

# ***Studies of Confined Systems Using Soft X-Ray Magnetic Microscopy***

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Advanced Photon Source*

***Workshop on Nanomagnetism Using X-ray  
Techniques - August 29 – September 1, 2004,  
Fontana, Wisconsin***

***Argonne National Laboratory***



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



# Outline

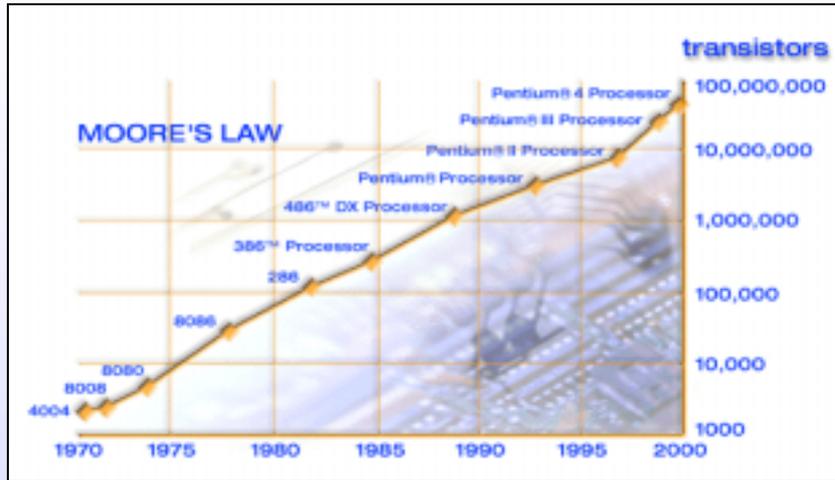
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- **Nanoscale magnets**
- **Current PEEM capabilities at APS**
- **Experimental Examples**
  - Lithographically patterned
  - Layered structures
  - Magnetic semiconductors
- **Future Upgrades**
  - Sample cooling
  - Micro-XPS?

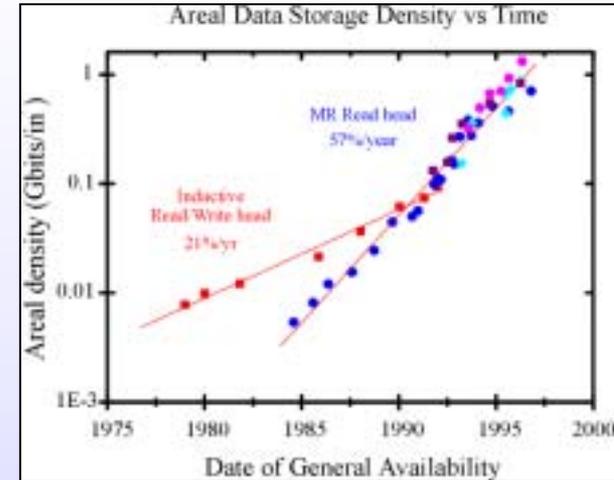


# Spintronics

Charge Devices (FETs)



Spin Devices (Magnetic Bits)



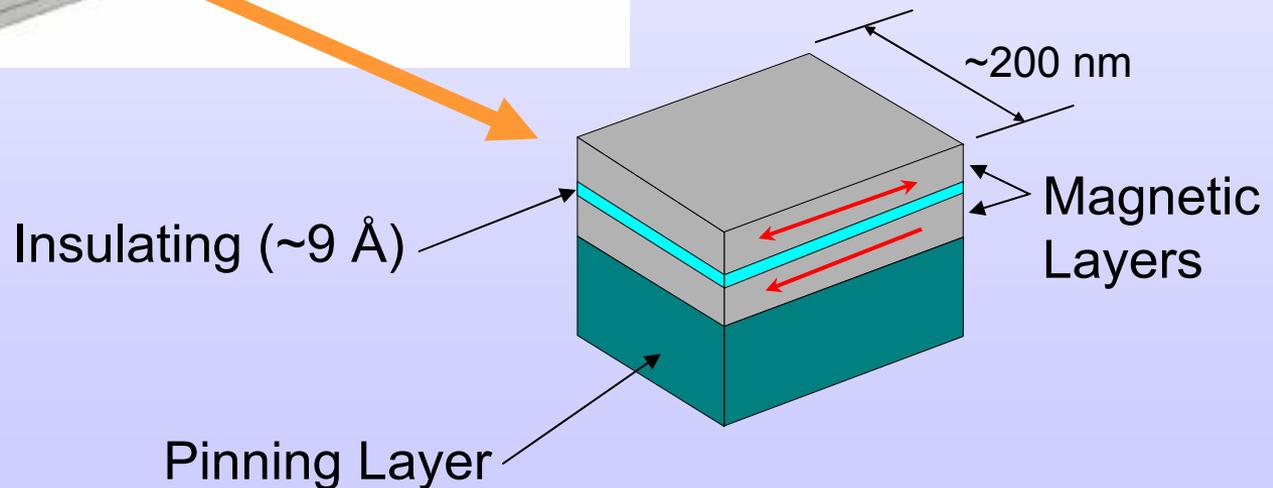
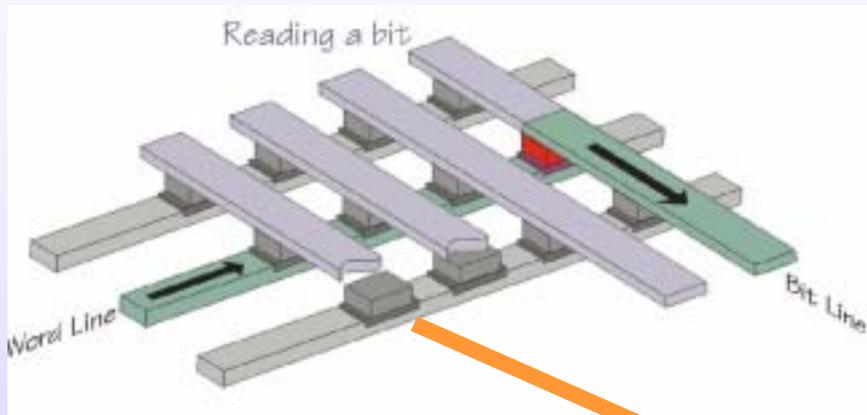
Non-volatile memory,  
field-programmable logic,  
etc.



