Technology of Hard Disk Drives

- Fundamentals of Magnetic Recording Technology
- Longitudinal vs. Perpendicular Recording
- Key Technology Components:
  - Magnetic Recording Media
  - Magnetic Write Heads
  - Magnetic Read Heads
- Future Technology Options

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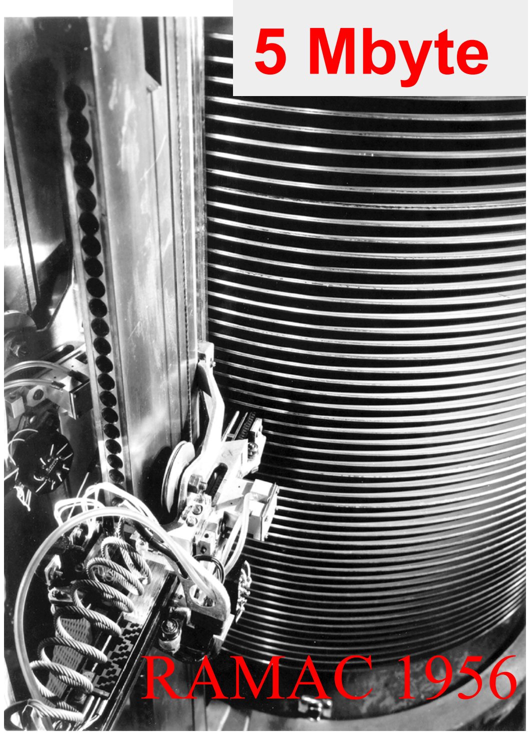
Magnetic storage: size, speed, and money



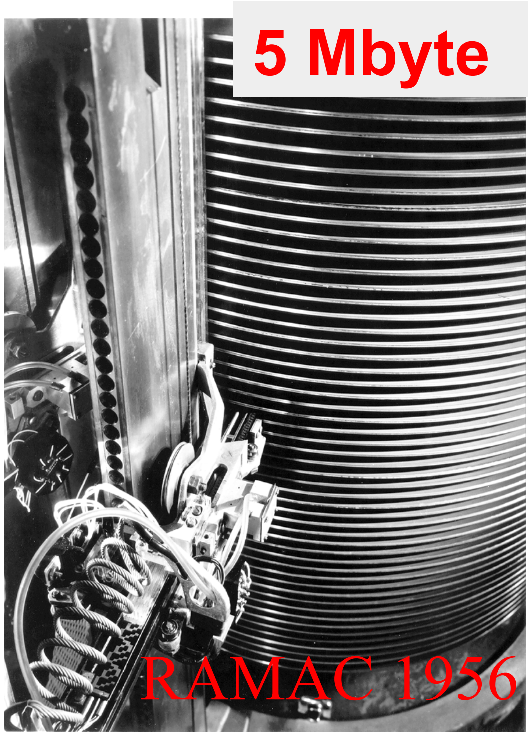
70 kbits/s
2 kbits/in^2
50 x 24" disks
$10,000/Mbyte

4 Tbyte

Samsung F4EG

1.870 Gbits/s
560 Gbits/in^2
4 x 3.5" disks
< $0.0001/Mbyte

Magnetic storage: size, speed, and money



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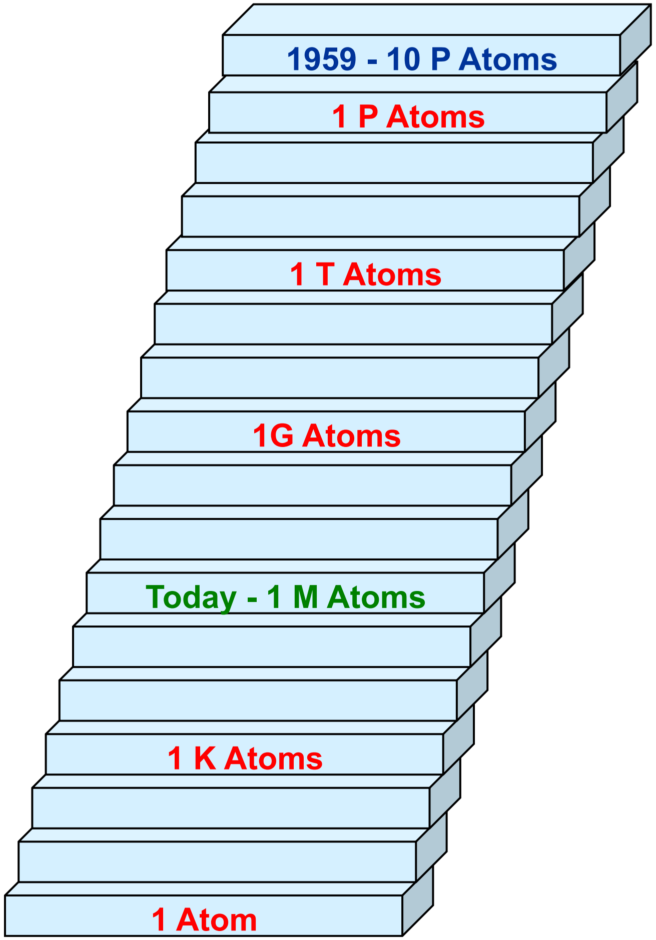


Richard Feynman (1959)

"There is plenty of room at the bottom"

Disk drive basics

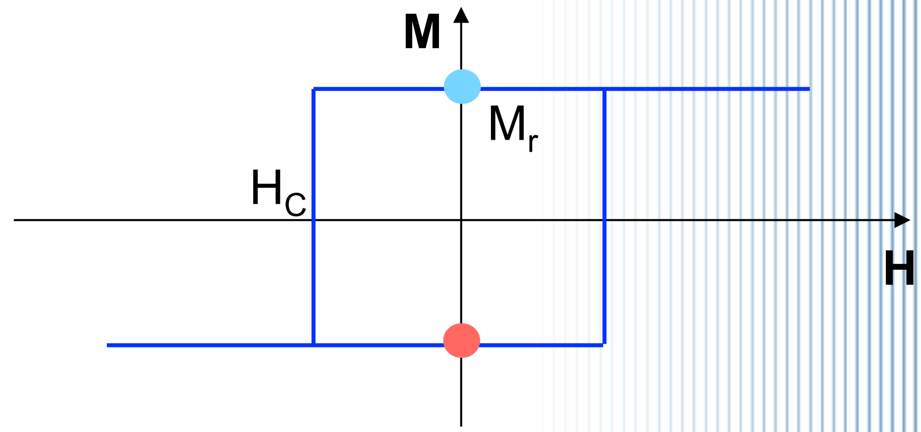
Rotating Disk(s):

Read-Write Head:

Disk drive basics

Rotating Disk(s):

Ferromagnetic layer (uniaxial)



Read-Write Head:

Disk drive basics

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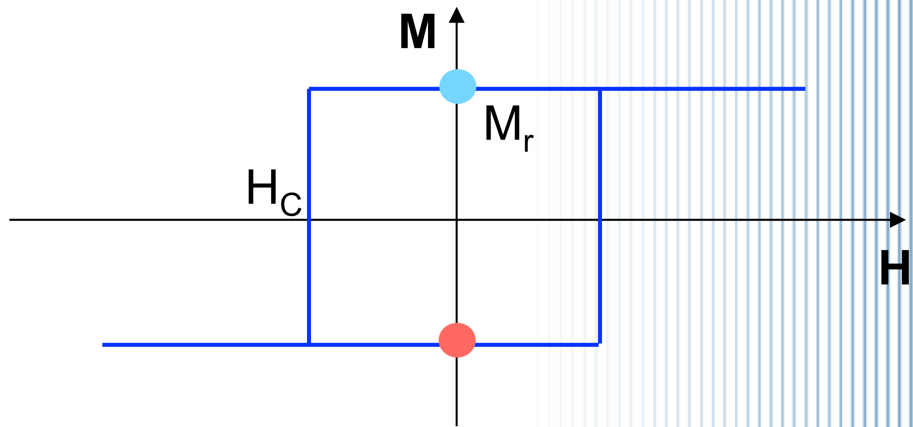

Read-Write Head:

Writer: **electromagnet**

tiny, fast, and high field

Reader: **field sensor**

tiny, fast, and electric

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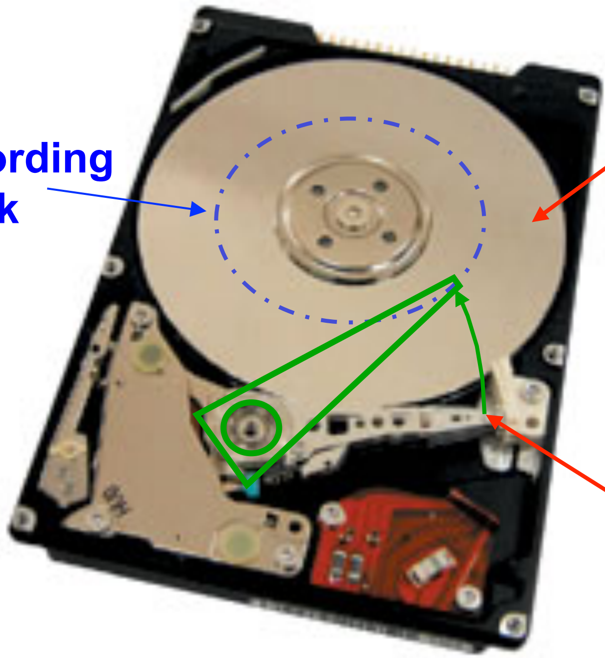
Disk drive basics

recording
track



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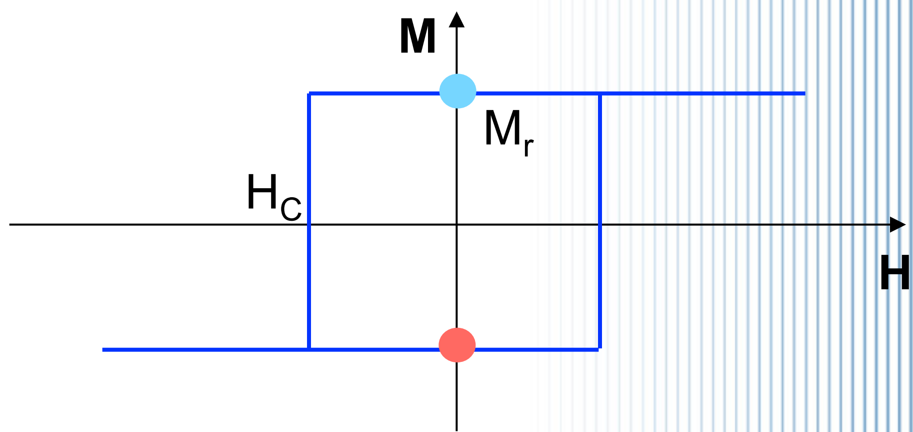

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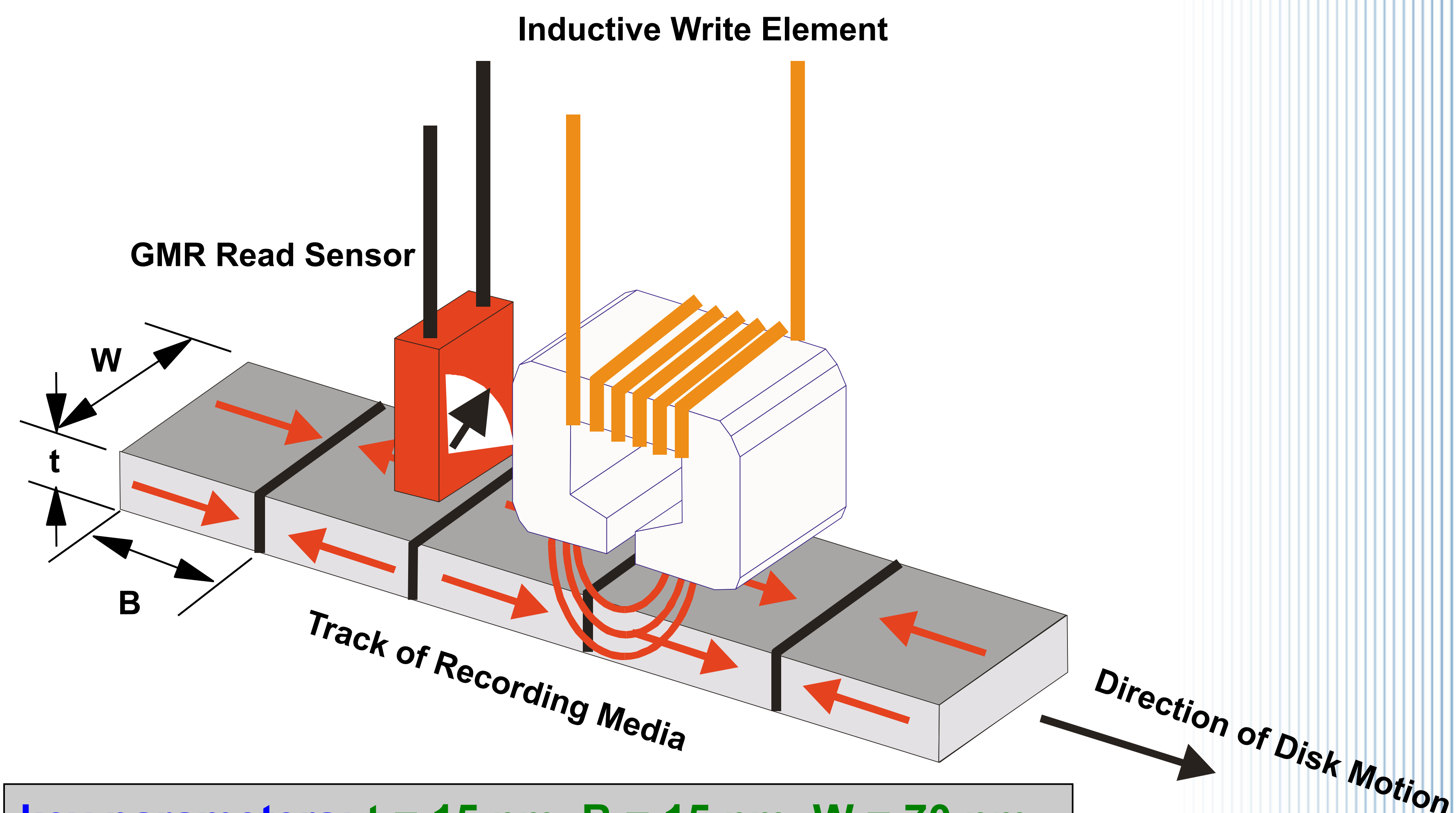
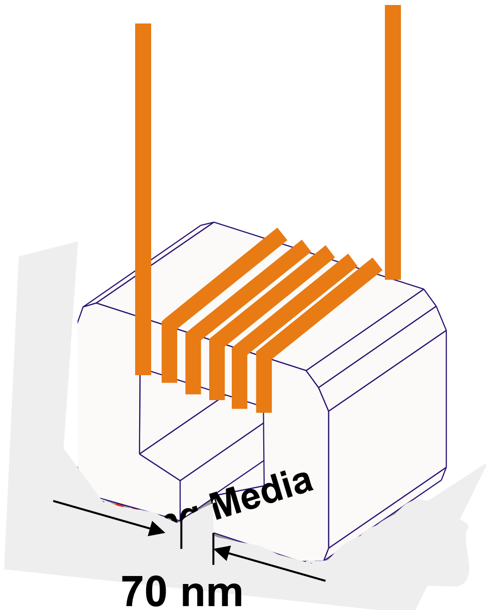
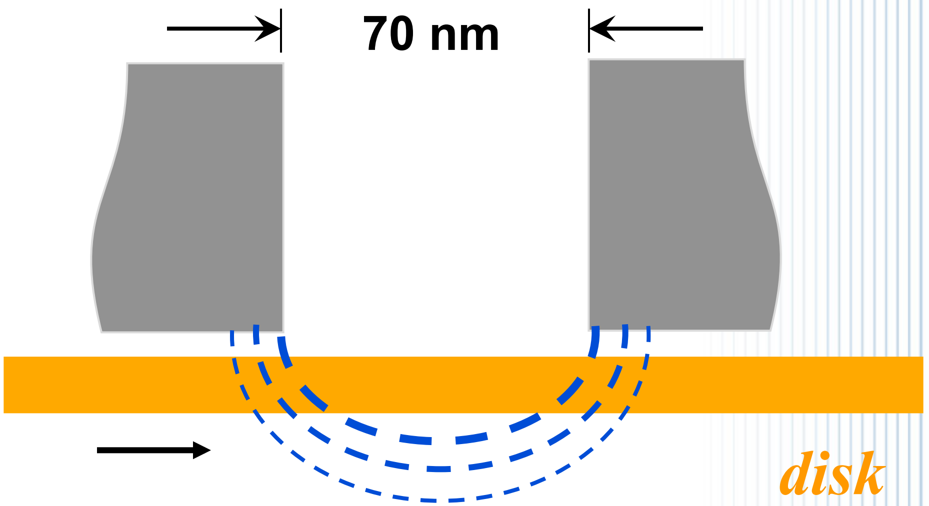
Disk drive basics: recording

