Hitachi Global Storage Technologies

Perpendicular Magnetic Recording and Beyond

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freedom to innovate

DISKCON USA 2005

FIRST HARD DISK DRIVE – RAMAC

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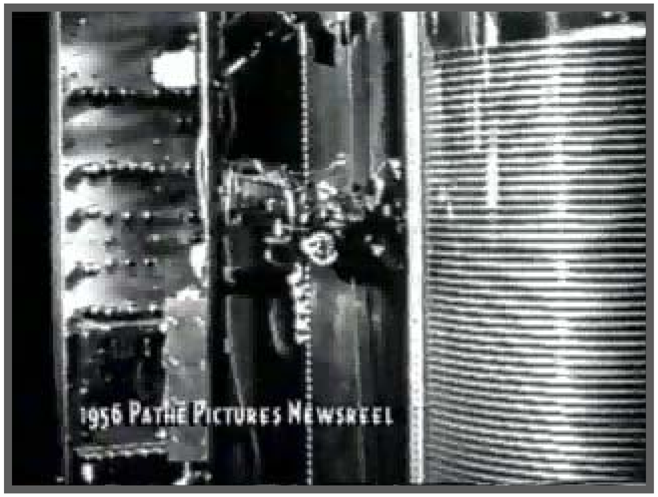
Magnetic recording on rotating disk

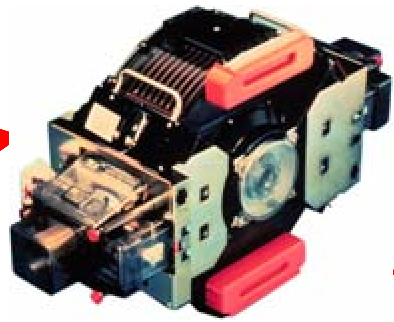
First Hard Disk Drive product
5 MB on 50 24" dia disks



Hard Disk Drive Innovation

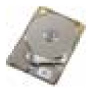
1956 -- RAMAC
- 5 megabytes (MB)
- Fifty 24” disks, 1200 RPM

