Advancements in Science & Engineering: Fueling the Future

Multilayered Magnetic Structures Novelties & Future

Yazan Hijazi, PhD

March 26, 2009

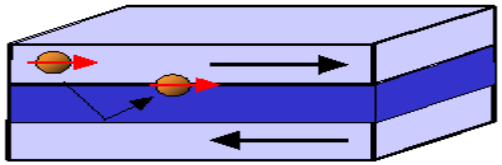
Supported by The Massie Chair of Excellence Program and DoE

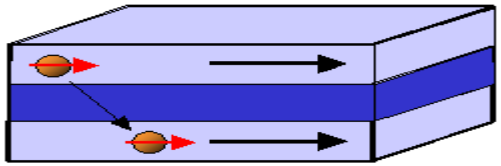
Outline

- Magnetic Multilayer Fundamentals
- A new paradigm → Spintronics
- Why my Hard Disk crashes?
- Magnetic multilayer research at UT

Fundamentals

A magnetic multilayer is any structure that includes two or more thin-films in which at least one is magnetic.





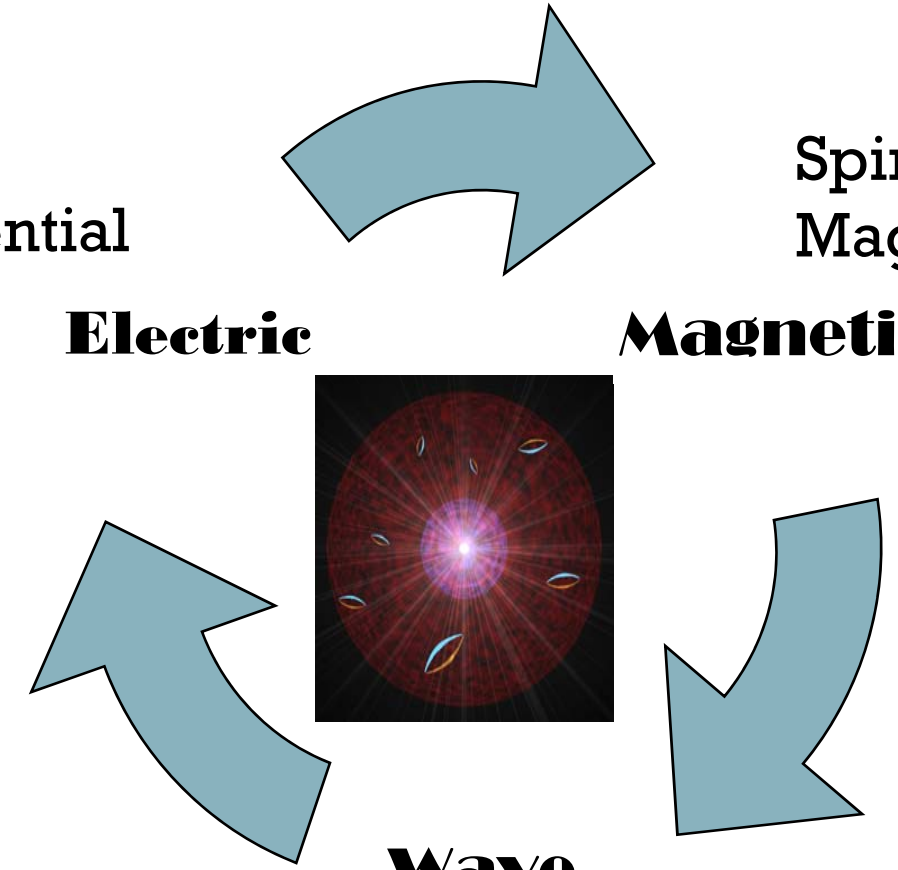
Magnetic multilayers exhibit **interesting electrical and magnetic properties**; these properties can be controlled giving rise to novel and useful devices.

Main controllable parameters:

i. Direction of magnetization
ii. Type of interacting materials
iii. Thickness of interacting material

The Magical Electron

Combines all these properties



Applications

- Giant Magneto-resistance (GMR)
- Tunnel Magneto-resistance (TMR)
- Spin-valve Transistor
- MRAM

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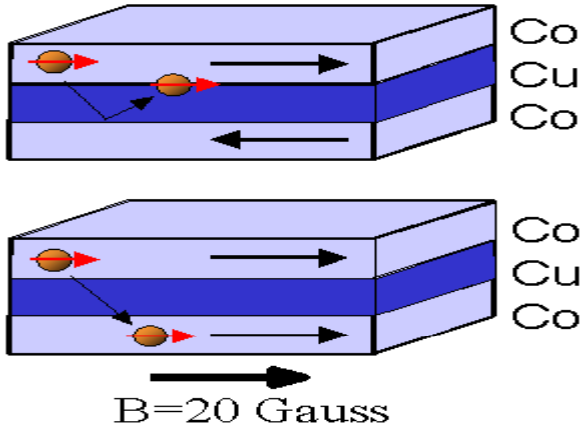
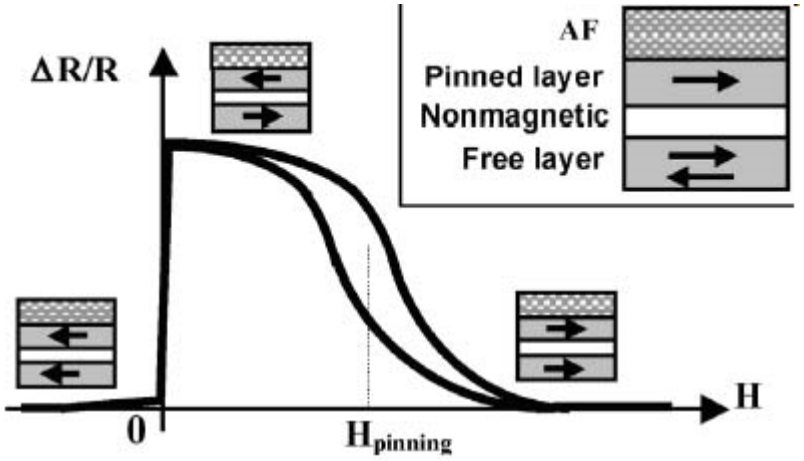
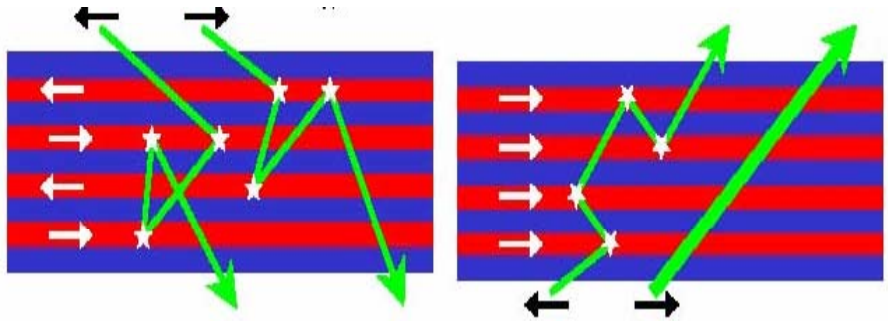




Two current model



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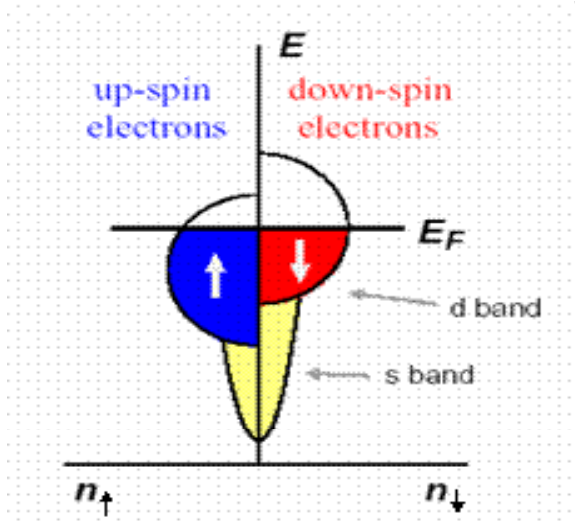
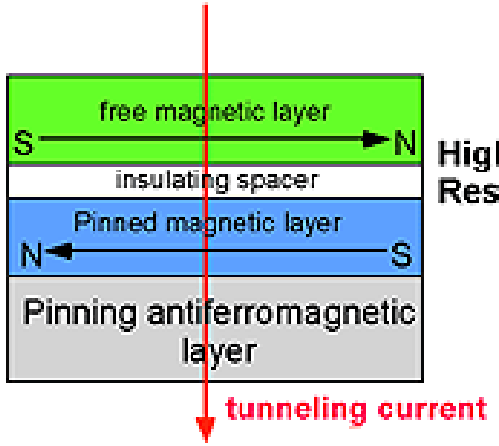
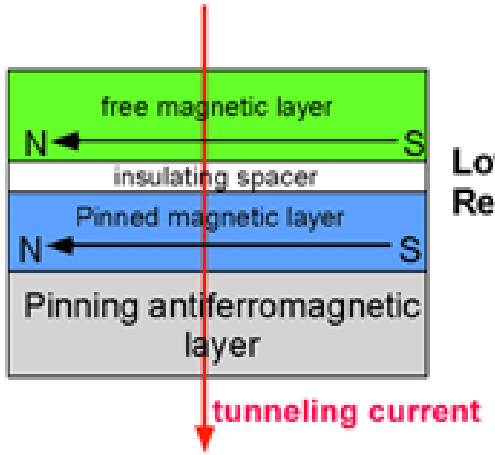


