Transition from AMR to GMR Heads in Tape Recording

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Outline

- Basics of magnetic recording
  - > AMR (Anisotropic Magneto-Resistance)
  - > GMR (Giant Magneto-Resistance)
- Transition in disk from AMR to GMR
- Issues surrounding the transition from AMR to GMR in tape

Digital Magnetic Recording

Channel converts digital user data to analog signal

↓

Head writes data to media

↓

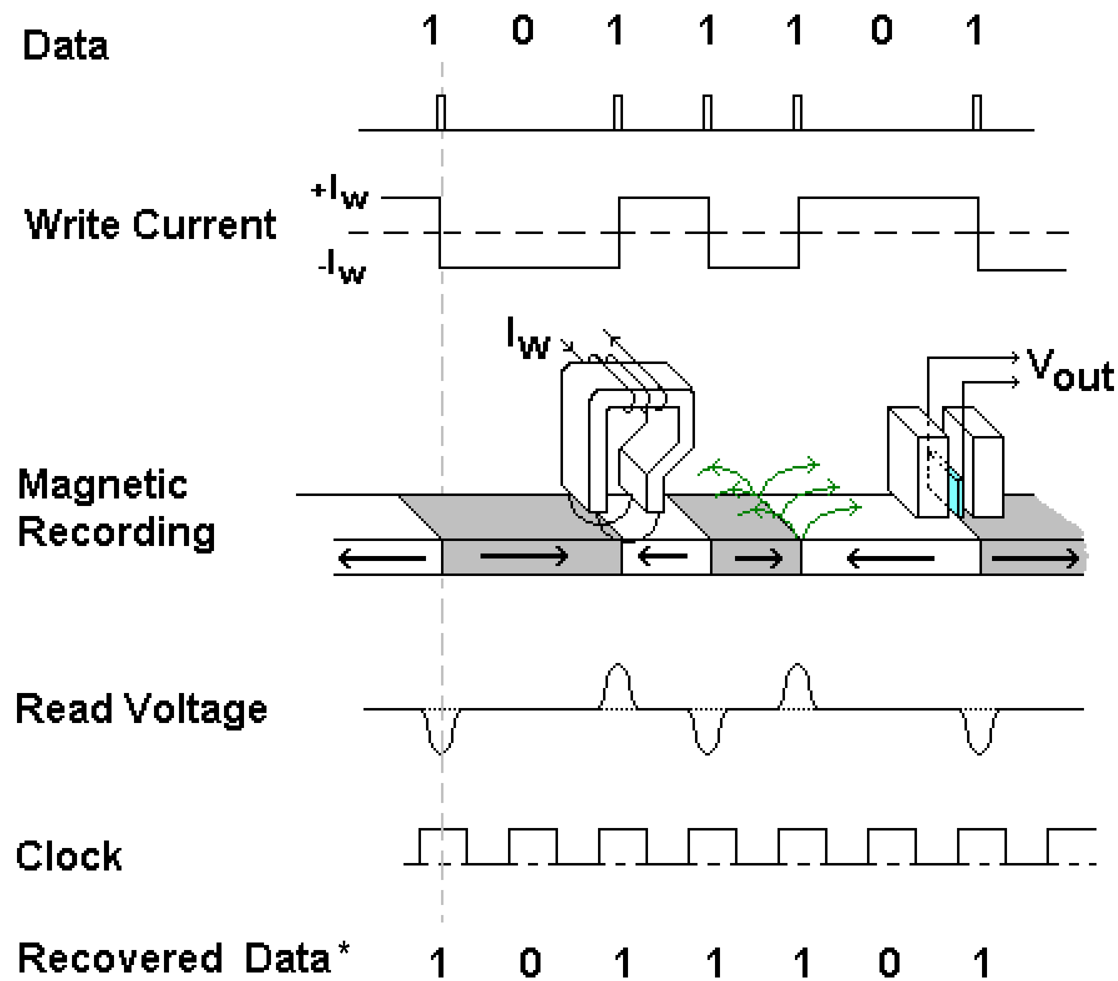
Media stores data

↓

Head reads data from media

↓

Channel converts analog signal to digital user data



*Using a peak detect channel

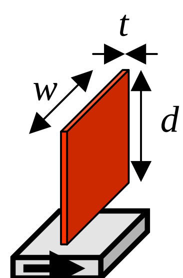
Magnetic Read Sensors

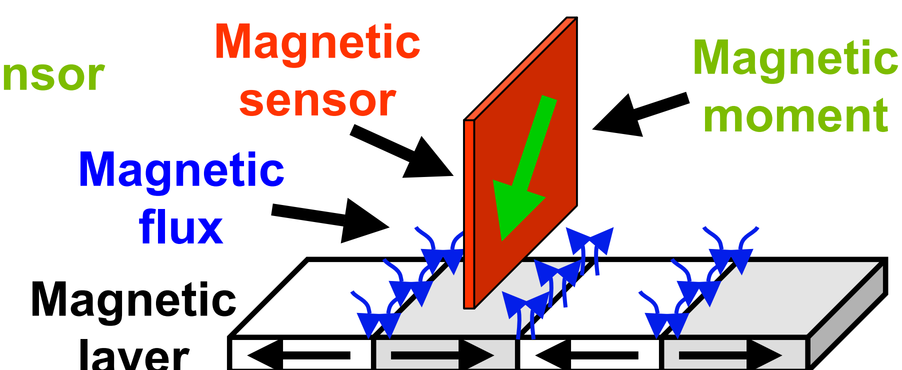
- Allow system to resolve changes in the magnetic media which stores the user information
- Two types in magnetic recording
  - Inductive: Faraday's Law ($\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$)
  - Magneto-Resistive (MR): electric resistance of the sensor changes with applied magnetic field

Rotation of the magnetization in a MR sensor gives rise to a resistivity change (Δρ)

$$\rho = \rho_0 + \Delta\rho \cdot f(\theta)$$

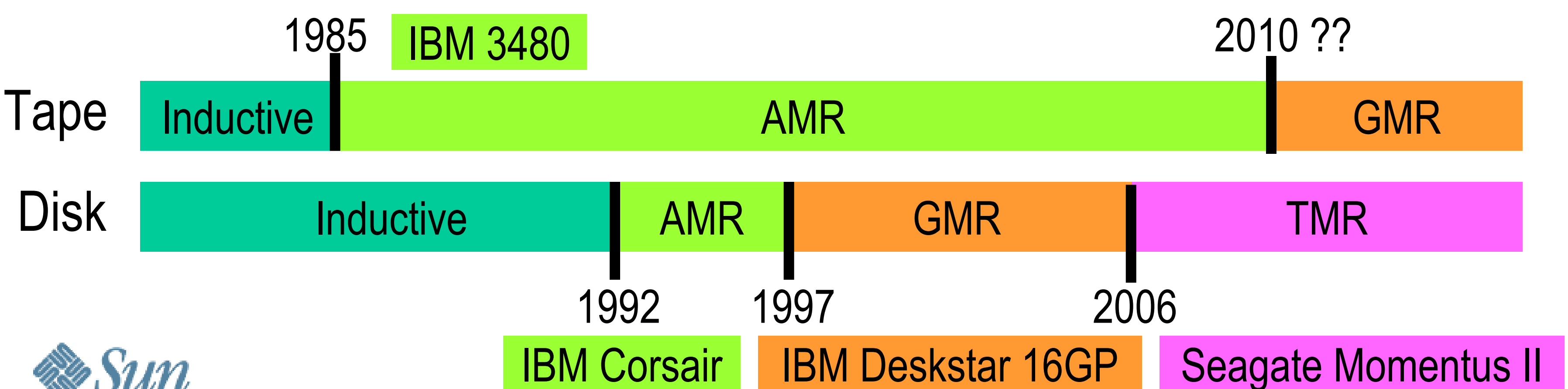
$$\Delta V = I \cdot \Delta R = I \cdot \Delta\rho \cdot \frac{w}{td}$$





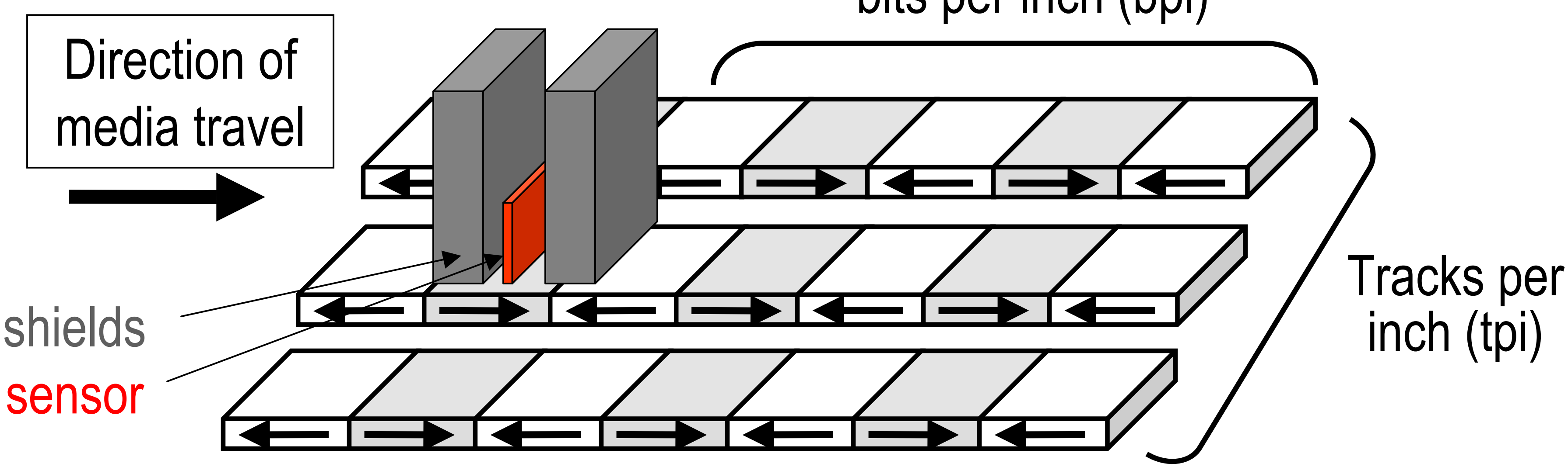
Tape and Disk Sensor Technology

- Inductive
  - > A variable magnetic field from the media will induce a variable voltage in a coil
- Anisotropic magneto-resistance ($\Delta\rho/\rho$ ~ 2% in $Ni_{80}Fe_{20}$)
  - > Bulk effect in ferromagnetic materials
- Giant magneto-resistance ($\Delta\rho/\rho$ ~ 20% in Co/Cu/Co)
  - > Interface effect in thin multilayers
- Tunneling giant magneto-resistance ($\Delta\rho/\rho$ ~ 250% in Co/MgO/Co)
  - > Coherent tunneling effect across an insulator