➢ **Made possible by magnetic, semiconductor and mechanical scaling**



1981 -- 3380 system
- 1.2 gigabytes (GB)
- Nine 14" disks, 3600 RPM

1991 -- 2.5” Travelstar
- 60 MB (120 GB today)
- Two 2.5” disks



2005 -- “Mikey,” smallest Microdrive
- 8 GB
- One 1” disk

Historical Areal Density Trend

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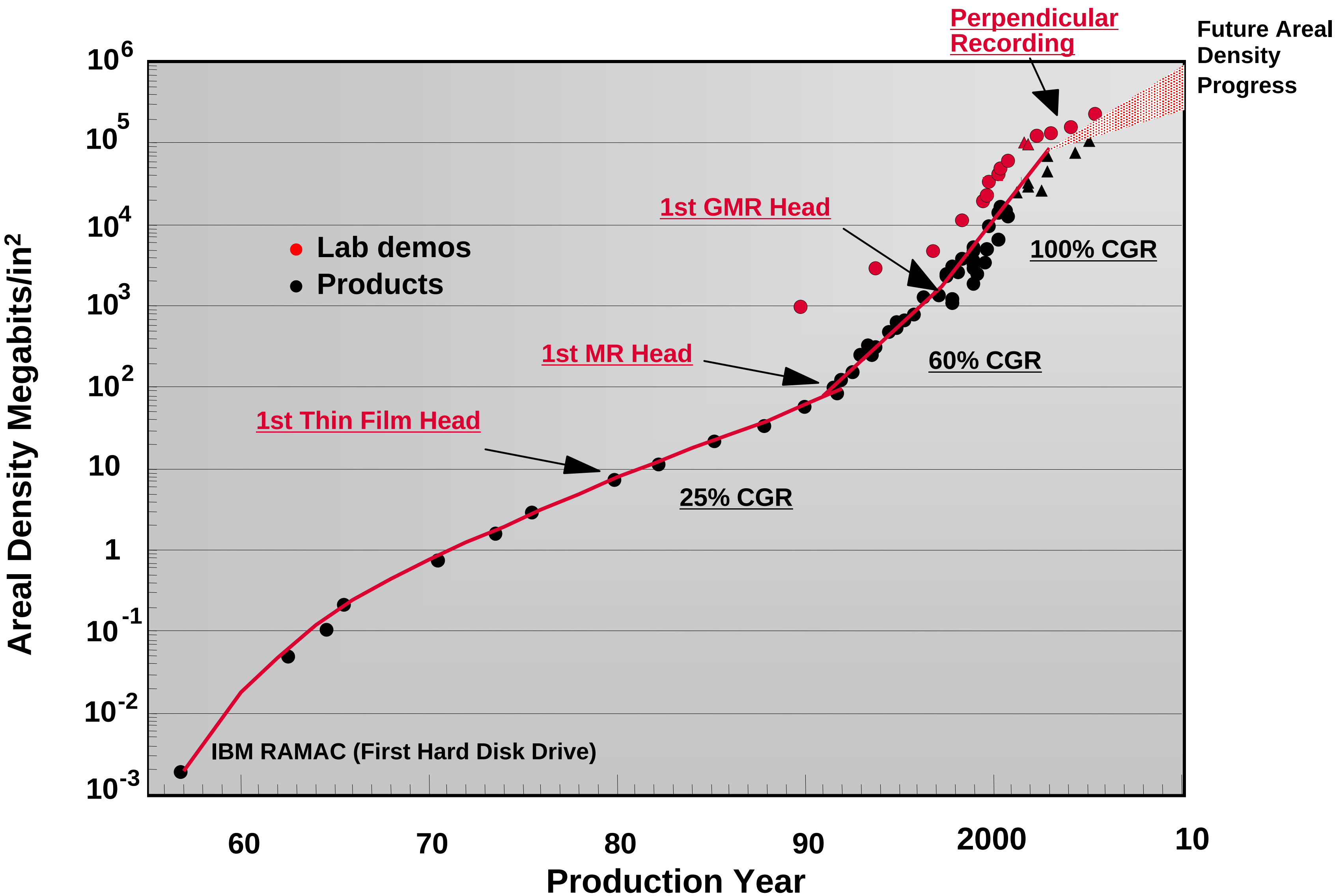
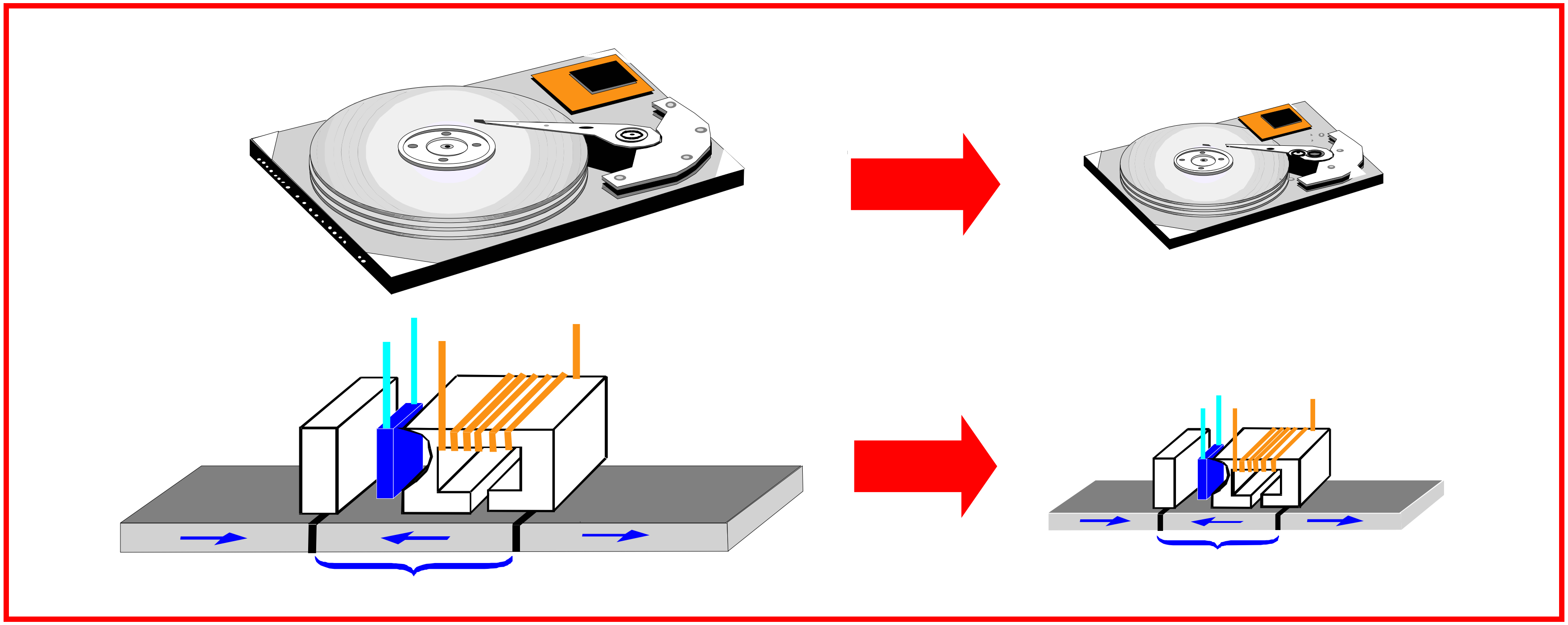