Tunneling is spin dependent!





aka Magnetic Tunnel Junction (MTJ)

Applications

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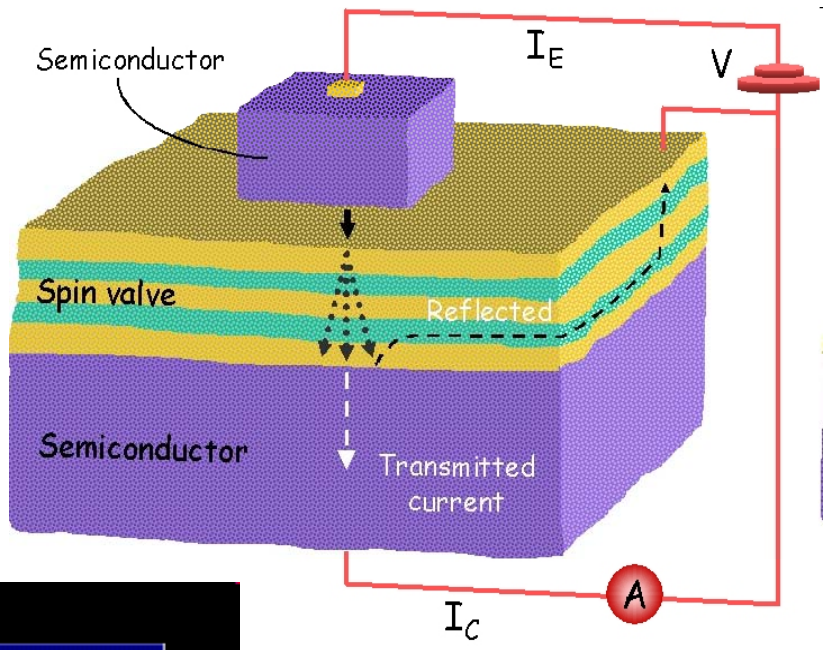
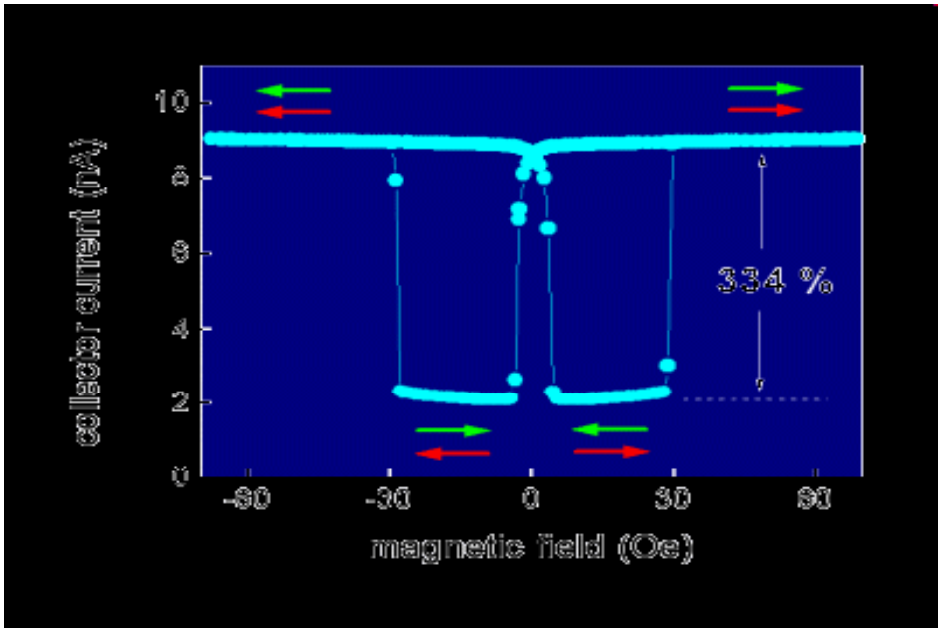
- **Spin-valve Transistor**
- MRAM





ΔI ~ %300!

Applications

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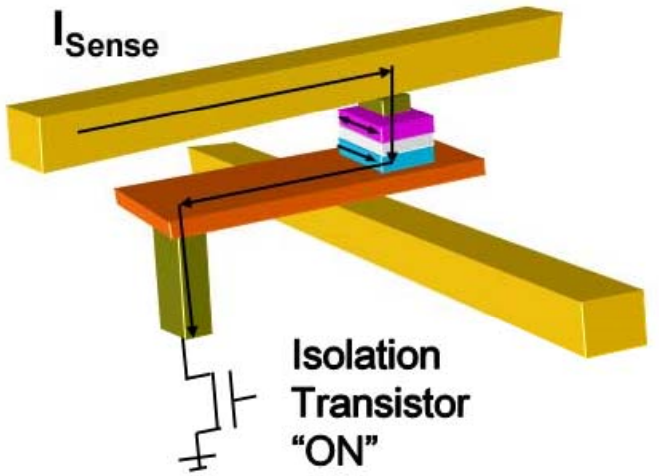
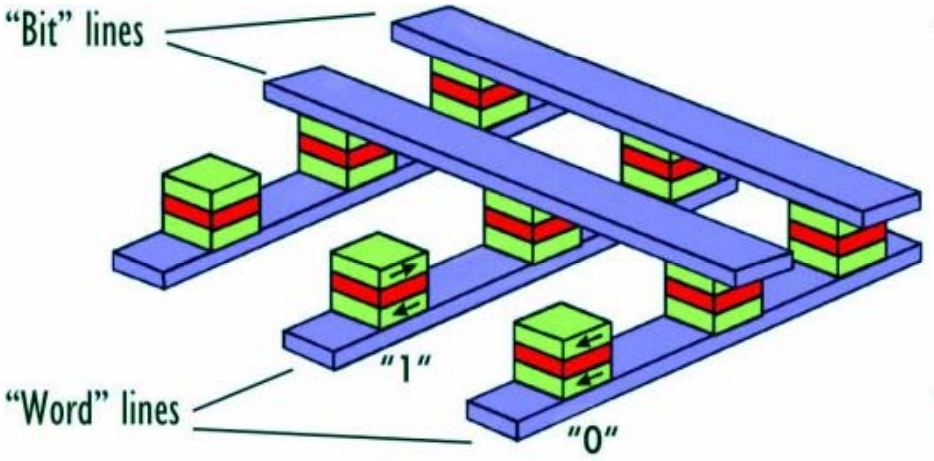
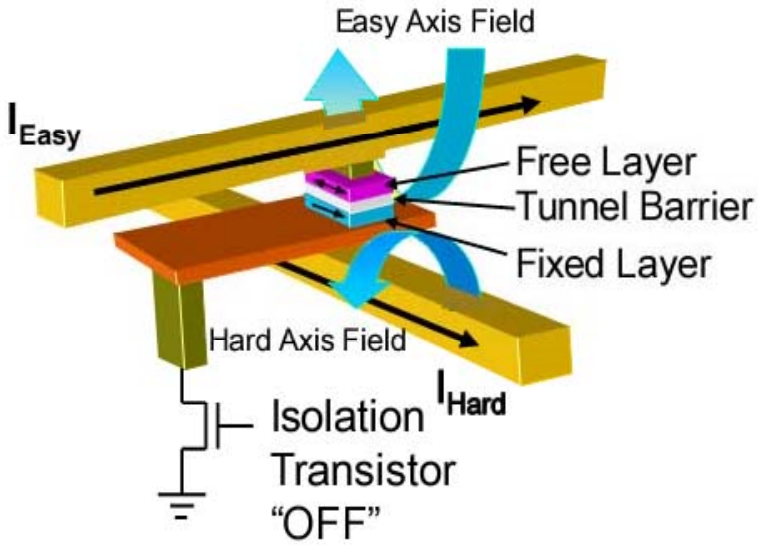


- **MRAM**





Applications

- Giant Magneto-resistance (GMR)
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- MRAM
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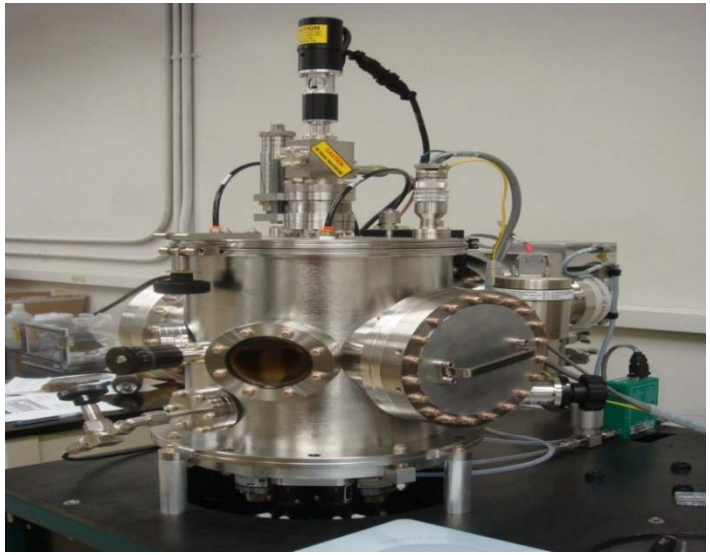
SPINTRONICS

Main challenge is maintaining polarized spin current!

