The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR.1664 - 9

Conference on Single Molecule Magnets and Hybrid Magnetic Nanostructures

27 June - 1 July 2005

Opportunities in Nanomagnetism

Sam D. BADER
Materials Science Division
Argonne National Laboratory
Argonne, IL 60439
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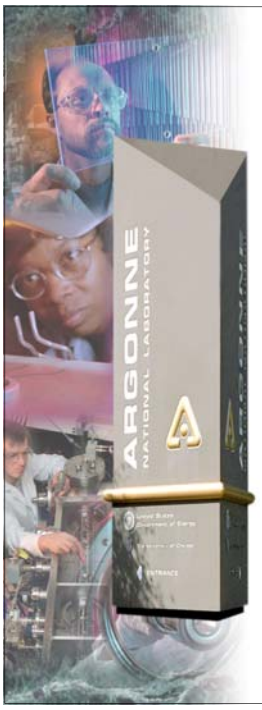


Opportunities in Nanomagnetism

Sam Bader

Conference on Single Molecule Magnets and Hybrid Magnetic Nanostructures

ICTP, Trieste, ITALY

June 27, 2005

World Year of PHYSICS 2005

Argonne National Laboratory

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

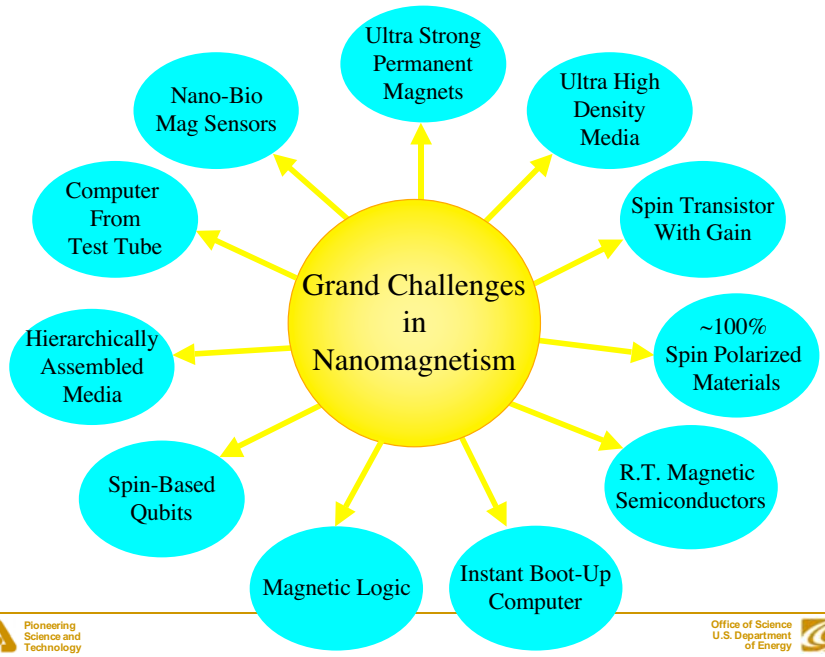
Office of Science U.S. Department of Energy

The Quest…

Create

Explore

Understand



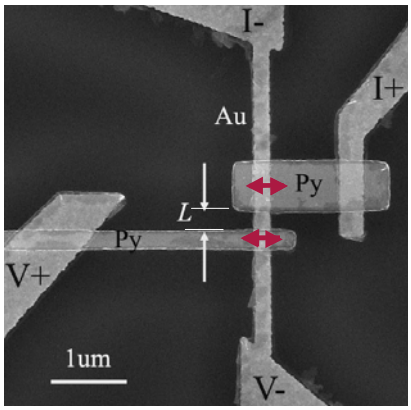
Approaches to Nano Fab . . .