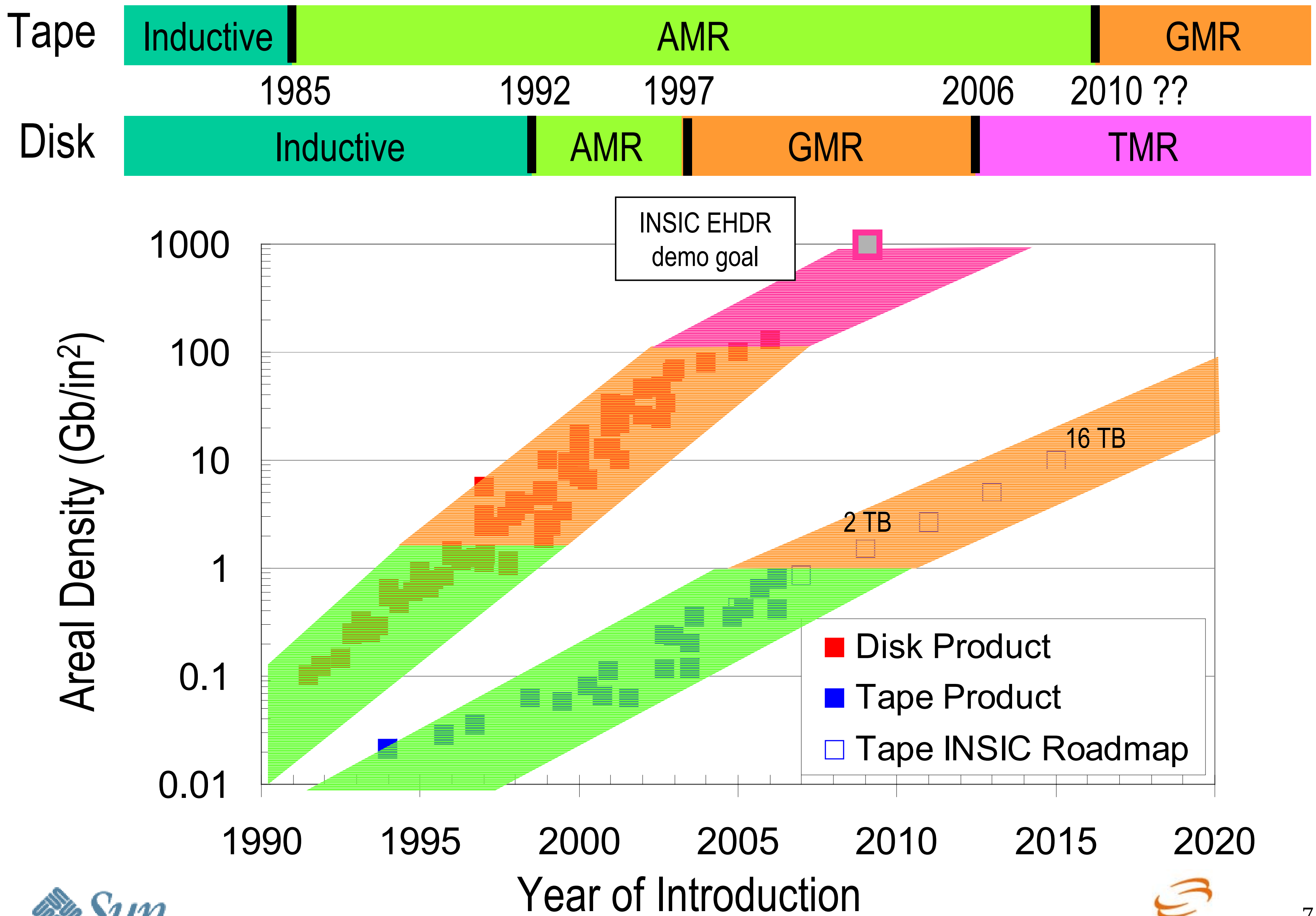


Magnetic Recording

- Tape area – width (½") and length (900 m)
  - > ~ 18,000 in^2
- Disk area – area of a platter and number of platters
  - > ~ 8 in^2 for 1 single-sided platter

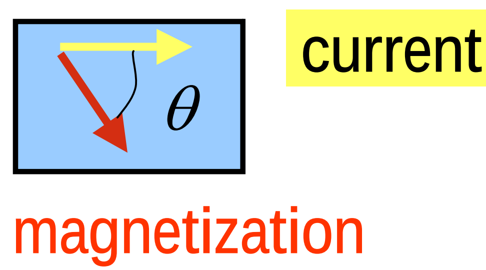


Areal density (bits/in^2) = tpi · bpi


Tape
Inductive
AMR
GMR
1985
1992
1997
2006
2010 ??
Disk
Inductive
AMR
GMR
TMR
INSIC EHDR demo goal
1000
100
10
1
0.1
0.01
Areal Density (Gb/in²)
16 TB
2 TB
Disk Product
Tape Product
Tape INSIC Roadmap
1990
1995
2000
2005
2010
2015
2020
Year of Introduction

AMR Response

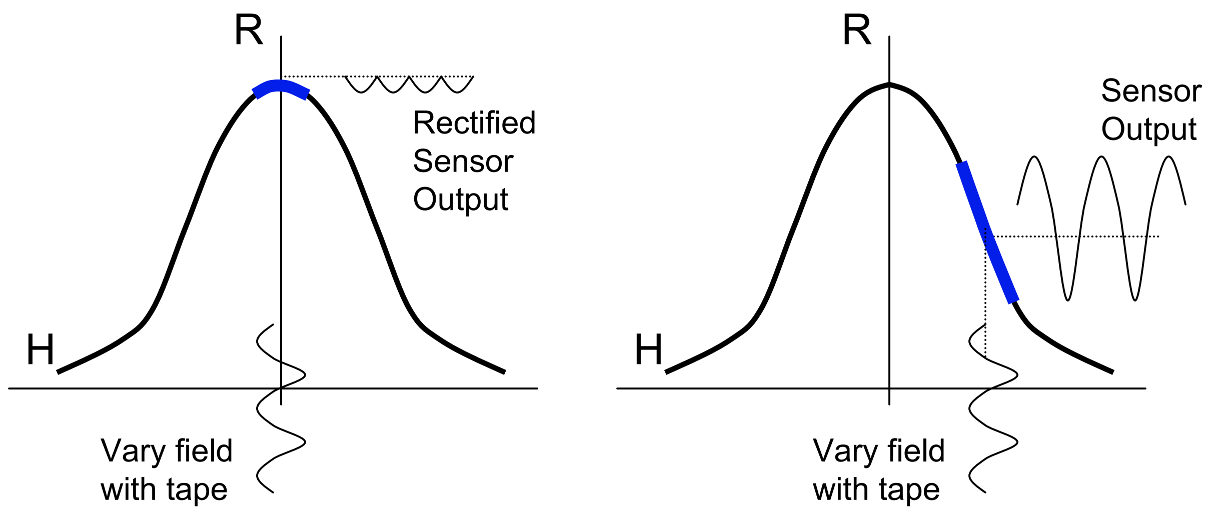
- Anisotropic Magneto-Resistance (AMR) is a bulk effect in Permalloy ($Ni_{80}Fe_{20}$) and other ferromagnetic materials
  - > Optimum bias at 45 degrees



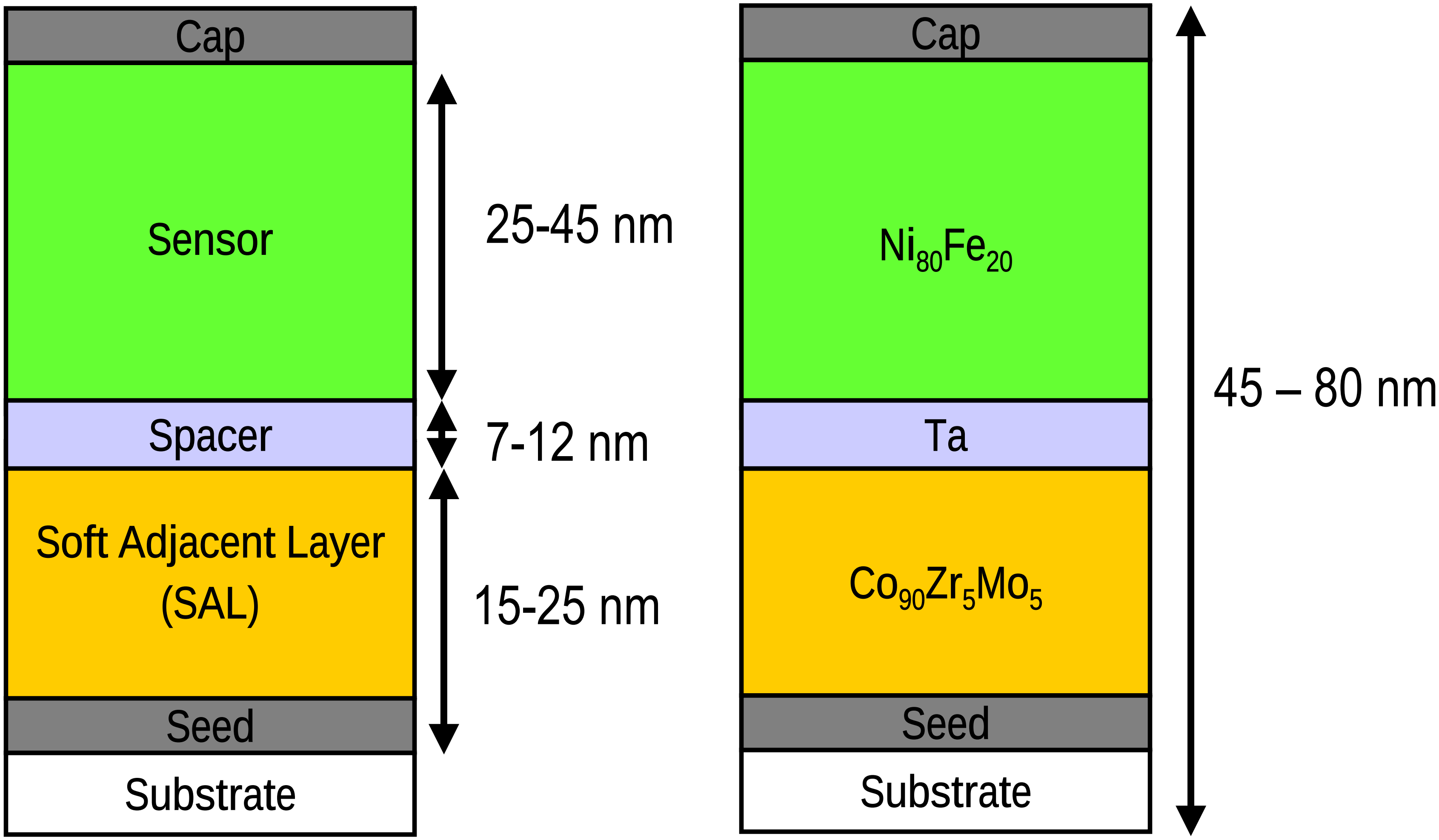
$$\rho(H) = \rho_0 + \Delta\rho_{AMR}\cos^2\theta(H)$$