Magnetic Multilayers @ Turabo

Students:

- Raymond Borges
- Kevin Colon (Graduated and working)
- Armando Velazquez



Collaborators:

- UPR
- FIU
- University of California, Riverside

Capability:

- Four target DC/RF magnetron sputtering system
- Lakeshore Guassmeter
- Two Tesla electromagnet with bipolar power supply
- Lock-in amplifier

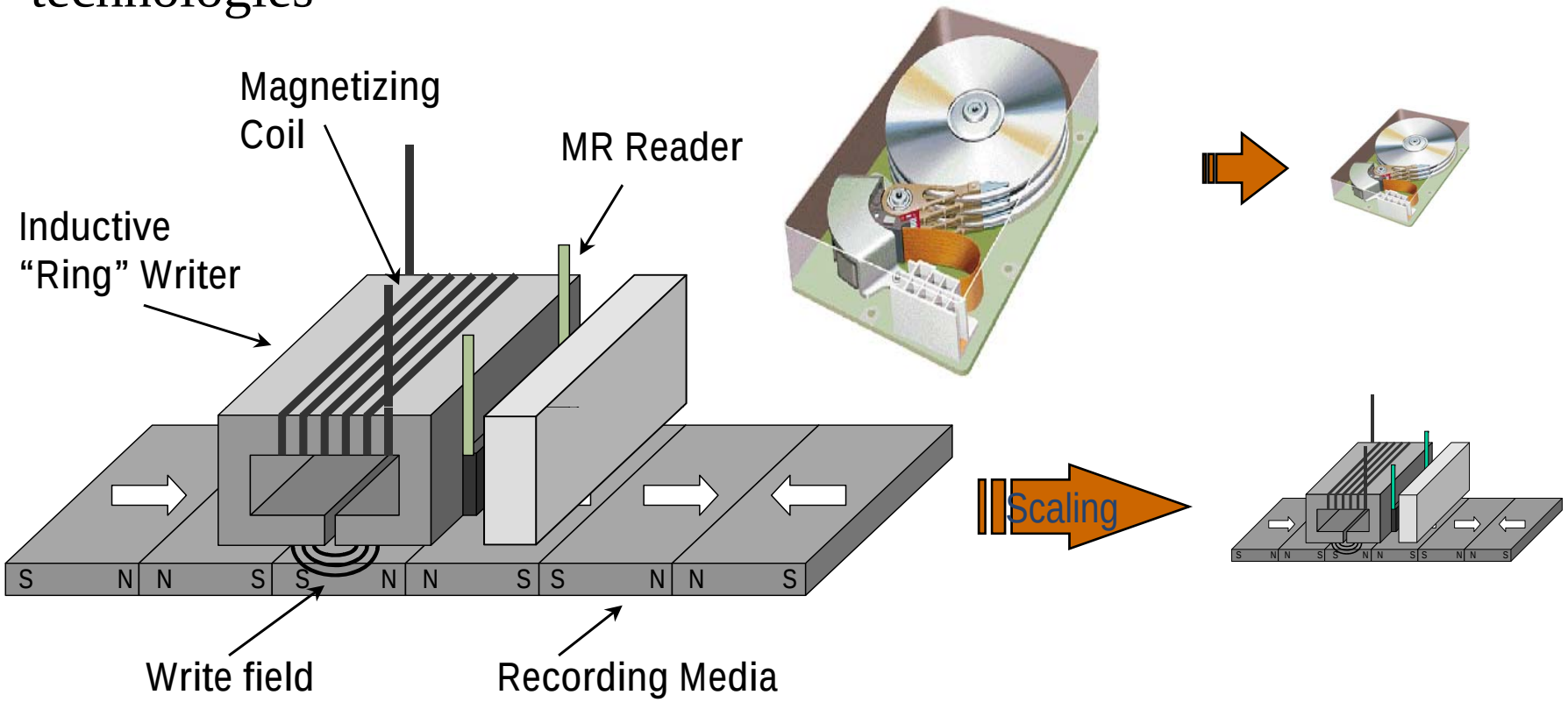
Magnetic Multilayers @ Turabo

Focus:

- Develop 3D magnetic media for
  - Magnetic Storage
  - Vertically integrated devices
- Use Gd within magnetic multilayers
  - Radiation detection

So why does my hard disk crash?

Traditionally, **Scaling Laws** were followed to advance data storage technologies



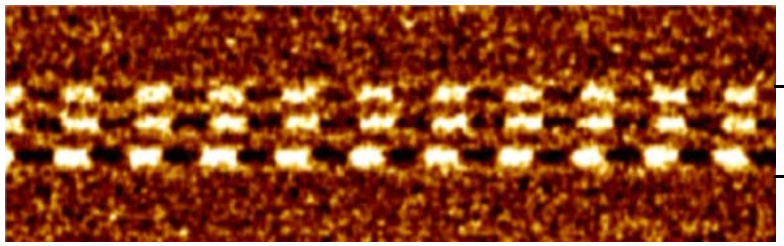
1 Gbit/in^2 → bit size: 400 x 1600 nm^2

100 Gbit/in^2 → 40 x 160 nm^2

1 Tbit/in^2 → 13 x 52 nm^2

Scaling → Smaller Transducers and Media

1 Tbit/in^2 information density requires **13 x 52 nm^2** Bit Sizes



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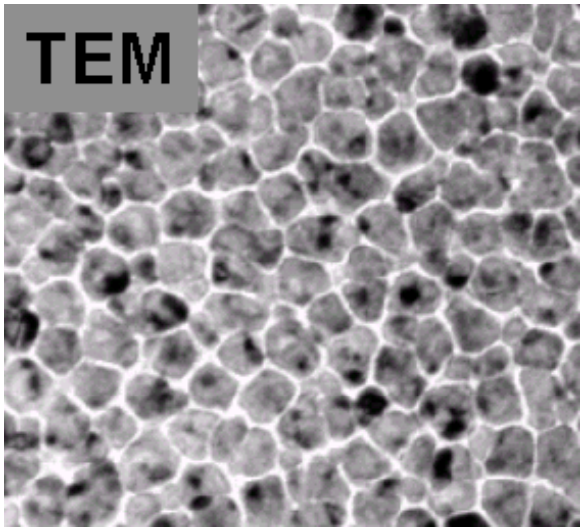
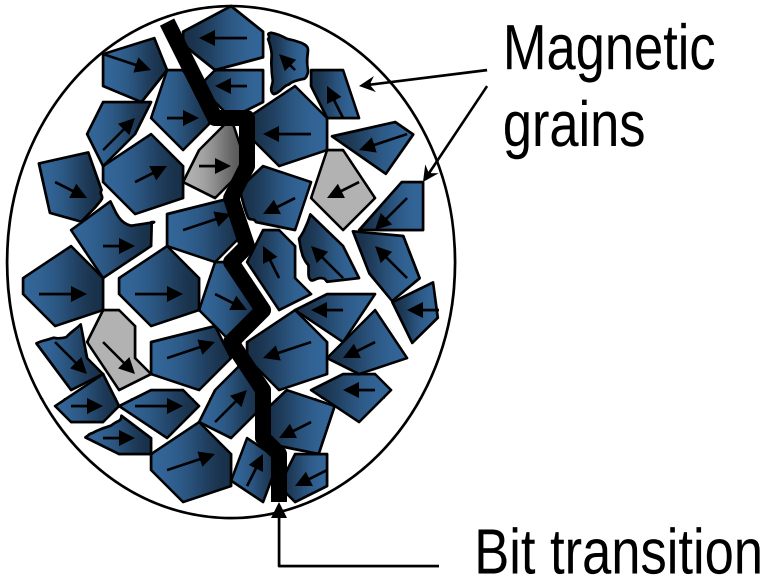
Superparamagnetic Limit





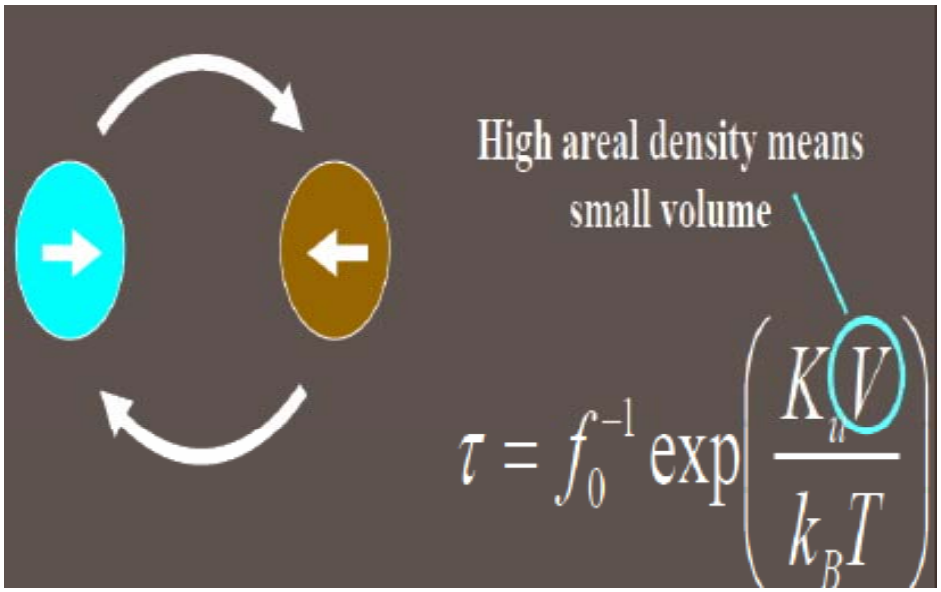
SNR ~ log(N), N - number of grains per bit