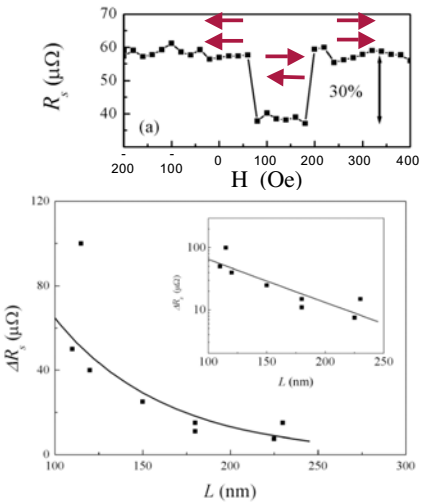
Top Down

Bottom Up

Virtual Fab

Spin Injection, Diffusion, and Detection in Lateral Spin-Valves



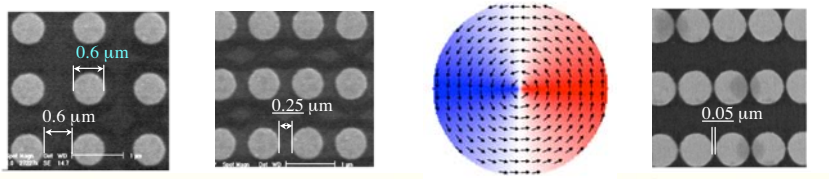


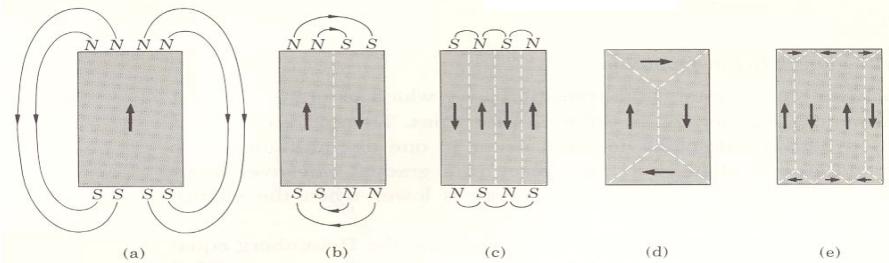
$\lambda_s = 63 \pm 15$ nm T = 10 K

Yi Ji *et al.,* APL 85, 6218 (2004)

Arrays of Magnetostatically Coupled Dots

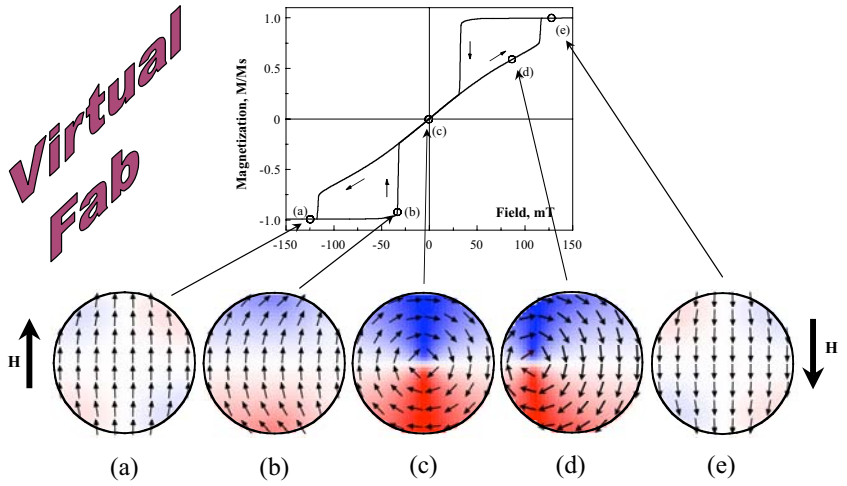
V. Novosad, *et al. PRB*





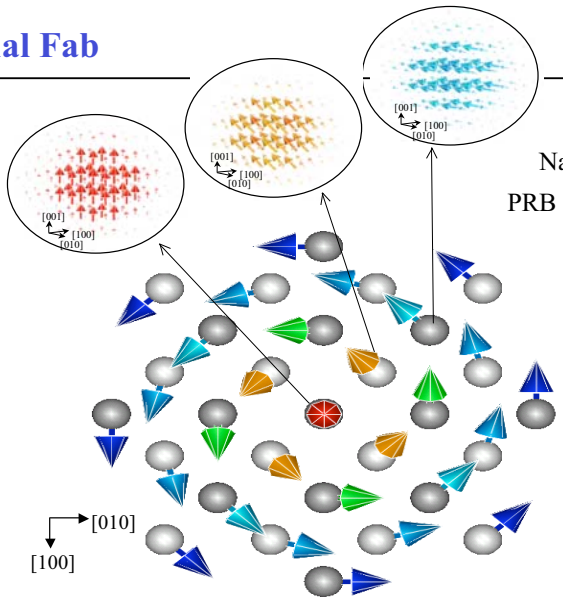
⇨ **Magnetostatic interaction affects the nucleation and annihilation fields, as well as the initial susceptibility (permalloy thickness = 60 nm).**