AMR:

Goal is to offset the bias field

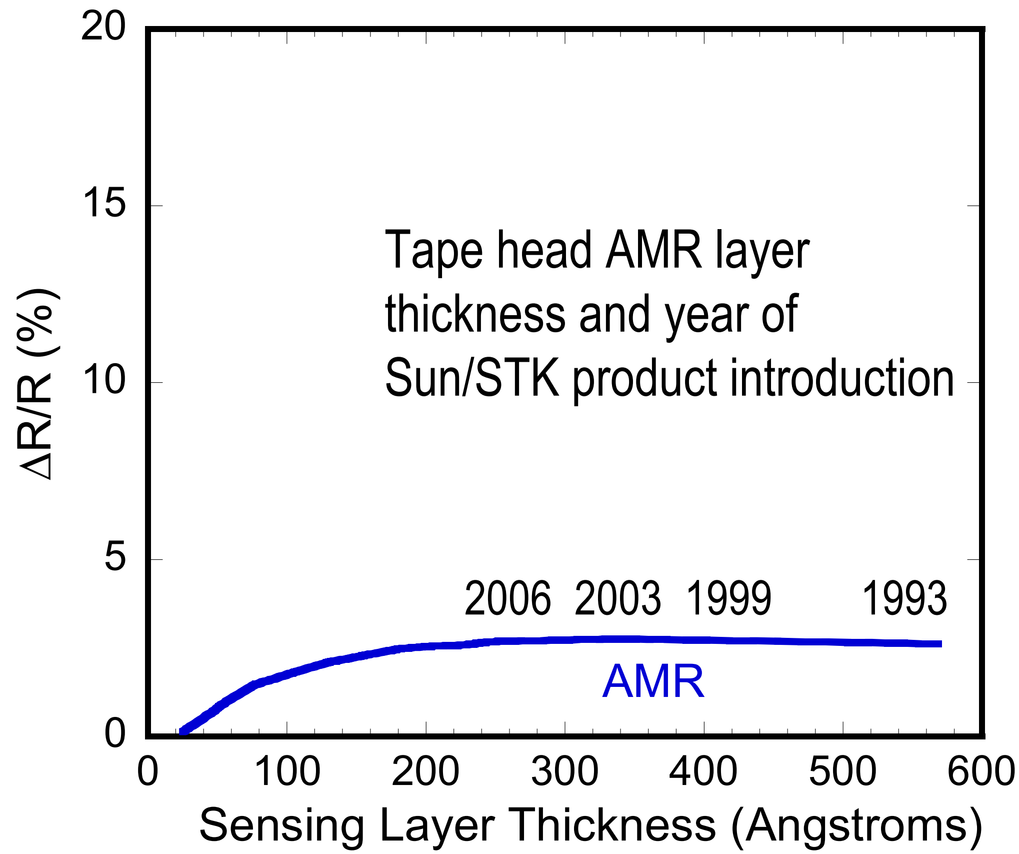


AMR Sensor Stack Materials

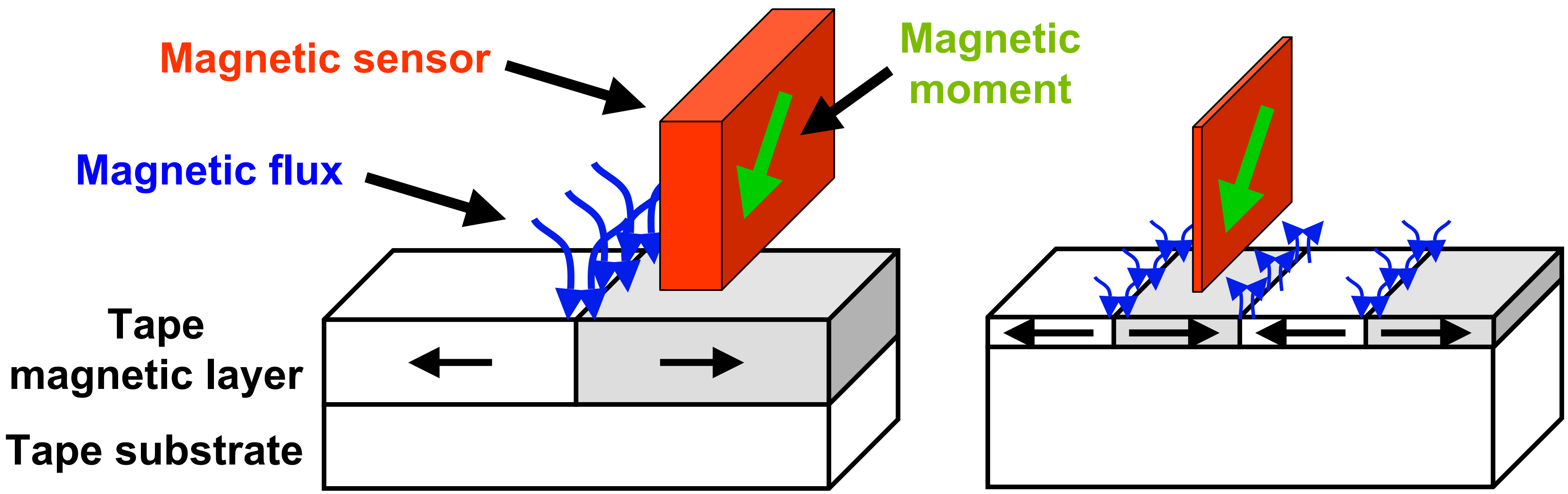


Why Switch from AMR?

- AMR is a good sensor (and still used by tape)
- BUT, it has a problem. Output decreases as sensor thickness decreases
- Why has sensor thickness decreased over time?



Achieving Higher Densities



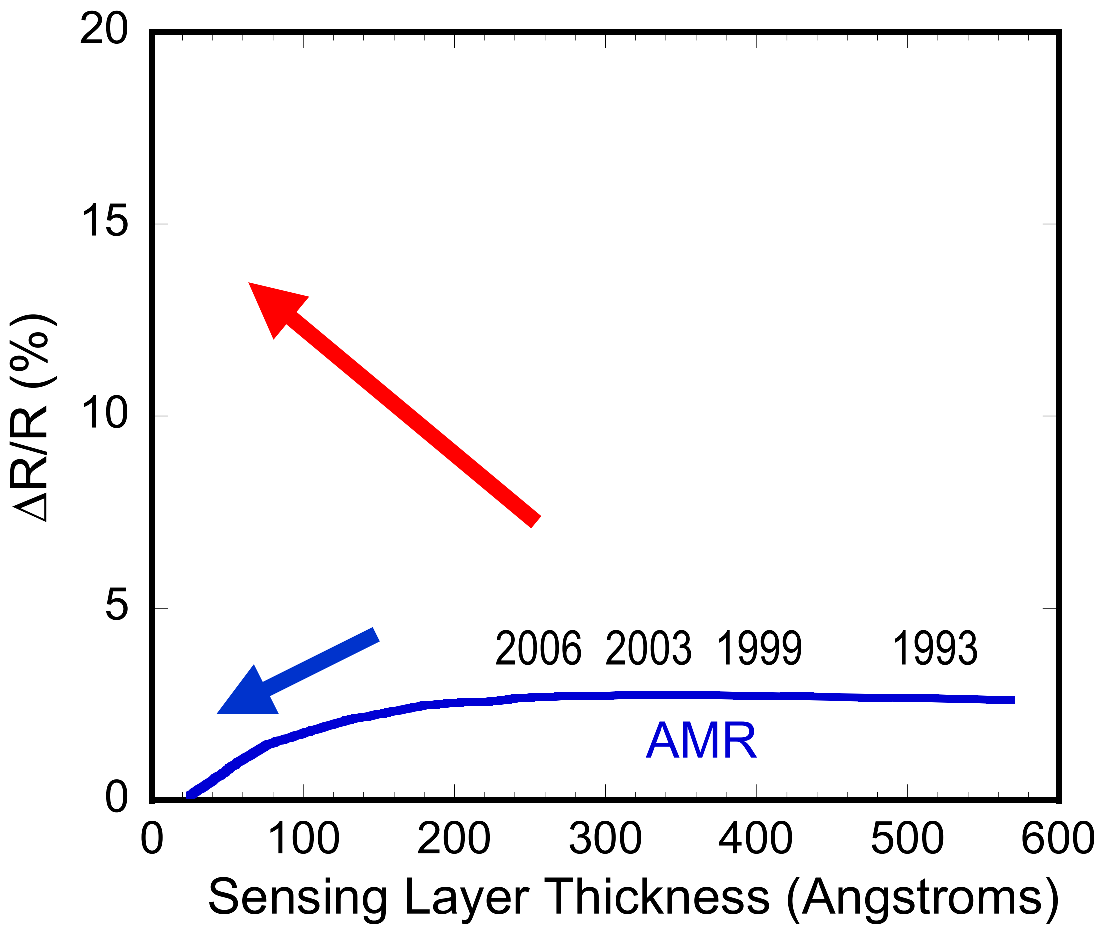
Thick media → low density → lots of flux
Thick sensor to match flux

Thin media → high density → less flux
Thin sensor to match flux

Sensor for higher densities:

1. Thinner sensor (for thinner media)
2. Higher sensitivity (to make up for reduced flux)

Decreasing Thickness Penalty in AMR



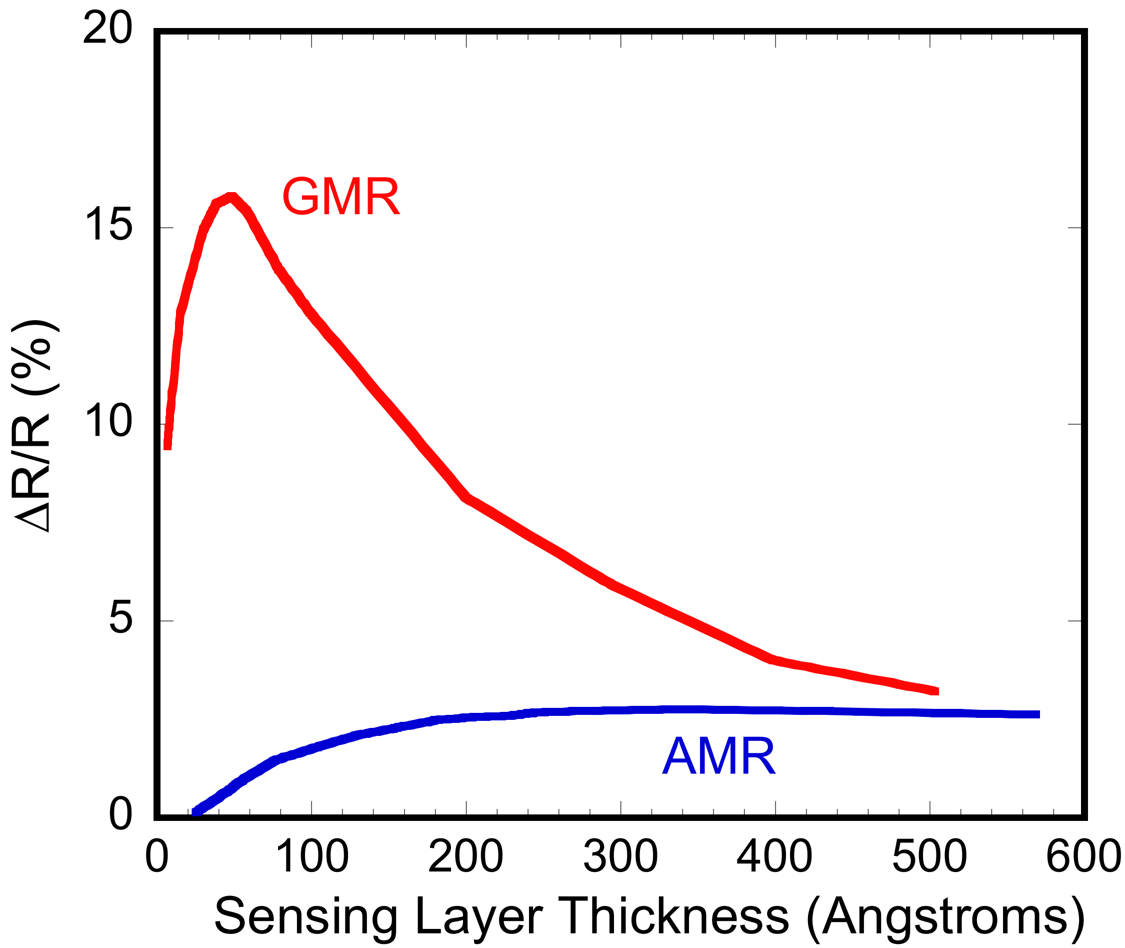
Thinning the sensor allows higher density BUT the signal goes down!

Want something that can increase output with decreasing sensor thickness

Advantage of GMR

GMR is an interface effect

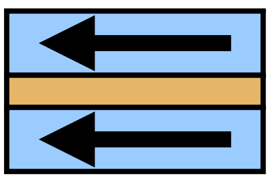
AMR is a bulk effect, interfacial scattering takes over at small thicknesses

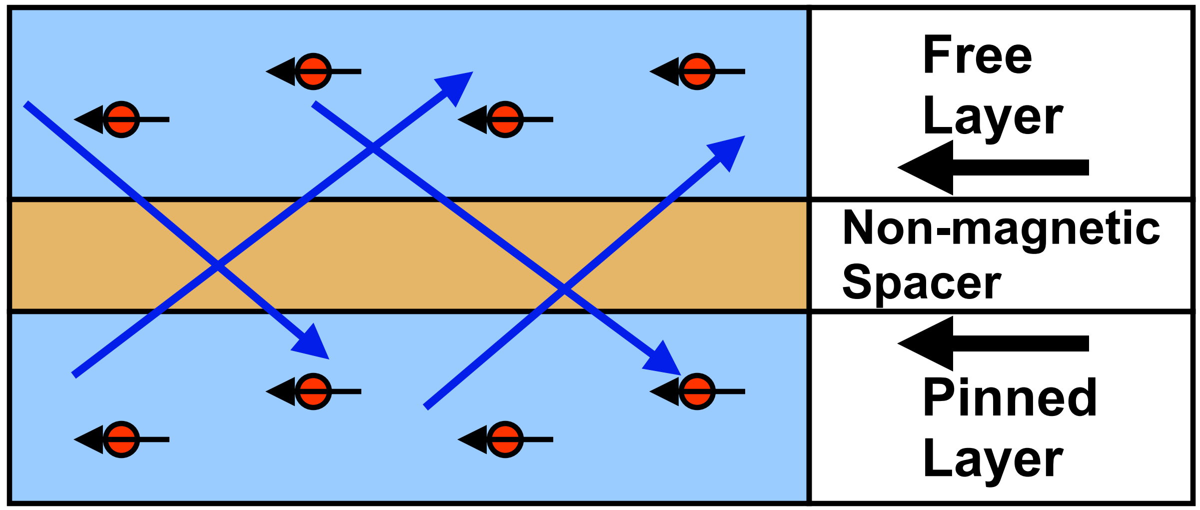


GMR – Spin Dependent Scattering

Aligned moments

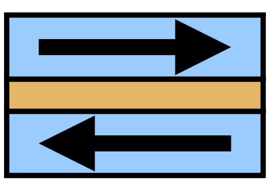
Low Resistance

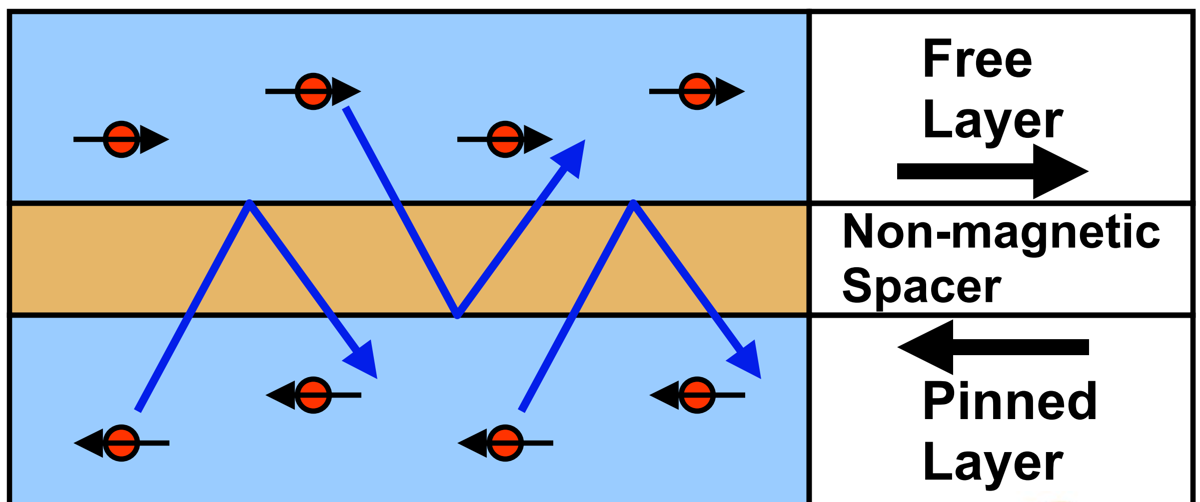




Anti-aligned moments

High Resistance

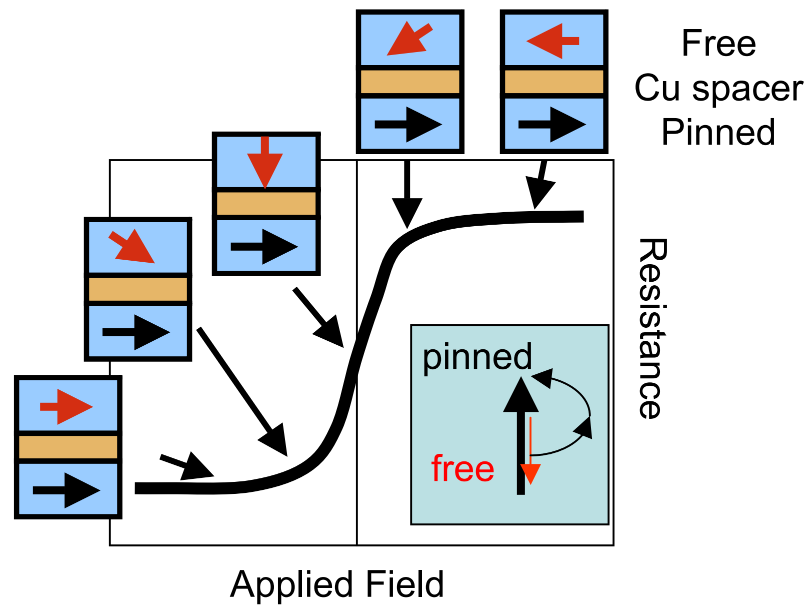




GMR Response

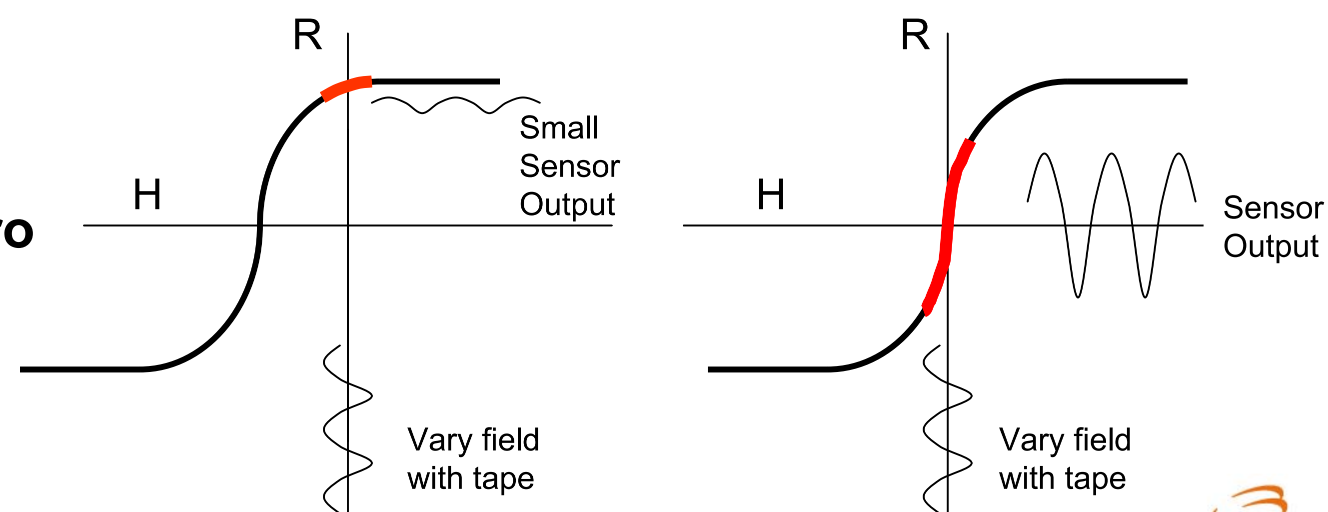
- GMR is an interface effect
  - > Bias at 0 degrees