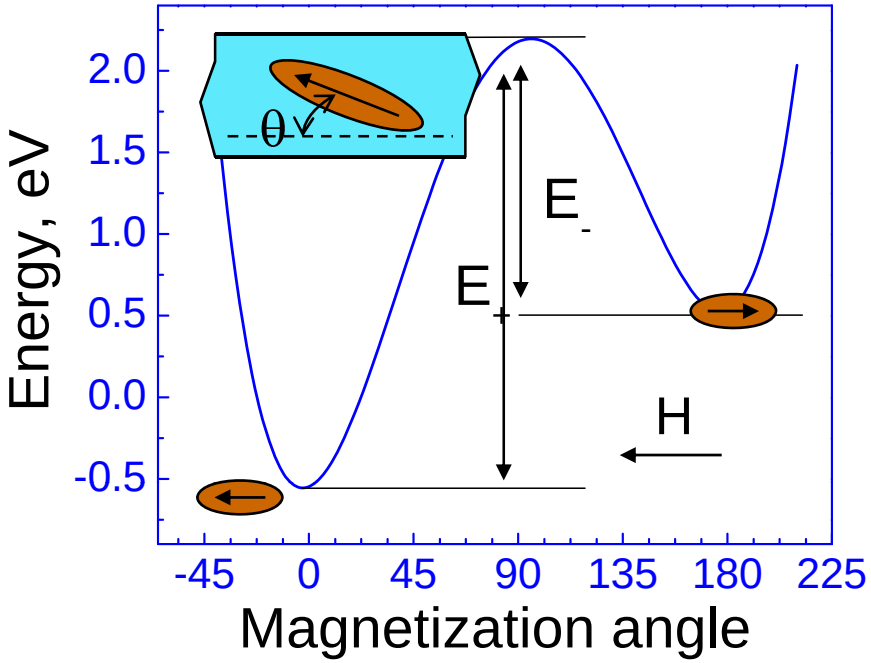
While scaling, need to preserve number of grains per bit to preserve SNR

Grain size is reduced for higher areal densities:

$$a \sim \frac{1}{\sqrt{Areal\ Density}}$$

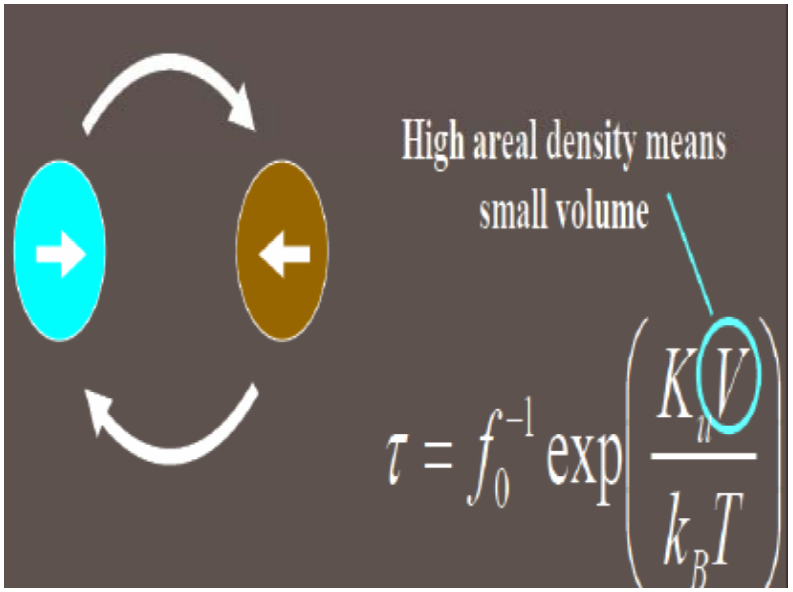
Media Stability

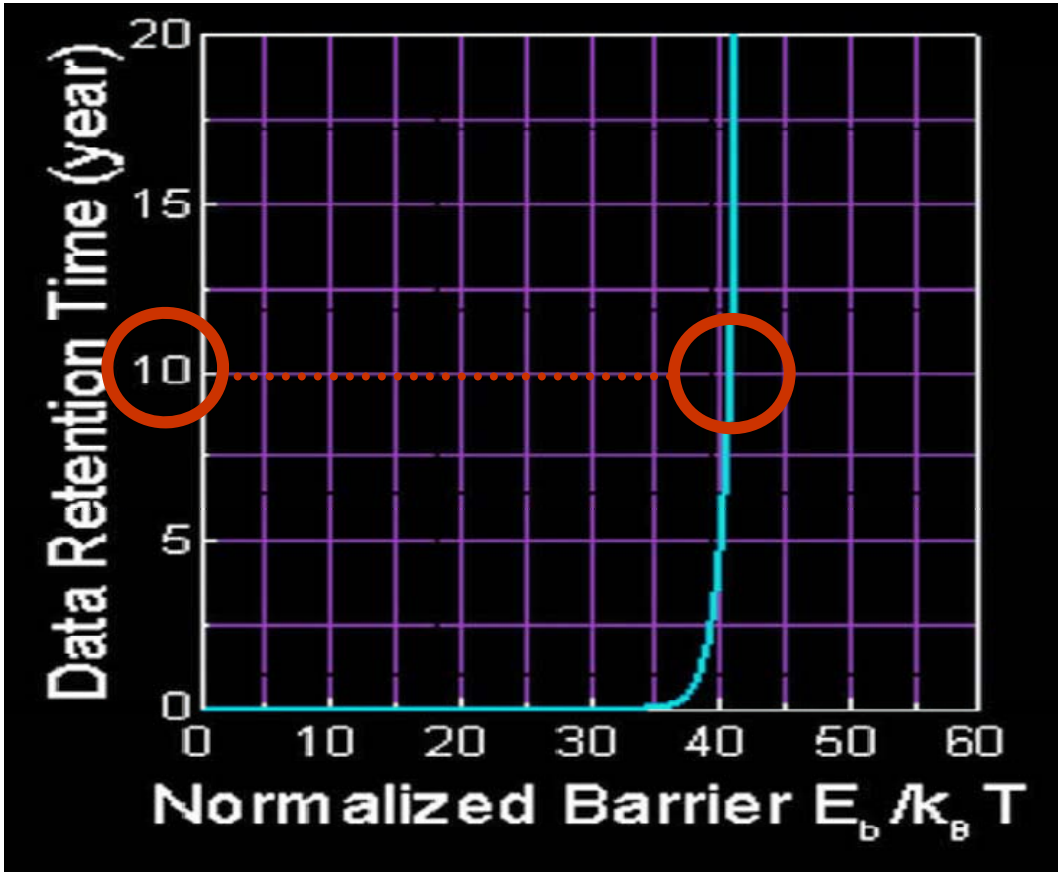




Thermally stable media: $\frac{K_U V}{k_B T} > 40 - 60$

Media Stability





Thermally stable media:

$$\frac{K_U V}{k_B T} > 40 - 60$$

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What can be done?

Higher anisotropy media

HAMR

Perpendicular Recording

Increase volume of grain

Patterned Media

$$\frac{K_U V}{k_B T} > 40 - 60$$

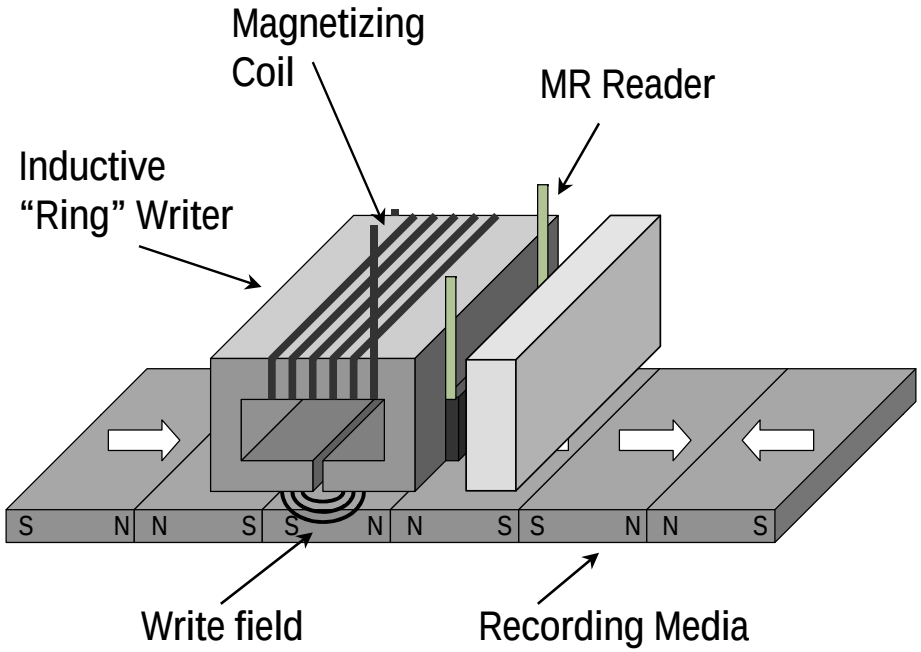
Change K_B

Good Luck!!