Magnetic Vortex State in disk-shaped nanomagnets



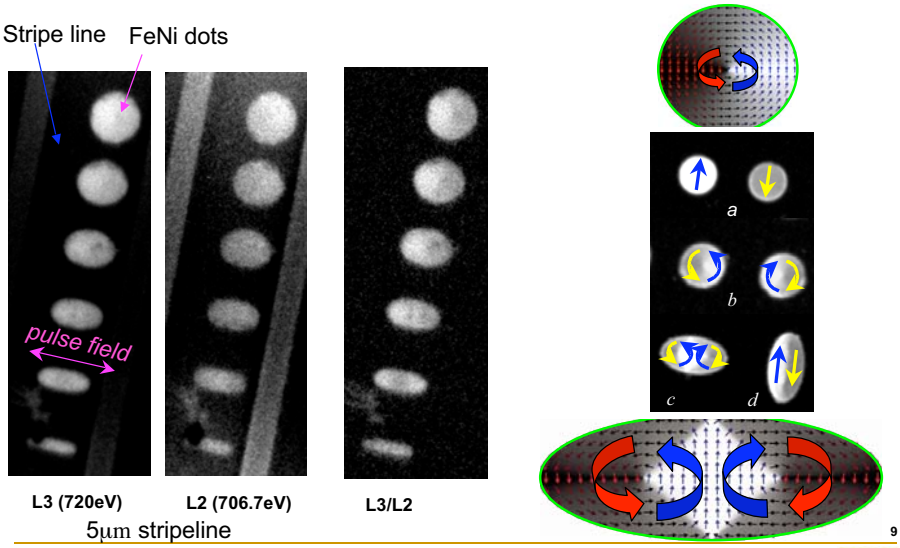
Magnetization reversal due to formation of the magnetic vortex state in circular dot

Virtual Fab



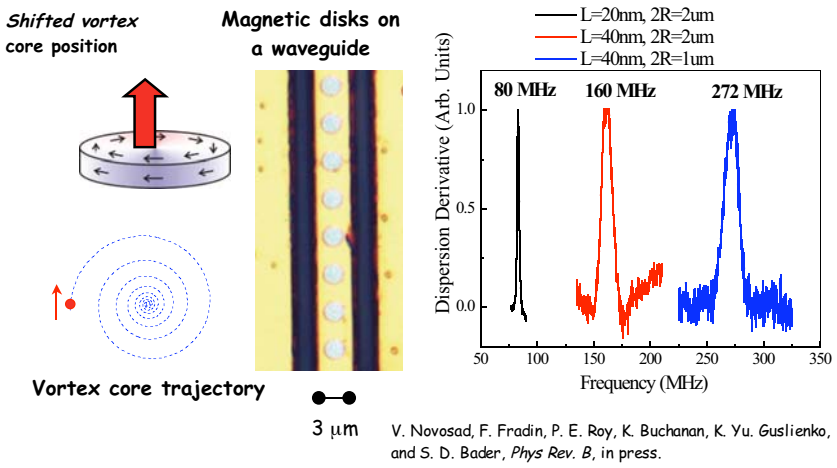
Nakamura et.al.
PRB **68**, 180404 (2003)

Size-dependent *metastable* remanent states



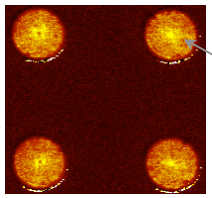
PEEM-II experiment at ALS-LBNL,
V. Novosad, Kristin Buchanan, A. Sholl And S.-B. Choe

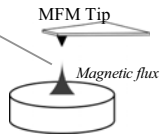
Vortex Dynamics in the frequency domain



V. Novosad, F. Fradin, P. E. Roy, K. Buchanan, K. Yu. Guslienko, and S. D. Bader, *Phys Rev. B*, in press.

- Measure impedence change due to magnetic resonance
- Sweep frequency and magnetic field





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Pioneering Science and Technology

Office of Science U.S. Department of Energy

Principles of Nanoscience

Geometric Confinement

Physical Proximity

Chemical Self-Organization

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Pioneering Science and Technology