$$\rho(H) = \rho_0 + \Delta\rho_{GMR} \sin\theta(H)$$



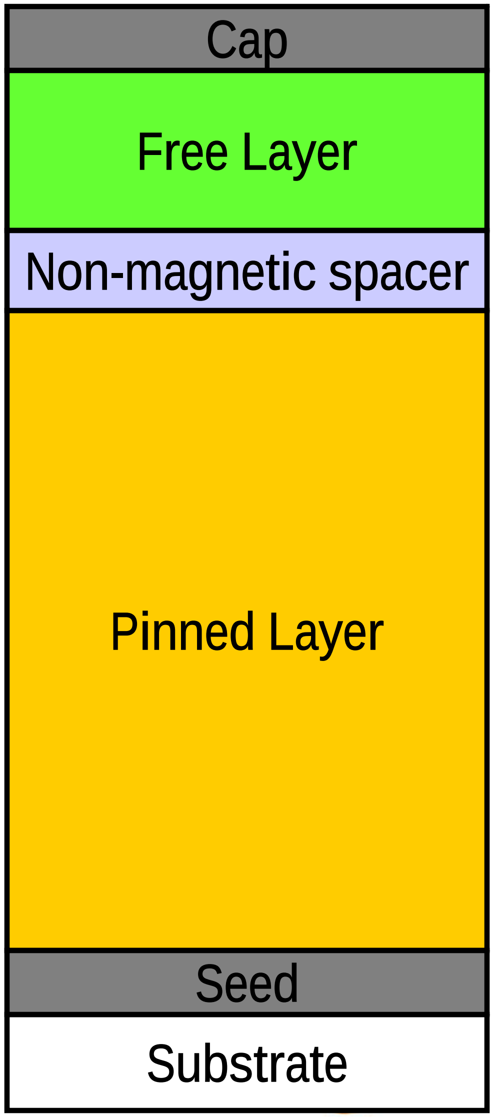
GMR:

Goal is to zero the bias field

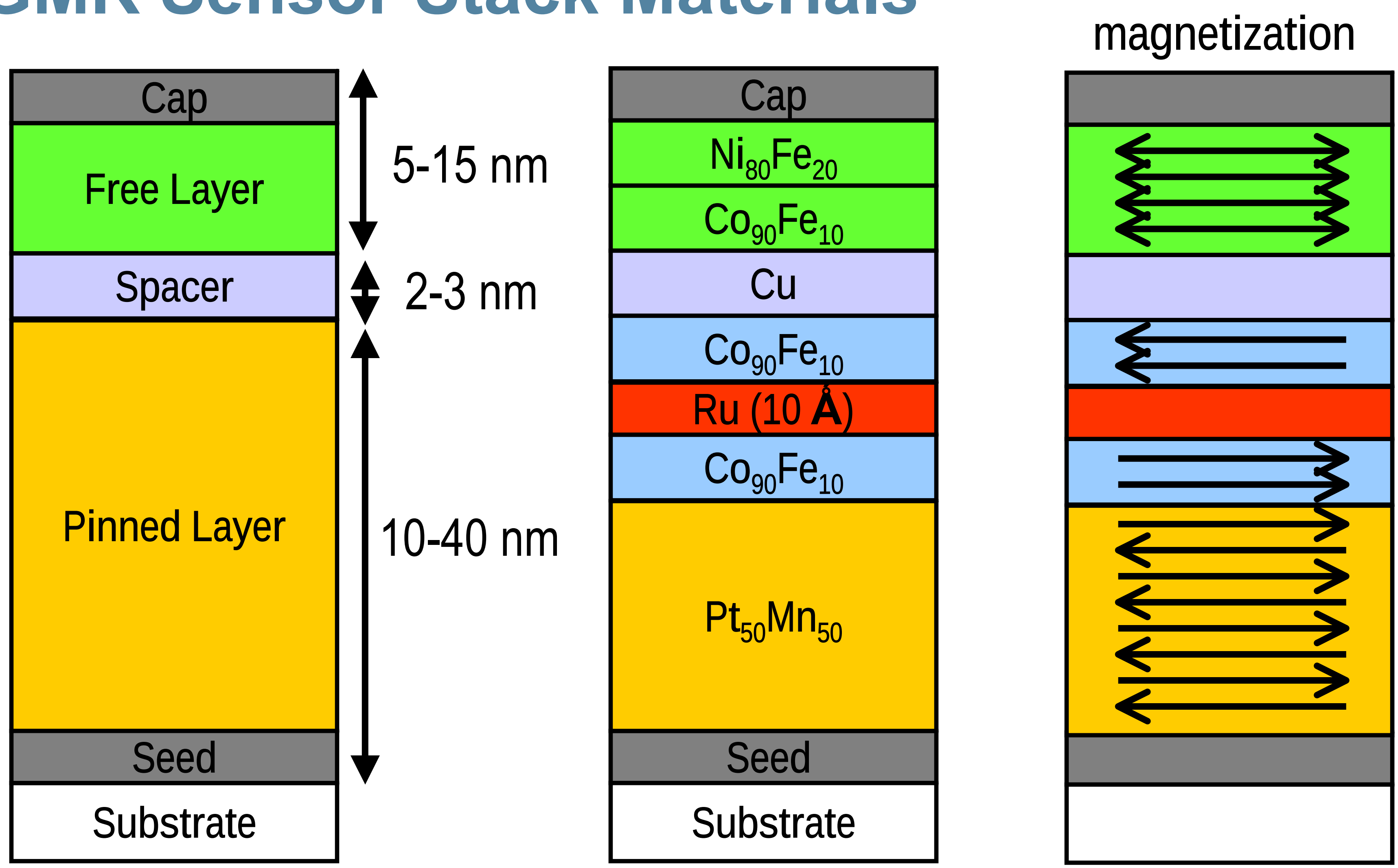


How Do We Make These Structures?

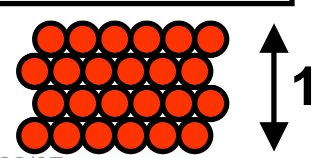
- GMR structures act as a spin valve
  - > Resistance depends on direction of applied magnetic field on the sensor
- 3 important components
  - > Free layer
    - > Well behaved
    - > Properly oriented and biased
  - > Non-magnetic spacer
    - > Interface properties are important
  - > A solid pinned layer
    - > Won't move with field from tape



GMR Sensor Stack Materials



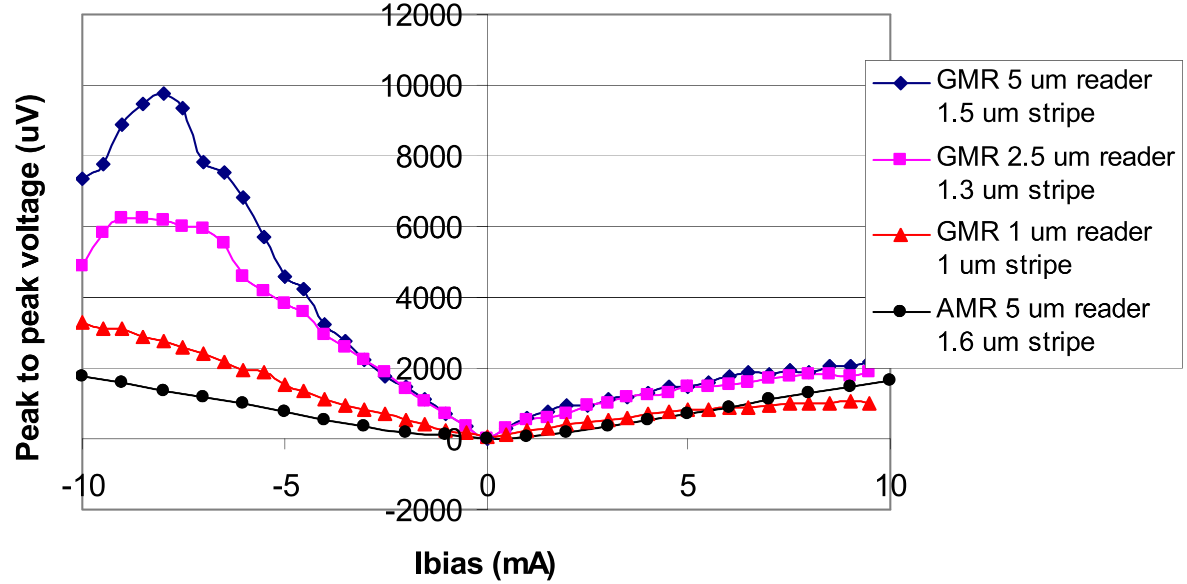
Ru atomic radii ~ 2.6 Å



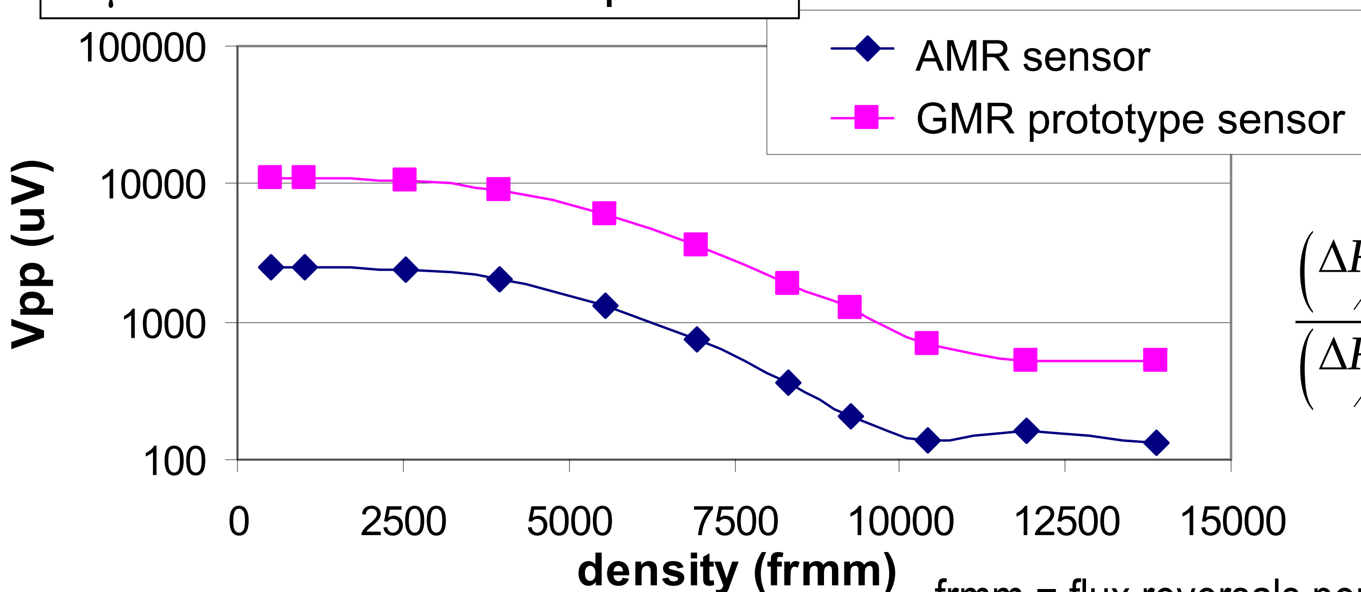
10 Å

Å = 10^{-10} m

GMR at Sun



5 µm reader width comparison



$$\frac{\left(\Delta R/R\right)_{GMR}}{\left(\Delta R/R\right)_{AMR}} = \frac{9\%}{2\%} = 4.5$$