Cooling

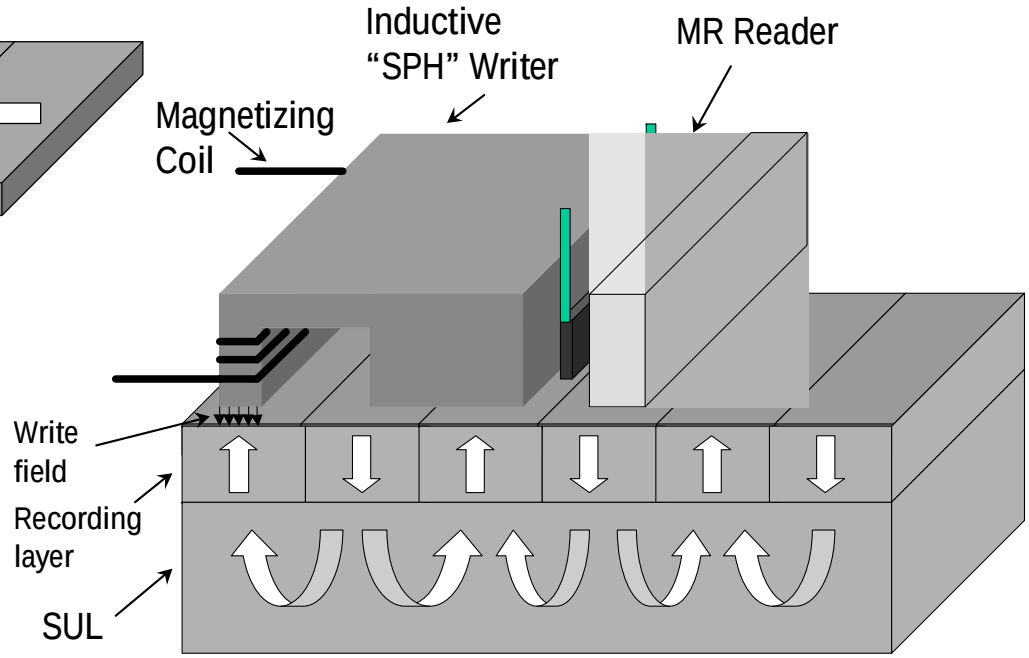
Impractical

Perpendicular Media → Narrow Transitions



Longitudinal

Perpendicular

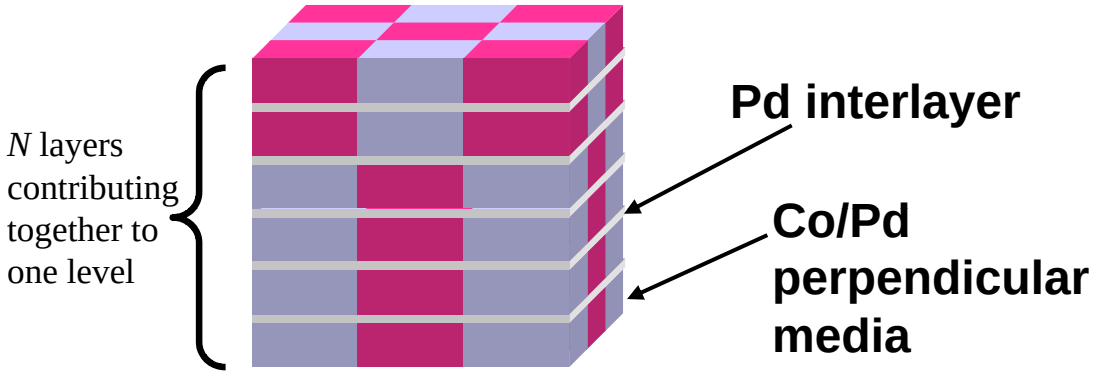


3-D vs. Multilevel Magnetic Recording

Two potential implementations:

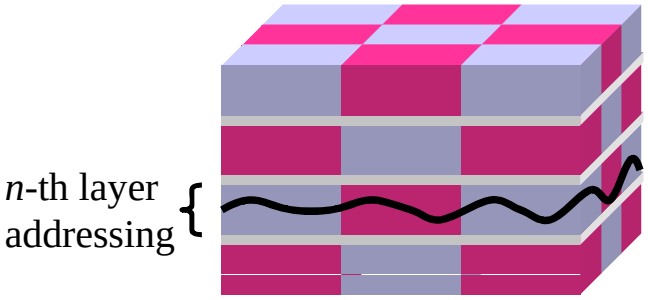
1. **Multi-level Recording**: not optimally utilized 3-D space

   Note: Effective areal density increase is $\mathbf{Log_2}\boldsymbol{L}$ (where $\boldsymbol{L}$ is the number of signal levels)



2. **3-D Recording**: each magnetic layer is separately addressed

   Note: Effective areal density increase is $\boldsymbol{N}$ (where $\boldsymbol{N}$ is the number of recording layers)



S. Khizroev, Y. Hijazi, N. Amos, R. Chomko, D. Litvinov, *Journal of Appied Physics*, 100, 63907 (2006).

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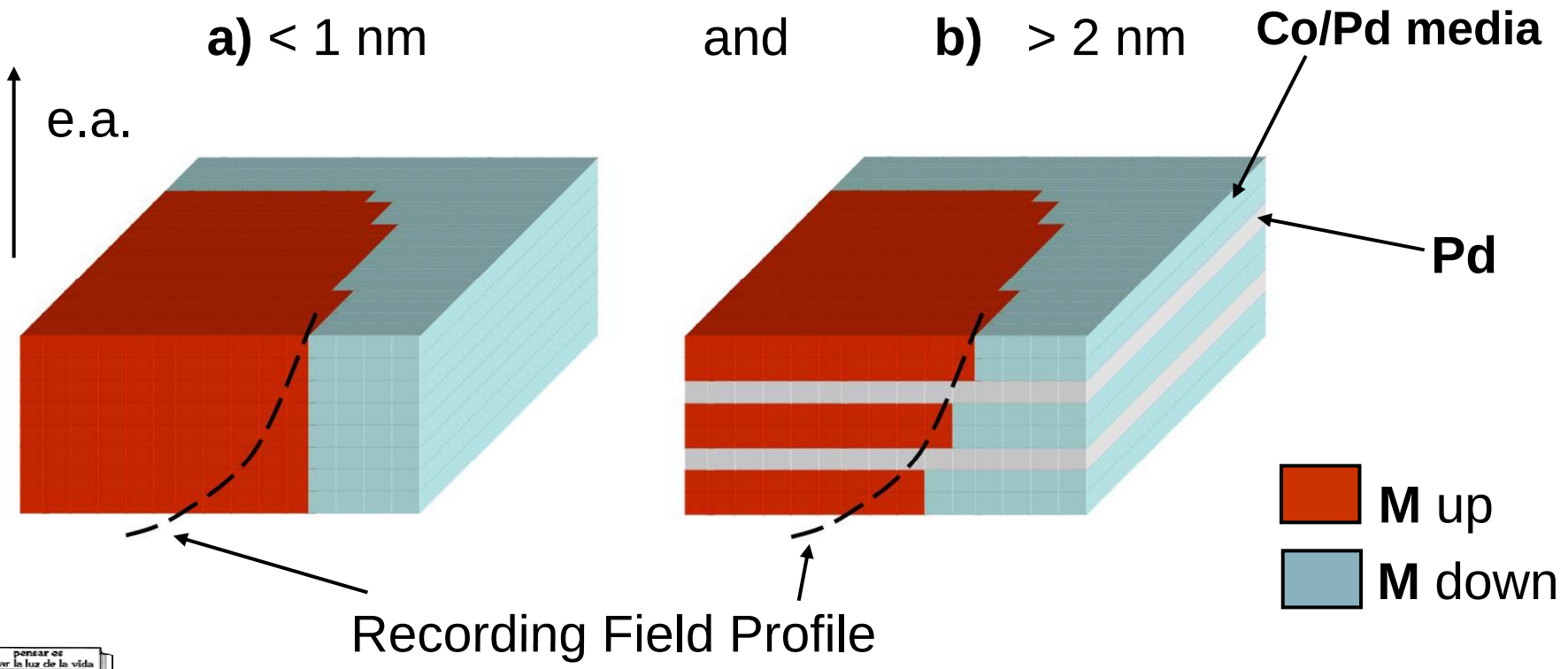
Multi-level/3D Magnetic Media

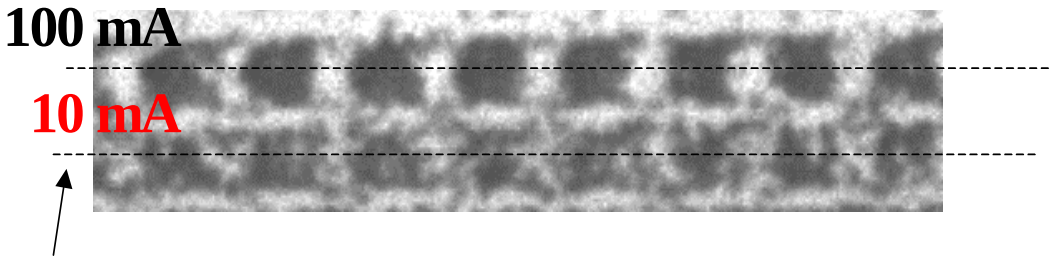
Note: The inter-layer separation should be sufficient to break the quantum-mechanical “exchange” coupling

Micromagnetic Simulation Illustrating Two Cases of Interlayer Separation:



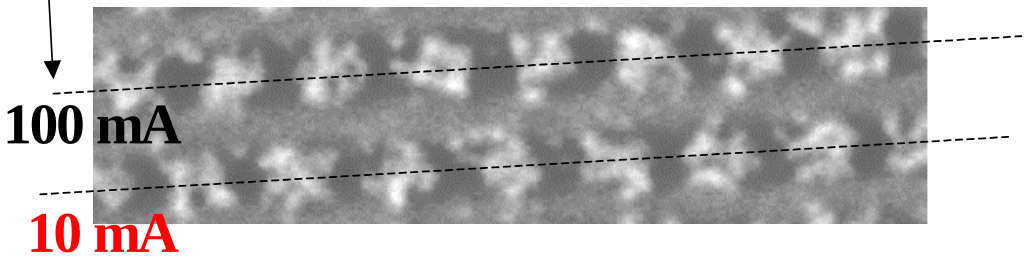
MFM Images of Two Types of Media

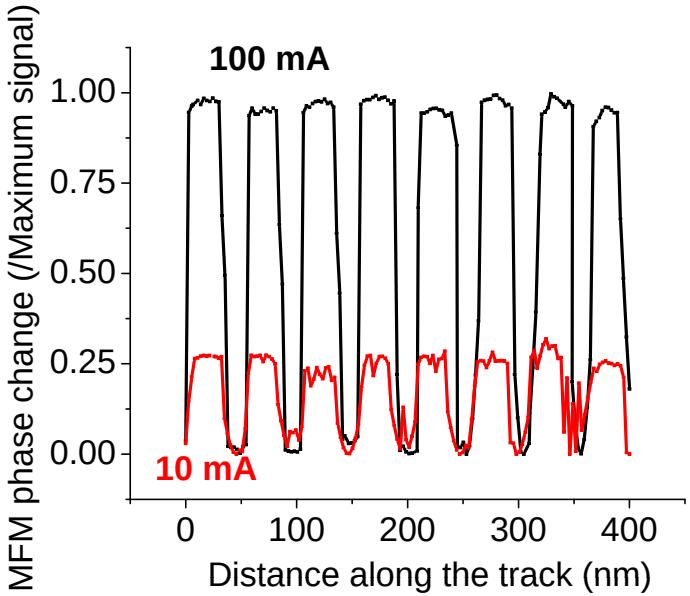
Three-layer Co/Pt multilayer with a net thickness of 30 nm

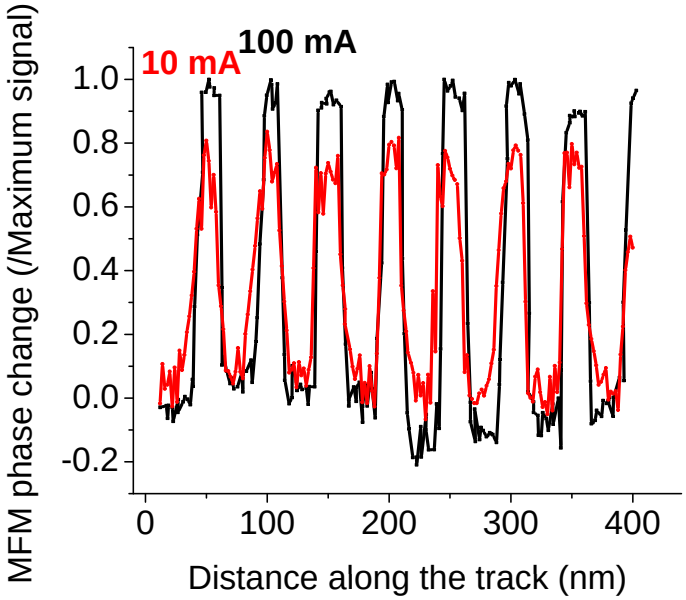


Section lines

One-layer Co/Pt multilayer with a thickness of 40 nm

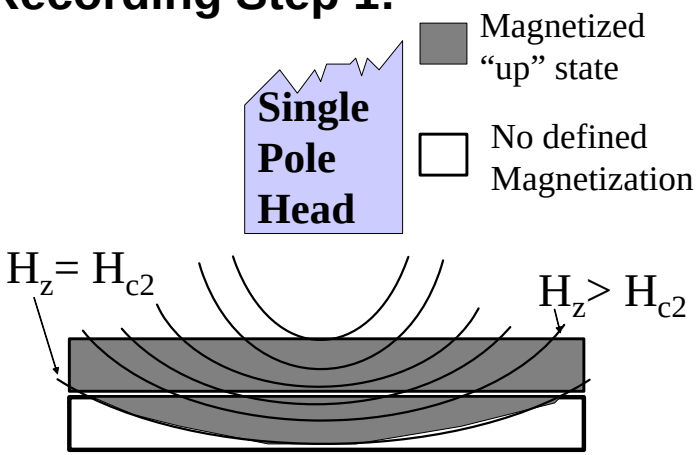




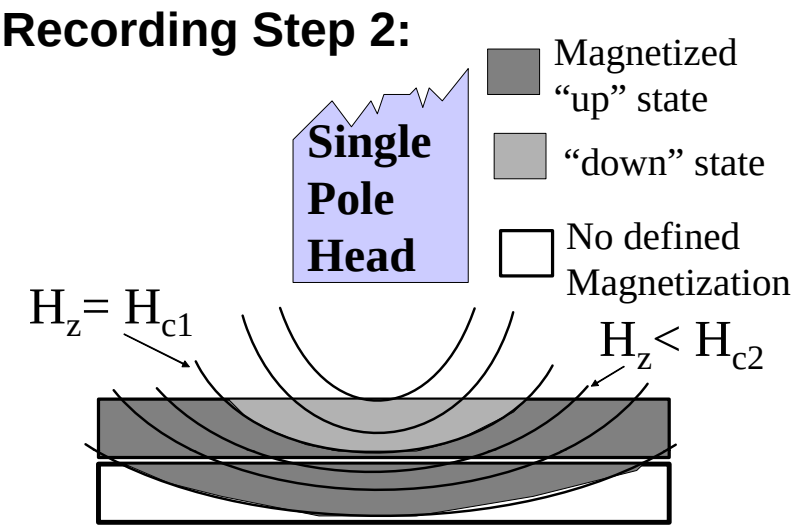


Multi-level Recording on a Continuous Medium

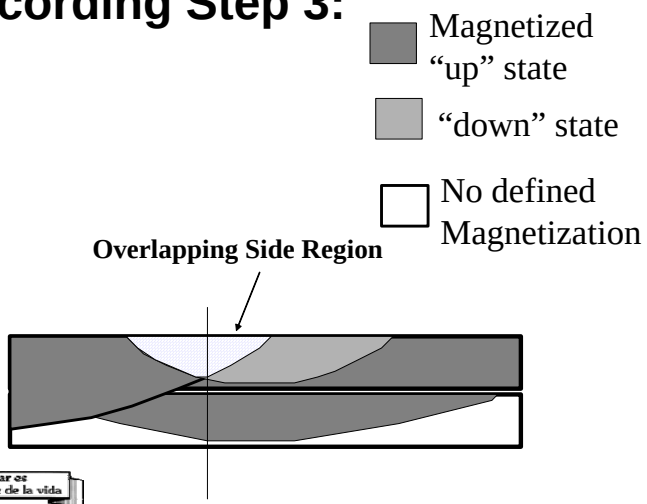
Recording Step 1:



Recording Step 2:



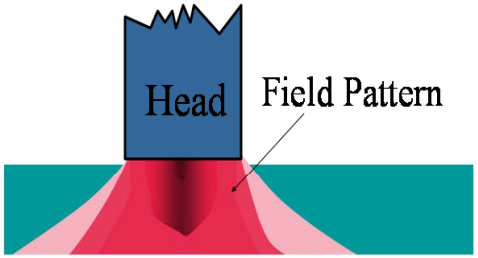
Recording Step 3:

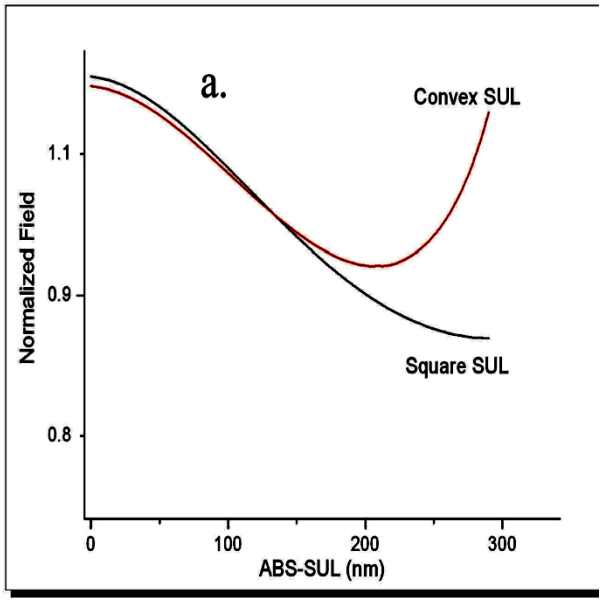


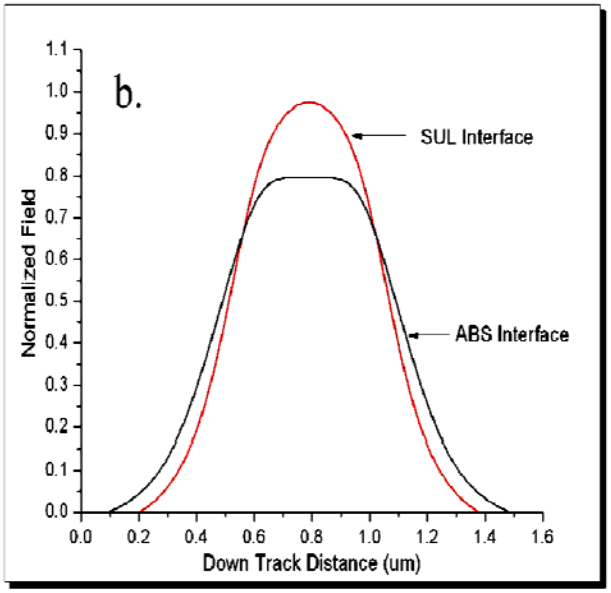
Major Disadvantages:

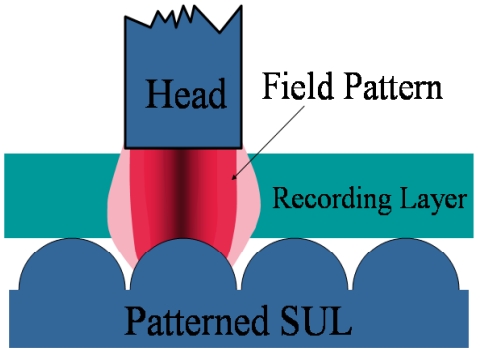
- Every time a track is recorded into the bottom layer, there are side regions in the top layer in which the earlier recorded information is lost because of the overlapping side region

Patterned Soft Underlayer SUL









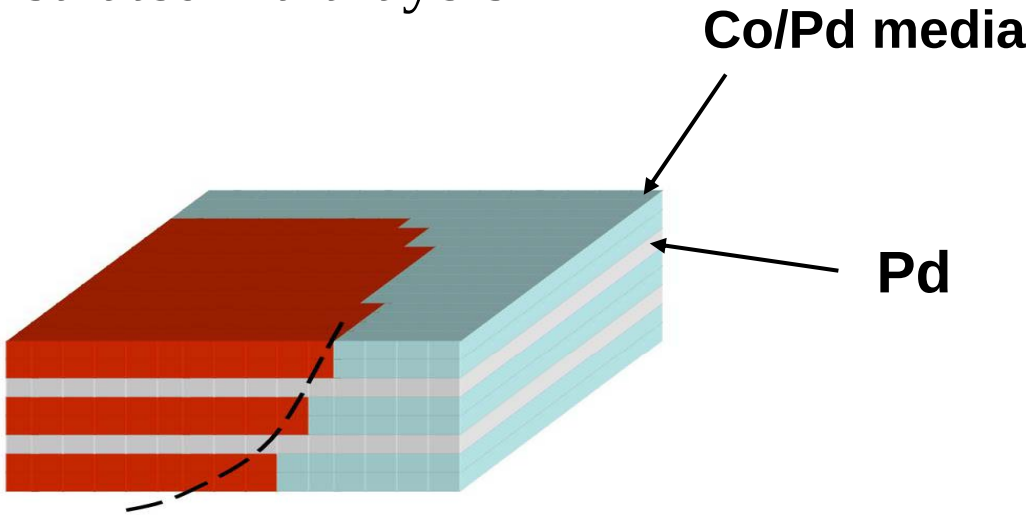
Y. Hijazi et. al. *IEEE Transactions on Magnetics*, vol. 42 (10), 2375-7, (2006).

Advantages:

1. Increases SNR
2. Localized field
3. Improved field gradient

3D Media Requirements

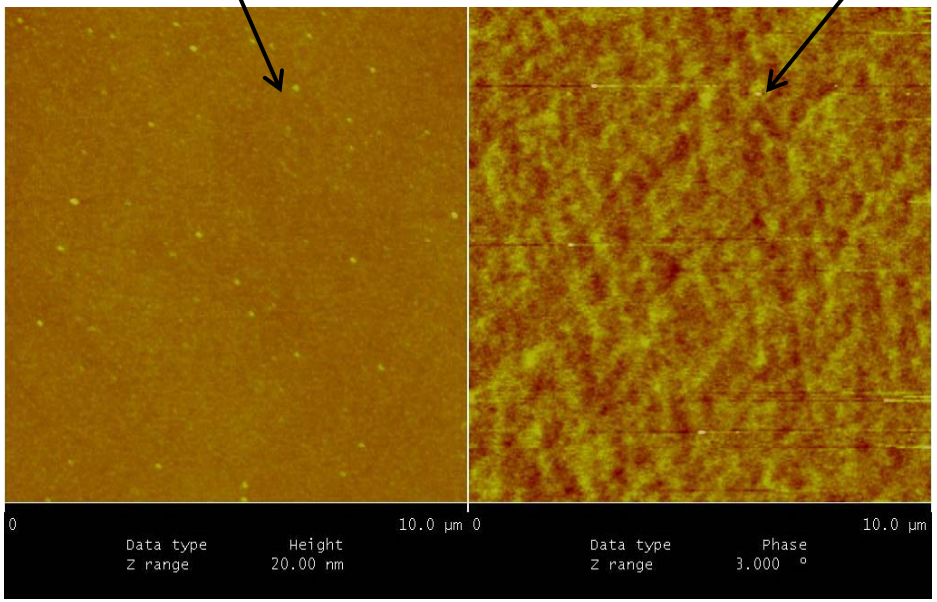
- Perpendicular magnetic anisotropy
- Patterned media → improved SNR & areal density
- Magnetically insulated multilayers



AFM/MFM data of Ta/(Co/Pd)$_{15}$

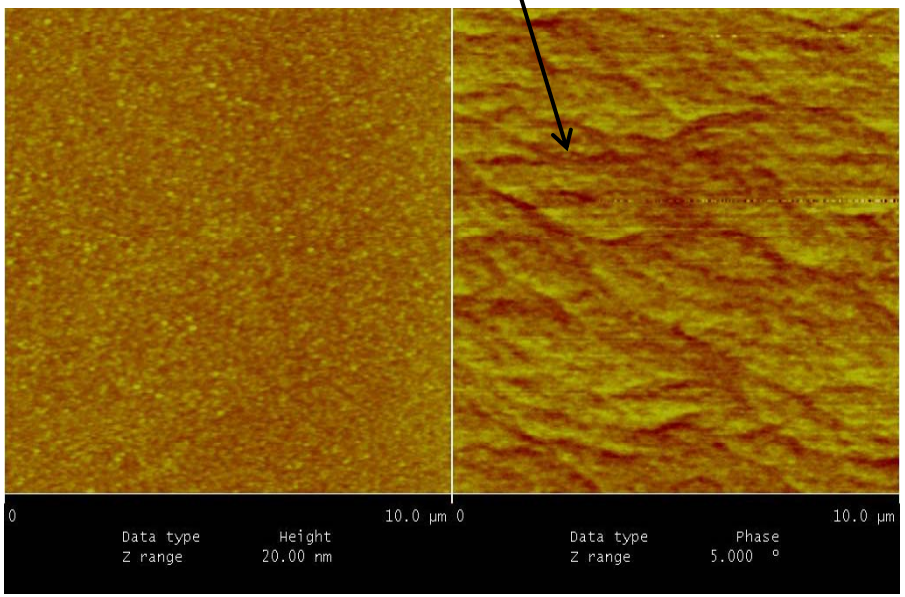
Topography

Magnetic image



Ta thickness10nm

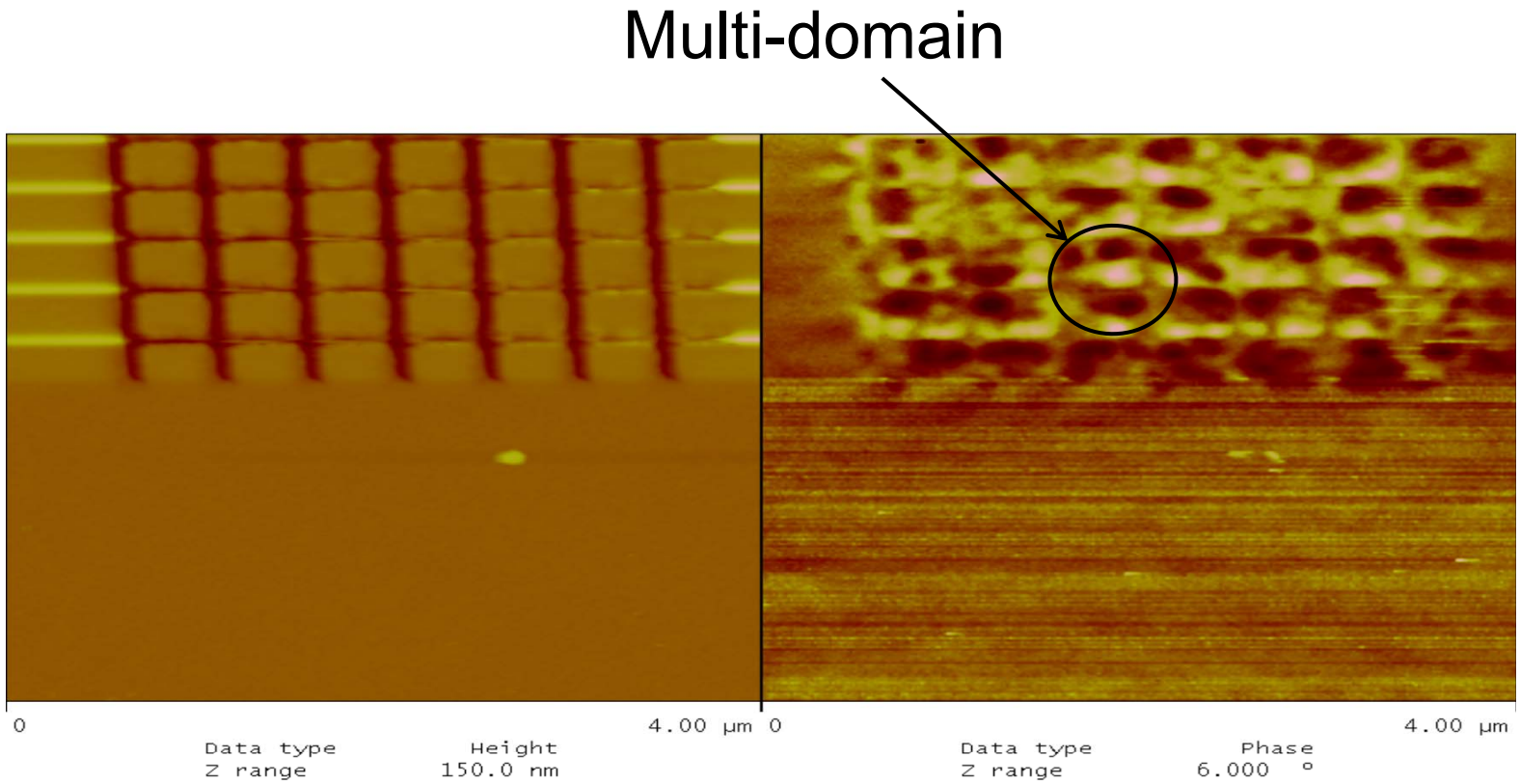
Improved magnetic structure



Ta thickness 40nm

Measurements done at Florida International University (FIU)