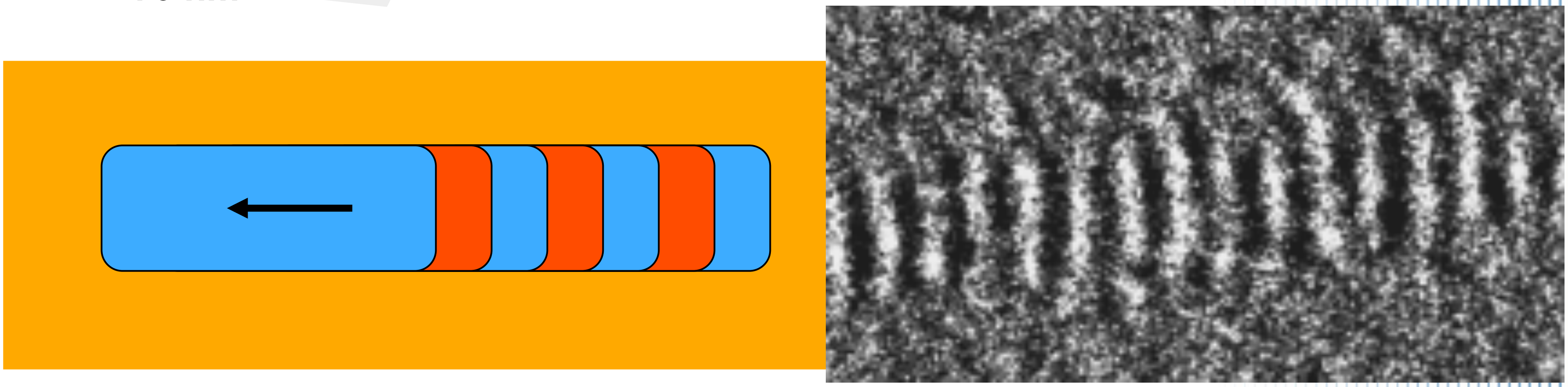


key parameters: t = 15 nm, B = 15 nm, W = 70 nm

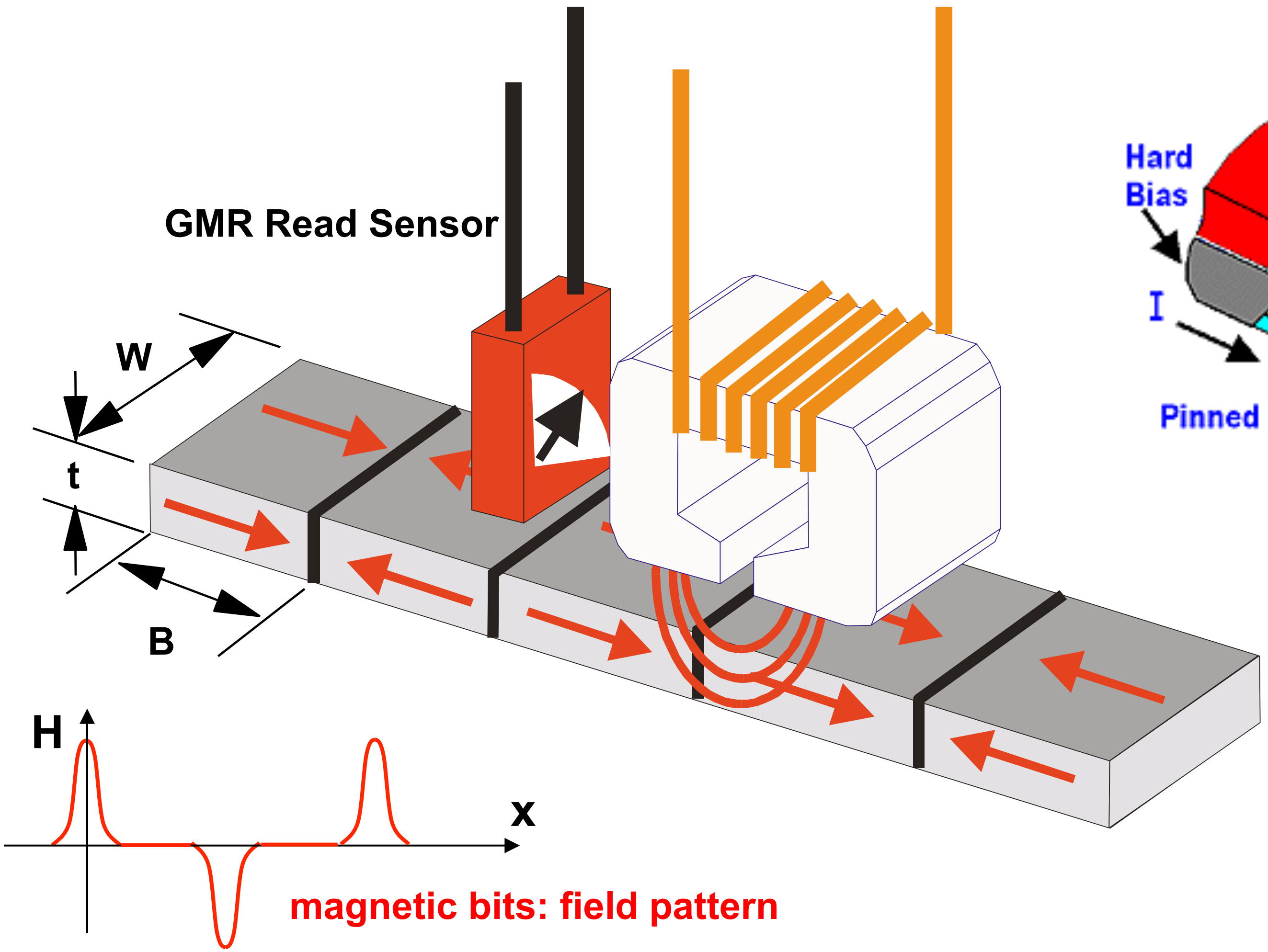
Disk drive basics: recording



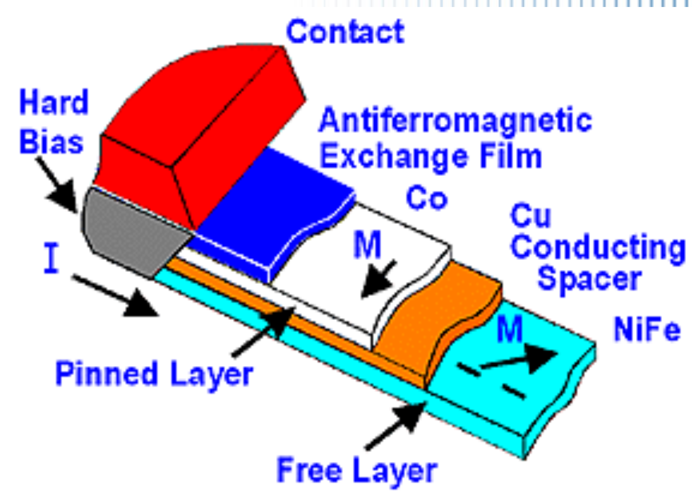




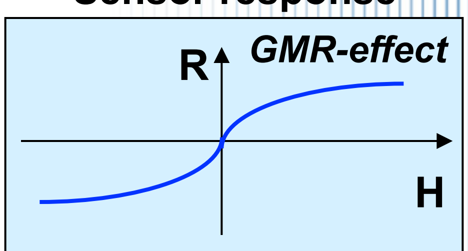
Disk drive basics: read-back



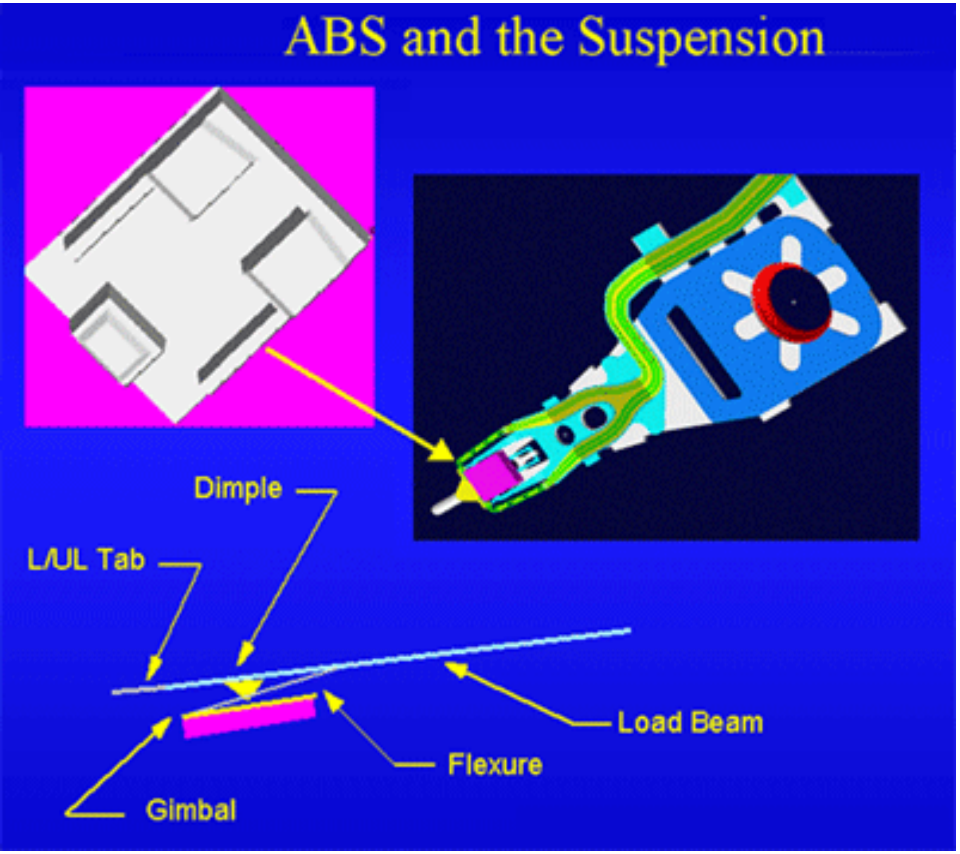
Sensor structure

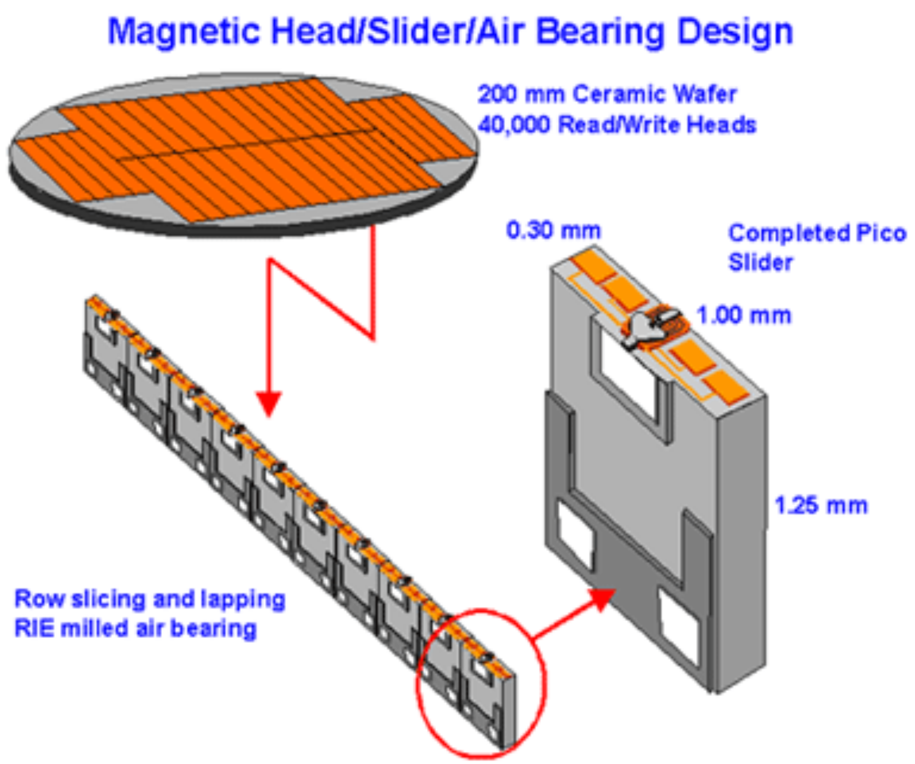


Sensor response

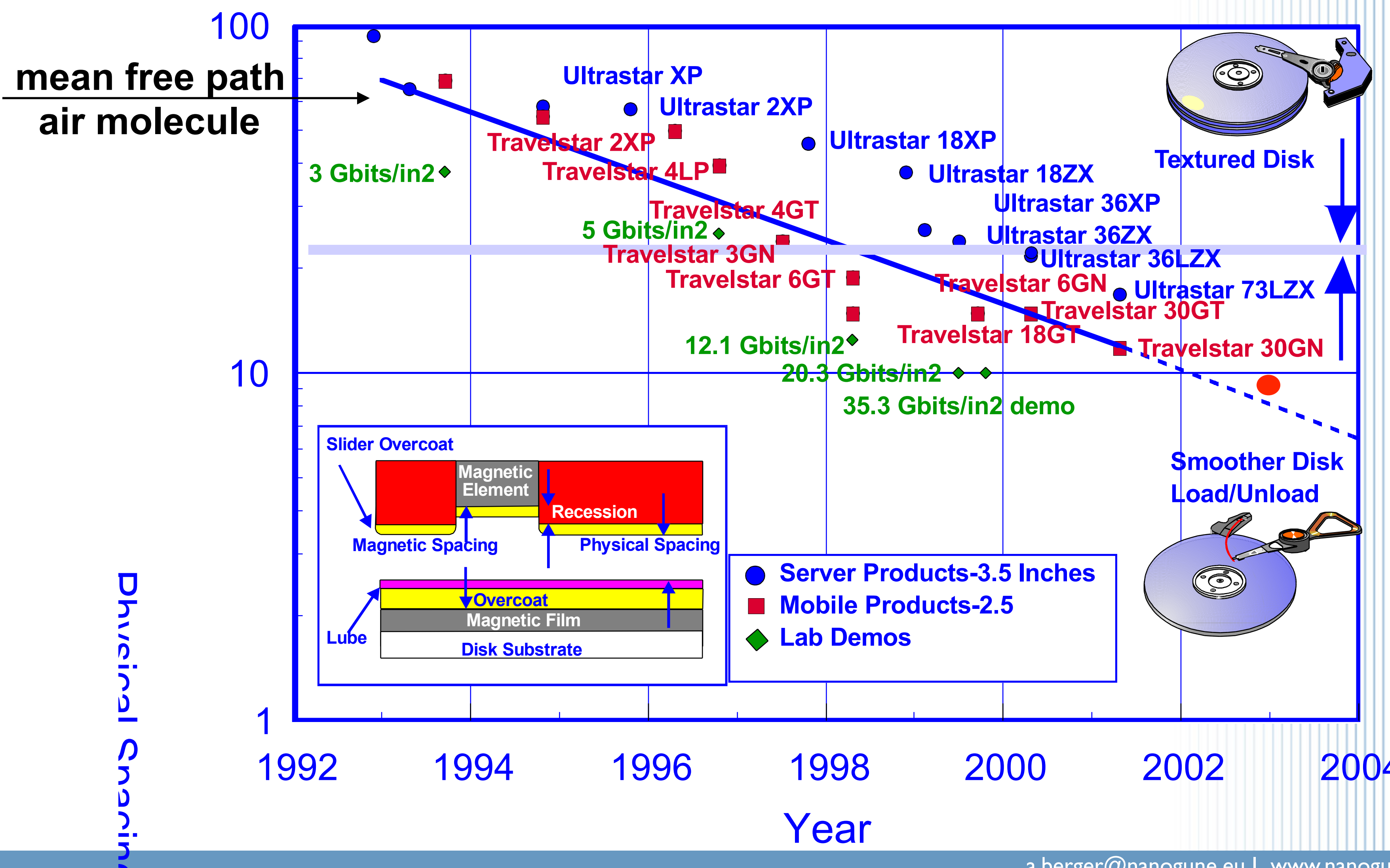


Disk drive basics: mechanics



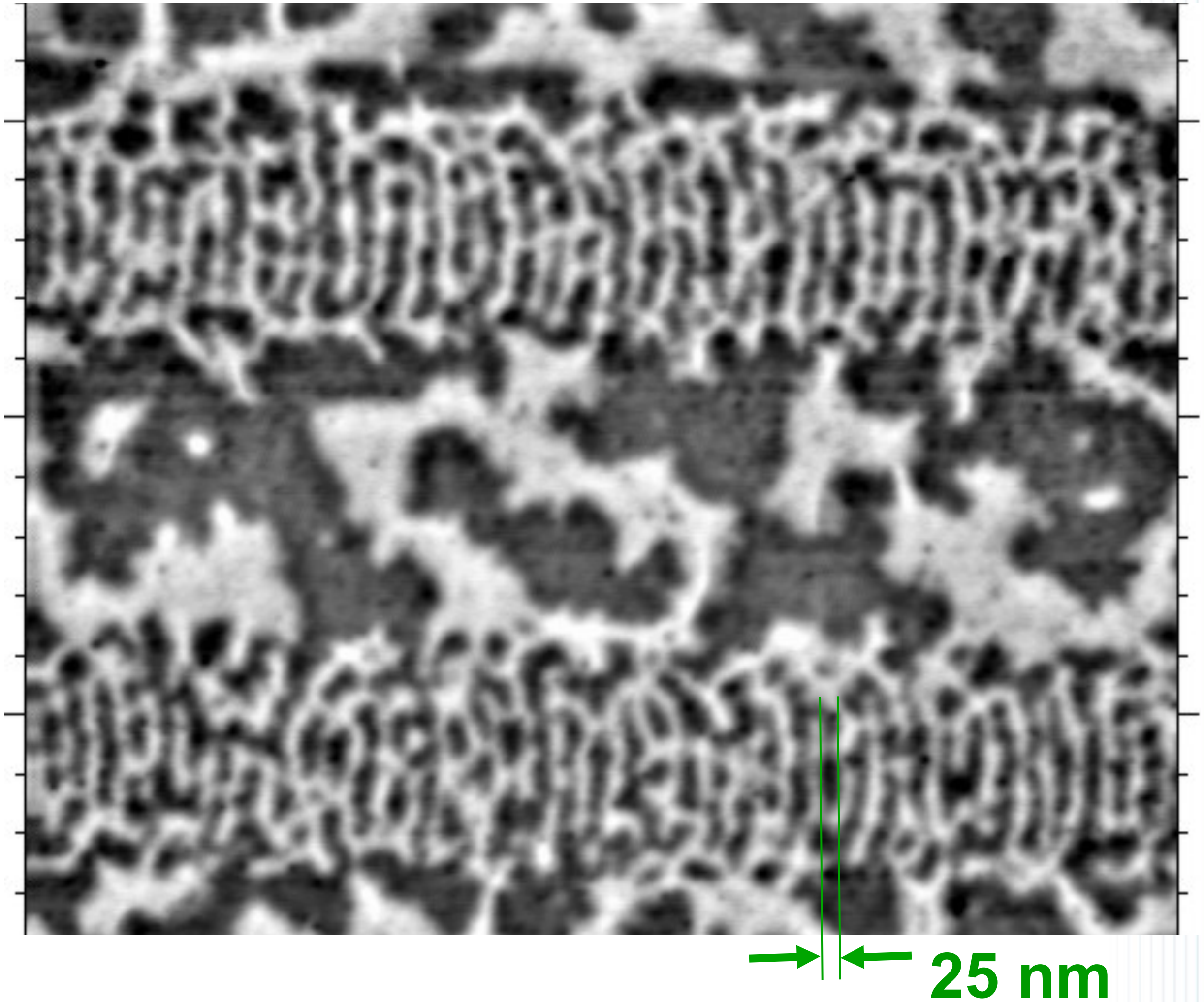


Disk drive basics: mechanics



Disk drive basics: Recording Density

Transitions recorded at 1000 kFCI (= linear density)



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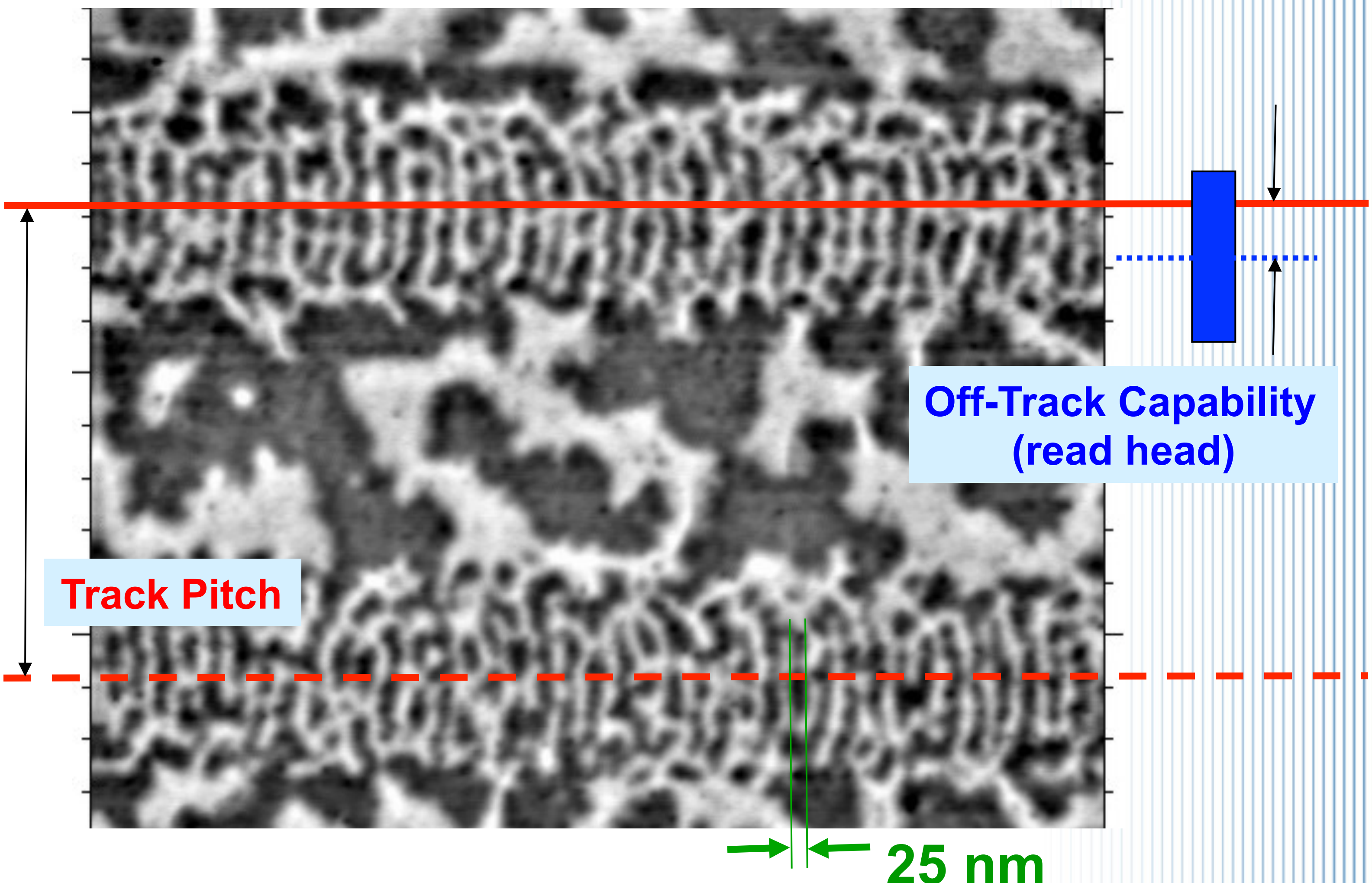
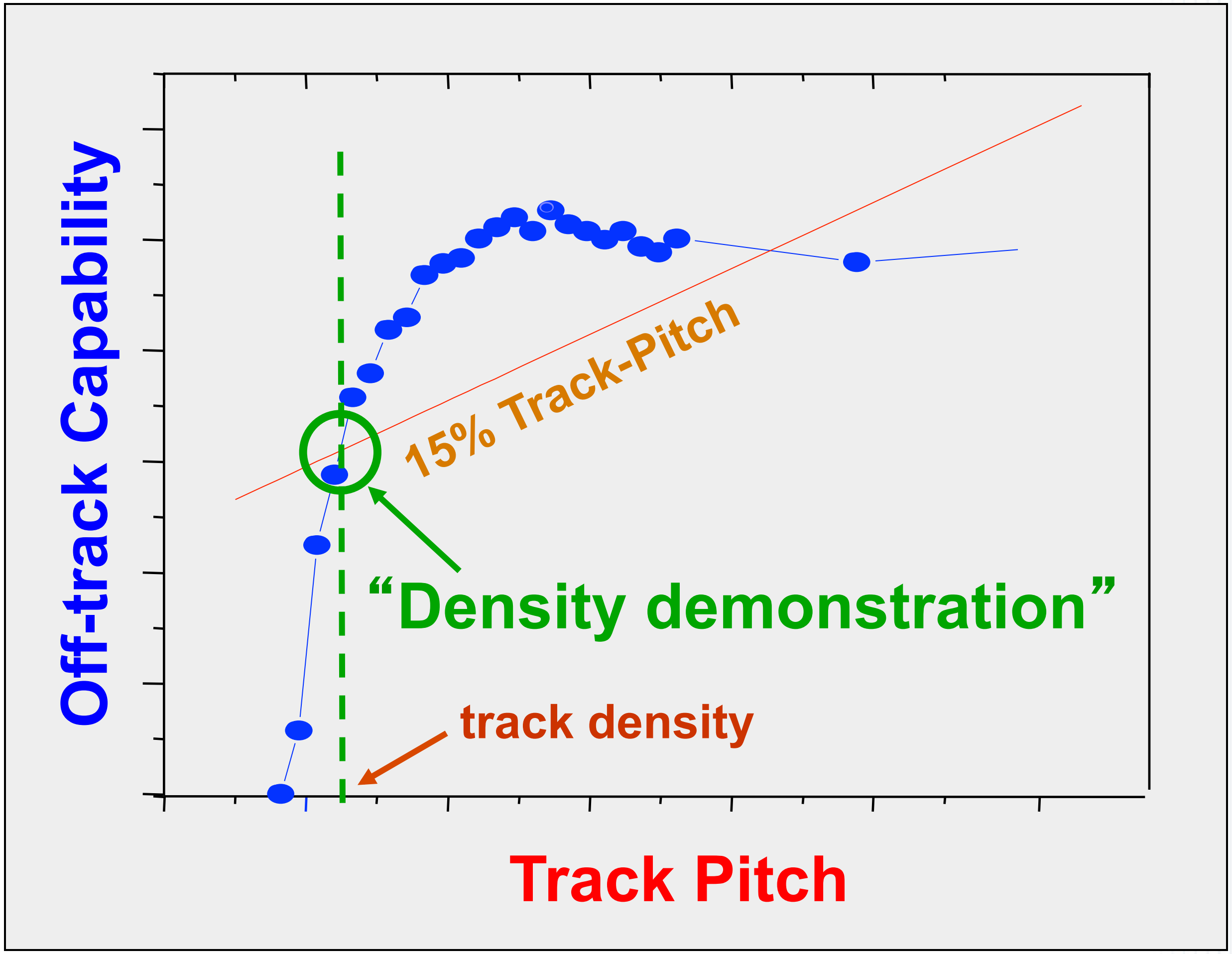


Disk drive basics: Recording Density



Areal density = linear density x track density

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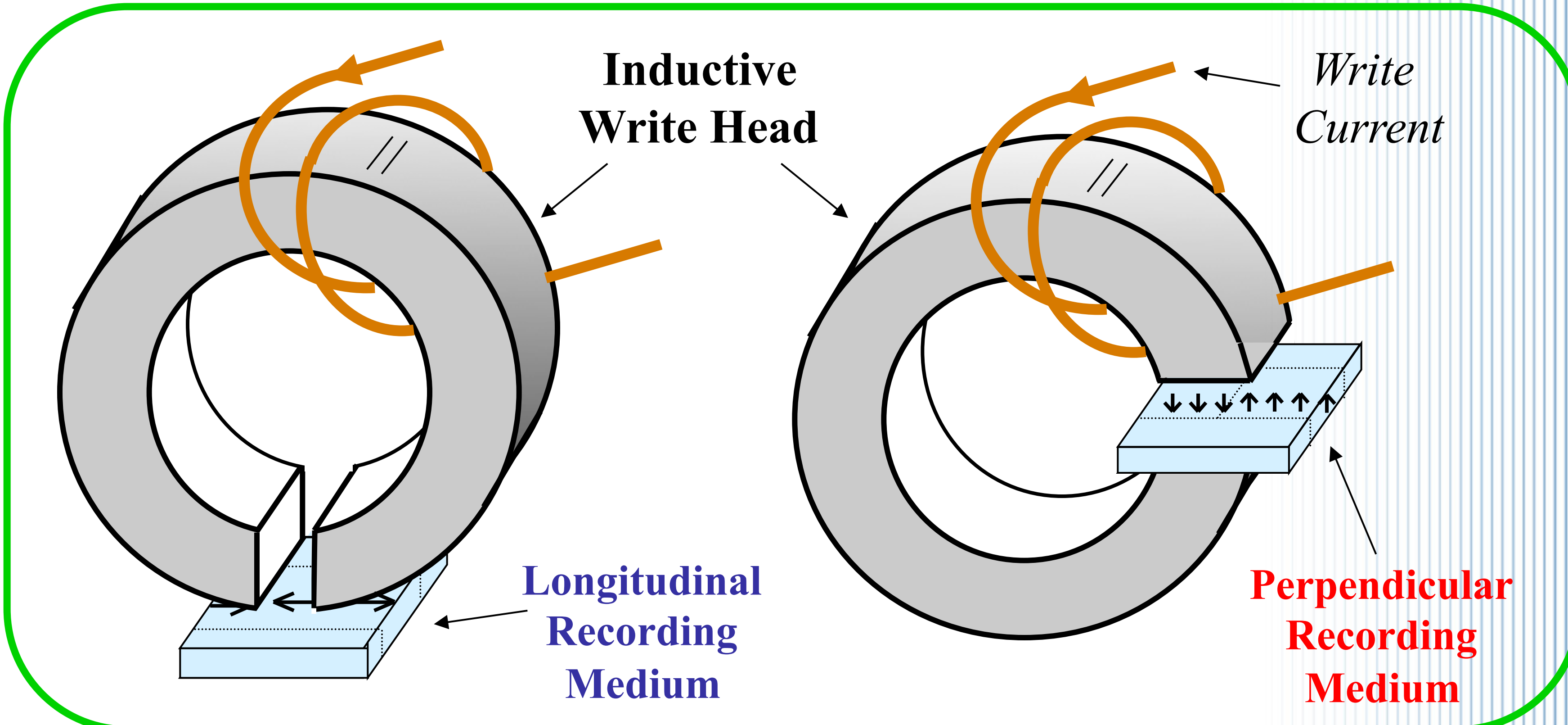
Beyond 100 Gbit/in^2: perpendicular recording!