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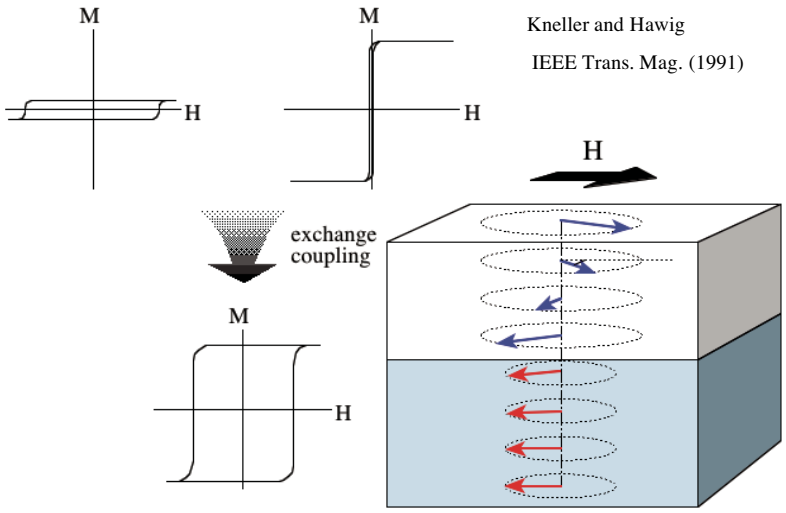
Exchange-Spring Principle for Hard Magnets

Energy Applications

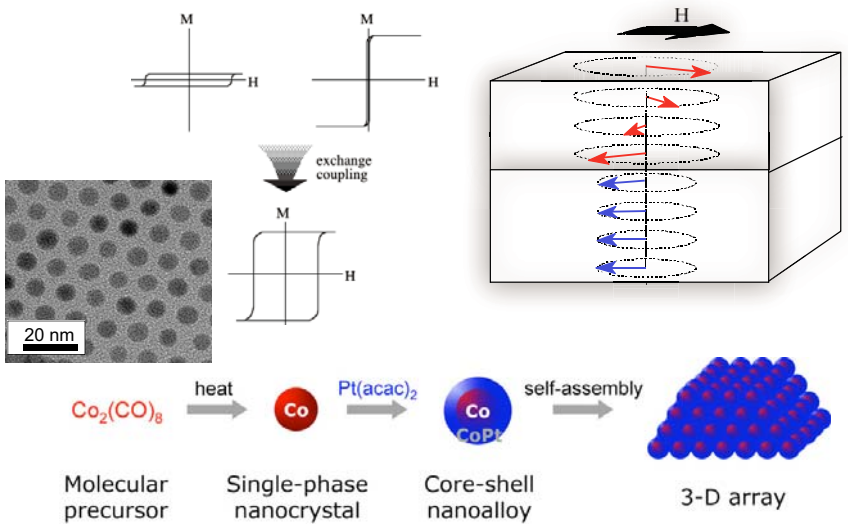
Exchange-Spring Principle for Hard Magnets



Kneller and Hawig

IEEE Trans. Mag. (1991)

Nanocomposite Spring Magnets



Pioneering Science and Technology

Anna C. Samia, *et al.* JACS **127**, 4126 (2005).