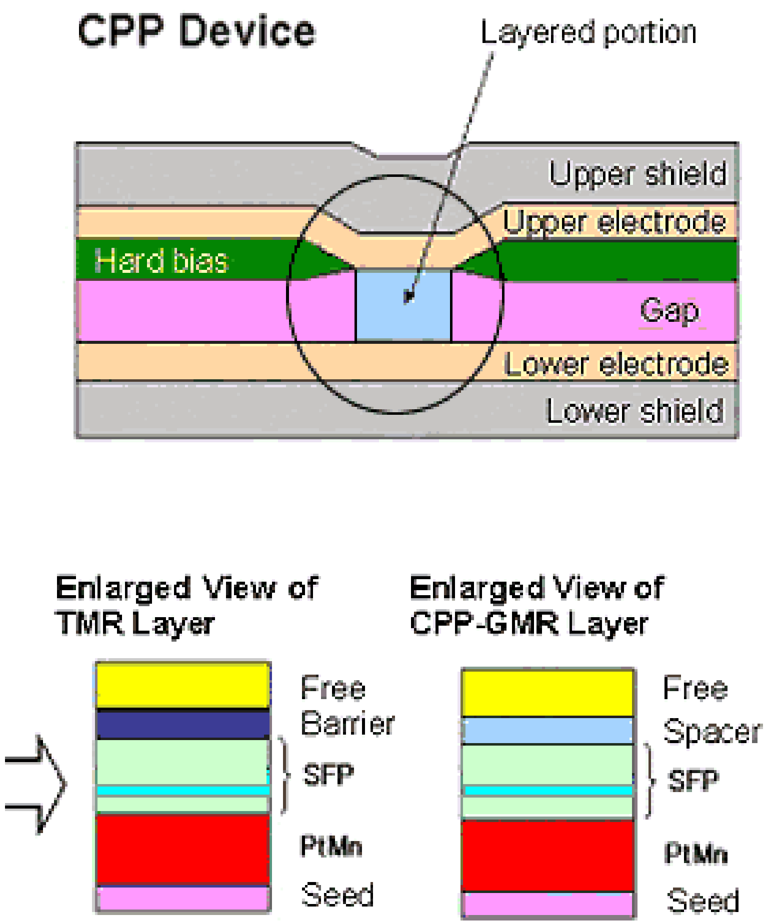
frmm = flux reversals per mm

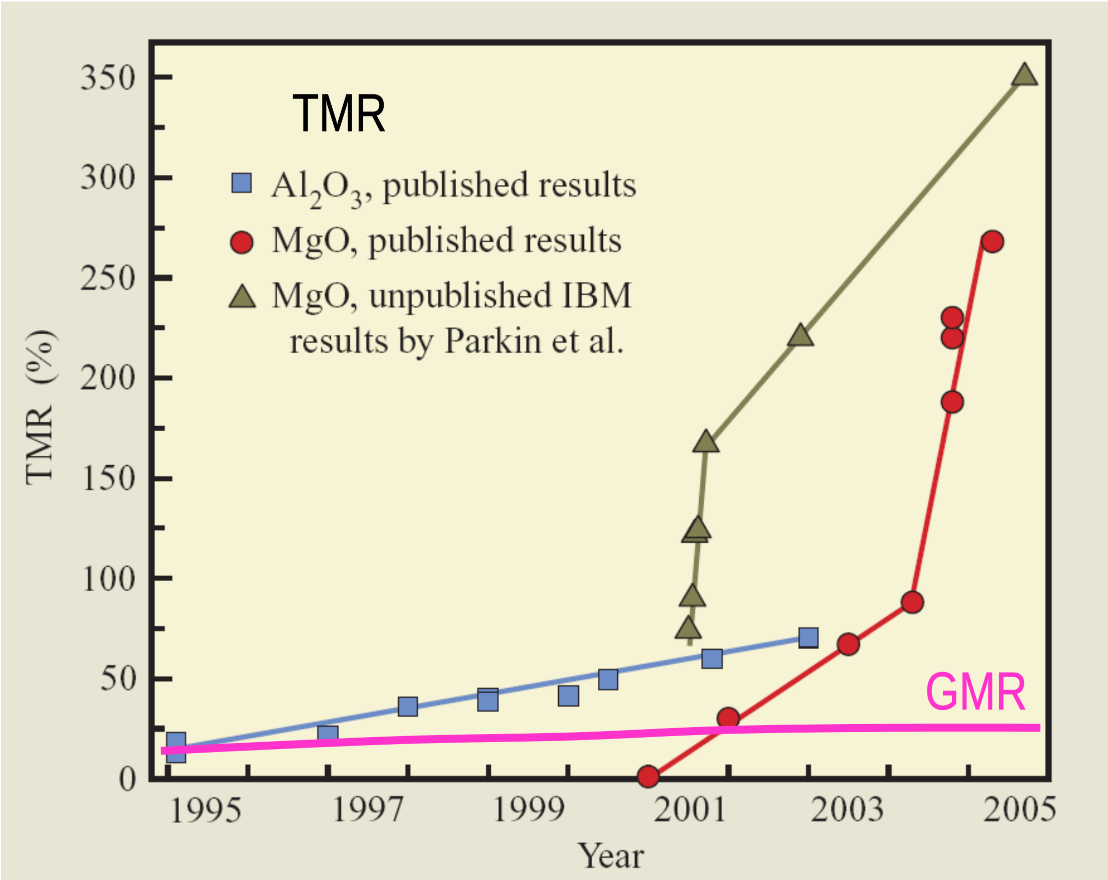
StorageTek

Recording Head Operations at Sun Louisville, CO

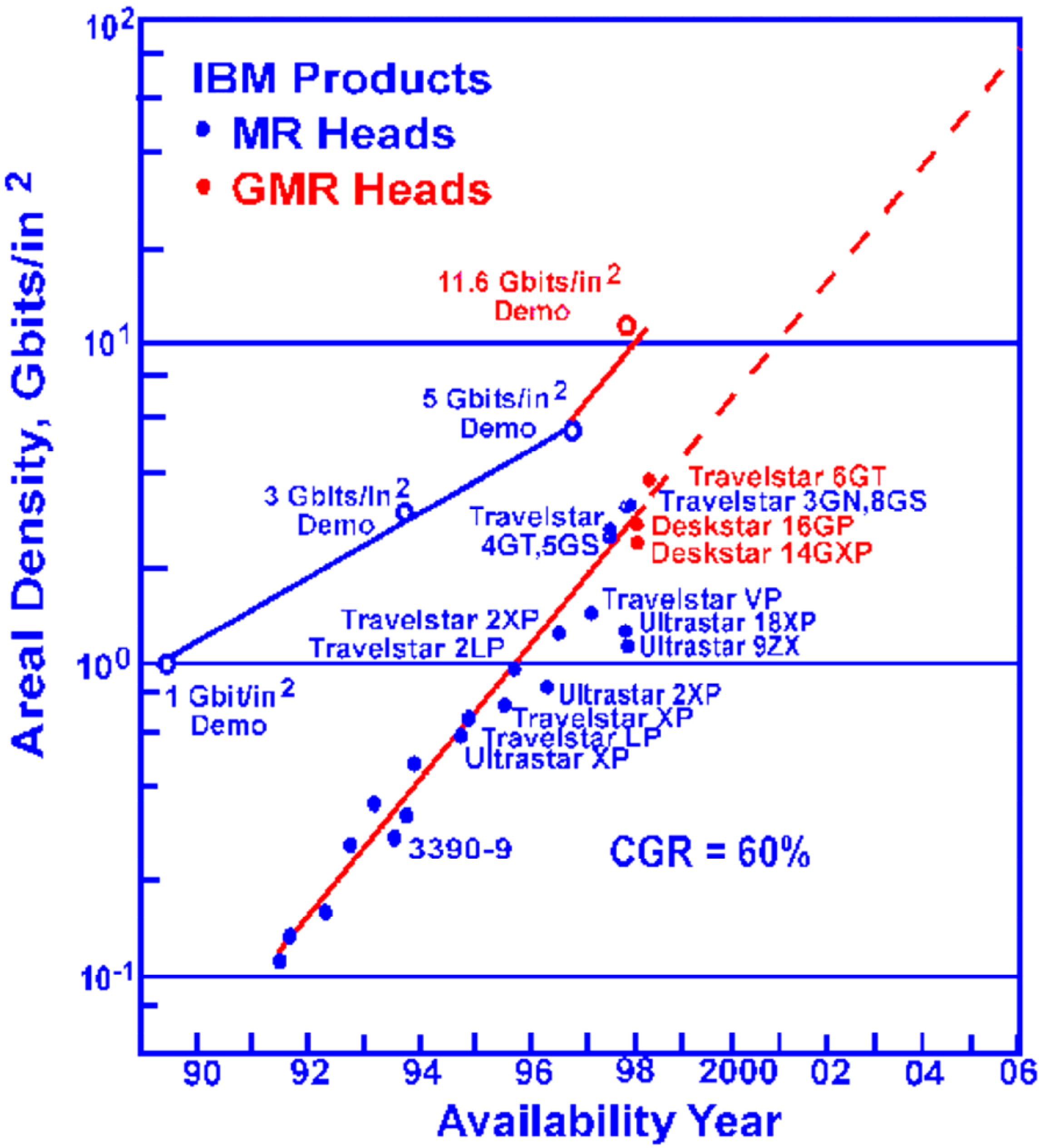
- Providing leading edge head technologies for Enterprise, Mid-Range, and Low-End tape drive products.
  - Sun Microsystems T10000 and 9x40 product lines; LTO2-LTO4
  - The first thin film helical scan read & write heads in production with VXA-3
- Developing the technology building blocks for future generation products now
  - GMR, increased device density, advanced materials
- Custom designed equipment technology to meet the unique requirements of tape head manufacturing
  - Dynamic testers, head assembly, critical dimension measurement
- State-of-the-art performance analysis capabilities to ensure product quality and competitive position
  - Dynamic performance, constructional analysis, magnetics analysis