Recording medium passes right through the head gap!

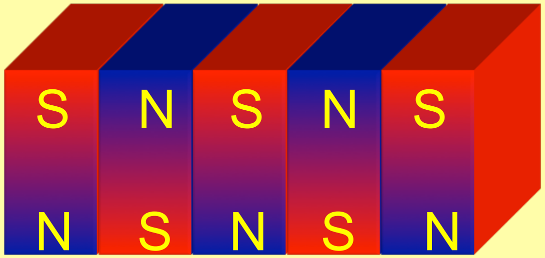
- rather than just through the gap fringing field

Higher fields can write higher K_U media → smaller grains

Beyond 100 Gbit/in^2: perpendicular recording!

Longitudinal Recording

Perpendicular Recording



Adjacent Magnets **Repel**
- difficult to increase areal density

Adjacent Magnets **Attract**
- high-density data is naturally more stable

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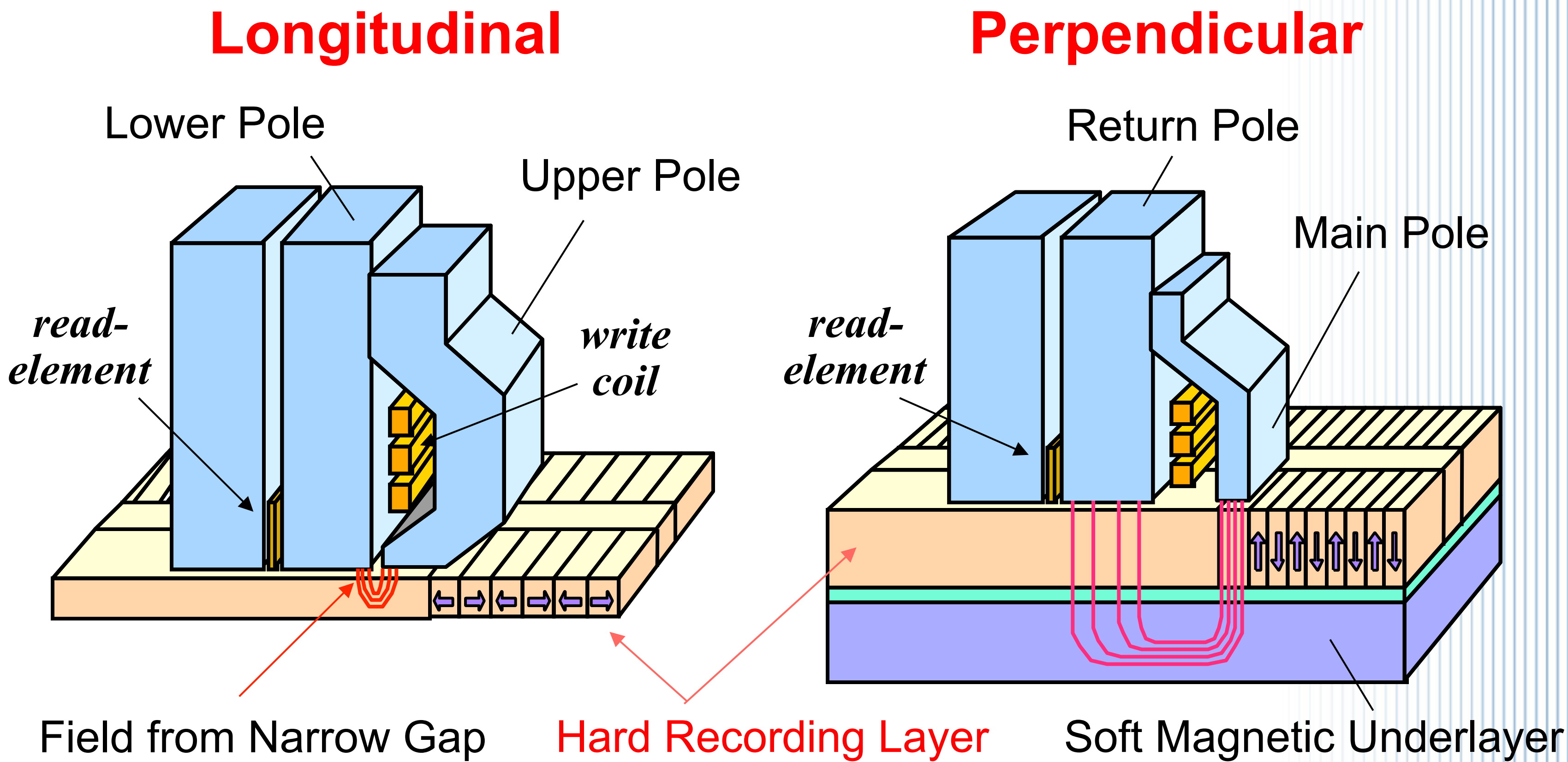
Beyond 100 Gbit/in^2: perpendicular recording!

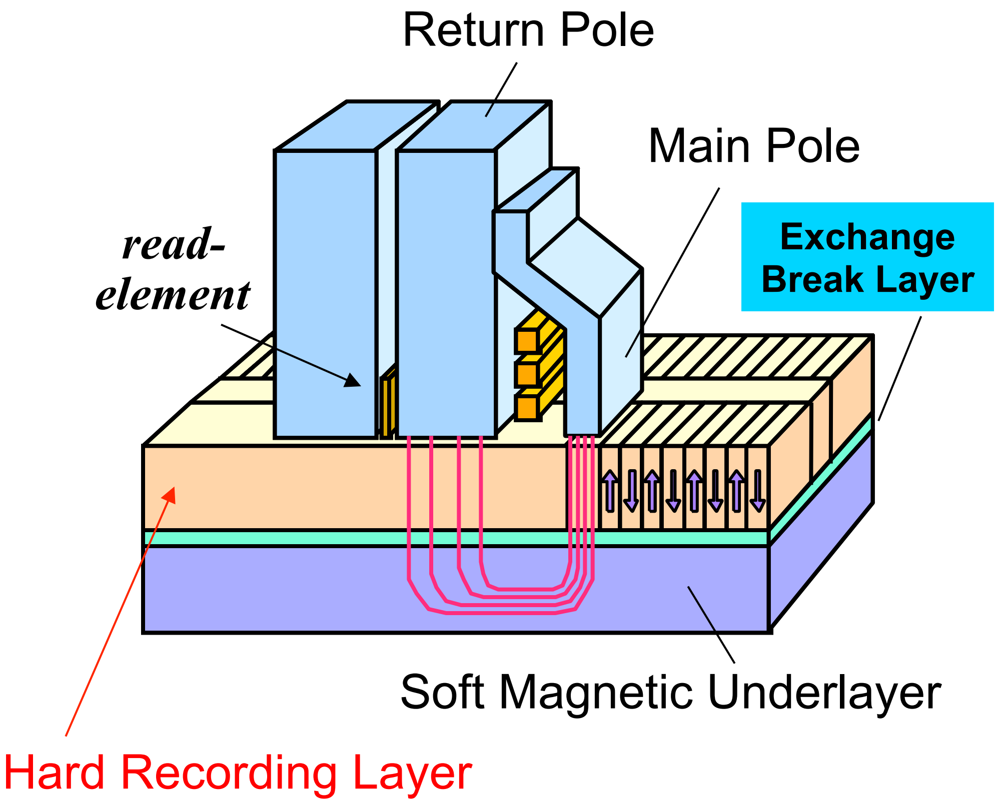


Part of the head structure must be built into the disk!

- **magnetically soft layer placed immediately under recording medium**
- **strong field concentrated under main pole writes on medium**

(diffuse 'return field' under return pole is too weak to affect medium)

Perpendicular recording



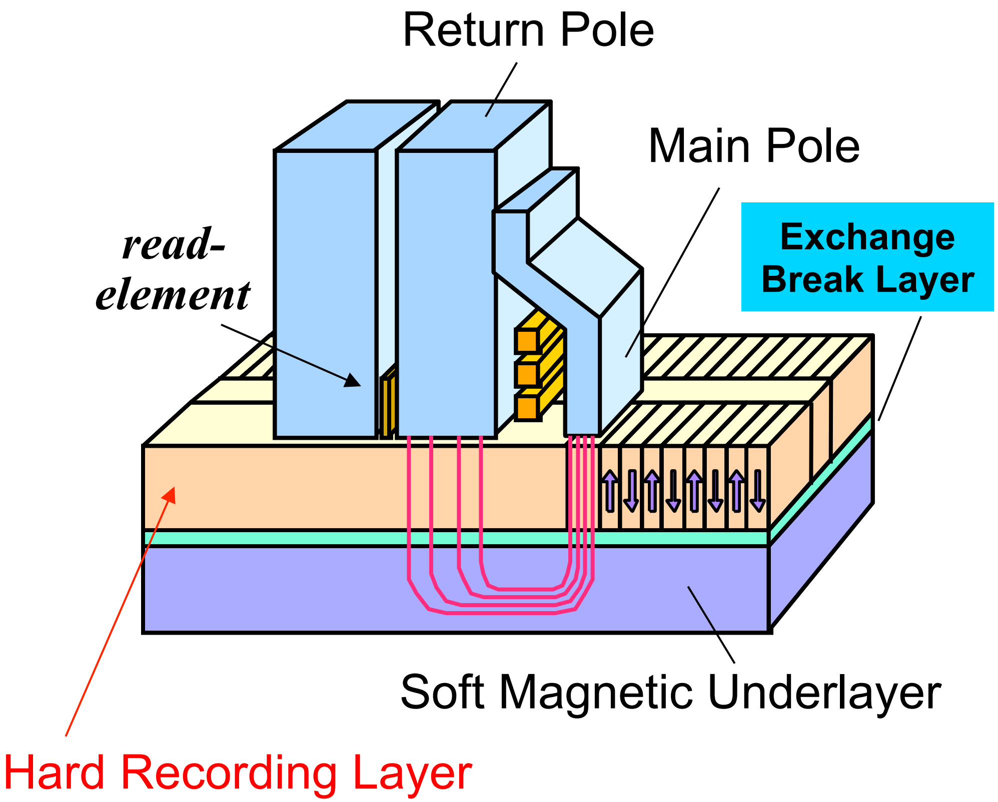
Advantages:

- higher write fields
- better high density stability
- smaller read-back spacing
- better grain orientation

Disadvantages:

- much thicker structure (surface roughness)
- more layers / complex processing (new tooling? - investment)
- exchange break (between HRL and SUL)
- SUL magnetization
- new materials/structures needed

Perpendicular recording



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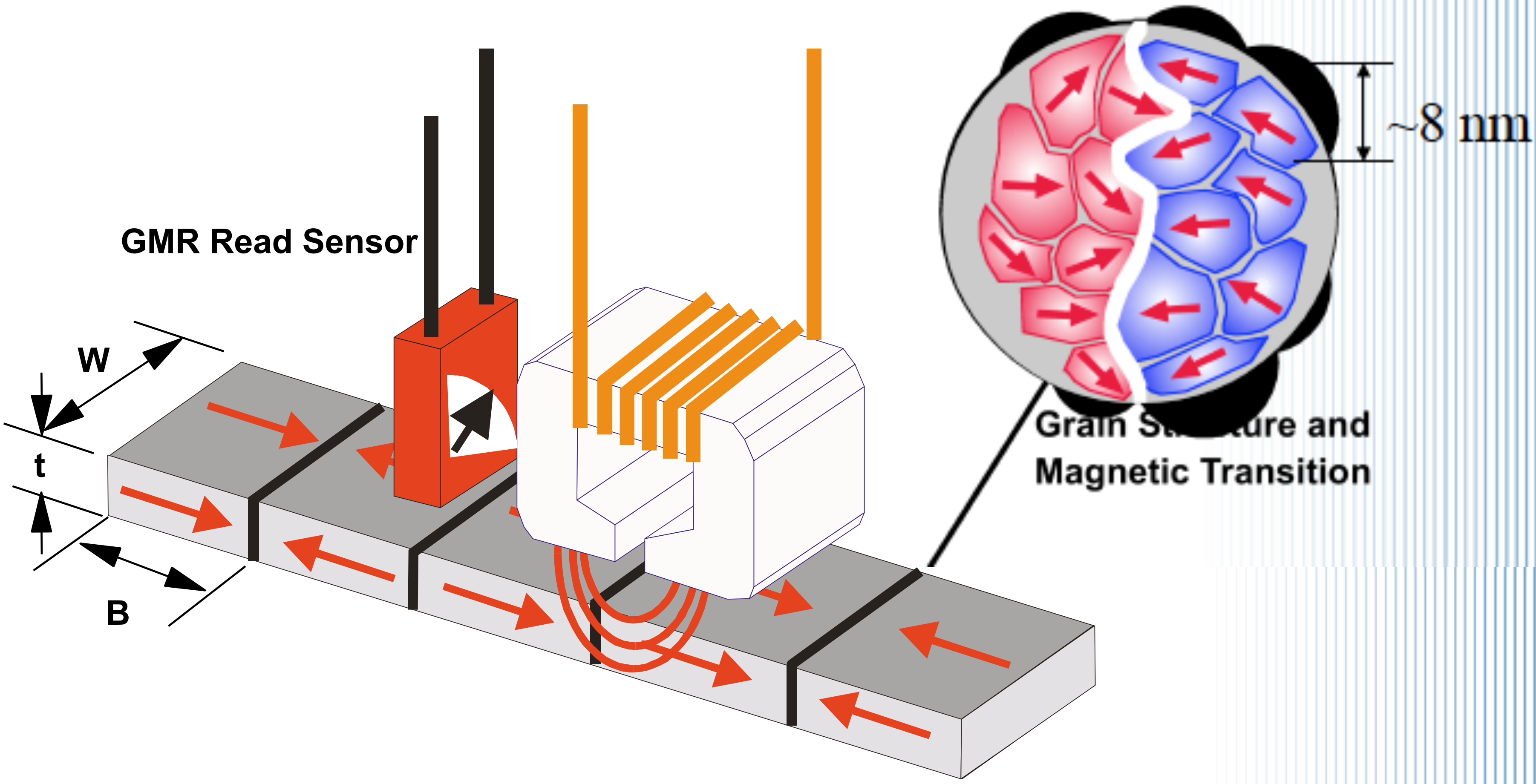
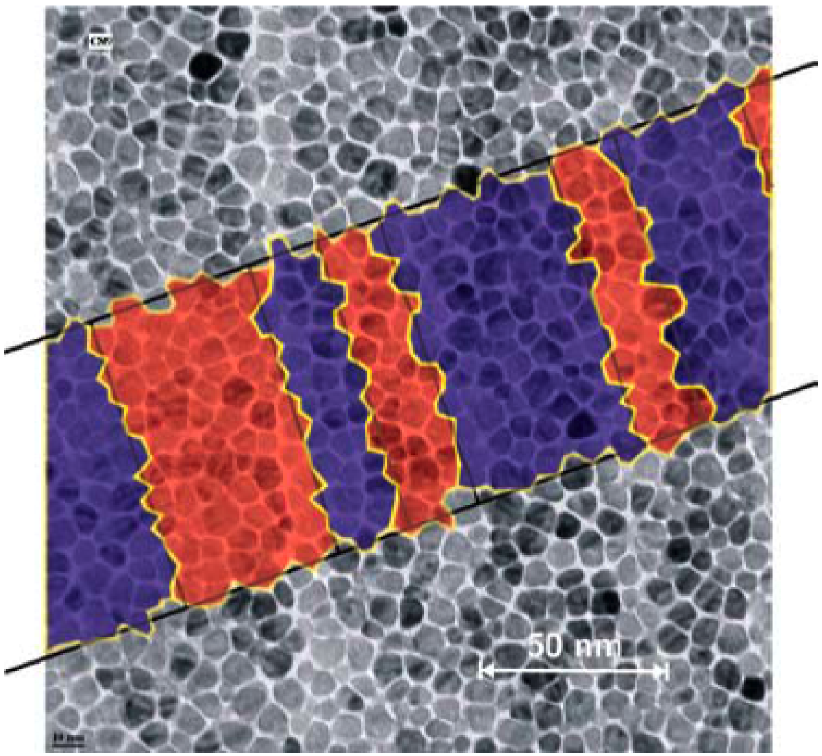


Media basics

Electron micrograph of media:



Grain size distribution

<D> = 8.5 ± 2.5 nm

Grain boundaries

<d> = 1 – 1.5 nm

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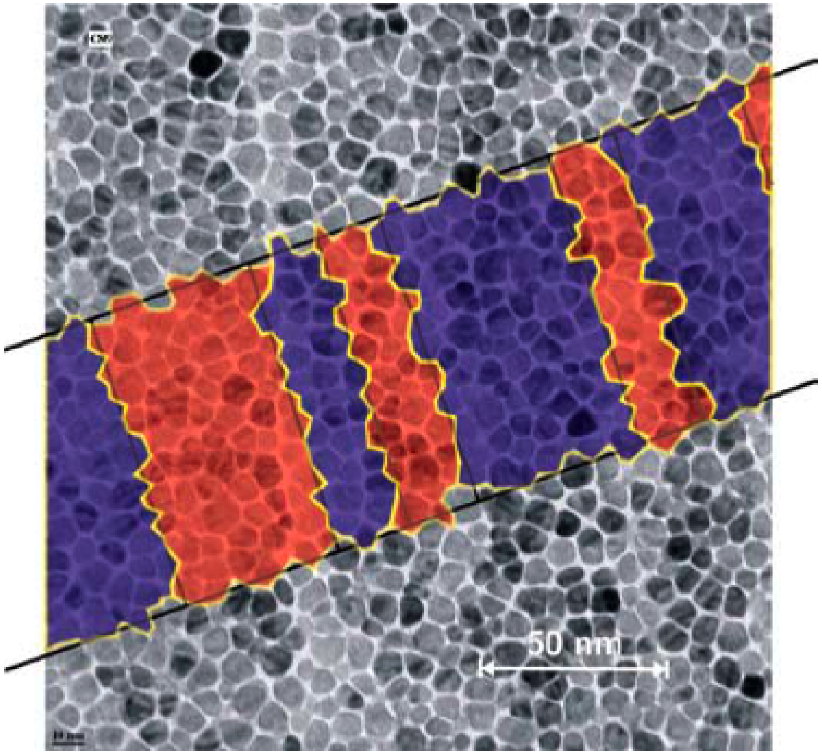

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How do you do that?

Media basics

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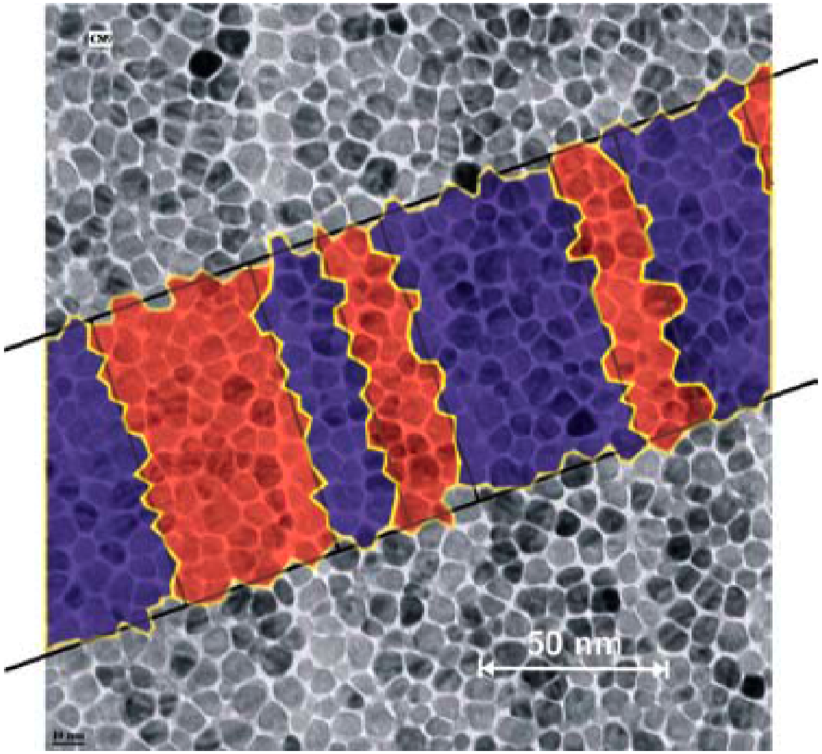

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How do you do that?

- **suitable layer structure**
- **deposition processes**

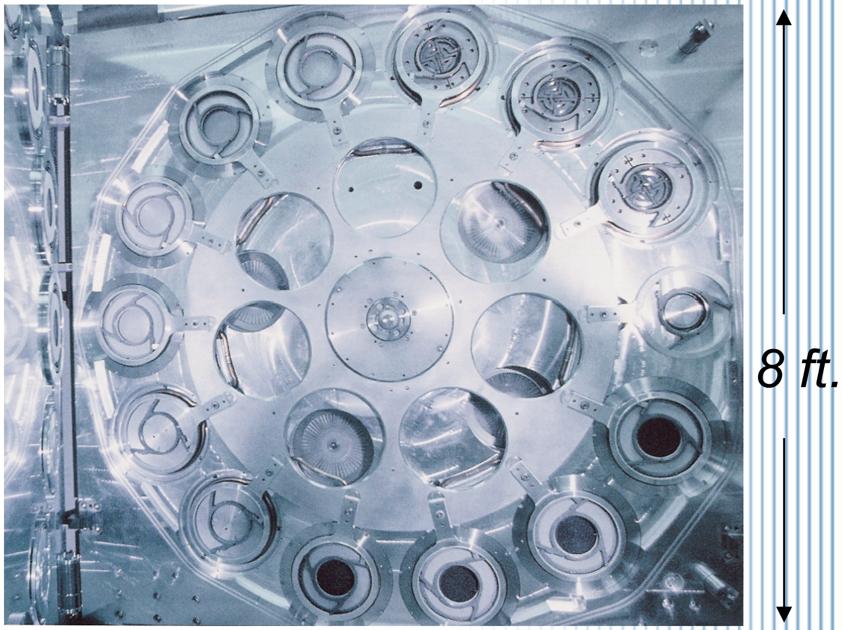
Media basics

Media manufacturing:

Circulus Tool: ***sputtering***

- 12 stations (12 simult. processes)
- 2 heaters, 1 cooling
- $P_{base} < 1 \times 10^{-7}$ Torr
- RF sputtering
- T < 450 C

~ 6 seconds cycle time



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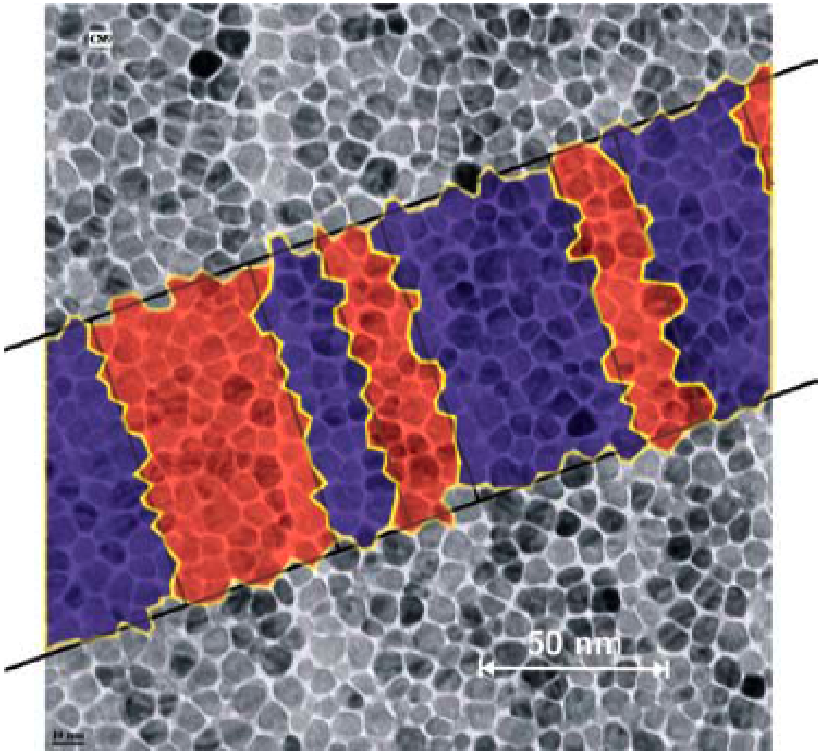