J. S. Jiang and S. D. Bader, Scripta Mat. **47**, 563 (2002).

Office of Science U.S. Department of Energy

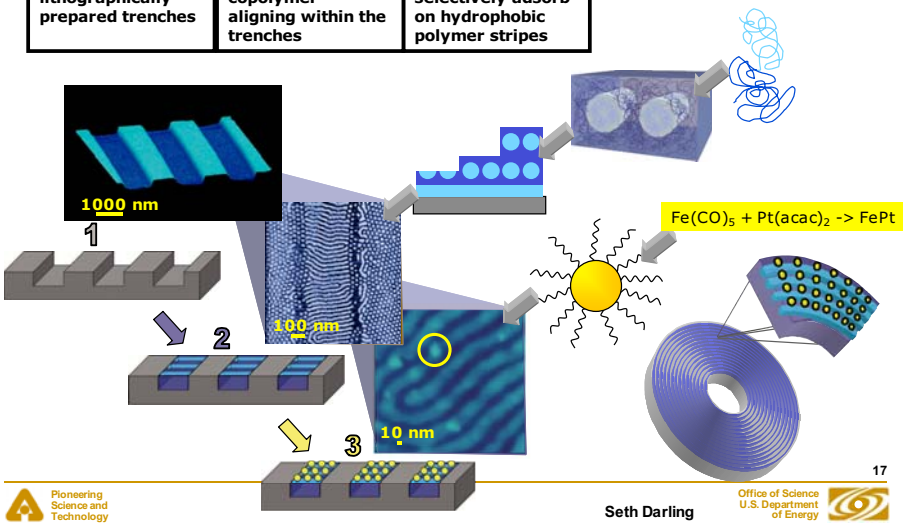
Magnetic Data Storage Technologies

Pioneering Science and Technology

Office of Science U.S. Department of Energy

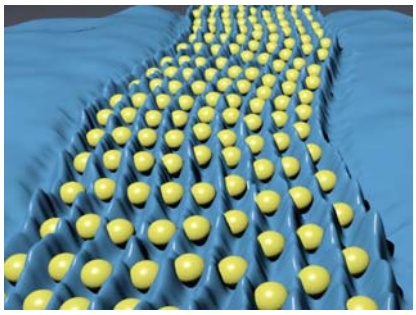
Hierarchical Assembly

Stage 1: Substrate with lithographically prepared trenches	Stage 2: Self-assembled diblock copolymer aligning within the trenches	Stage 3: 1-D nanomag array selectively adsorb on hydrophobic polymer stripes



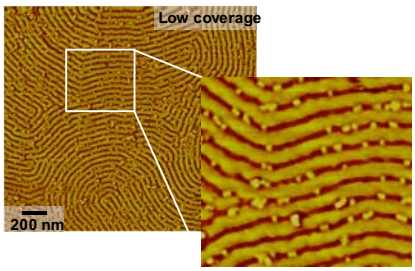
Polymeric Templating

The goal



PS-b-PMMA diblock copolymer aligned in lithographic channel templates highly ordered ferromagnetic nanoparticles

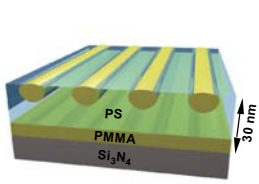
Where we are now

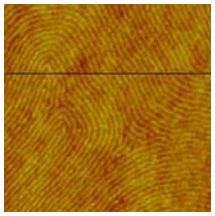


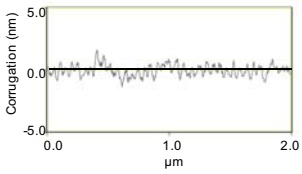
UV-modified PS-b-PMMA diblock copolymer film is highly selective template for oleic acid-capped *fcc*-FePt nanoparticles

S.B. Darling *et al. Adv. Mater.* in press

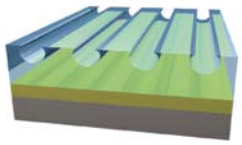
Photochemically Modified Template

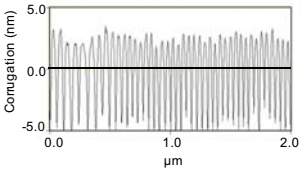






VUV irradiation

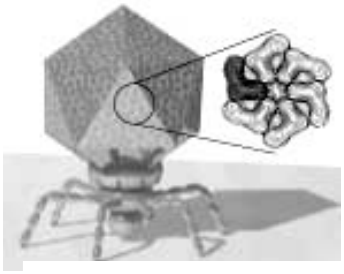


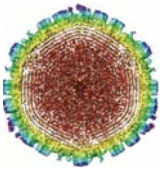


Magnetic Virus Concept

Bio-Inspired Solution to object size and placement control

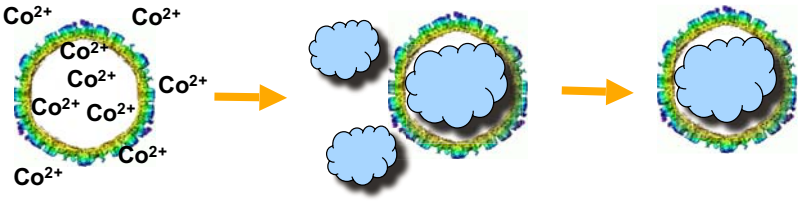
Artificial Magnetic Virus:





1) Osmotic shock

2) Alkaline treatment



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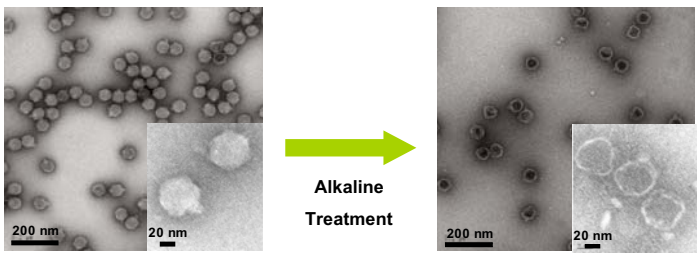
Pioneering Science and Technology