Scaling of Magnetic Recording



- **Scaling means that everything shrinks and the system still works**
  - Requires vastly improved processes
  - Higher mechanical precision
- **Signal-to-noise ratio drops when things are scaled smaller**
  - Requires new sensors and materials
  - Improve signal processing

Typical Components in a Modern Disk Drive

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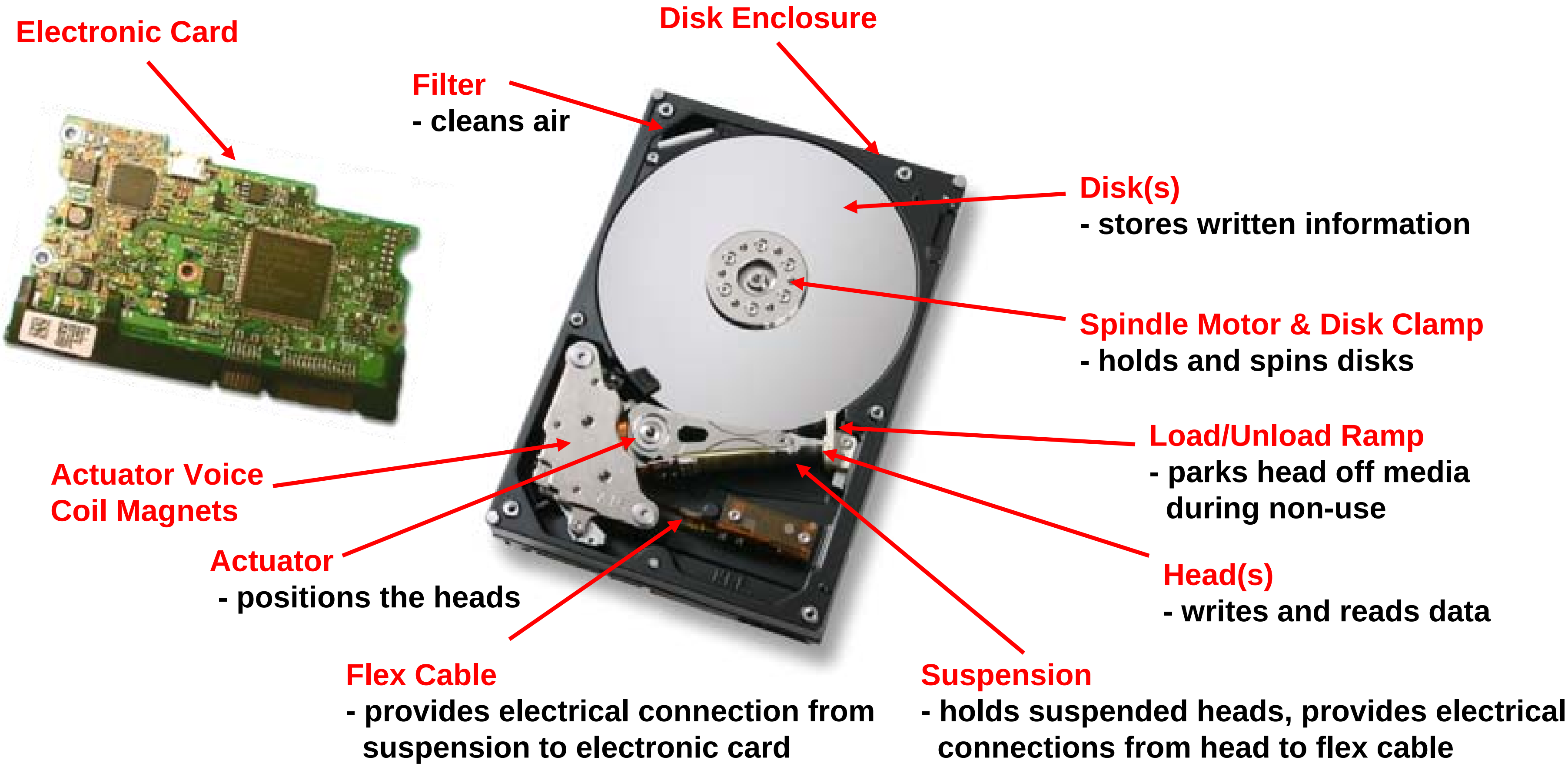