# Magnetic Random Access Memory (MRAM)

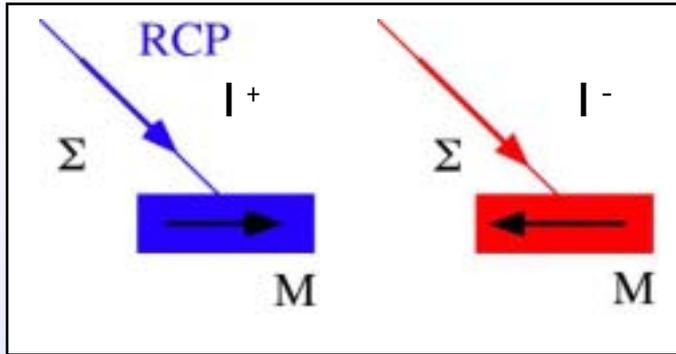
Non-volatile memory using spin-dependent tunneling through an insulating layer

- Magnetic/Insulator interface
- Inter-element coupling

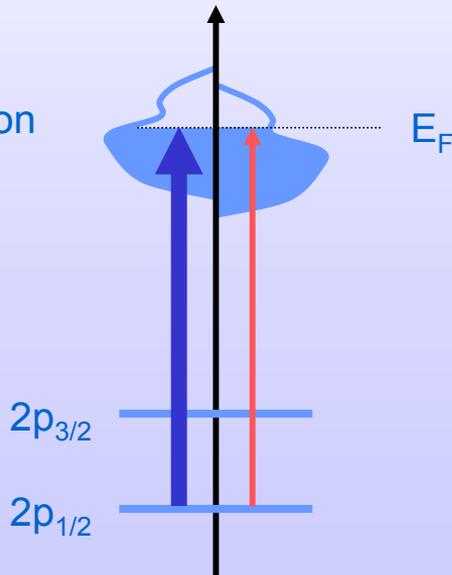


# X-ray absorption spectroscopy and magnetic circular dichroism

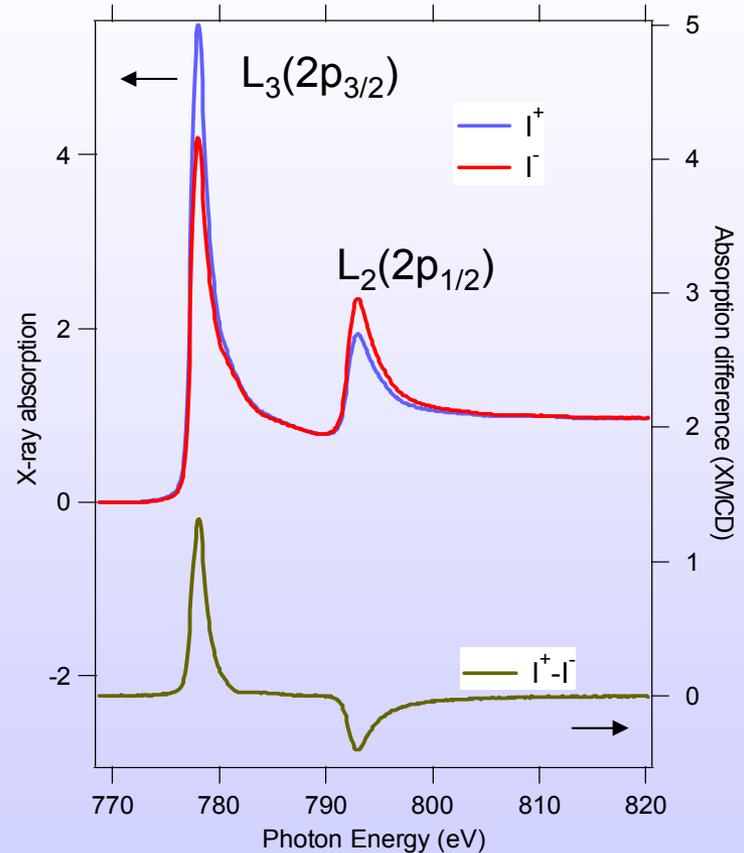