S.-H. Chung, A. Hoffmann, L. Chen, B. Kay, L. Makowski

Office of Science U.S. Department of Energy

TEM Images of Magnetic Virus Fabrication



Alkaline Treatment

Normal T7 Virus

Ghost T7 Virus

Capsid Proteins

Biomineralization

$(NH_4)_2Fe(SO_4)_2 + O_2 \xrightarrow{pH = 6.5} Fe_2O_3 \downarrow$

T7 Capsid Shell with Iron Oxide Inside

Magnetic Virus

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Pioneering Science and Technology

Chinmei Liu, Seok-Hwan Chung, April Sutton, Funing Yan, Qiaoling Jin, Axel Hoffmann, Brian Kay, Sam Bader, Lee Makowski, Liaohai Chen

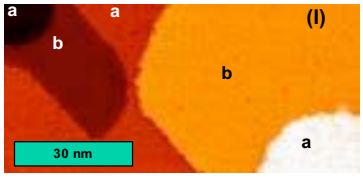
Office of Science U.S. Department of Energy

Novel Instrumentation

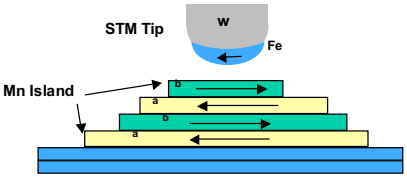
Spin-Polarized Scanning Tunneling Microscopy (SP-STM)

Spin-Polarized STM

Topography

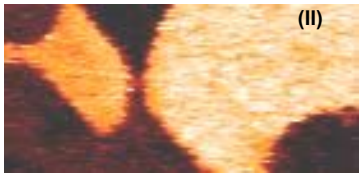


Mn on top of single Fe terrace



Fe(001) whisker terrace

Magnetic image



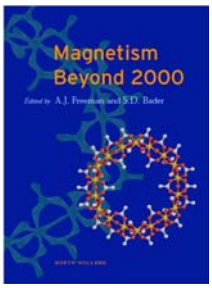
Resolve antiferromagnetism of Mn on Fe

Haifeng Ding, John Pearson, Dongqi Li, Frank Fradin, Ruihua Cheng, Sam Bader

Road Maps

SYNCHROTRON FRONTIERS

Research Frontiers in Magnetic Materials at Soft X-ray Synchrotron Radiation Facilities
J. Kortright, D. Awschalom, J. Stöhr, S. D. Bader, Y. Idzerda, S. Parkin I. K. Schuller, H. -C. Siegmann, J. Magn. Magn. Mater. **207** (1999) 7-44



MATERIALS FRONTIERS

Magnetism in Low Dimensionality
S. D. Bader, Surface Science **500** (2002) 172-188

NEUTRON SCATTERING FRONTIERS

Neutron Scattering Studies of Nanomagnetism and Artificially Structured Materials
M. R. Fitzsimmons, S. D. Bader, J. A. Borchers, G. P. Felcher, J. K. Furdyna, A. Hoffmann, J. B. Kortright, I. K. Schuller, T. C. Schulthess, S. K. Sinha, M. F. Toney, D. Weller, S. Wolf, J. Magn. Magn. Mater. **271** (2004) 103-146

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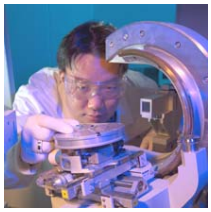
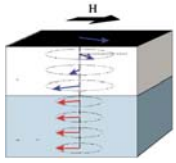
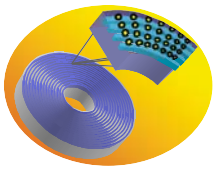
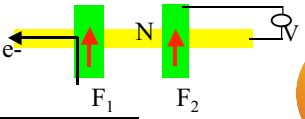
Collaborators

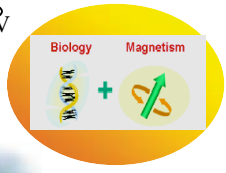


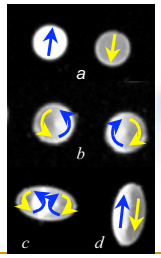
S. Jiang
J. Pearson
V. Novosad
K. Buchanan
M.Grimsditch
F. Fradin
X.-M. Lin
S. Darling
Y. Ji
S.-H. Chung
A. Hoffmann
L. Chen
L. Makowski
H. Ding

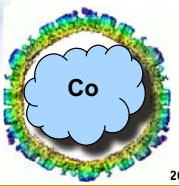












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