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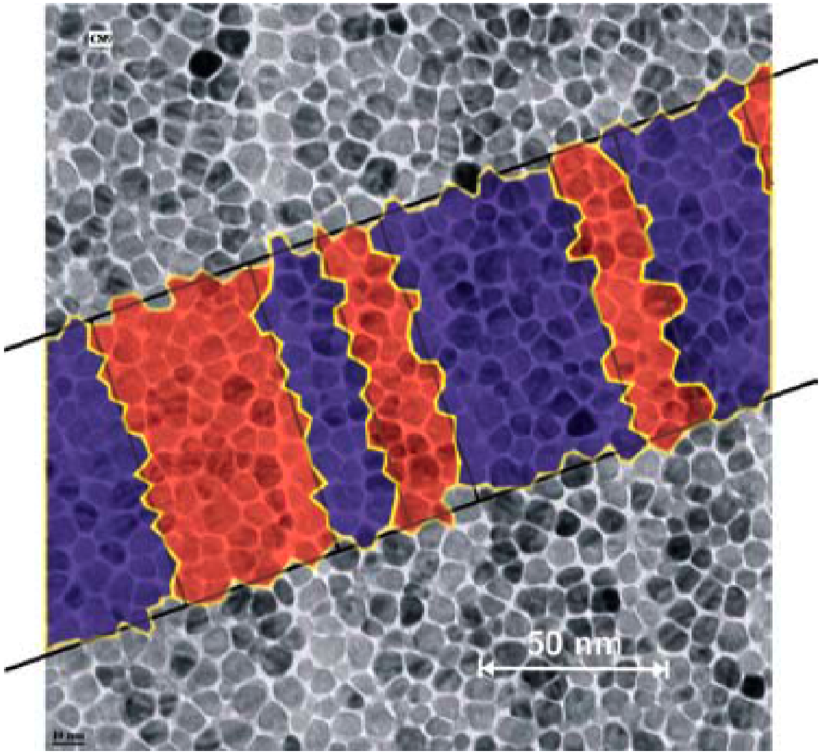

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Grain boundaries

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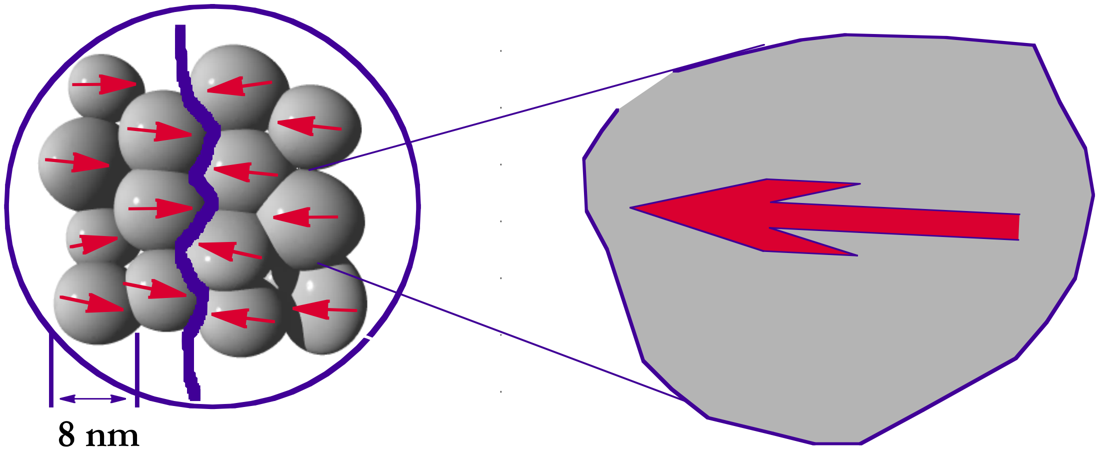
Why do you need that?

- stability
- recording performance

Media stability

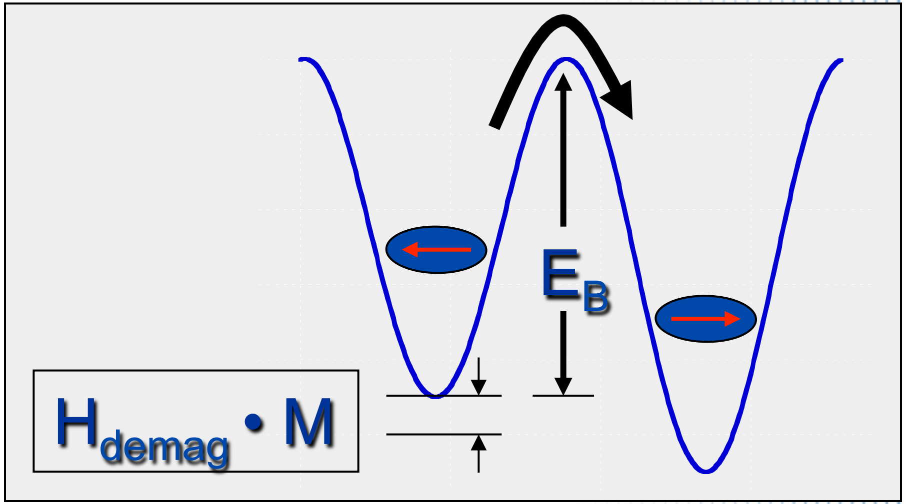


$$\tau^{-1} \sim f_0 \exp(-E_B/k_B T)$$

$$E_B \sim K_U V (1 - H/H_S)^2$$

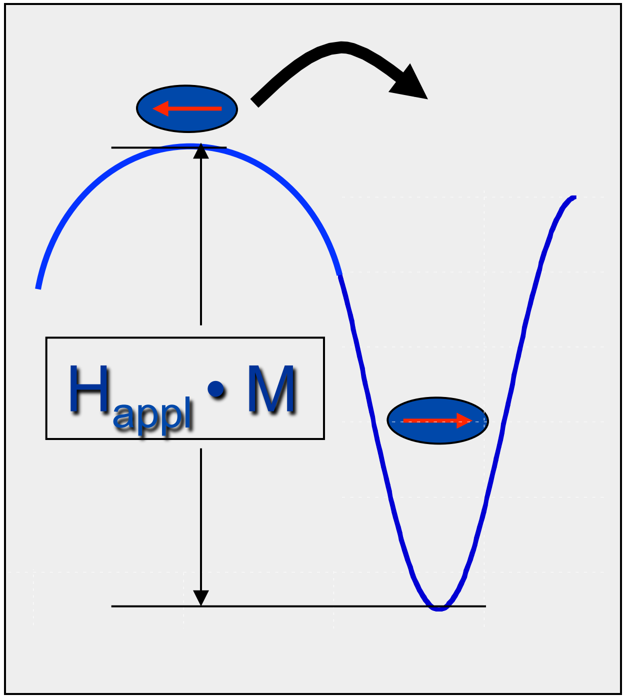
$$K_U V / k_B T > \sim 55\text{-}70$$

lower limit for $K_U V$



recording I "writing at all"

- fast (<1 ns)
- no thermal activation



$E_B < 0$

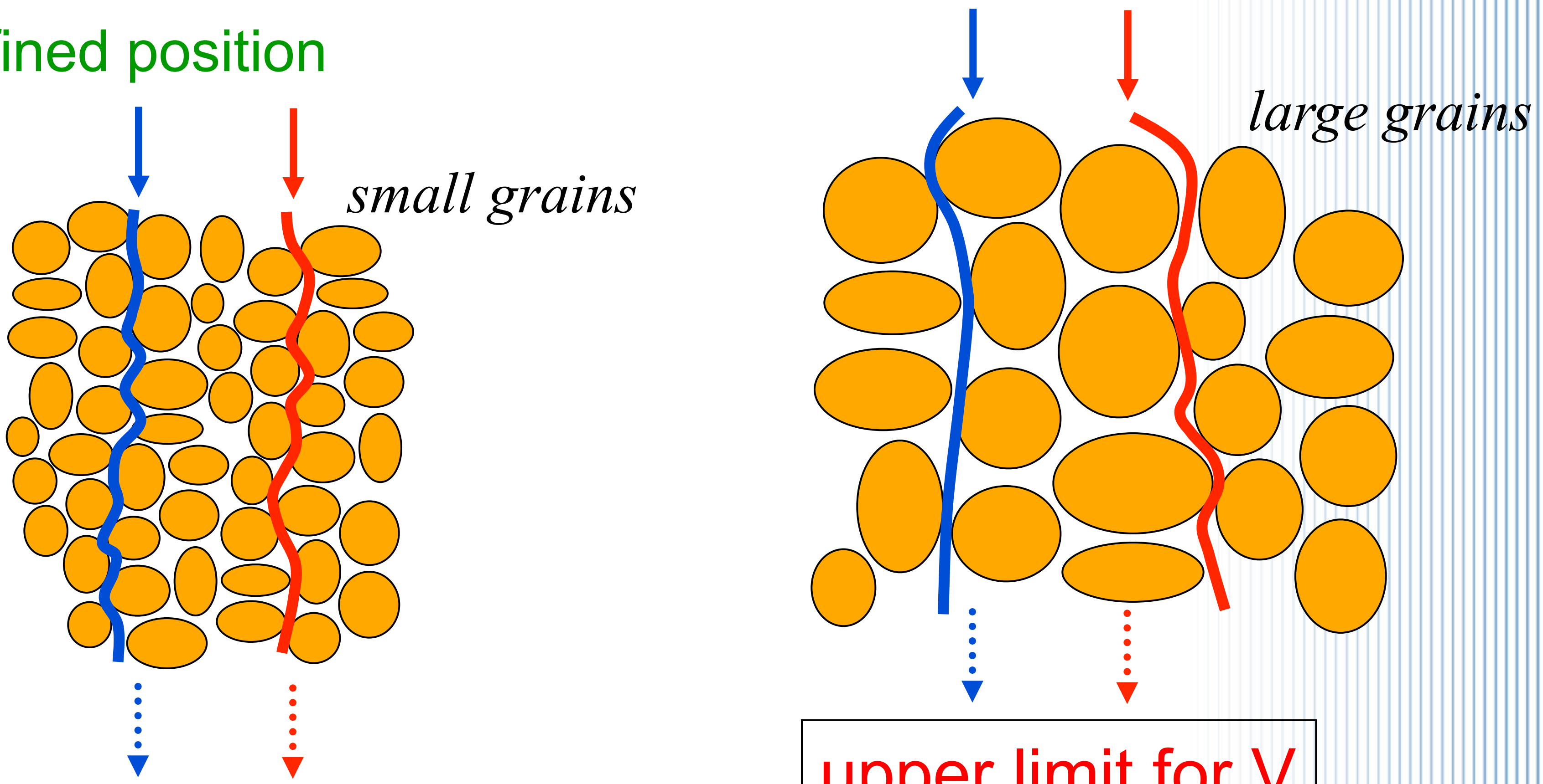
$H_{appl} > H_S$ ($\sim K_U$)

upper limit for K_U

lower limit for V

recording II "only recorded information can be read back"

- defined position



<u>upper limit for V</u>

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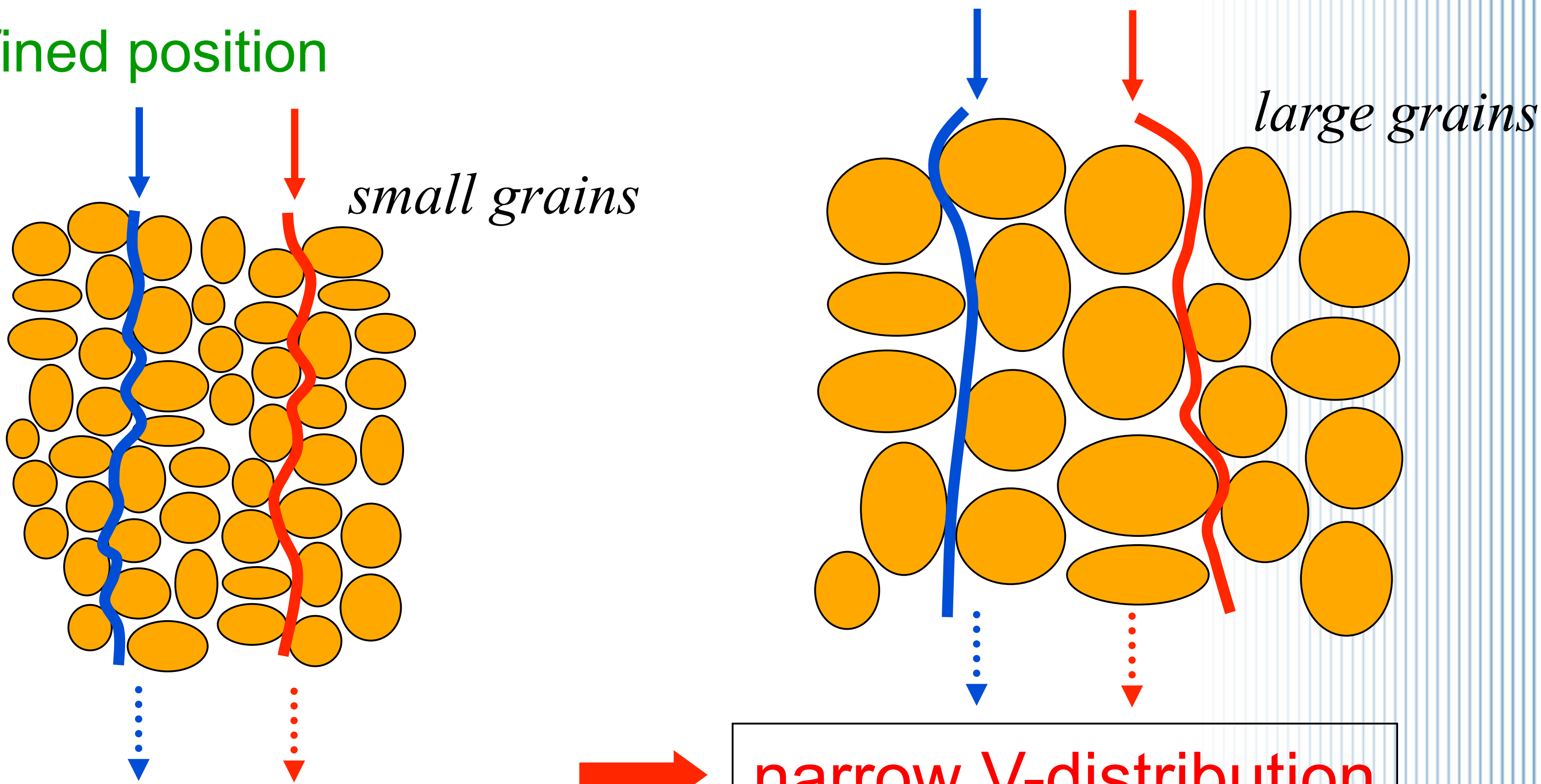
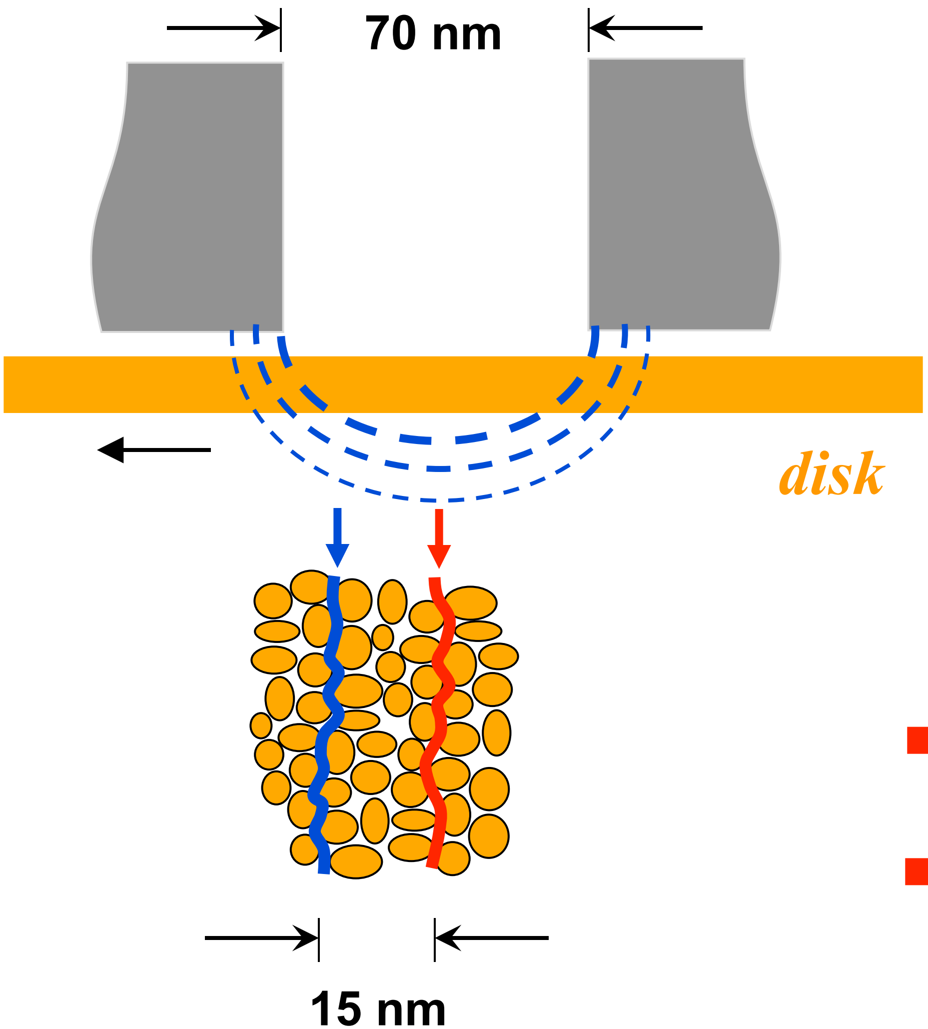
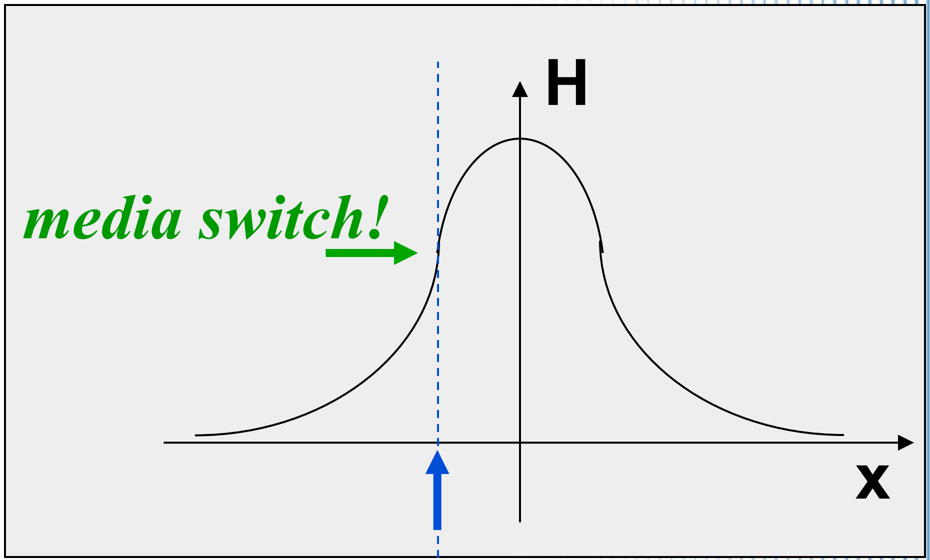


narrow V-distribution

recording III "magnetic super-resolution"



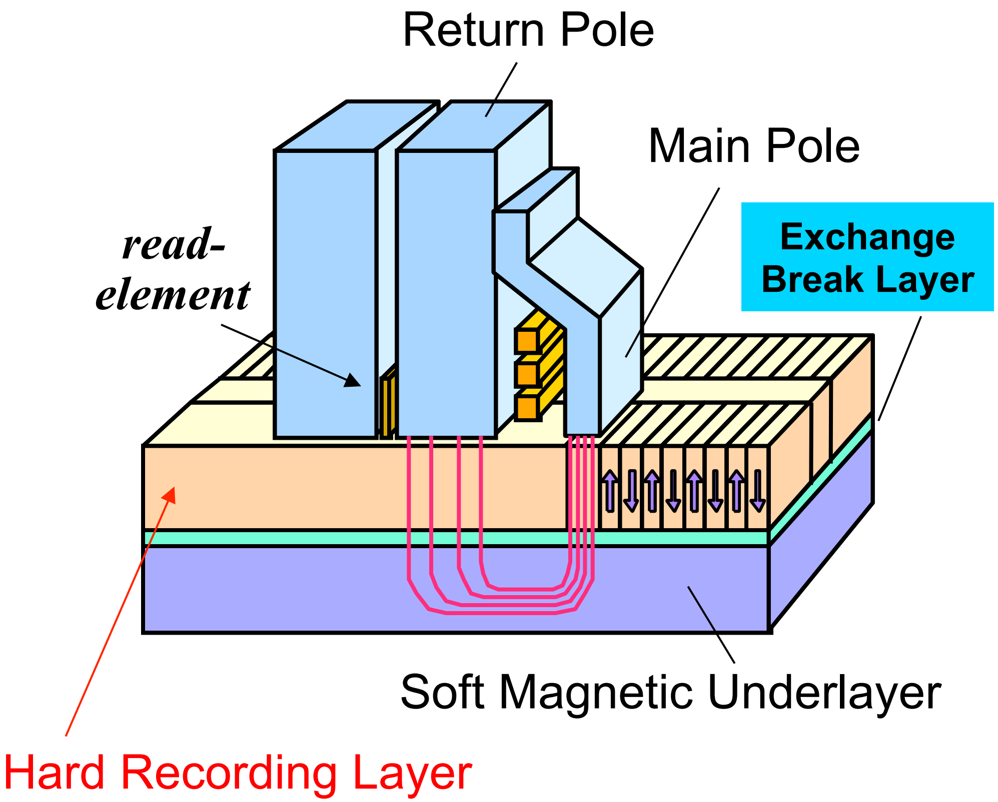


narrow H_K-distribution

narrow K_U-distribution

narrow M_s-distribution

Perpendicular recording



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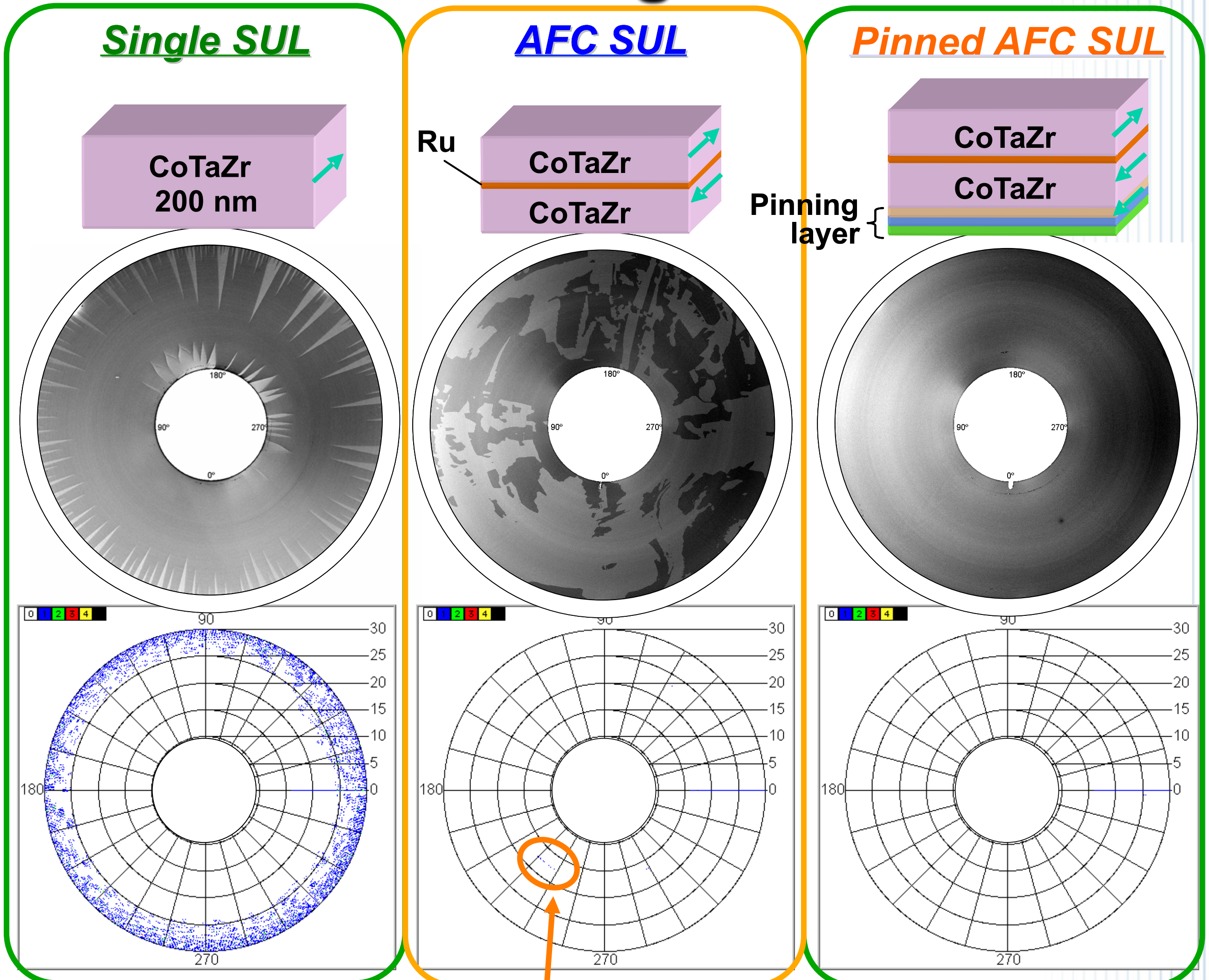
Perpendicular recording: AFC-SUL