$$I^+ - I^- \sim \Sigma \cdot M$$



conduction band



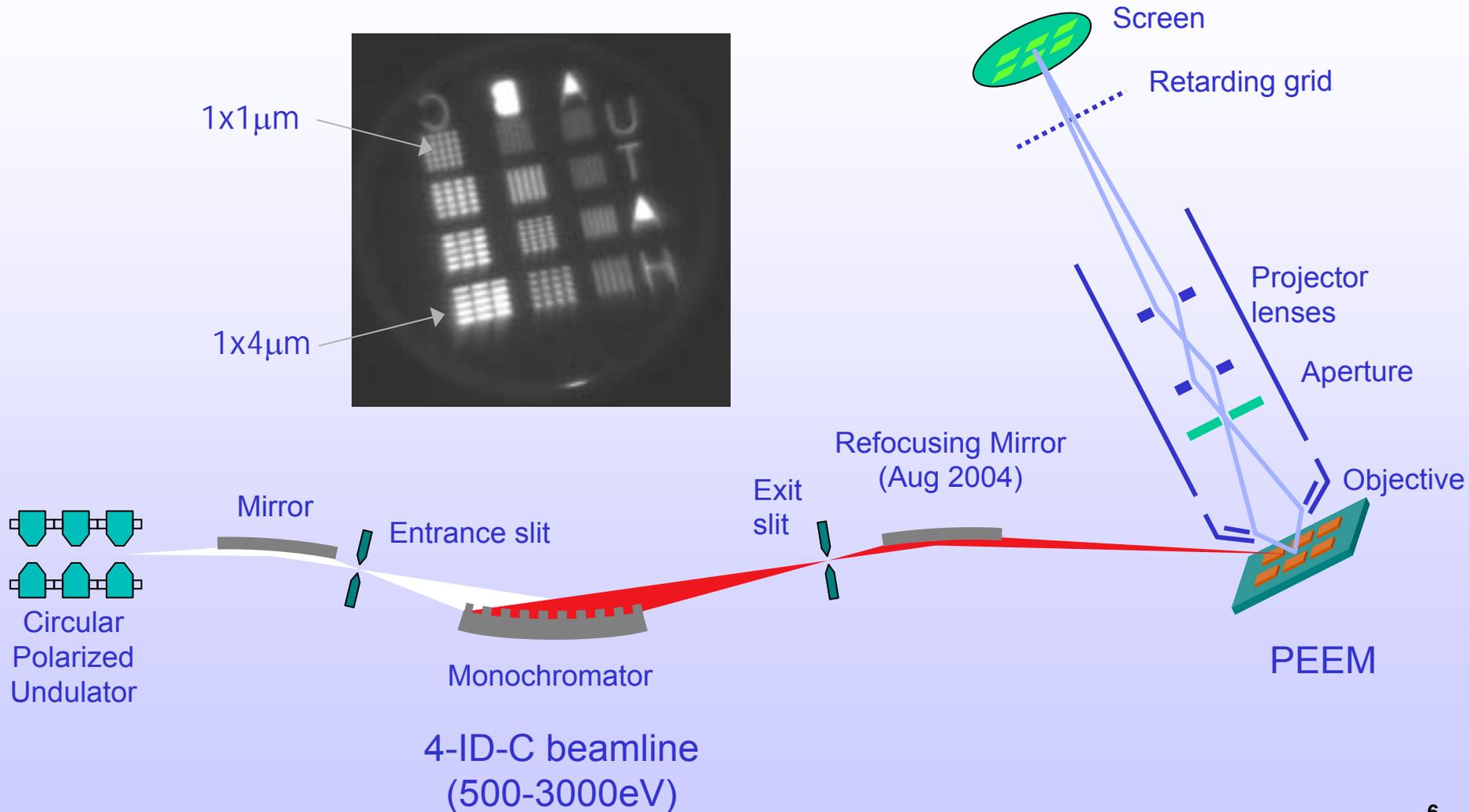
Transition Metal L edges



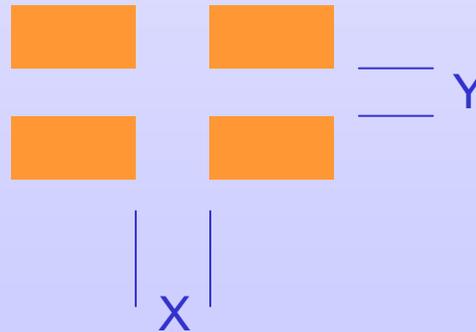
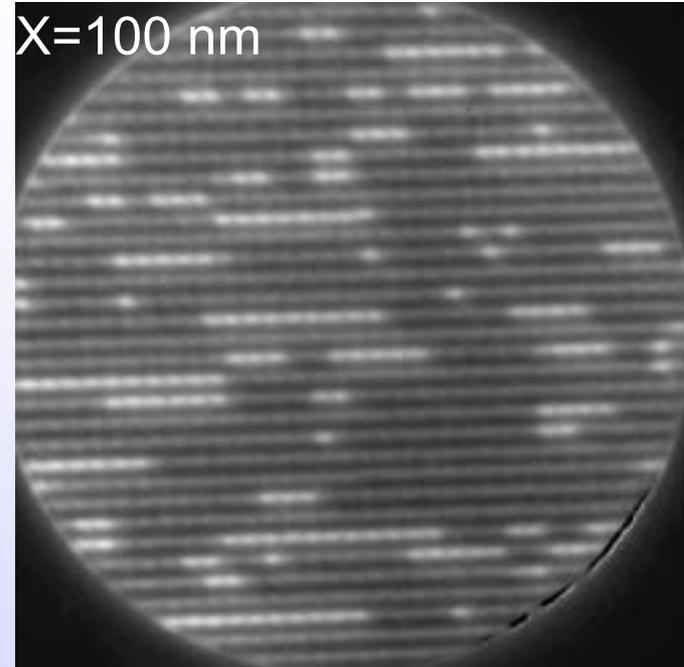
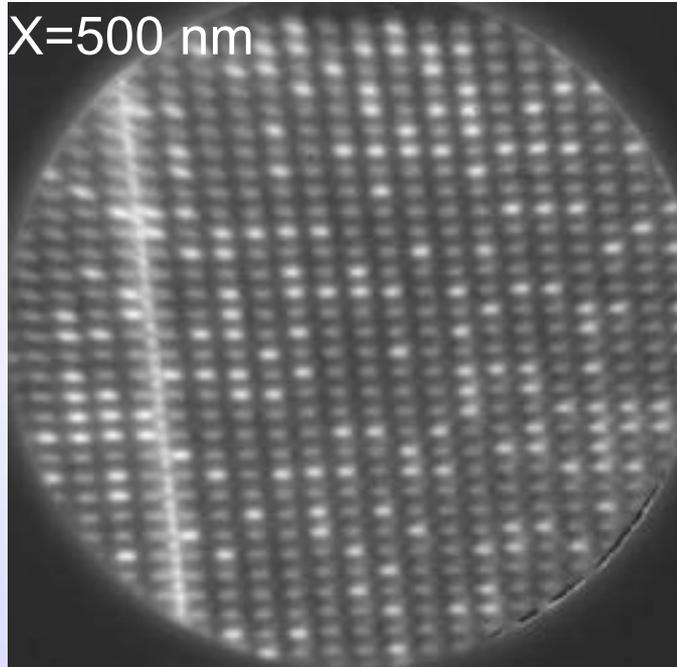
L edge excitation ( $2p \rightarrow 3d$  resonance)



