicular Anisotropy* Phys. Rev. Lett., 98 (11) 117204 (2007)

Gornakov VS, Kabanov YP and Tikhomirov OA *Experimental Study of the Microscopic Mechanisms of Magnetization Reversal in FeNi/FeMn Exchange-biased Ferromagnet/Antiferromagnet Polycrystalline Bilayers* Phys. Rev., 73 (18) 184428 (2006)

Cheng XM, Nikitenko VI and Shapiro AJ *Unusual Magnetization Reversal in [Co/Pt](4) Multilayers with Perpendicular Anisotropy* JAP, 99 (8) 08C905 (2006)