Soft Under-layer

Kerr image

Spike-noise map (spin-stand)

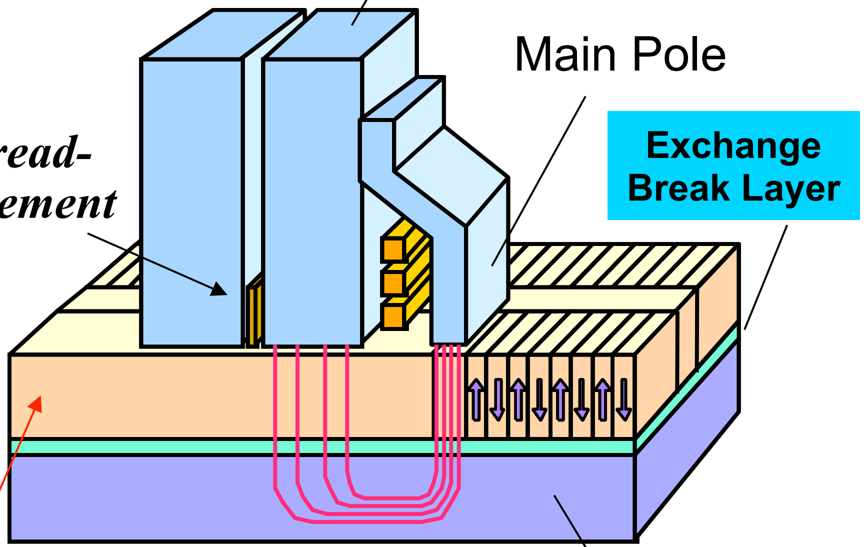


Much spike noise

Very minor evidence of spike noise

No spike noise

Perpendicular recording



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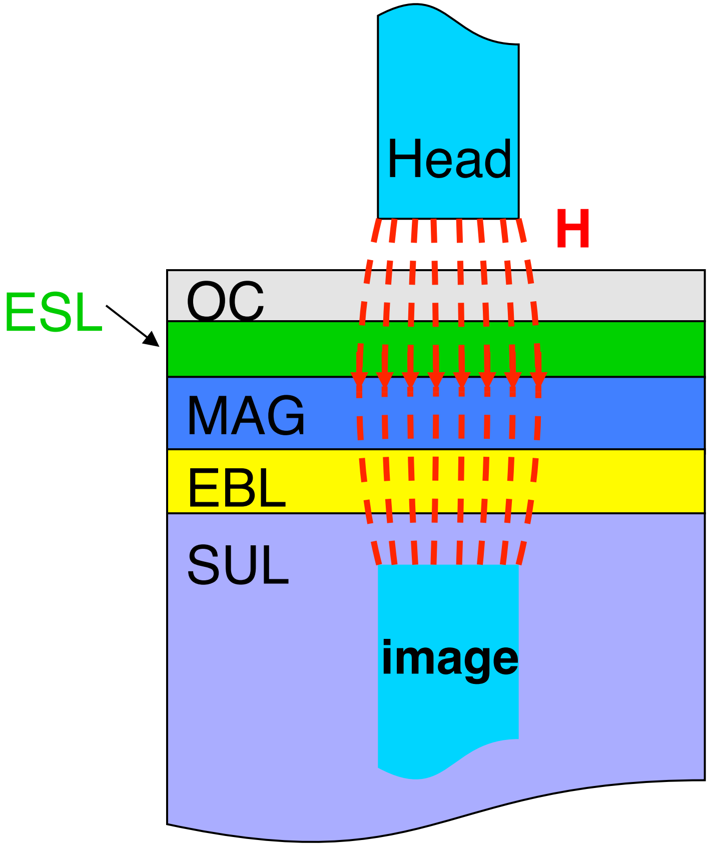
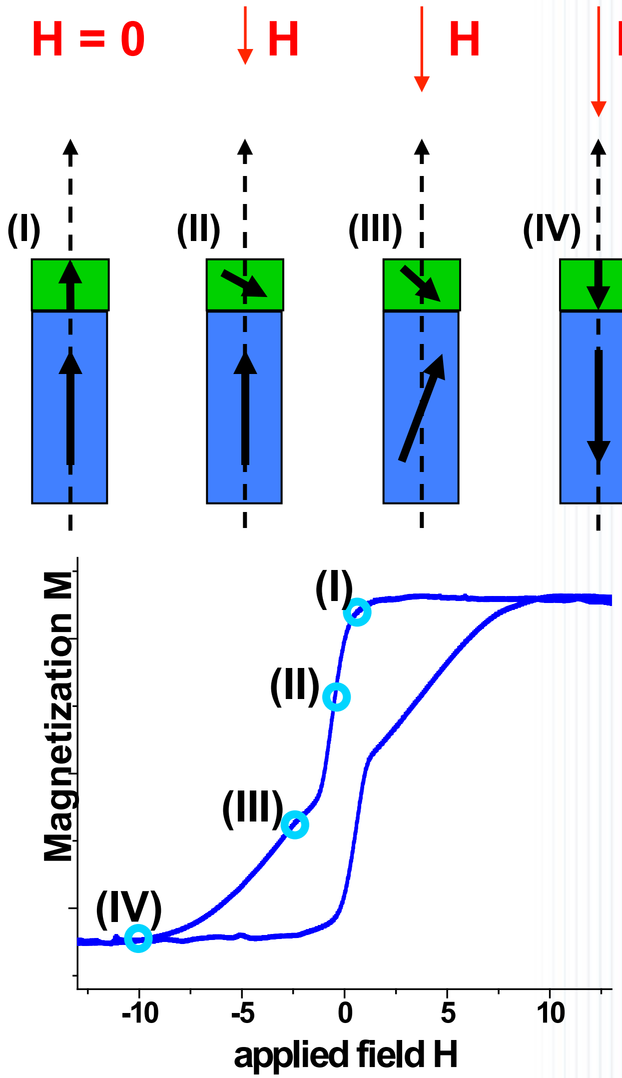
Perpendicular recording: Exchange Spring Media

basic functionality





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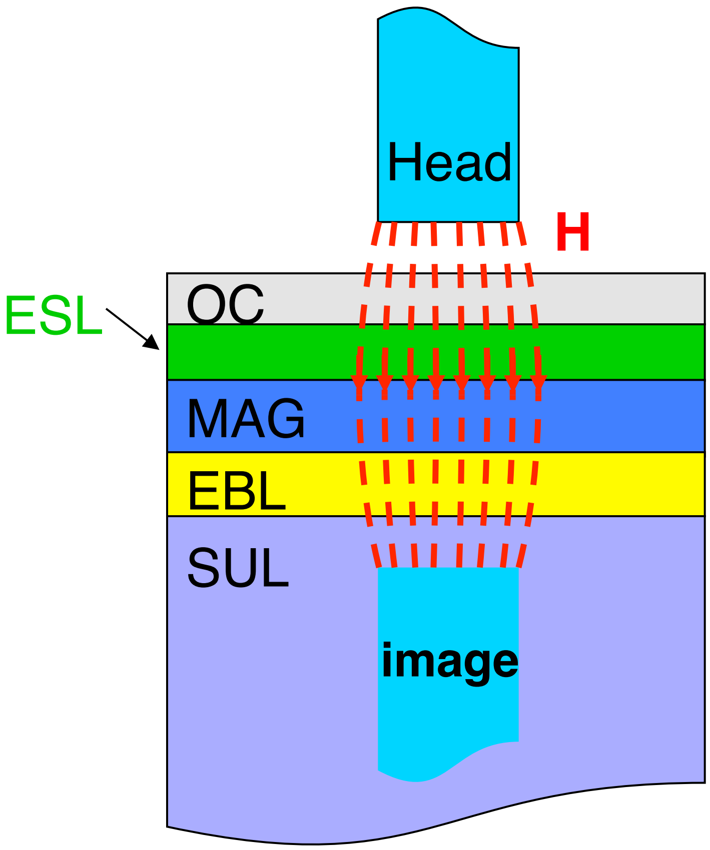

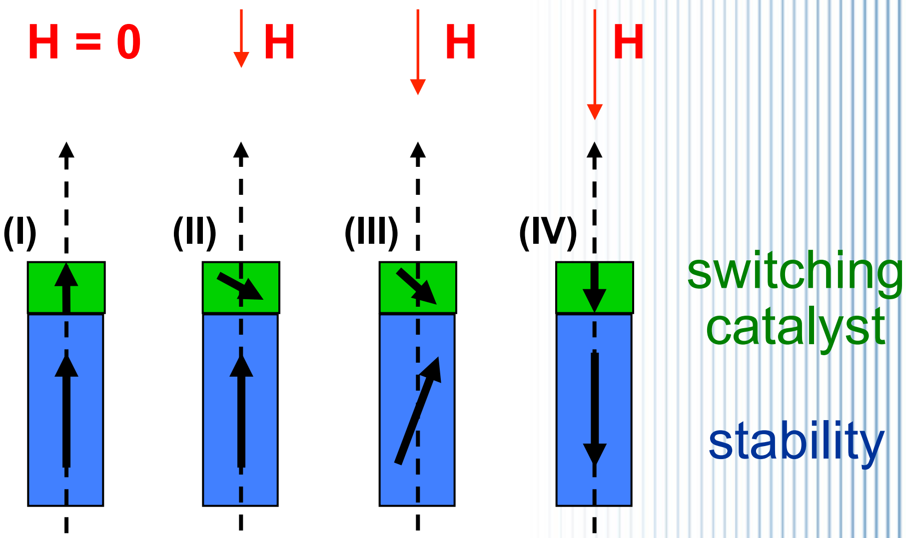

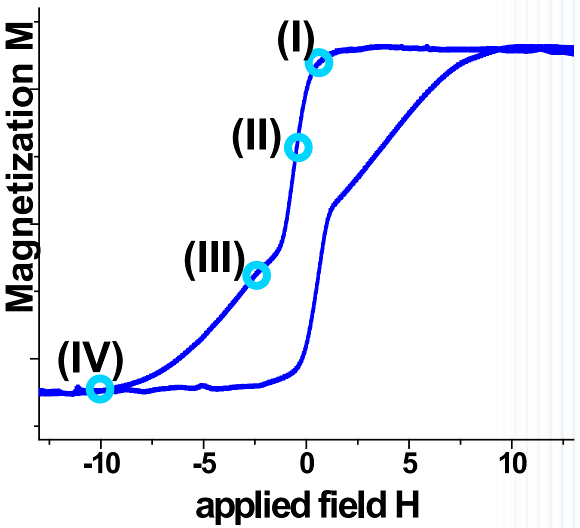

Perpendicular recording: Exchange Spring Media

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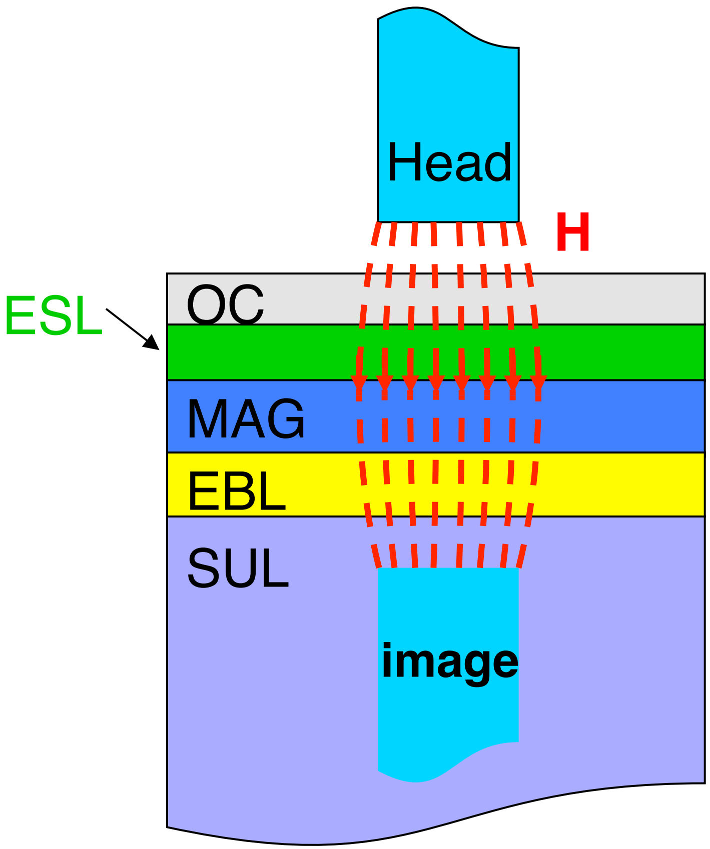

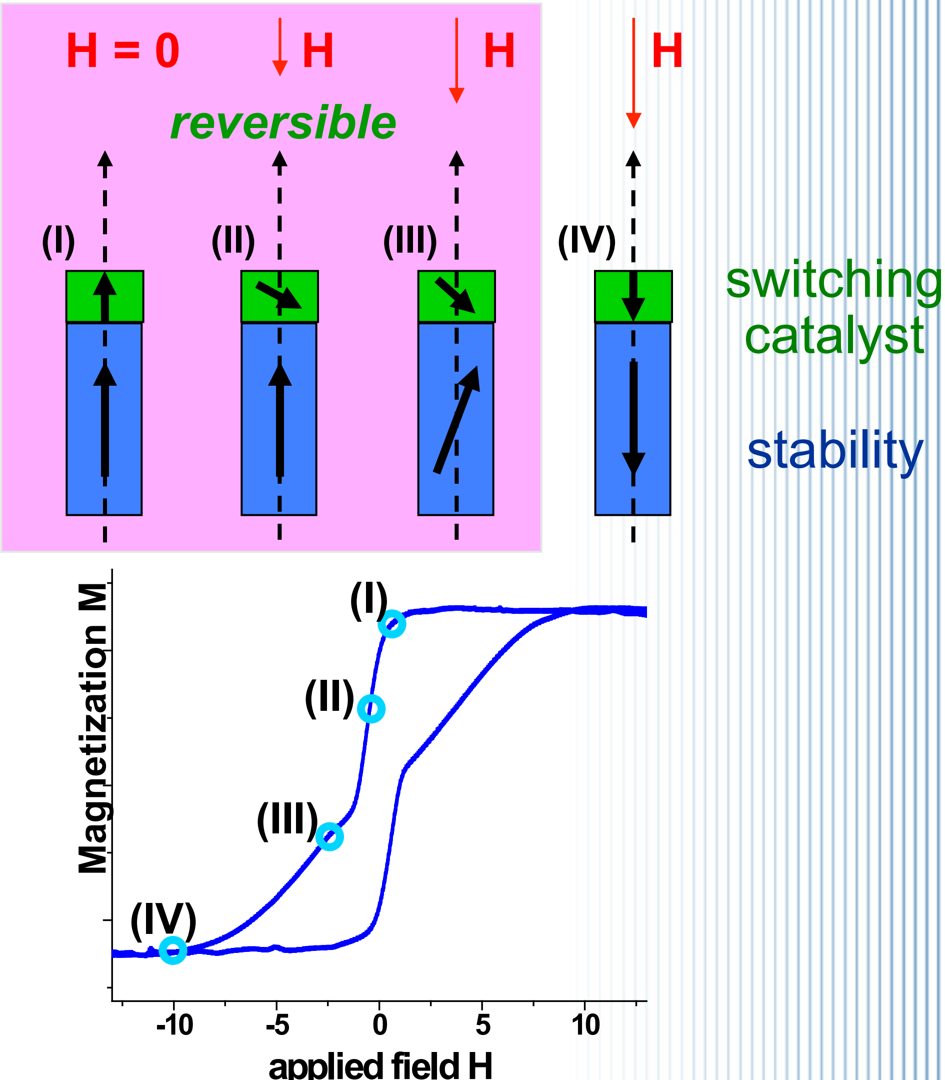

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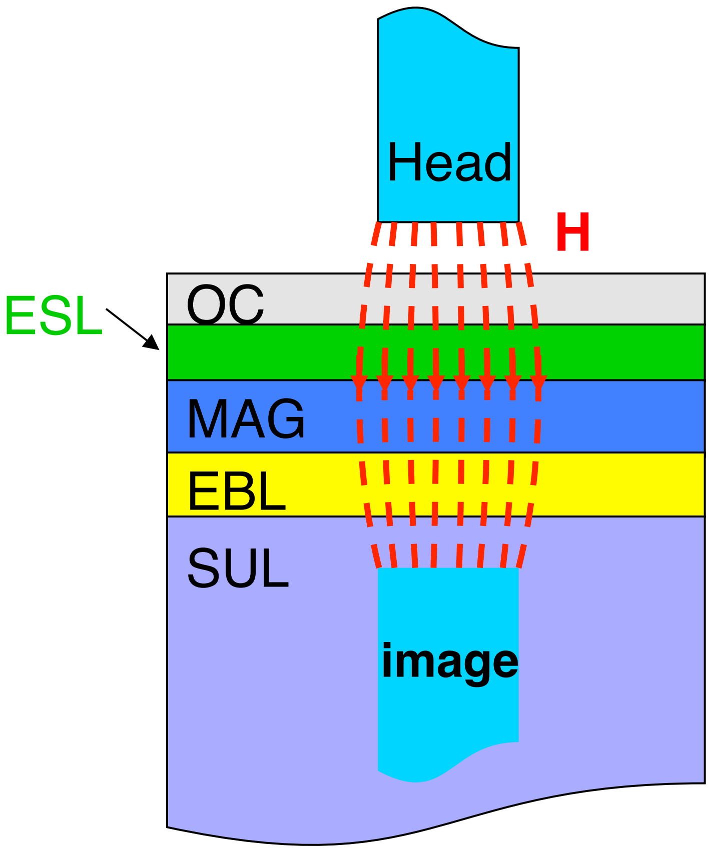
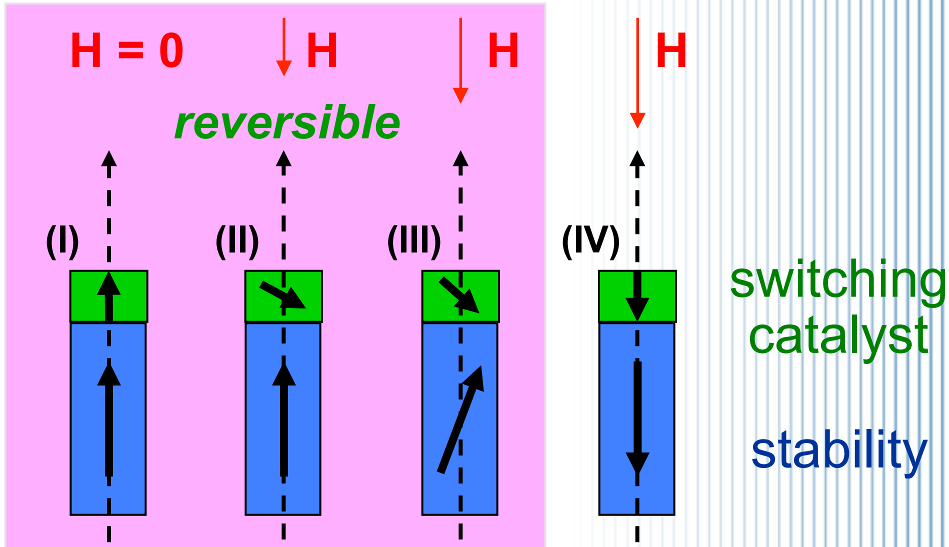




Exchange Spring Structure

A. Berger, N. Supper, Y. Ikeda, B. Lengsfield, A. Moser, and E. E. Fullerton, Appl. Phys. Lett. 93, 122502 (2008).

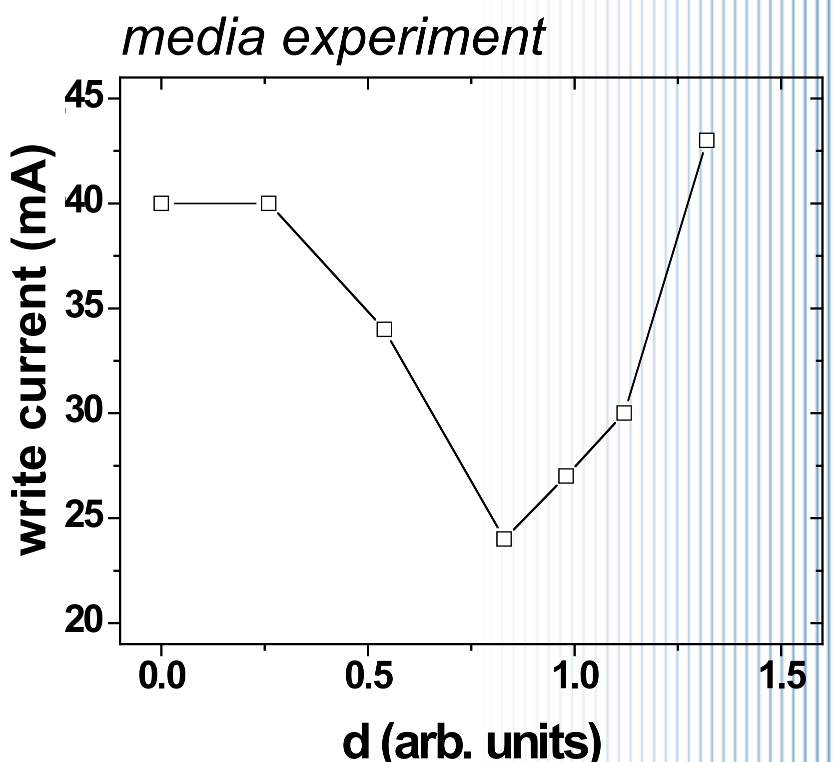
A. Berger, E. Fullerton, H. Do, and N. Supper, US Patent No. US7687157