# X-ray Photoemission Electron Microscopy



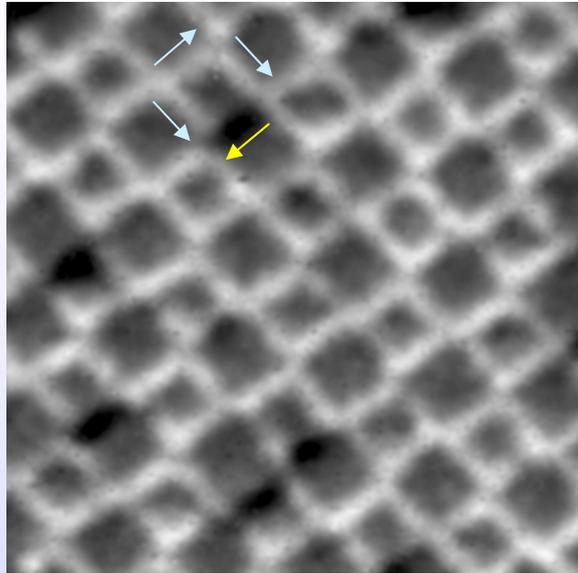
# *200 × 600 nm Co rectangles*



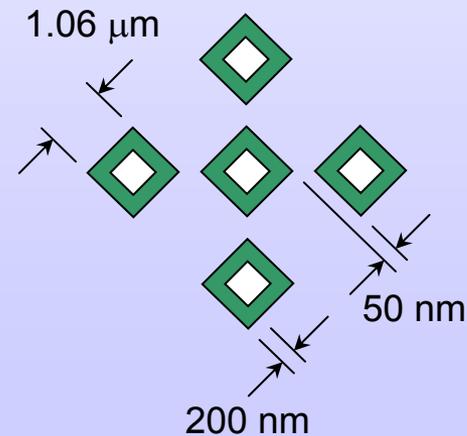
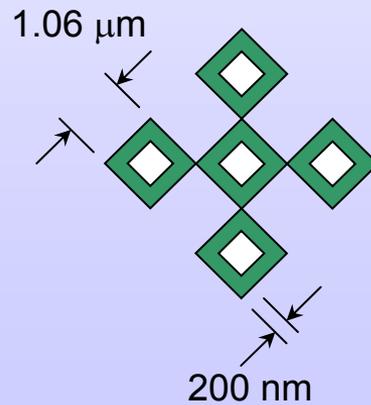
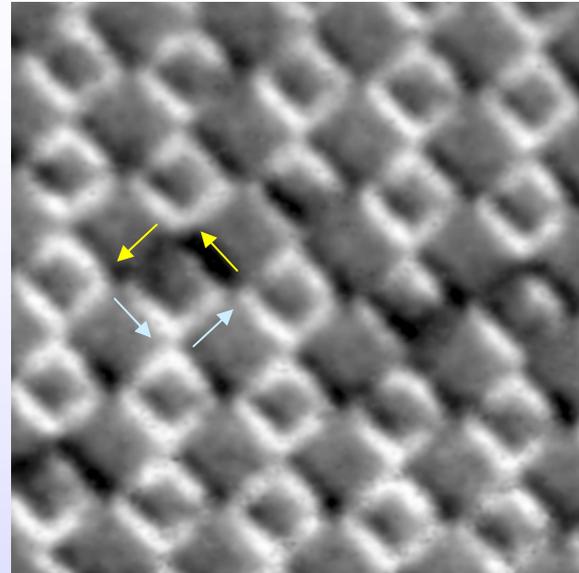
W.C. Uhlig and J. Shi, Univ of Utah, Dept. of Physics

