UIC ECE Nanotechnology Core Facility

ECCS 0823813 : The Challenges of Integrating Magnetic Nanostructres into Functional 3-D Devices

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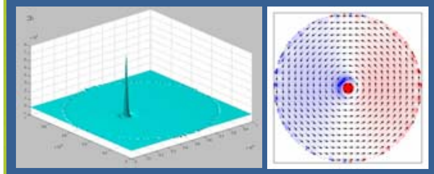
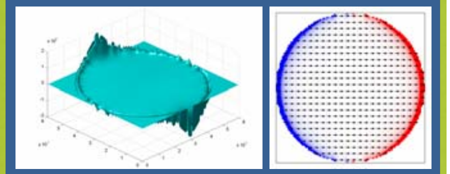
ABSTRACT

With CMOS technology rapidly reaching its scaling limit, alternatives are needed to manage and process digital information. Information storage will be realized by magnetoresistive random-access memory (MRAM). The design challenges faced by CMOS and MRAM are very similar, and fabrication techniques common to both must take into account the problems that arise as a consequence of the reduction in feature size as lithography improves. MRAM devices will utilize giant magnetoresistance (GMR) for device operation. Since the GMR effect is stronger when the current is passed vertically through the thin films comprising the GMR stack, contacts on the bottom of the device are mandatory. The problems associated with conventional techniques to handle bottom-side contacts, such as chemical-mechanical polishing (CMP), are aggravated by the reduction in channel size available with advances in lithography. Because of this, the topographical influence of contacts on the overlying magnetic device must be taken account from the very beginning of the design process. While the properties of nano-scale magnetic devices are very well understood in isolation, real devices must be fitted with contacts. The presence of contacts on magnetic devices is capable of radically altering the behavior of the devices, rendering all previous analysis useless. However, it may be advantageous to incorporate the changes in the magnetic properties into the device, changing its mode of operation.

DISKS

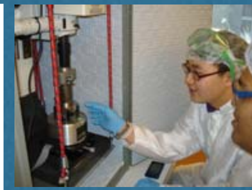


VORTEX STATE

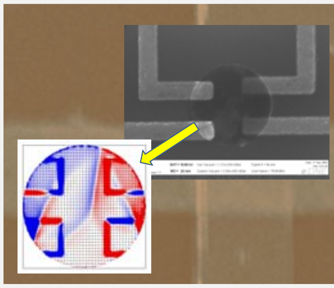


SATURATION STATE

Nanoscale thin-film magnetic disks have shown great promise as candidates for device elements in MRAM. The vortex state of magnetic disks is characterized by a spiral sample magnetization that is entirely in-plane, except near the center of the spiral, where exchange forces the magnetization out-of-plane. This magnetic vortex core is only a few nanometers across. The vortex state of a flat disk is immune to minor variations in shape.

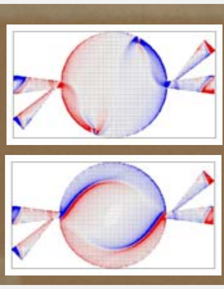


Hyun Jing Son (IMSA student) and Kasun Punchihewa (Ph.D student) imaging with Atomic Force Microscope in Nanotechnology Core Facility at UIC.

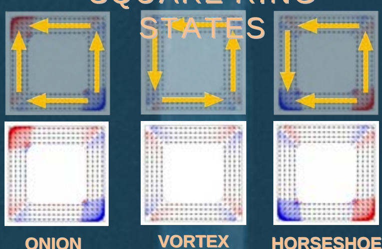


The magnetic states of disks can be switched using external magnetic fields. Future spintronic devices, however, will be switched using spin-transfer torque, which requires contacts to placed on the device. To maximize GMR, contacts will be required on both the bottom and top of the device. Including contacts underneath the device, however, completely destroys the vortex state of the disk

Using magnetic contacts is also futile – a vortex state can be induced in the disk, but it's switching properties are no longer predictable or reliable. In addition, the magnetic vortex core also becomes unstable when the width of the disk is reduced below 100nm. An alternative design solution is needed for functional devices.