A. Berger, B. Lengsfield, H. Do, N. Supper and E. Fullerton, US Patent No. US7550210B2

A. Berger, B. Lengsfield, H. Do, and N. Supper, US Patent No. US7582368B2

Perpendicular recording: Exchange Spring Media

Media structure: adding a Coupling Layer (CL) → tuning the Link



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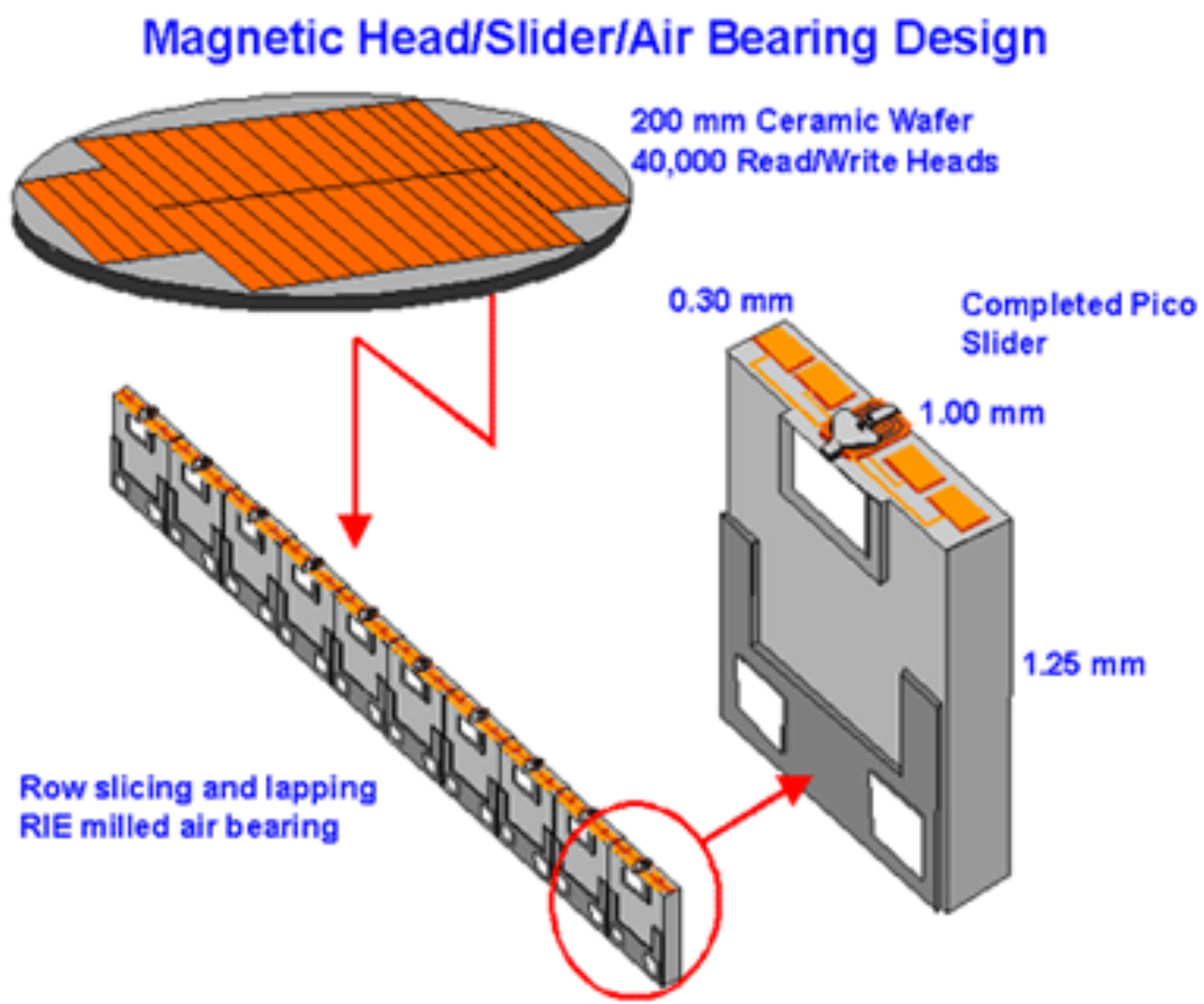
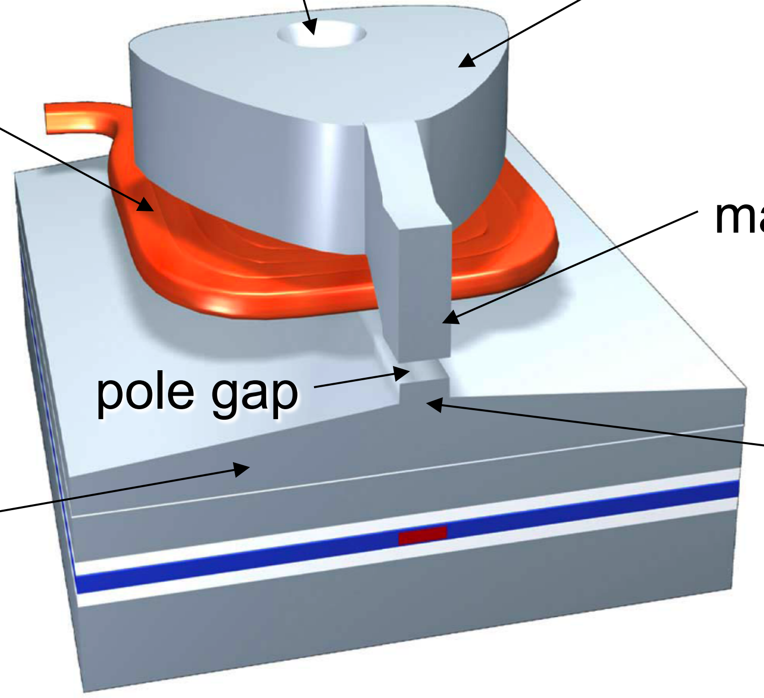
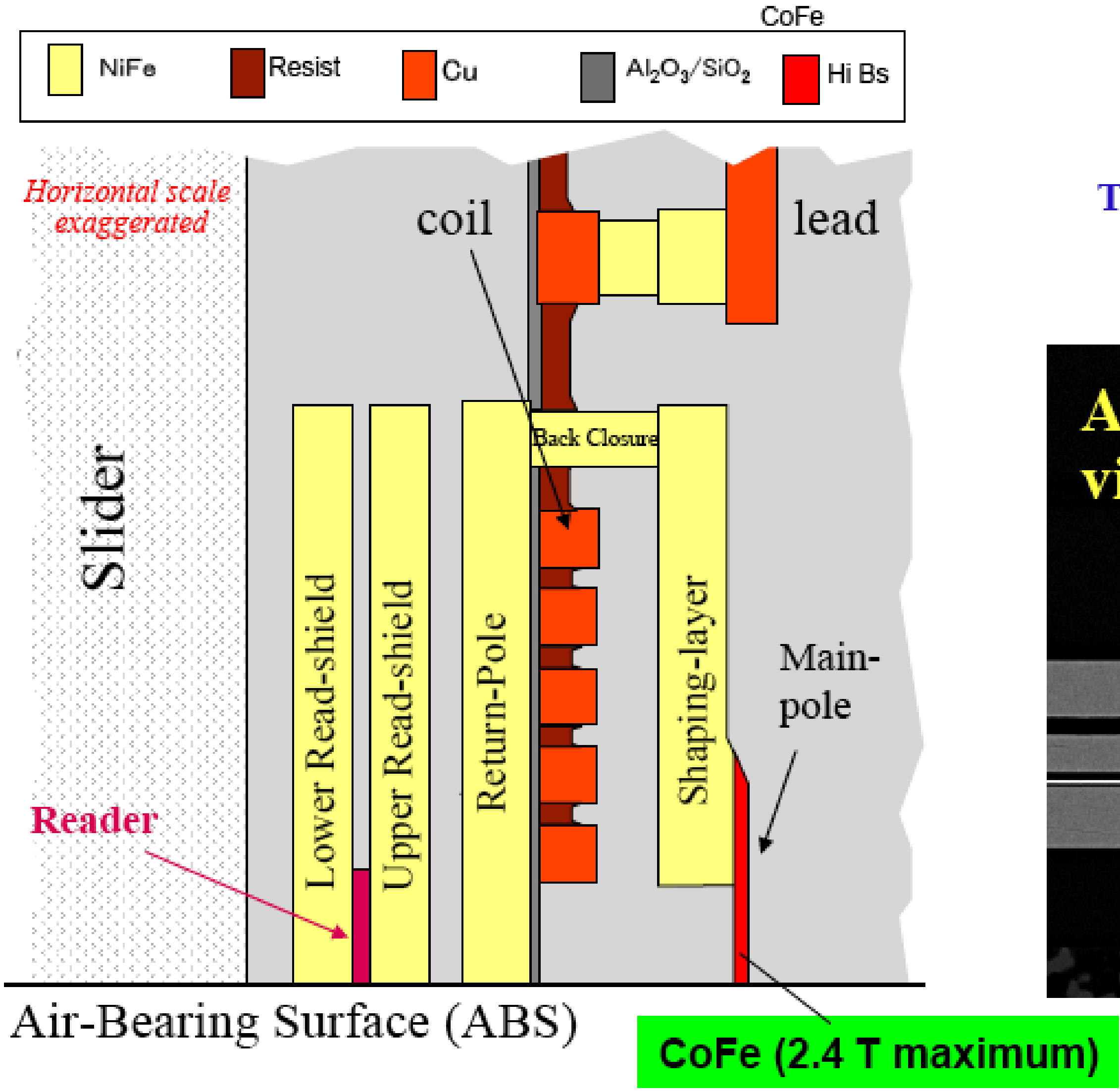
Magnetic Write Heads: Slider

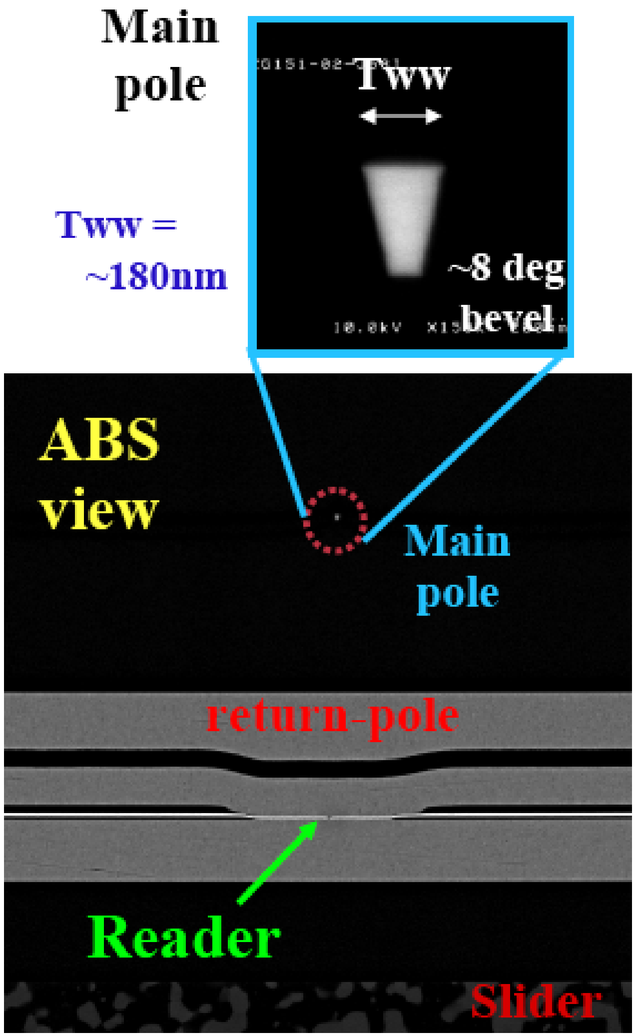


Magnetic Write Heads: components



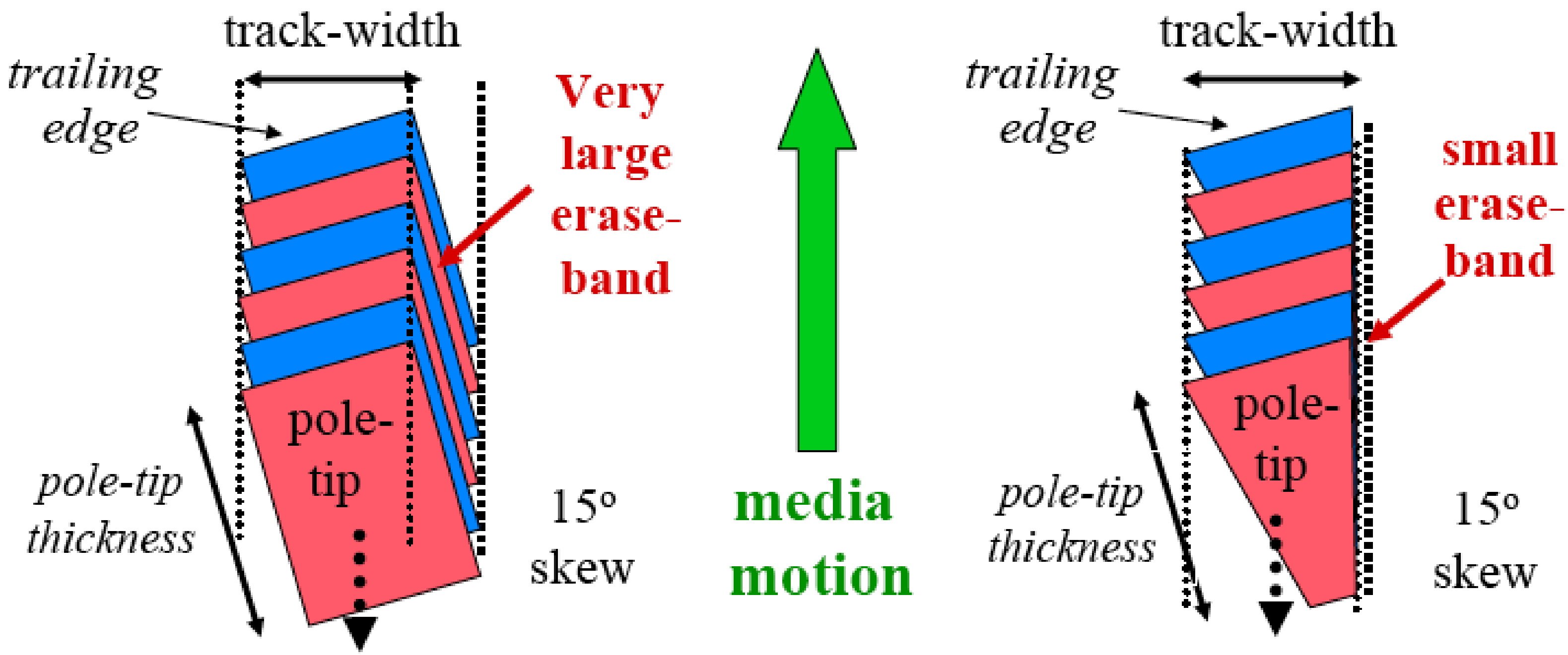
Magnetic Write Heads: advanced geometry

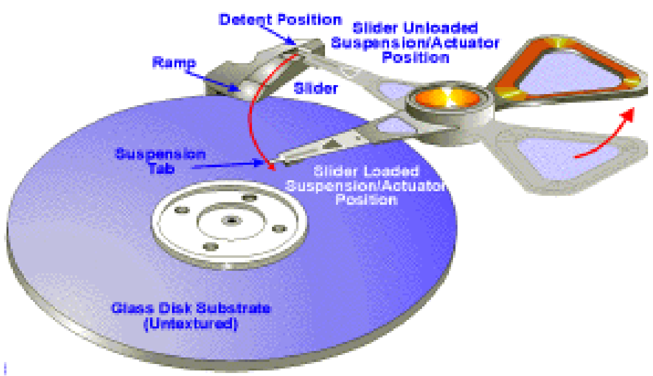




Magnetic Write Heads: advanced geometry

Rectangular Pole-tip | **Trapezoidal Pole-tip**





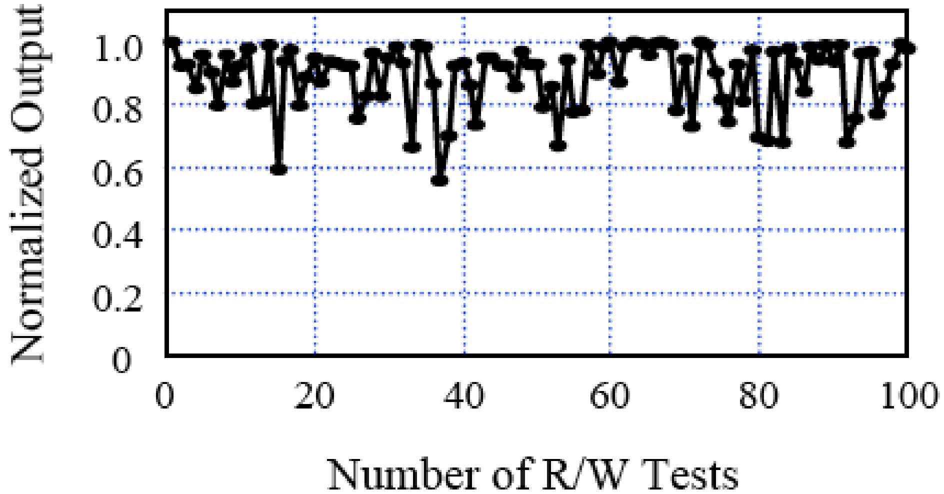
At large actuator angles rectangular pole-tip can damage adjacent track and leaves large 'erase-band'