# Coupling in NiFe rings

Touching



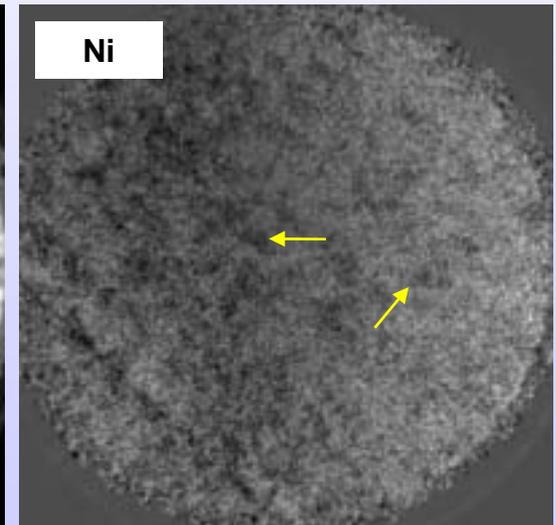
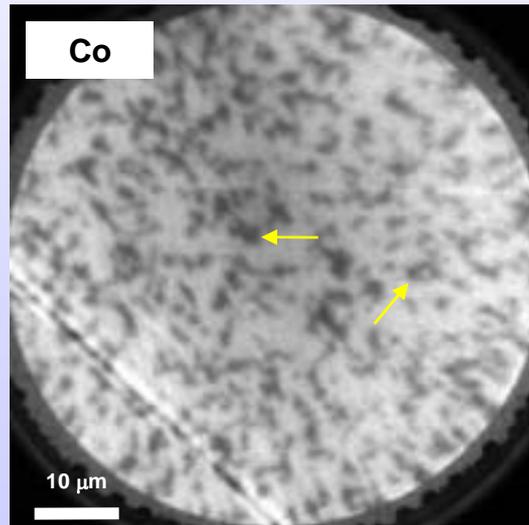
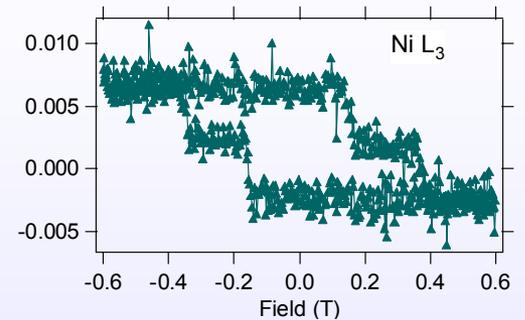
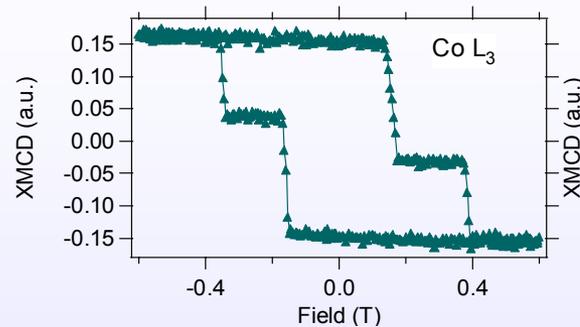
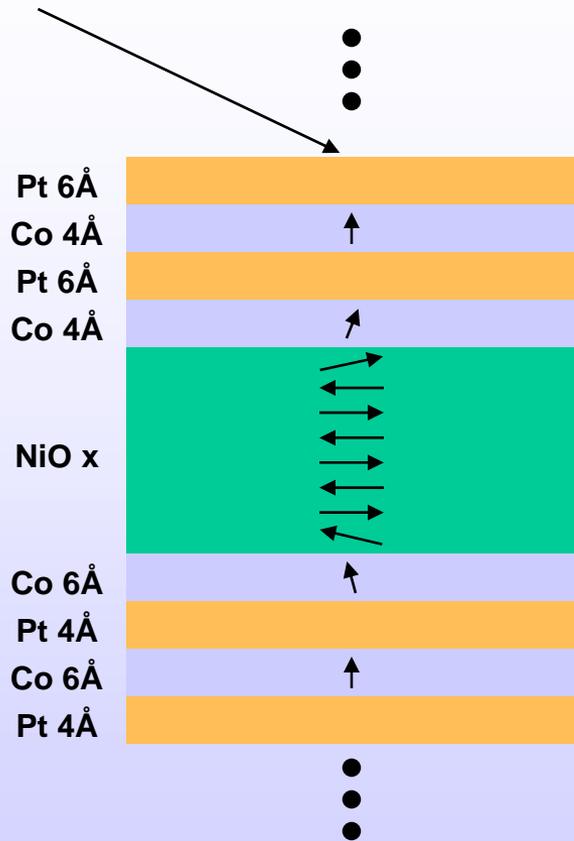
Non-touching