SQUARE RING STATES

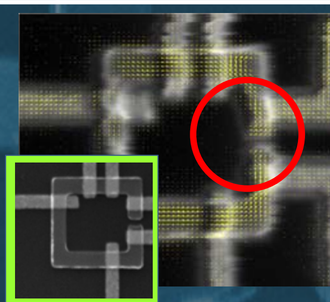


The magnetic vortex core in flat, nano-scale disks becomes unstable when the lateral dimension of the disks is smaller than around 100nm. The solution to this problem is to remove the center of the disk, and create a ring structure. Ring structures can assume many states with predictable, reliable switching properties with feature sizes below 100nm.

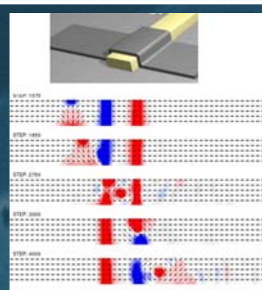
Prof. Metlushko's team in class 100 UIC Nanotechnology Core Facility: Peter Nebres (IMSA student, left), David Derry (IMSA students, right) and Joshua Sautner (Ph.D. student).

PI of this project, Prof. Metlushko, has been a scientific mentor of the IMSA students Peter Nebres and David Derry. The Illinois Mathematics and Science Academy (IMSA) is an internationally recognized educational institution created by the State of Illinois to develop talents in science and engineering. IMSA's advanced residential college preparatory program enrolls 650 Illinois students in grades 10-12. PI believes that providing hands-on research experience for advanced and highly motivated high school students is one of the most effective methods of training.

Peter Nebres and David Derry were the winners of the 2009 IMSA Student Inquiry and Research (SIR) Program, later they won the best in category of material science and received a gold award at the Illinois Junior Academy of Science (IJAS) science expo for their SIR work and presented their work at national (the American Junior Academy of Sciences conference at the American Association for the Advancement of Science annual conference, Feb. 17-21, 2010, San Diego, CA) and international (the Seventh Annual Japan RITS Super Science Fair, Oct. 29-Nov. 5, Kyoto, Japan) science fair events.



Placing contacts on circular or square nanoscale magnetic rings destroys the vortex state in the rings. The magnetization is disrupted in the neighborhood of the contacts, preventing the rings from assuming discrete, well-characterized states.



Top: The contact line (yellow), under narrow permalloy conduit (gray); Bottom: Domain wall translation over a single contact in a 75nm-wide permalloy conduit from with J = 1-3 x 10^{12} A/m^2 current density. Our simulations demonstrate that shape and roughness of the contact lines *under* magnetic conduit could modify the DW in narrow magnetic conduits from transverse DW into vortex-type DW.

This project has led to collaboration with MSD and APS of Argonne NL, the new world-class INFM National Center for Research and Development, aimed at a multidisciplinary approach to nano-Structures and bio-Systems at Surfaces (S^3), Italy, new Cooperative Research Center (CIC nanoGUNE), San Sebastian, Spain, Institute for Nanoscale Physics and Chemistry (INPAC) at Katholieke Universiteit Leuven, Belgium, Cornell Nanofabrication Facility, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland, Universidad Autónoma de Madrid, Madrid, Spain, National Institute of Standards and Technology, Groupe NanoMatériaux CEMES-CNRS, Toulouse, France and Research Center for Spin Dynamics & Spin-Wave Devices, Seoul National University, Seoul, South Korea.

Summary: Nanoscale magnetic devices are extremely sensitive to topographical variations due to the presence of underlying features, contacts in particular. Because of this, contacts must be included from the very beginning of the design process – magnetic devices can no longer be considered in isolation.

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Our work has been supported by . . .

- "The Challenge of Integrating Magnetic Nanostructures into Functional 3-D Devices" , The Electrical and Communications Systems (ECS) Division, National Science Foundation grant # ECCS-0823813