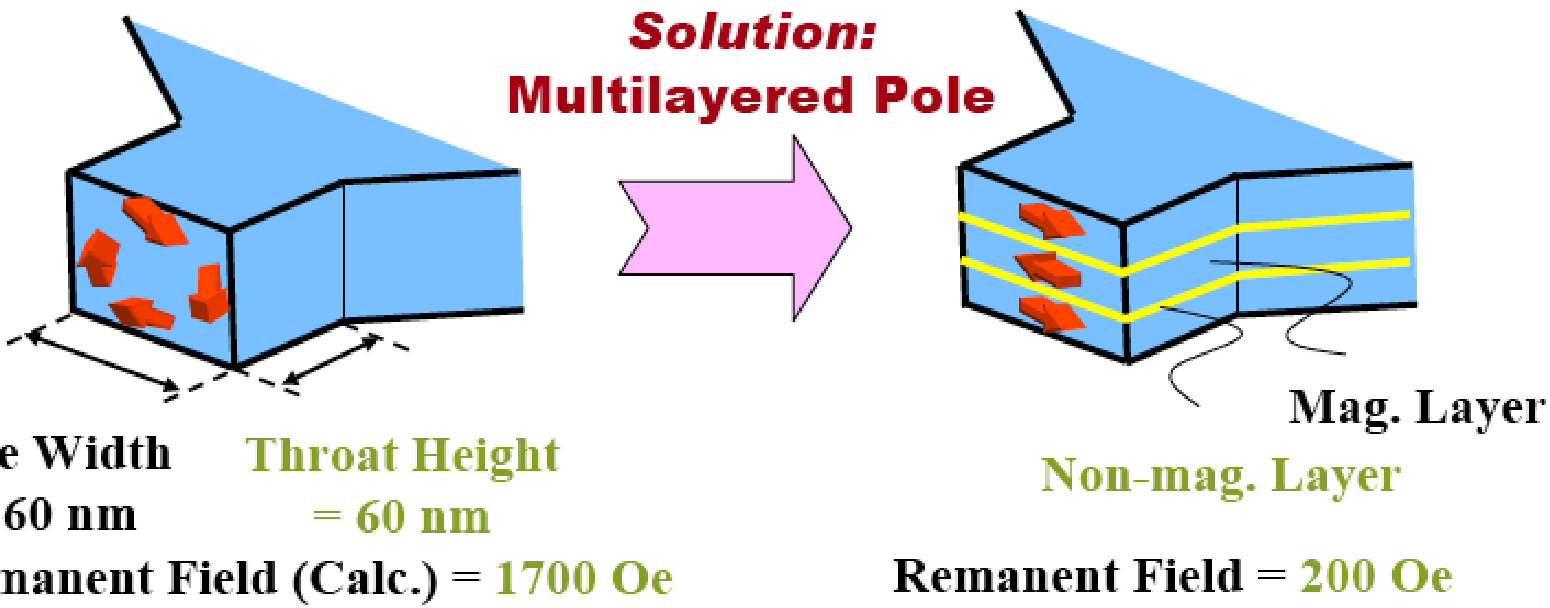
Solution: side-wall bevel

Ensures all features of pole-tip always stay within trailing edge

Magnetic Write Heads: remanence

Output Instability
due to unpredictable
head remanence
causing data erasure





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- Key Technology Components:
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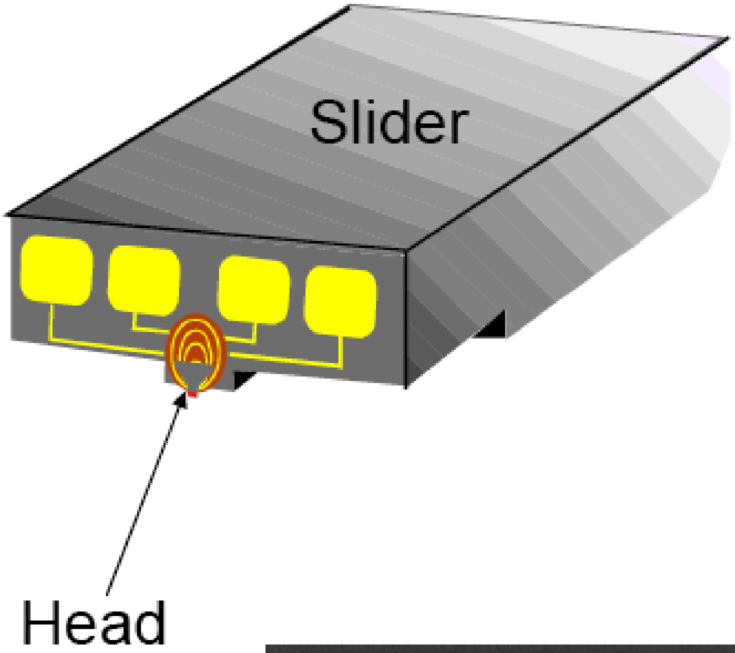
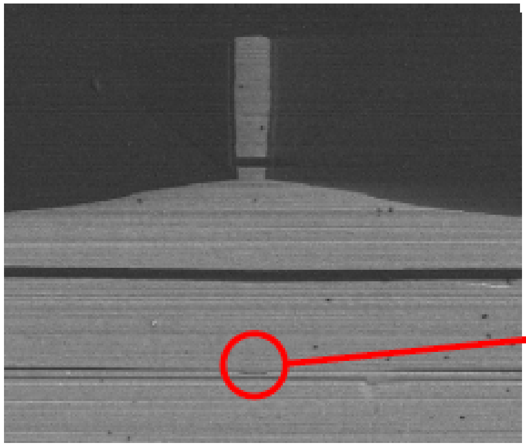
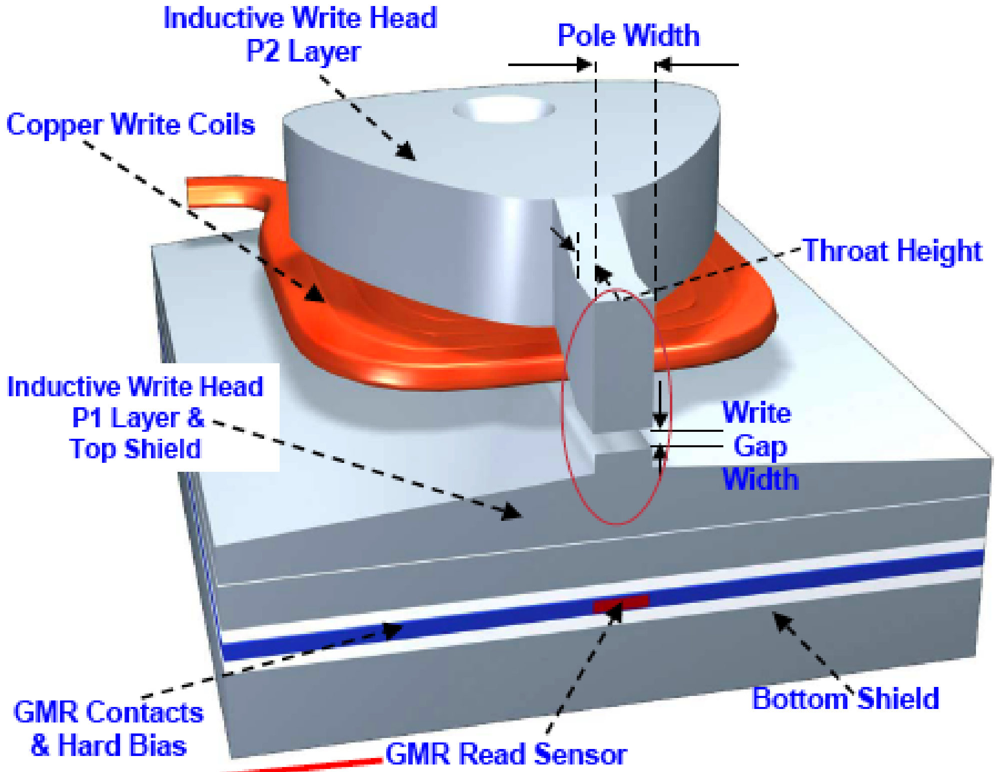
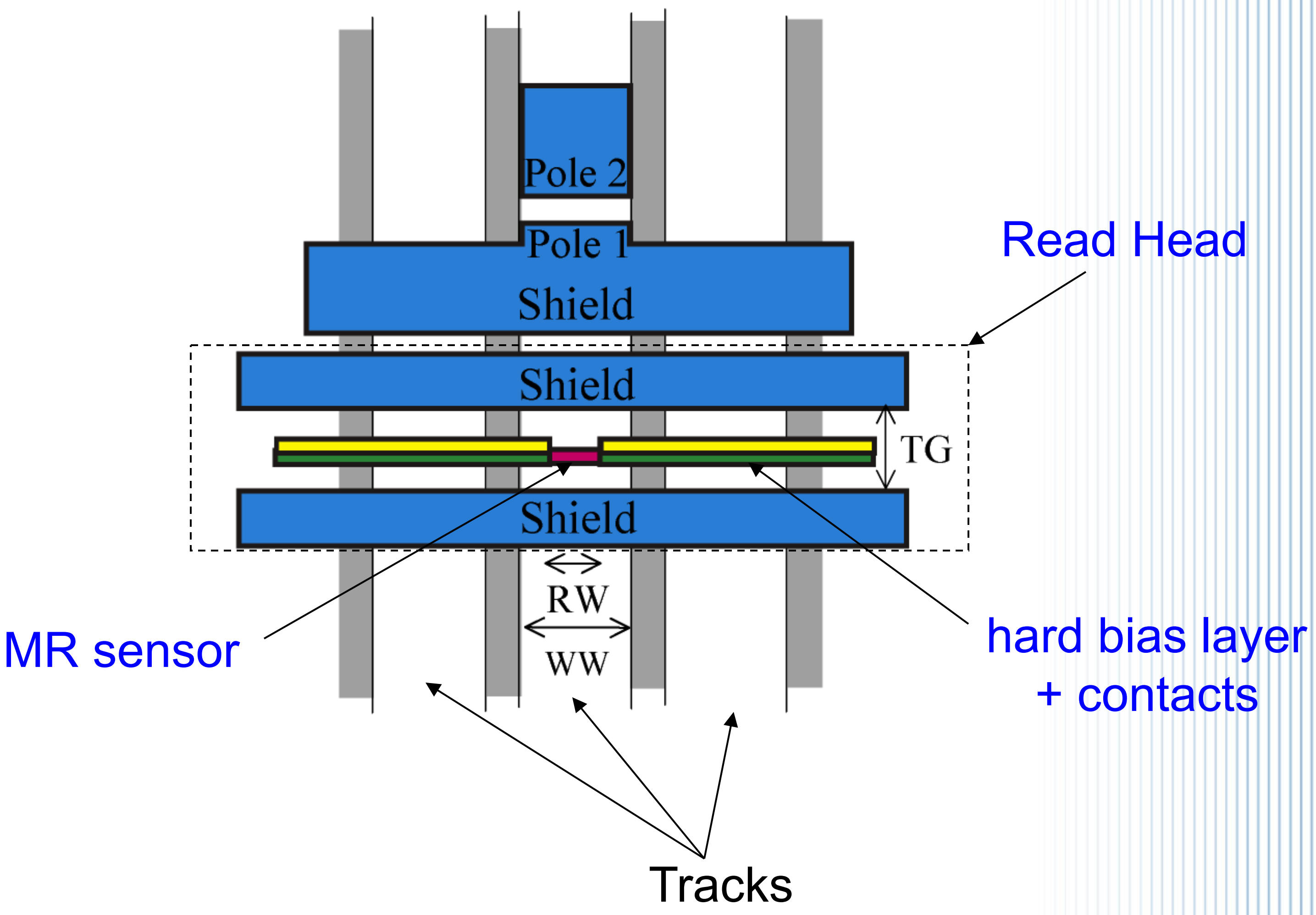
Magnetic Read Heads





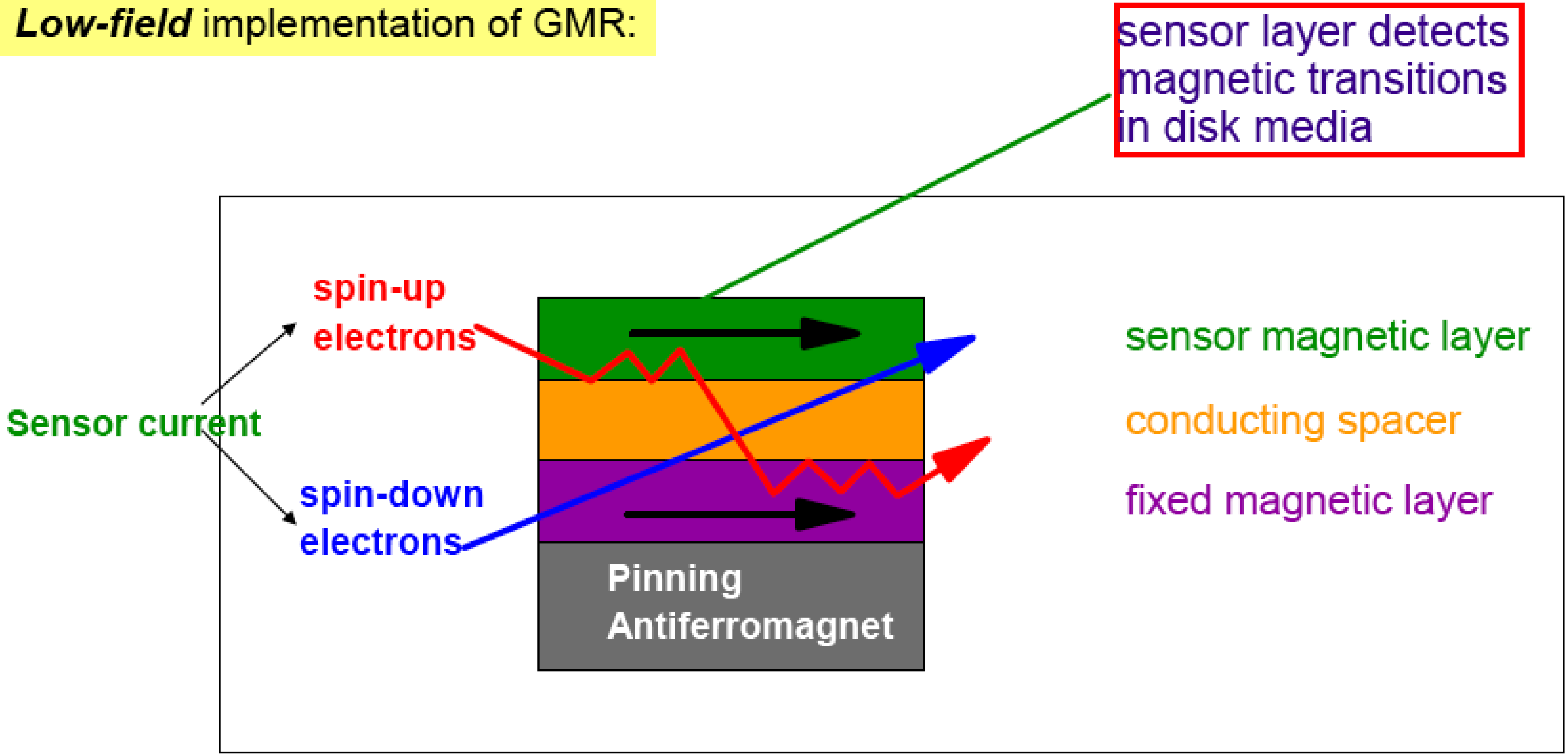


Magnetic Read Heads



Magnetic Read Heads

Low-field implementation of GMR:

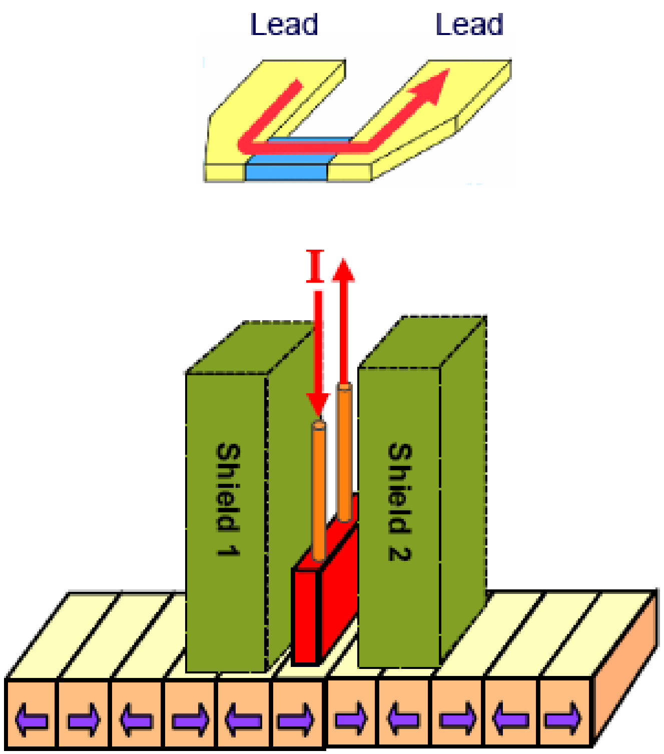


Parallel state: $\rho_{down} << \rho_{up}$ [short-circuit]

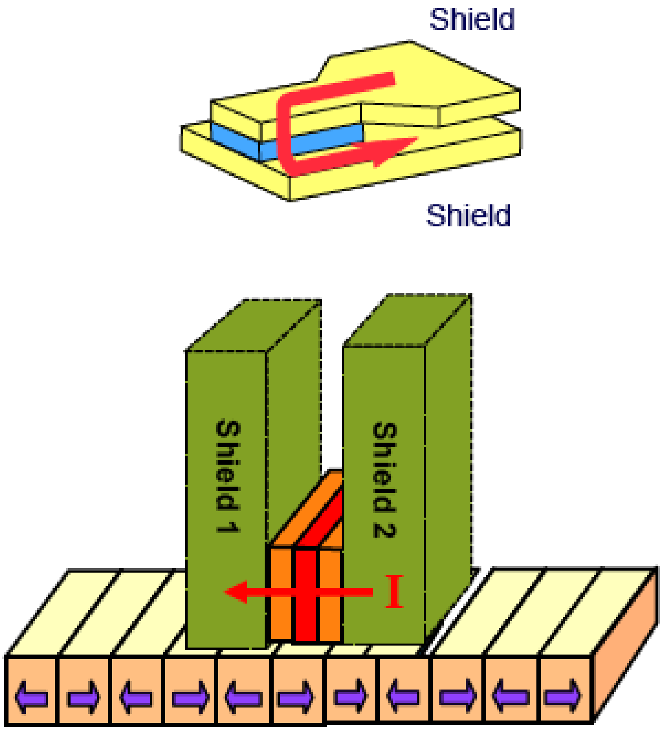
Antiparallel state: $\rho_{down} \sim \rho_{up}$ [average resistivity]