With V. Metlushko, UIC  
and D.R. Lee, APS



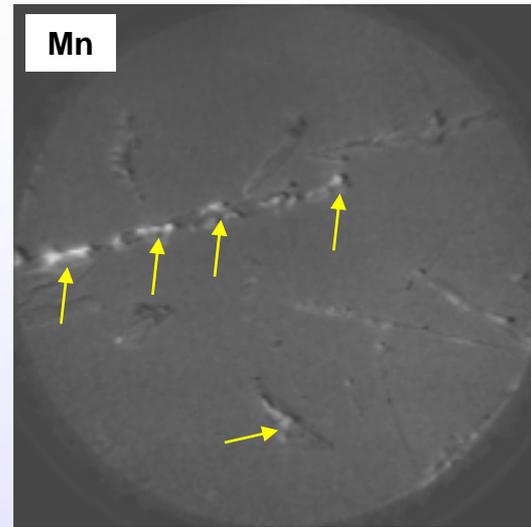
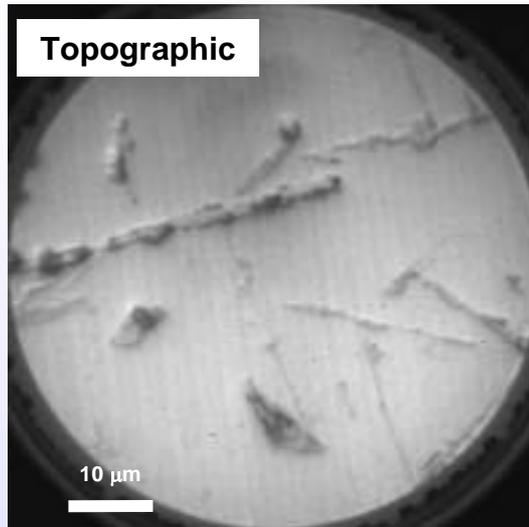
# Layered Structures