GMR to TMR





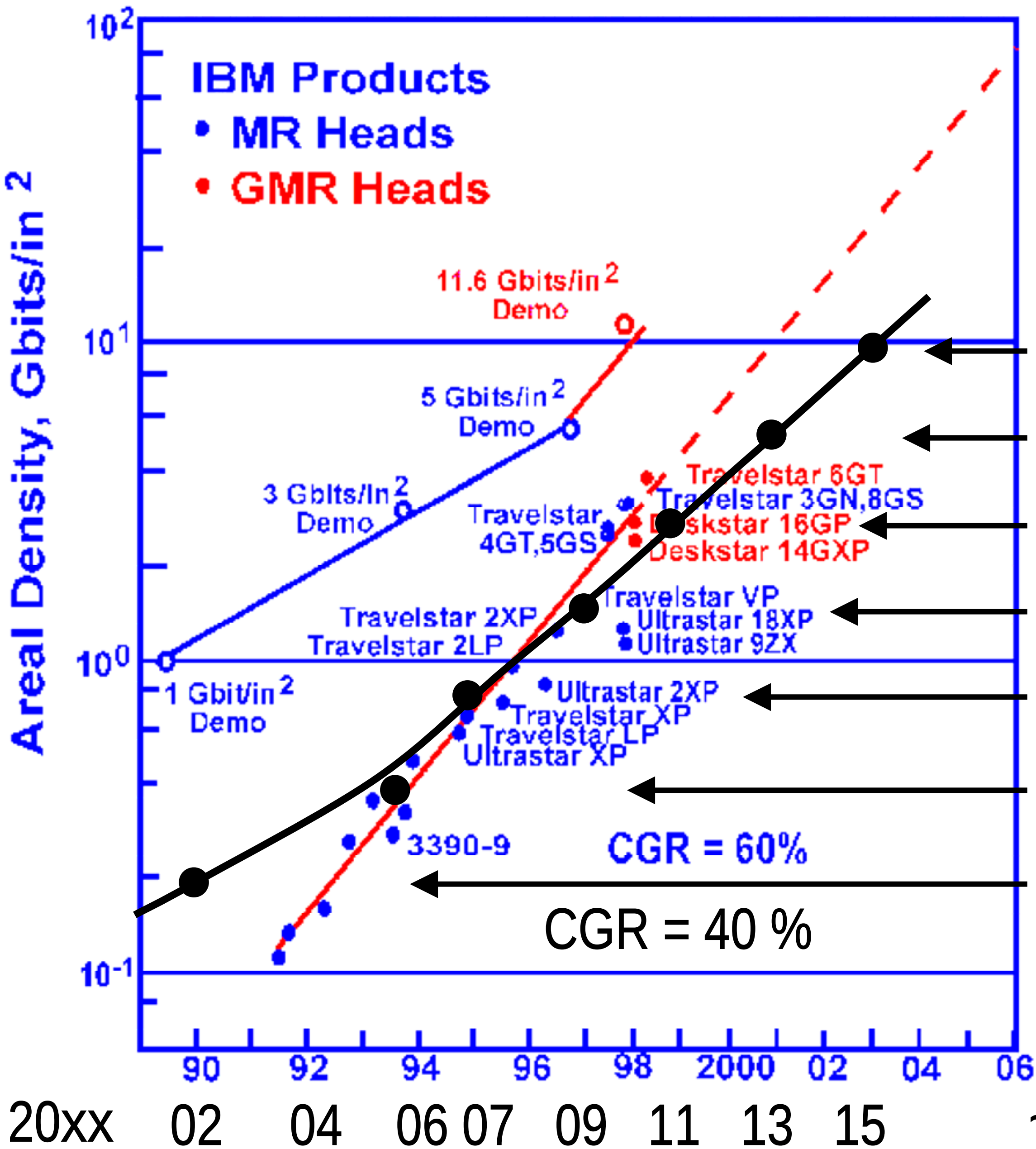
Gallagher and Parkin, IBM J. Res. Dev. 50, 5 (2006)



AMR to GMR Transition for IBM

www.hitachigst.com/hdd/technolo/gmr/gmr.htm

AMR to GMR Transition for tape



INSIC (2015), 10 Gb/in^2 (16 TB)

INSIC (2013), 5 Gb/in^2 (8 TB)

INSIC (2011), 2.7 Gb/in^2 (4 TB)

INSIC (2009), 1.5 Gb/in^2 (2 TB)

INSIC (2007), 0.8 Gb/in^2 (1 TB)

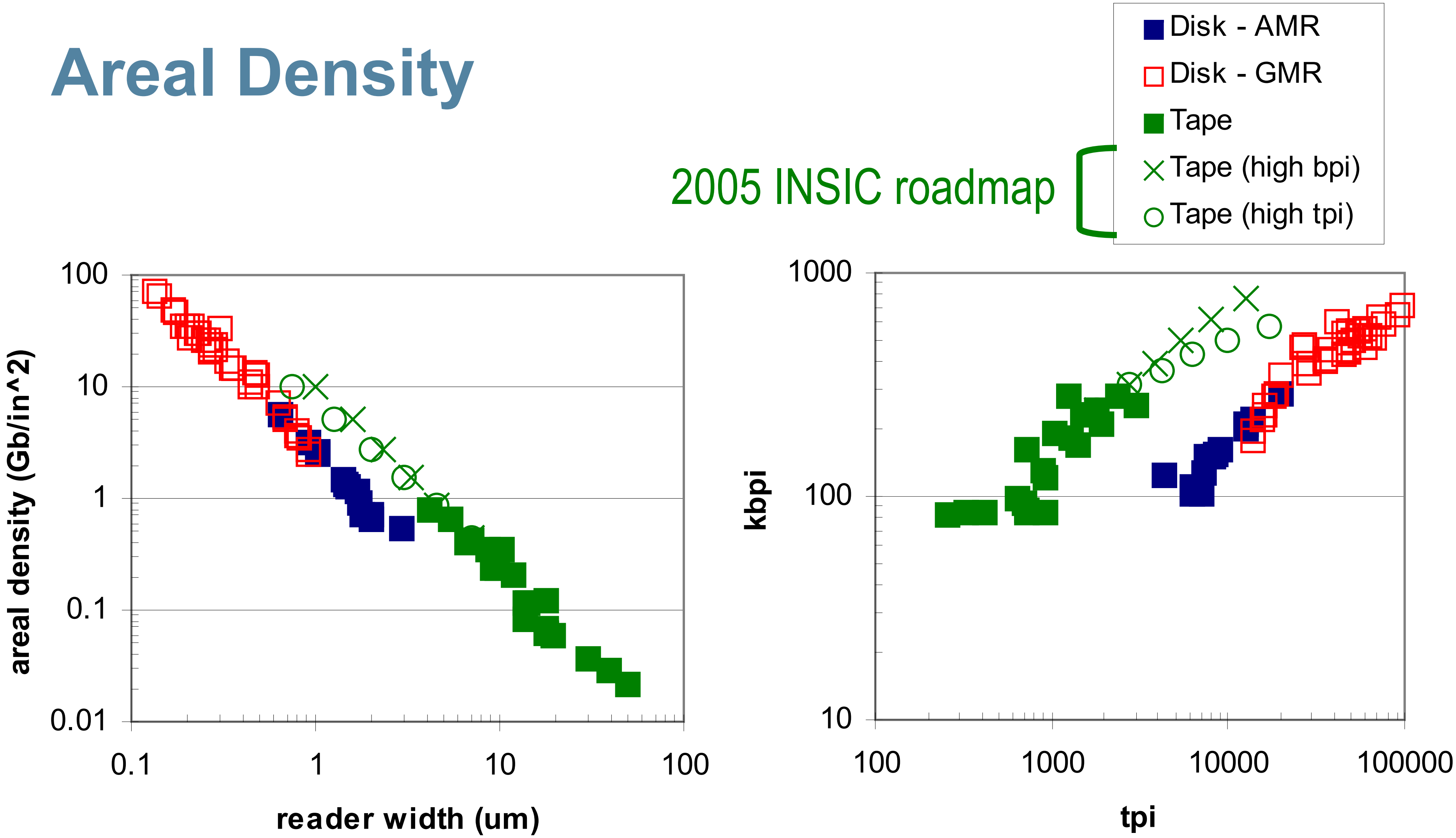
T10000 (2006), 0.4 Gb/in^2 (500 GB)

9940B (2002), 0.2 Gb/in^2 (200 GB)