Magnetic Read Heads

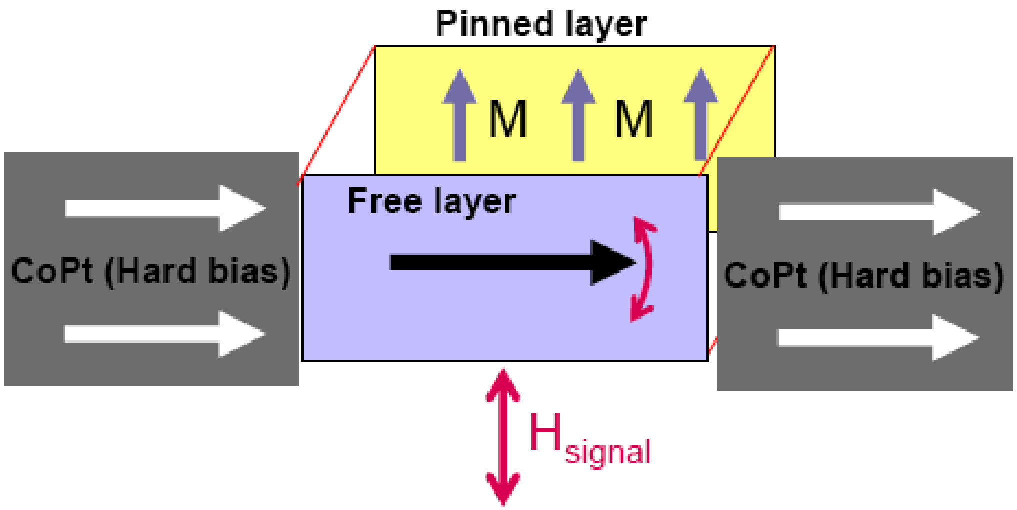
CIP: Current
In The Plane

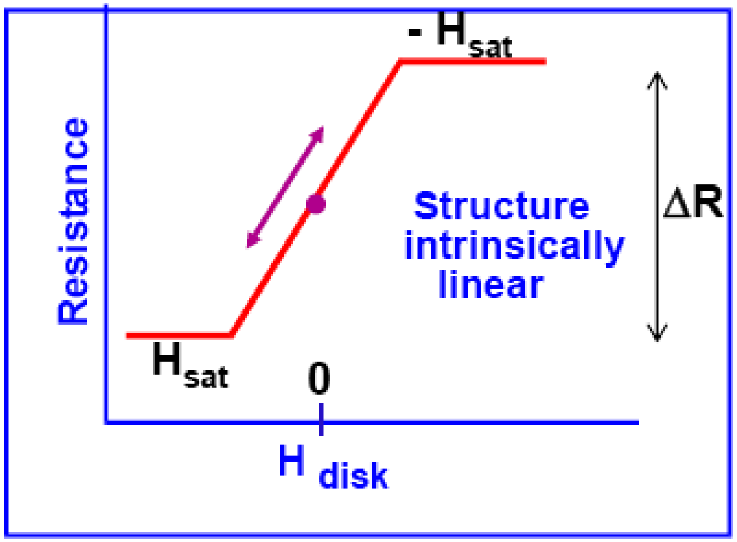


CPP: Current
Perpendicular
To The Plane



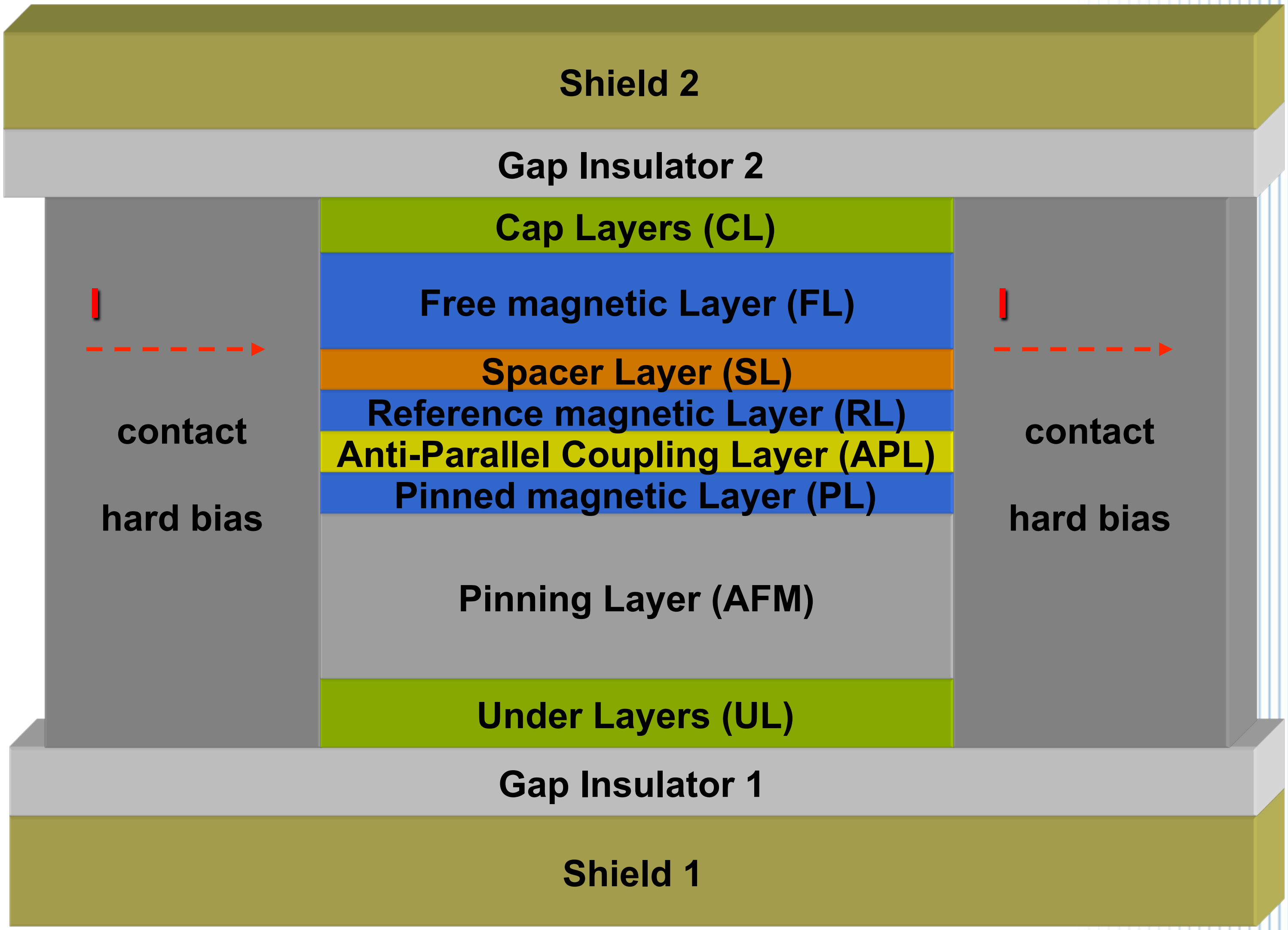
Magnetic Read Heads



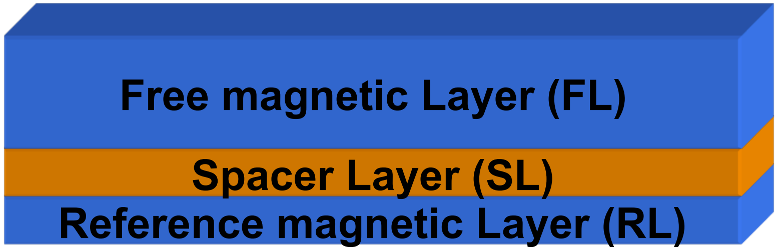


$$R = R_0 + (\Delta R/2)[1\text{-}\cos(\theta)]$$

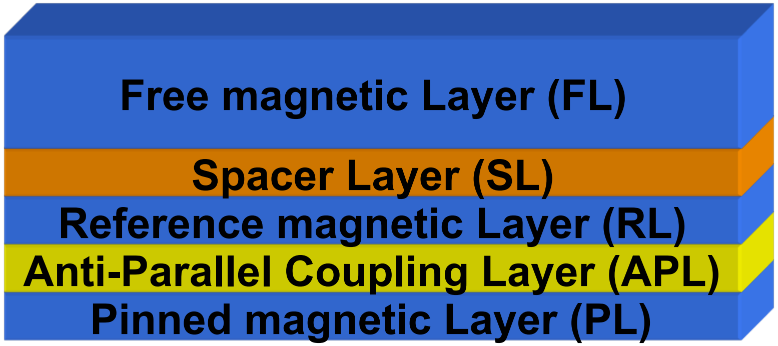
Magnetic Read Heads



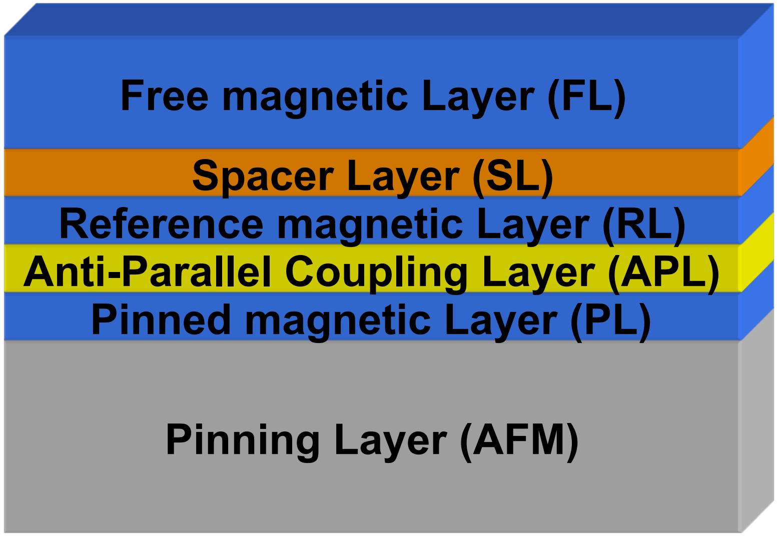
Magnetic Read Heads



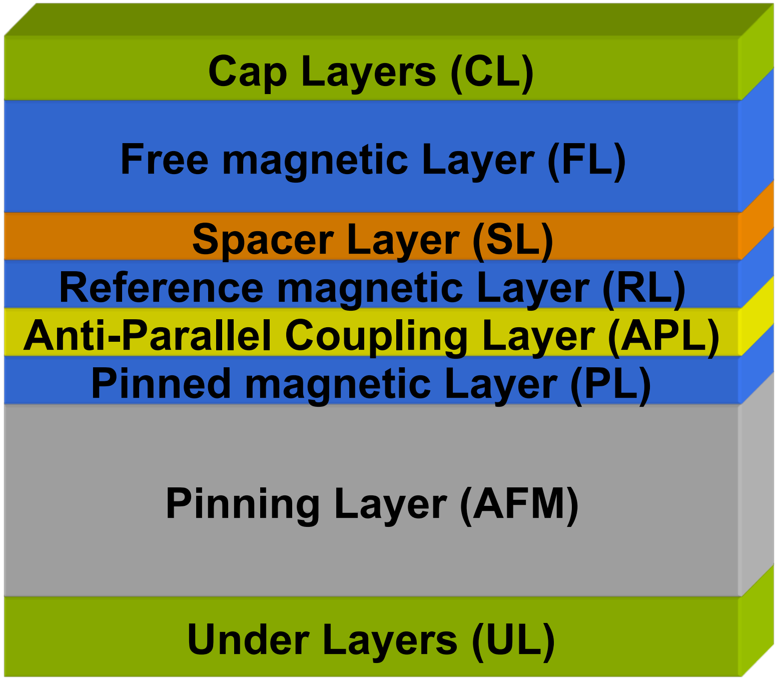
Magnetic Read Heads



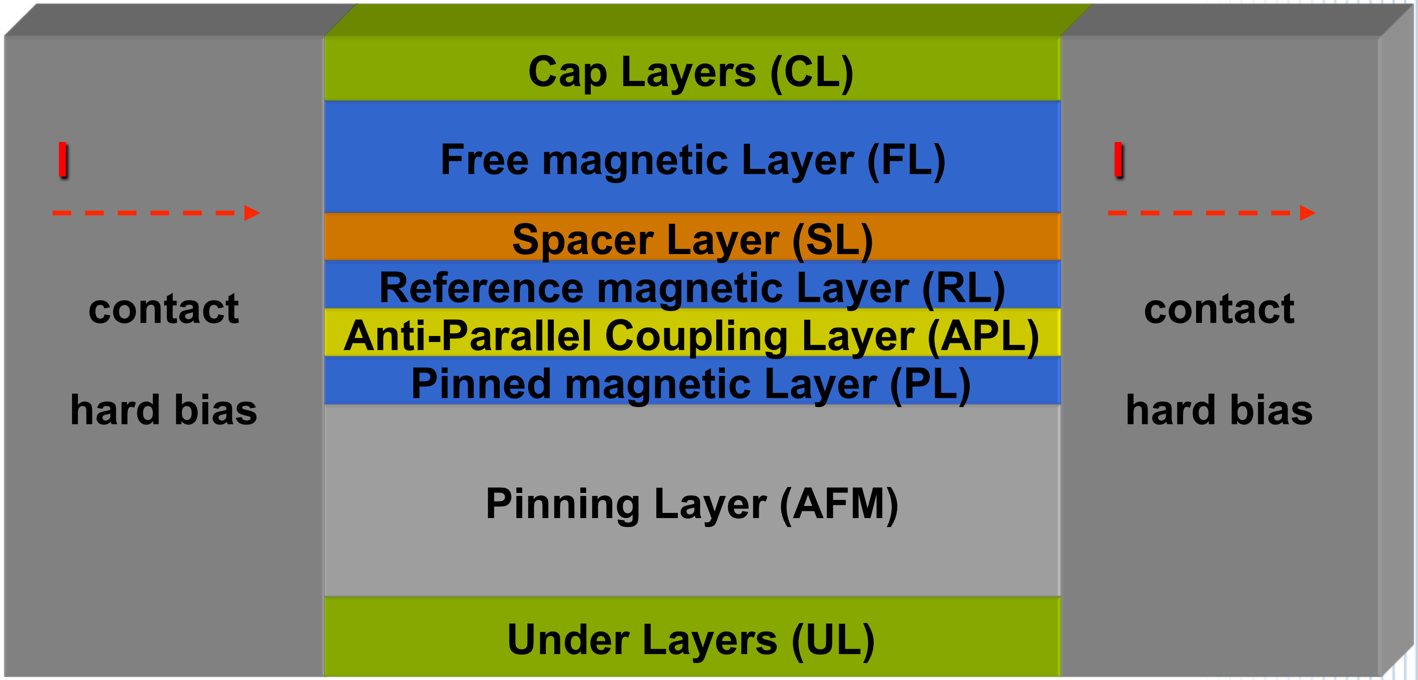
Magnetic Read Heads



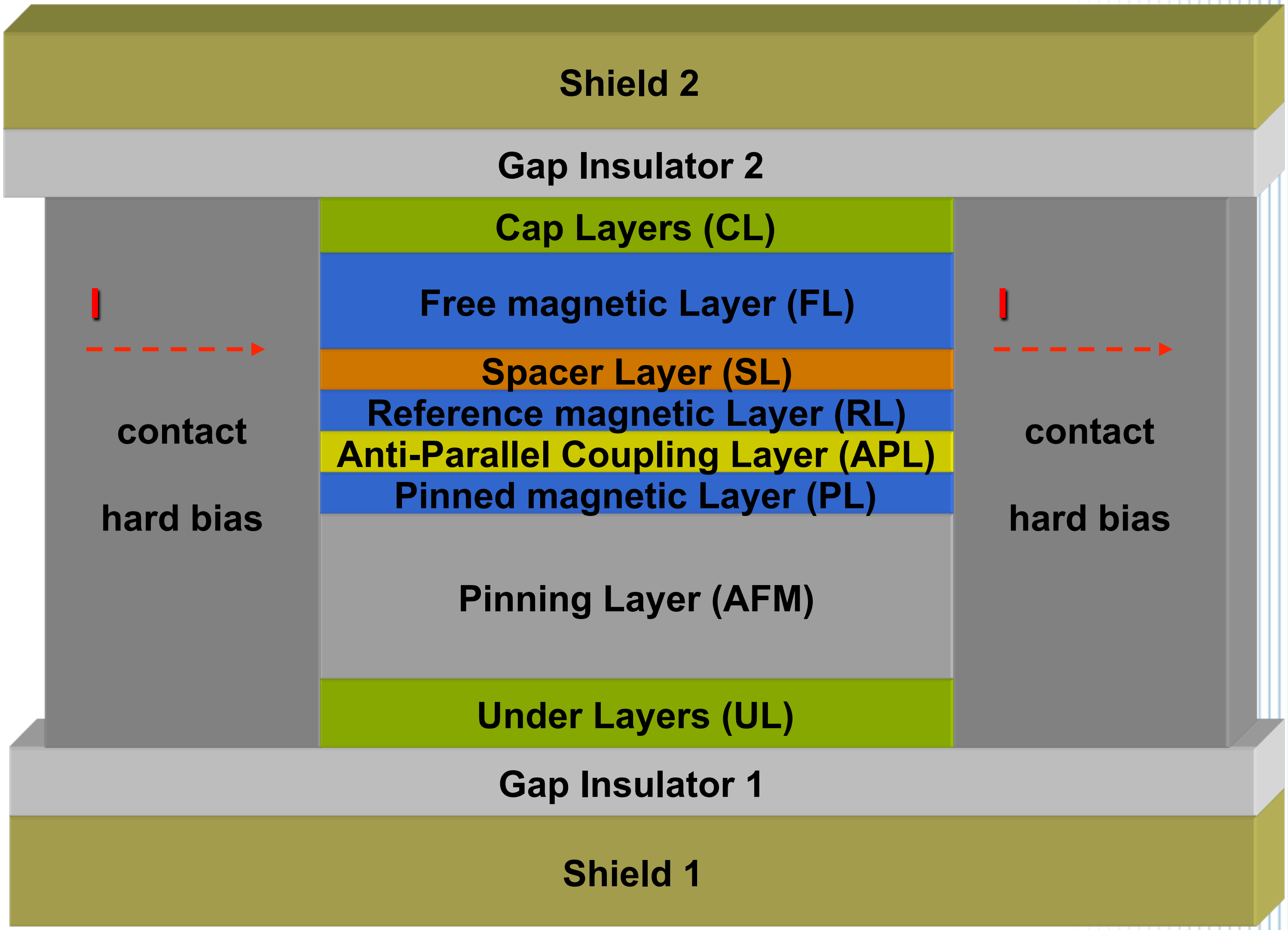
Magnetic Read Heads



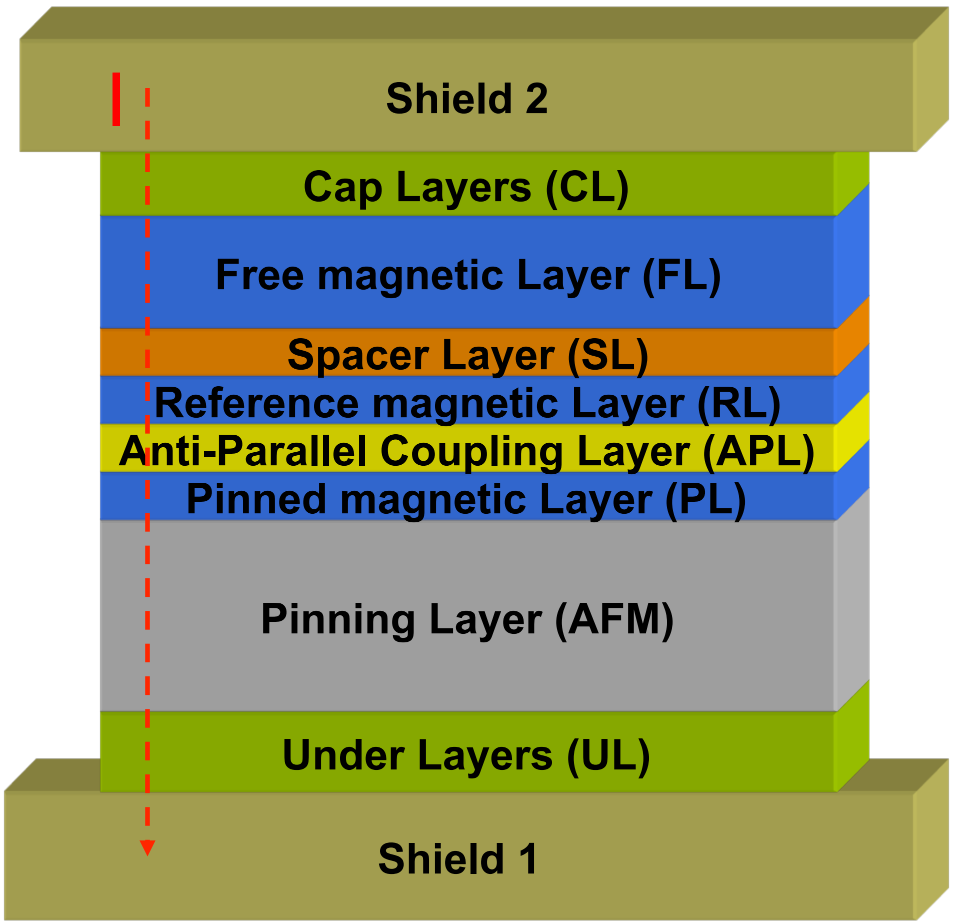
Magnetic Read Heads



Magnetic Read Heads



Magnetic Read Heads



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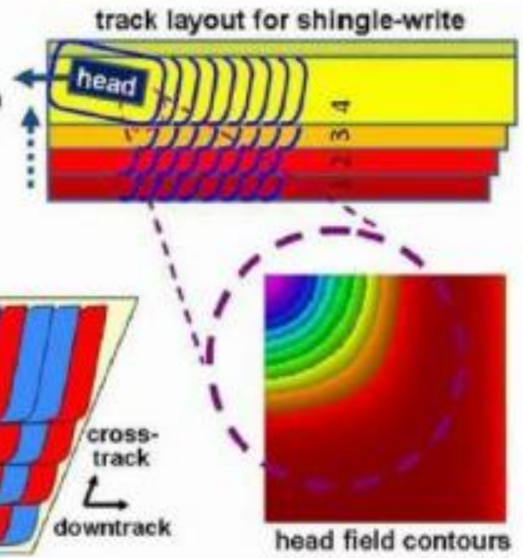
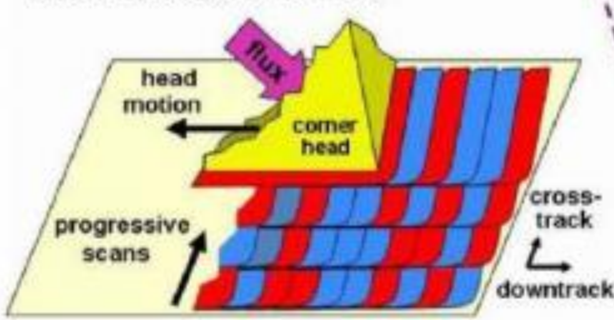
Future Technology Options

SMR (Shingled Magnetic Recording)

Shingle-write Process

- Tracks are heavily overlapped.
- Insensitive to pole-width variation
- Only one corner of write-head is important for design.
- No flux constrictions into head
- No ATE (no repetitive writes)





- ❑ 1.5 times stronger write field
- ❑ Continuous Media
- ❑ Band (Block) write same as SSD
  - Complex write process, but much less ATE concern.
- ❑ No pole width related yield loss.
- ❑ About 30% higher TPI due to smaller side erase band.

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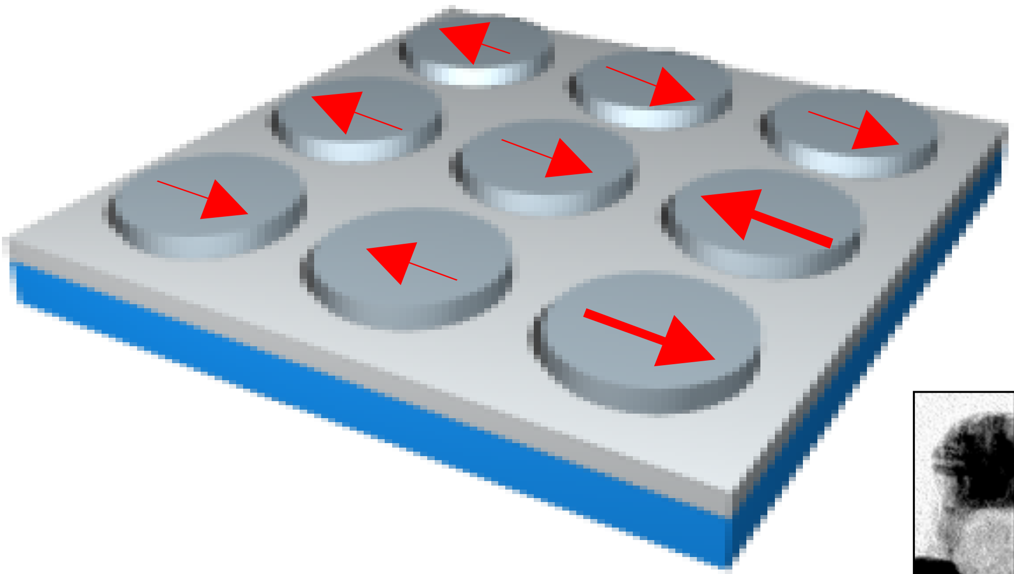
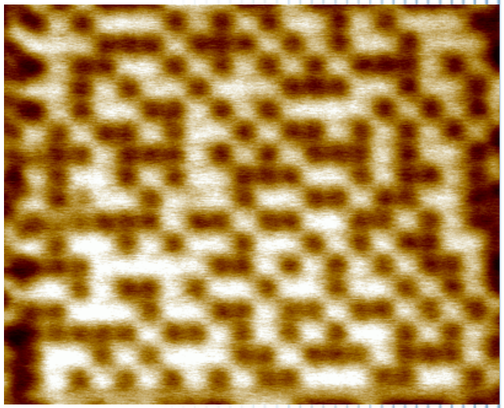
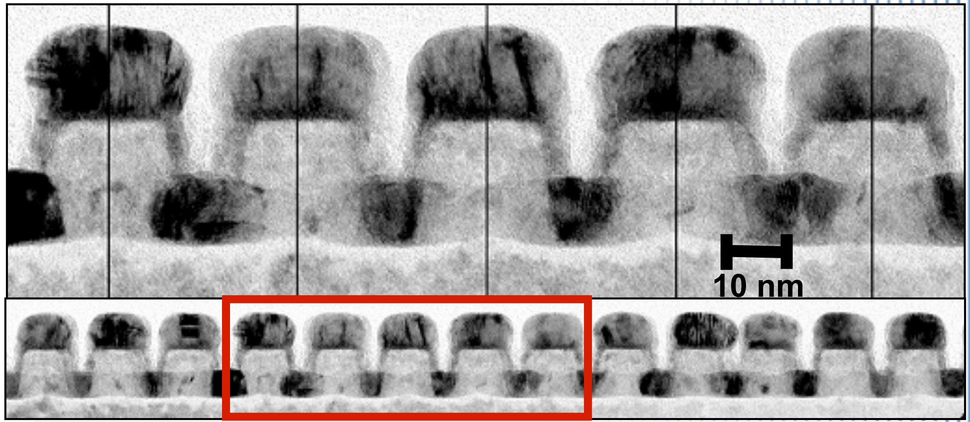
Future Technology Options

Bit Patterned Media





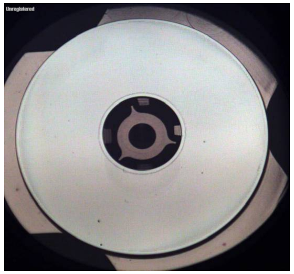


Magnetic dots - 500 Gb/in^2 patterns

Future Technology Options

Bit Patterned Media

Existing
New

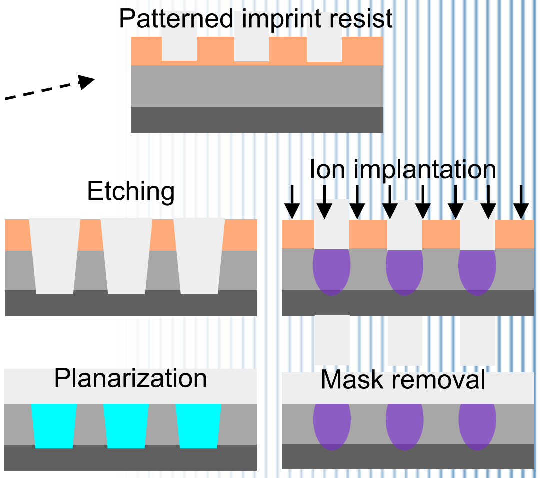


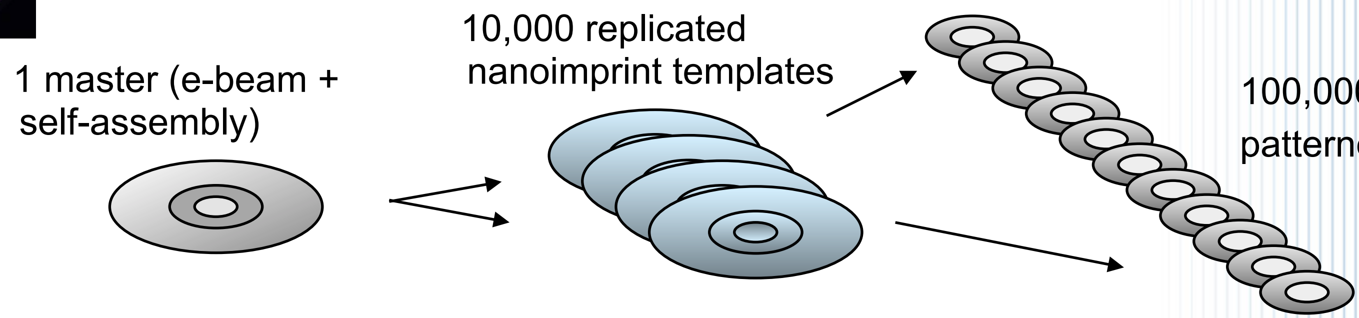
Template Fabrication

- Rotary stage e-beam Patterning
- Directed self-assembly
- Master template fabrication
- Template replication

Media Fabrication Process

- PMR media deposition
- Nanoimprint
- Pattern transfer (etch / implant)
- Planarization
- Lube and burnish
- Inspection

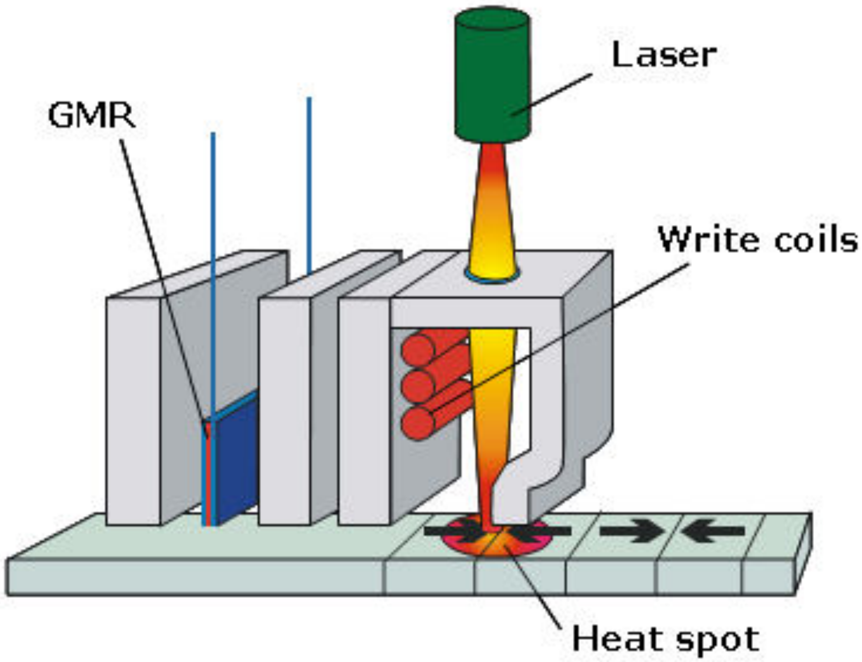




HITACHI
Inspire the Next

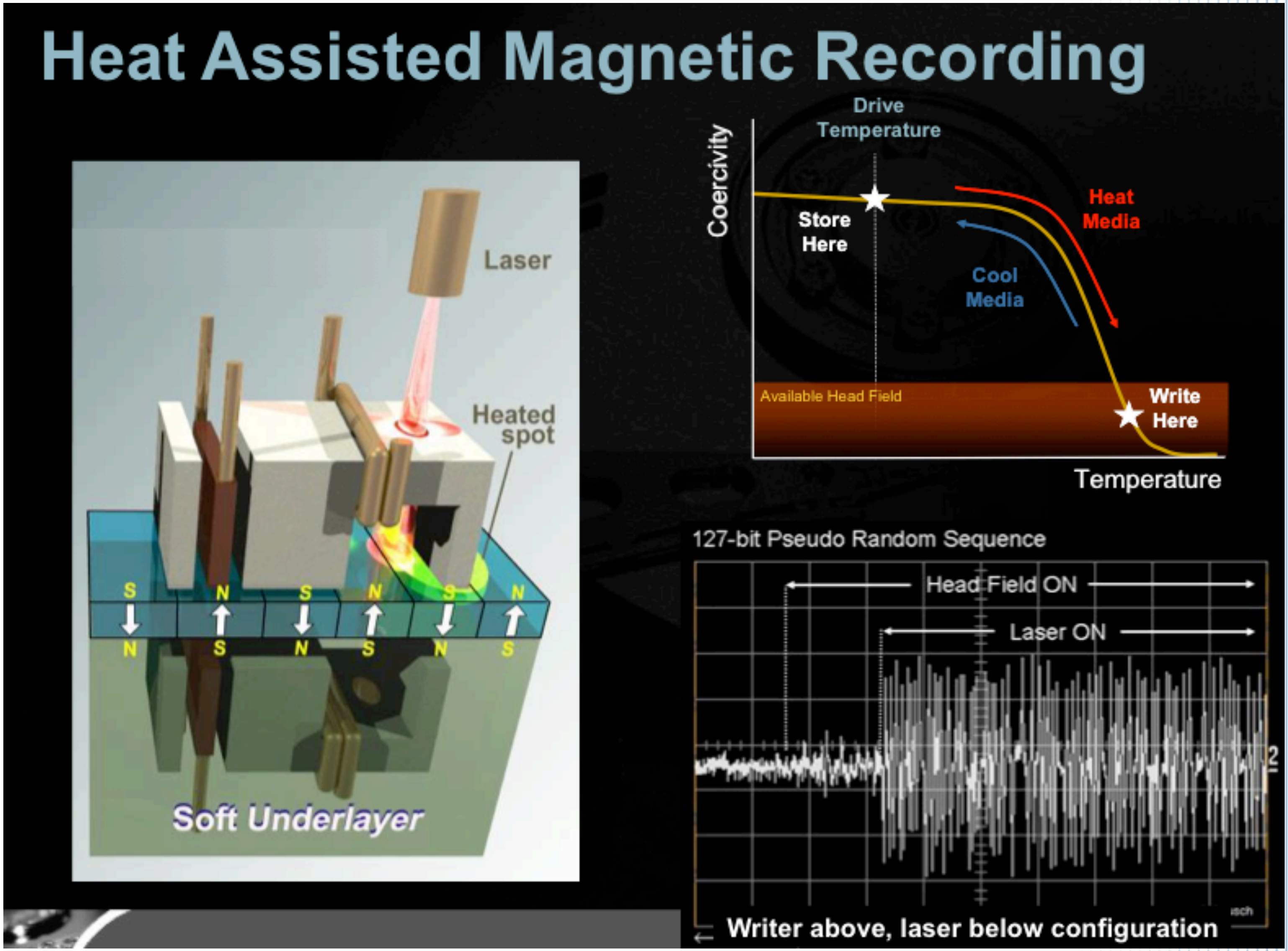
Future Technology Options

Heat Assisted Magnetic Recording



- Writing process at high temperature (other phase)
- Storage and Stability at room temperature

Future Technology Options



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