A. Baruth, Z. Liu, and S. Adenwalla, Univ. of Nebraska, Dept. of Physics & Center for Materials Research and Analysis

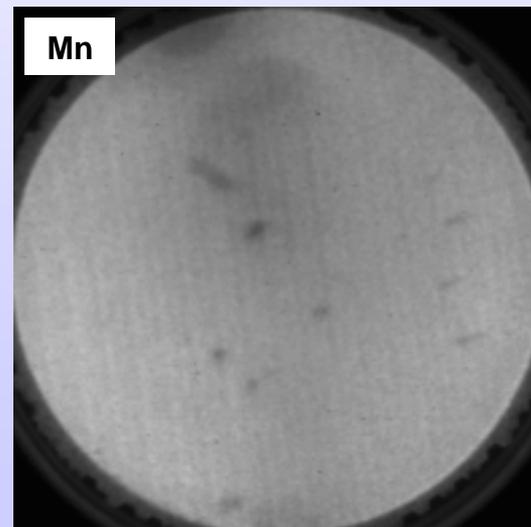
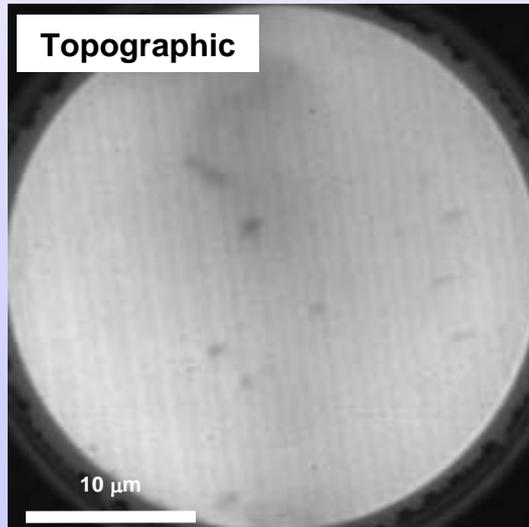
# Ferromagnetic Semiconductors

GaMnN



Reactive MBE

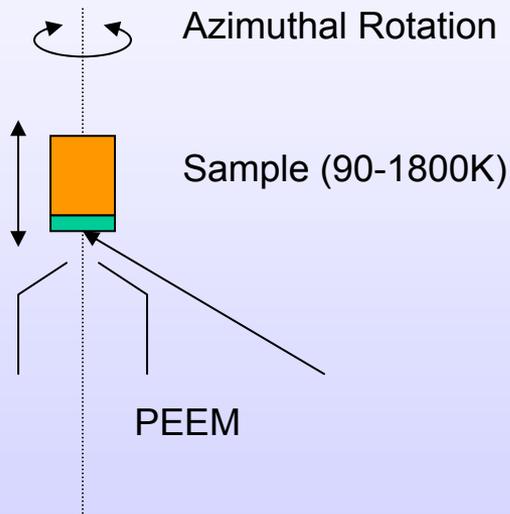
H-plasma  
assisted



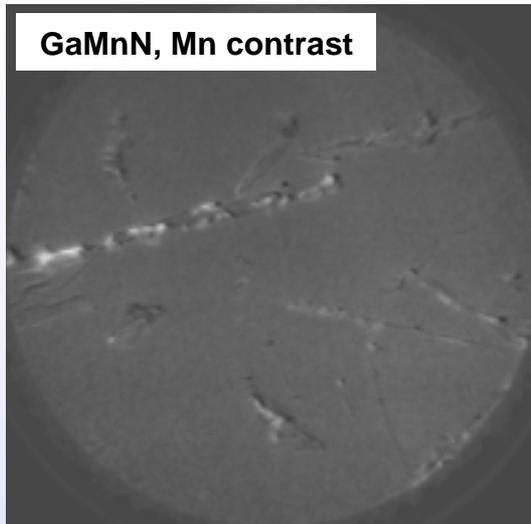
# ***Future Directions – Low temperatures***

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High stability sample stage to allow sample cooling and rotation

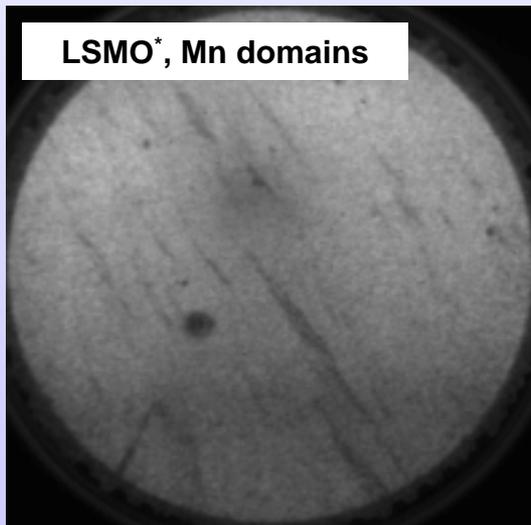
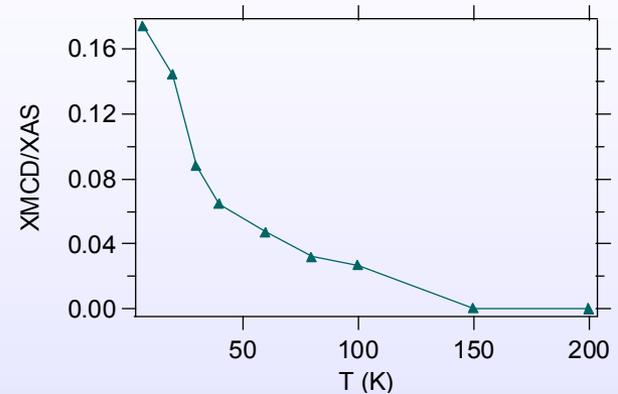