INSIC high bpi scenario

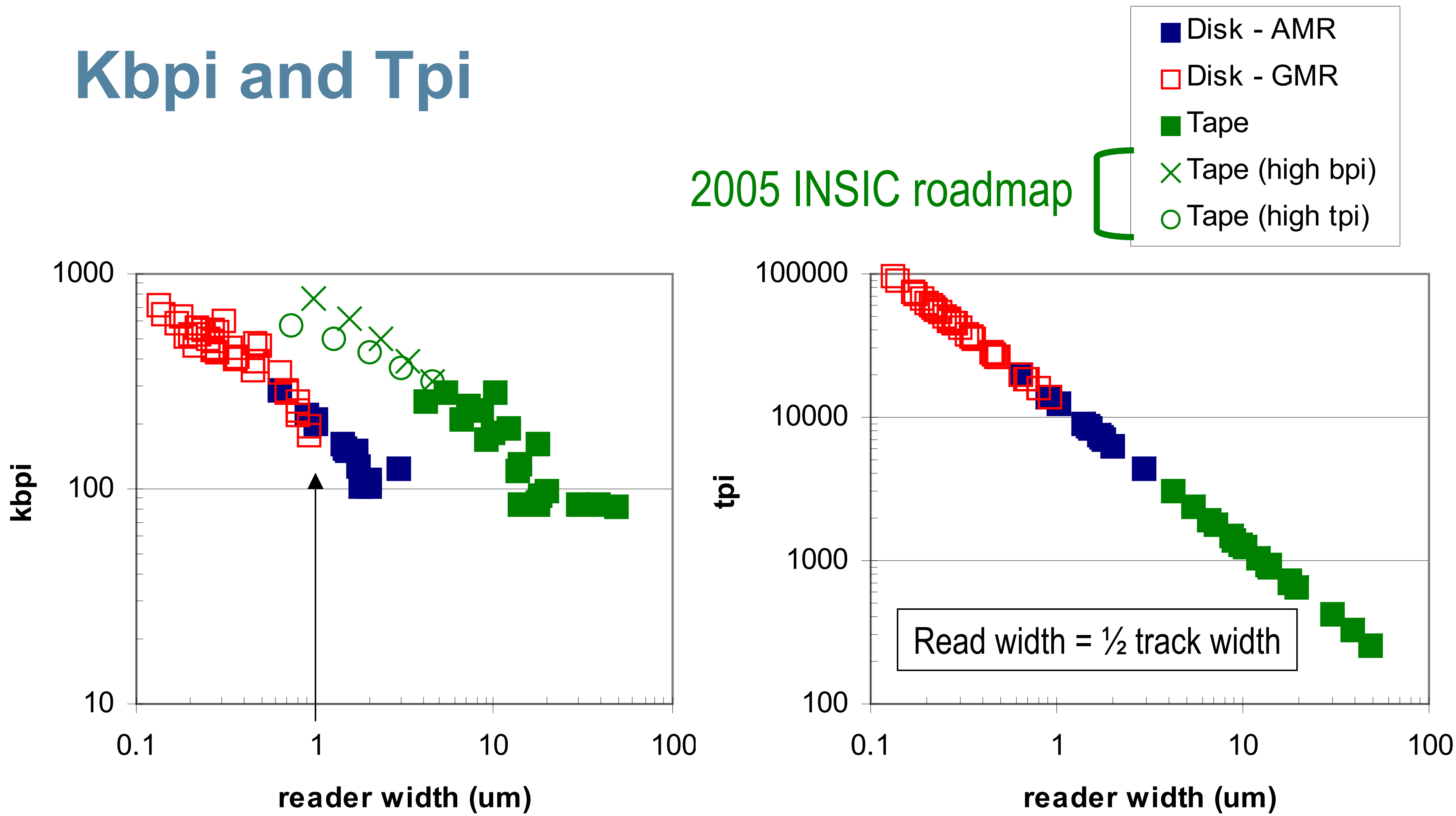
~ 12 year technology offset

Areal Density



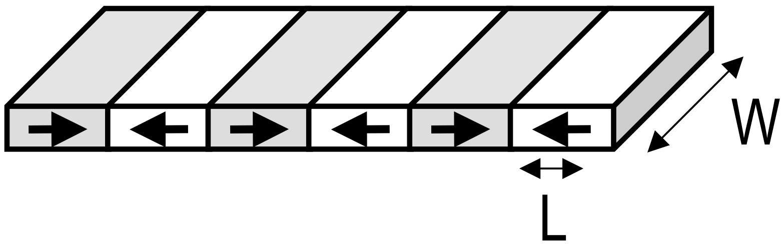
- Disk change to GMR ~ 2 - 5 Gb/in^2
- Tape change to GMR ~ 1 - 2 Gb/in^2

Kbpi and Tpi



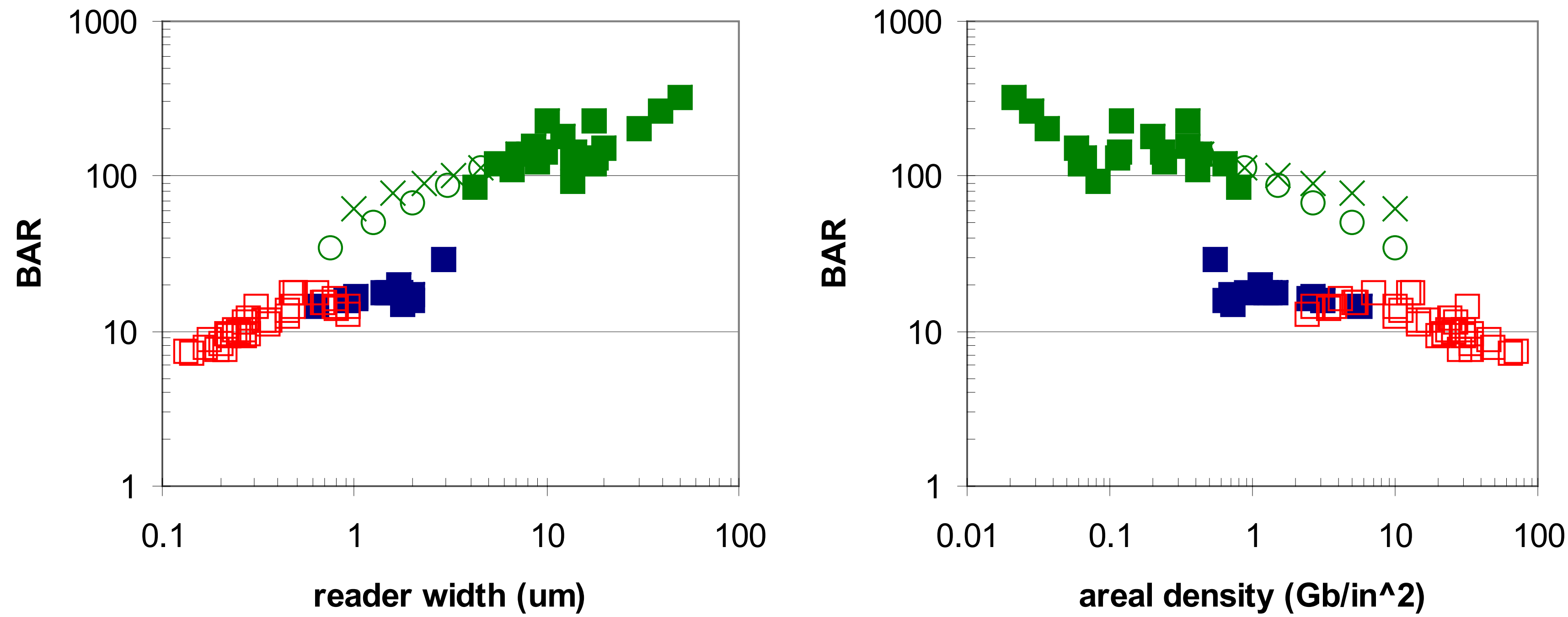
- Disk change to GMR ~ 1 µm, but only at 200 kbpi
- Tape change to GMR ~ 2 - 3 µm, but only at 300 - 400 kbpi

Bit Aspect Ratio (BAR)



$$BAR = bpi/tpi = W/L$$

- ■ Disk - AMR
- □ Disk - GMR
- ■ Tape
- × Tape (high bpi)
- ○ Tape (high tpi)



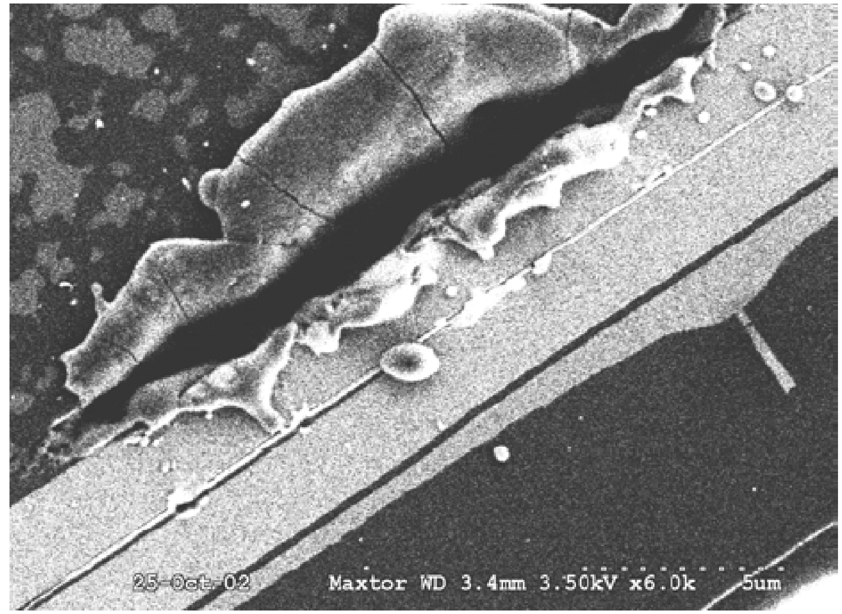
Tape has much higher BAR since bpi is pushed more

Similarities and Differences

- Similarities
  - > Fundamental physics of recording is identical
- Differences
  - > Interchange is needed for tape
  - > Disk is a “closed” environment compared to tape
    - > Contamination and corrosion
  - > Tape does read while write
  - > Area (18,000 in^2 vs. 8 in^2)
  - > Rigid disk vs. flexible tape media (sputtered vs. particulate)
  - > Number of tracks
    - > 32 data + 4 servo tracks in Sun T10000 drive (crosstalk is a major issue)
    - > But disk can have lots of platters (5 two-sided disks with 10 heads)
  - > Manufacturing yield: tape, 36/36 with 36 tracks, disk, 1/1
    - > $(\text{device yield})^{36}$ = head yield
    - > $(83\%\ \text{device yield})^{36}$ = 0.1% head yield
    - > $(99.5\%\ \text{device yield})^{36}$ = 83% head yield

Electro-Static Discharge

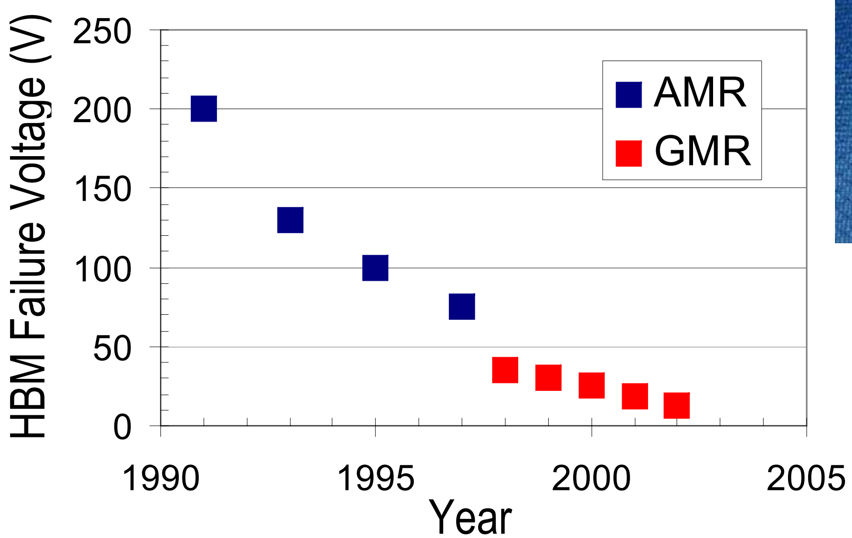
- GMR sensors are extremely sensitive to ESD
- Two failure modes
  - High temperatures melt and fuse materials together
  - Moderate temperatures heat PtMn anti-ferromagnet above it's blocking temperature
    - PtMn can reorient ~ 350º C
    - NiFe free layer ~ 660 º C
    - Cu spacer ~ 1000 º C



(Al Wallash – Maxtor Corporation)

ESD Sensitivity

- Hard drive
  - > Preamp on slider
- Tape
  - > Long flex to preamp



(Al Wallash – Maxtor Corporation)

2006 Maxtor hard drive
Sun T10000 head, flex, and voice coil

Conclusion

- Fundamental physics will drive the transition from AMR to GMR in tape just as it did in disk
  - > Disk migrated at 2 – 5 Gb/in^2, ~ 200 kbpi, and 1 μm reader width
  - > Tape will migrate ~ 1 – 2 Gb/in^2, ~ 300 – 400 kbpi, and 2 – 3 μm reader width
- Engineering tradeoffs have pushed disk to high tpi and tape to (relatively) high bpi due to track following issues in tape
- Disk migrated to GMR successfully (and then TMR)
- Tape will migrate to GMR but issues exist
  - > Corrosion
  - > ESD
  - > Media

Questions?