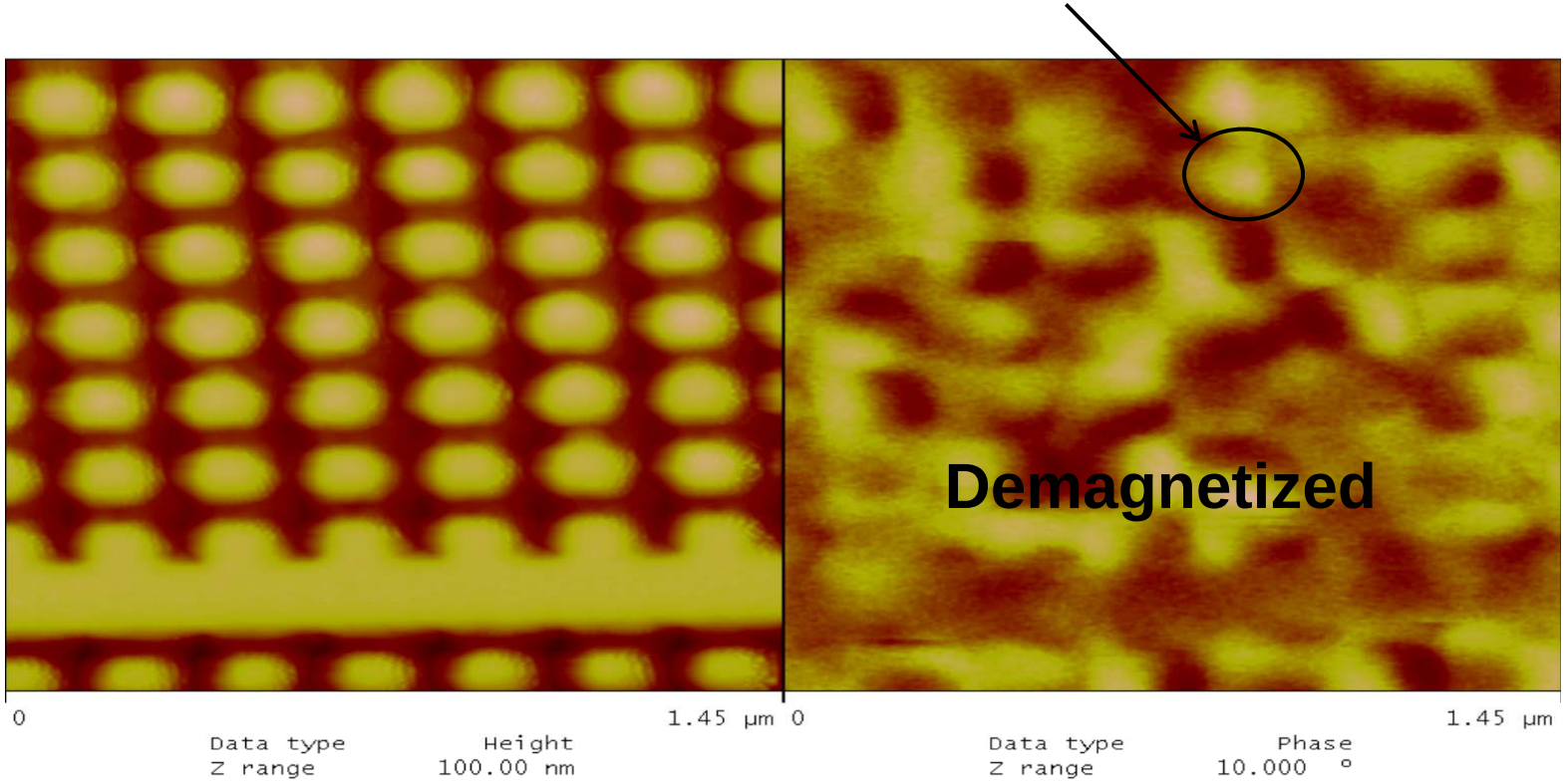
Single Layer $(Co/Pd)_{15}$ 400nm Island Size



Measurements done at Florida International University (FIU) by Nissim Amos

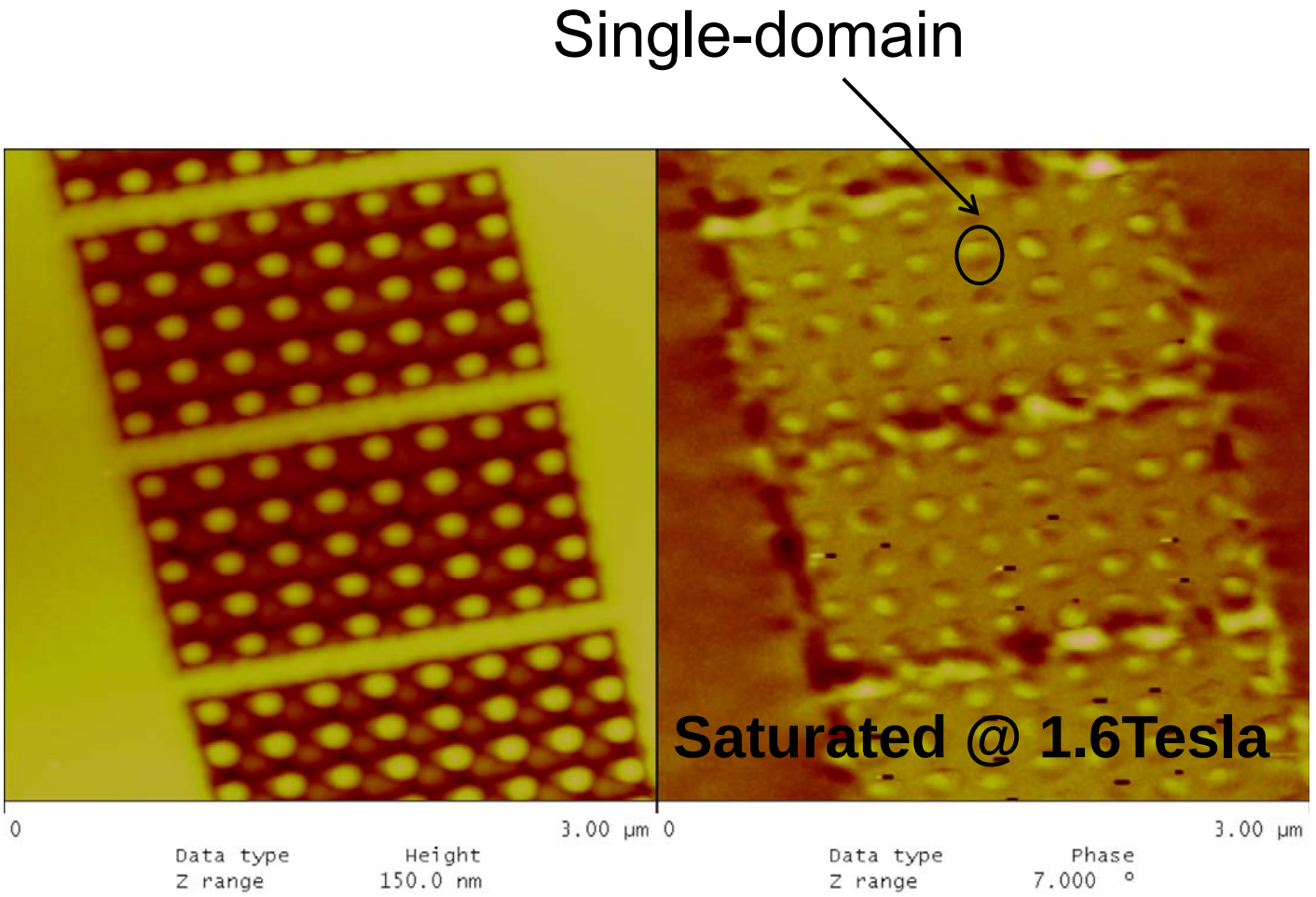
Single Layer $(Co/Pd)_{15}$ 110nm Island Size

Single-domain



Measurements done at Florida International University (FIU) by Nissim Amos

Single Layer $(Co/Pd)_{15}$ 110nm Island Size



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Summary

- Magnetic multilayers are fundamental in novel applications utilizing the spin degree of freedom of the electron i.e. Spintronics.

- Patterned magnetic multilayers offer unique advantages and will play a key role in future magnetic data storage systems.

- As Moore's law is exhausted it is time to stack things vertically to increase density and functionality → 3D magnetic media.

- Universidad del Turabo has established in-house capability of producing structured magnetic multilayers for a wide variety of applications.

Thanks!