# Future Directions – Complex materials



## Ferromagnetic semiconductors

- Magnetic phase behavior
- Clustering issues



## Complex oxides

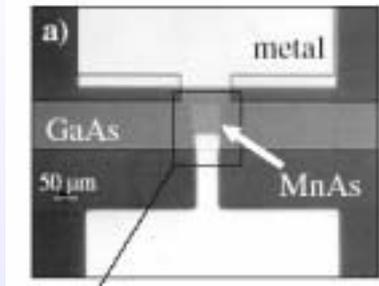
- Magnetic domains at transition temperature
- Magnetic “dead” surface layer
- Phase separation

**Need low temperature imaging!**

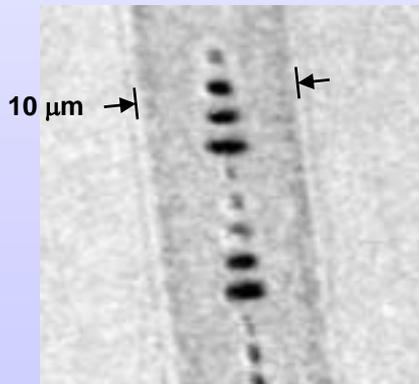
\*J. Eckstein, UIUC



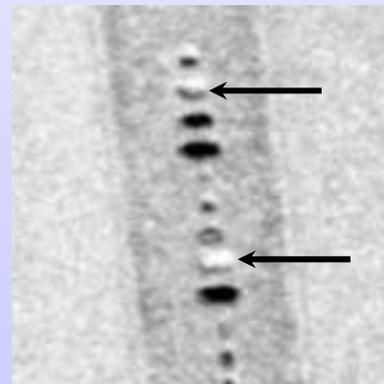
# Future Directions - Devices



J. Stephens, J. Berezovsky, J. P. McGuire, L. J. Sham, A. C. Gossard, and D. D. Awschalom, Phys. Rev Lett. **93**, 097602 (2004).

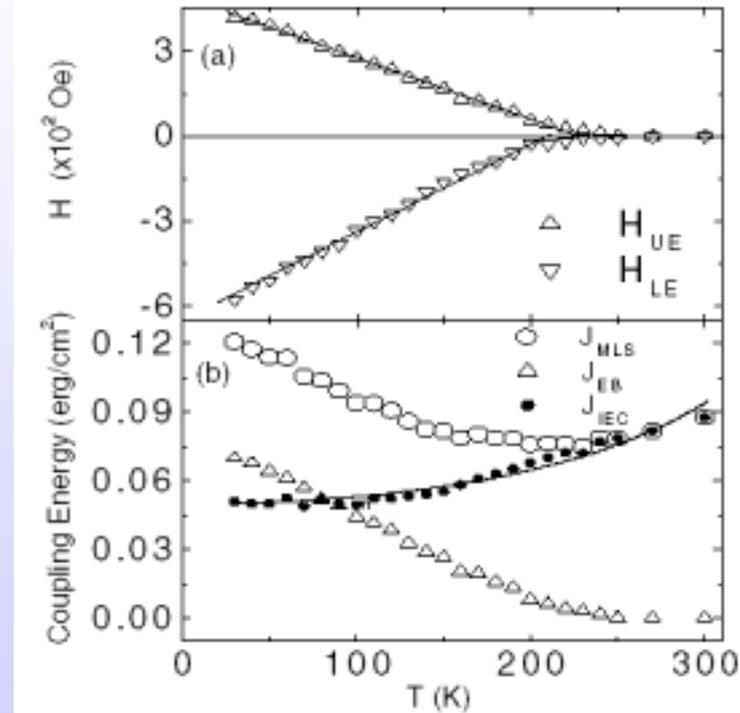
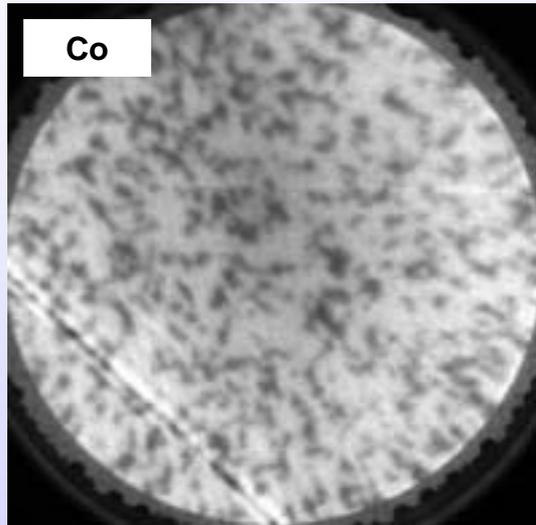


Before Pulse



After Pulse

# Future Directions – Layered Structures



Z. Liu and S. Adenwalla, Phys. Rev. Lett. **91**, 037207 (2003).

# Summary

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- PEEM provides a combination of chemical and magnetic sensitivity
  - Magnetic imaging
  - Layered structures
  - Complex materials
  - Devices
- Low temperature imaging will significantly enhance these efforts