Electronic card

- Provides data interface to disk controller
- Control operation of disk drive (spindle, actuator, position servo)
- Encodes written data and decodes read back data
- Provide read/write signals to heads via flex cable

Current Longitudinal Magnetic Recording Method

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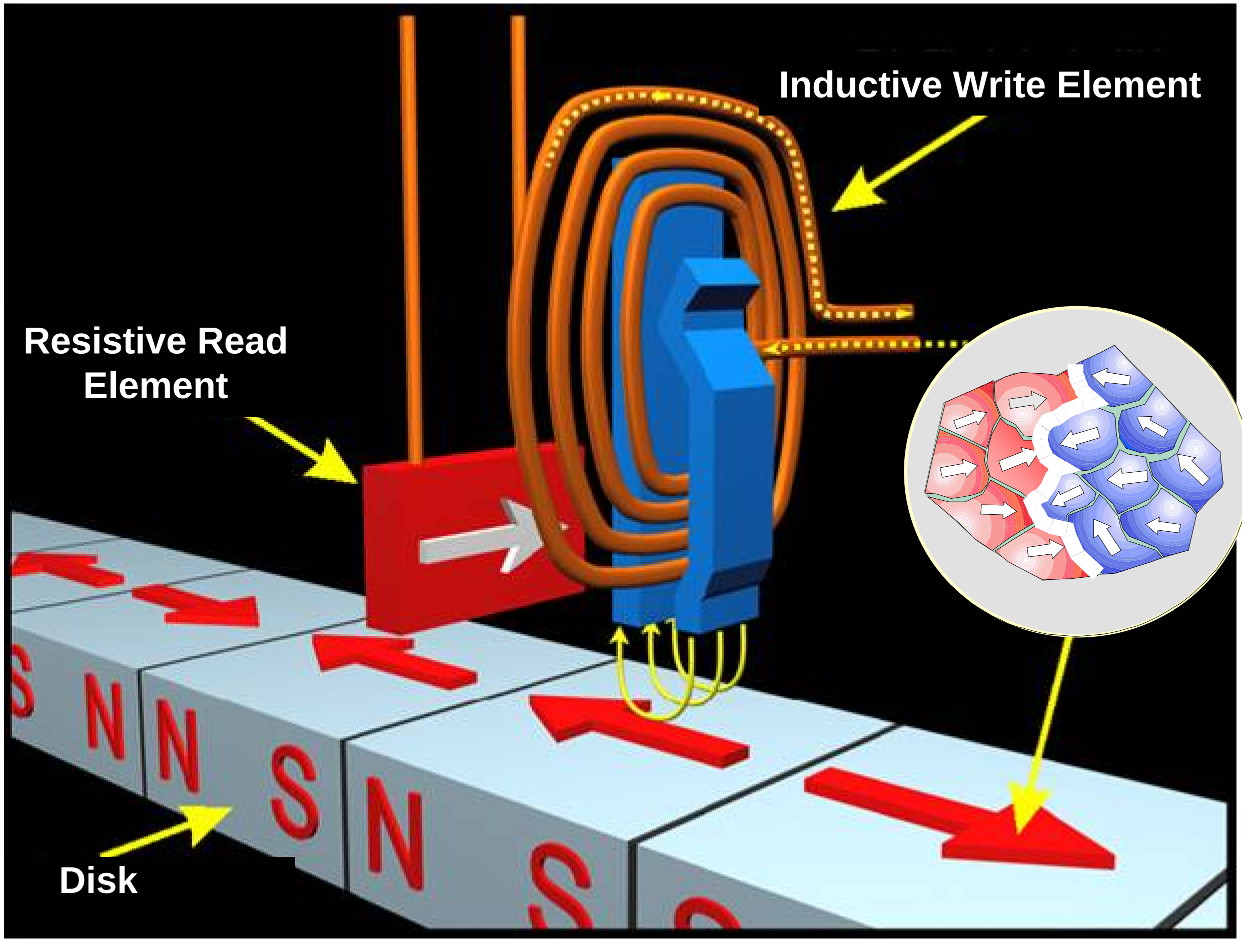
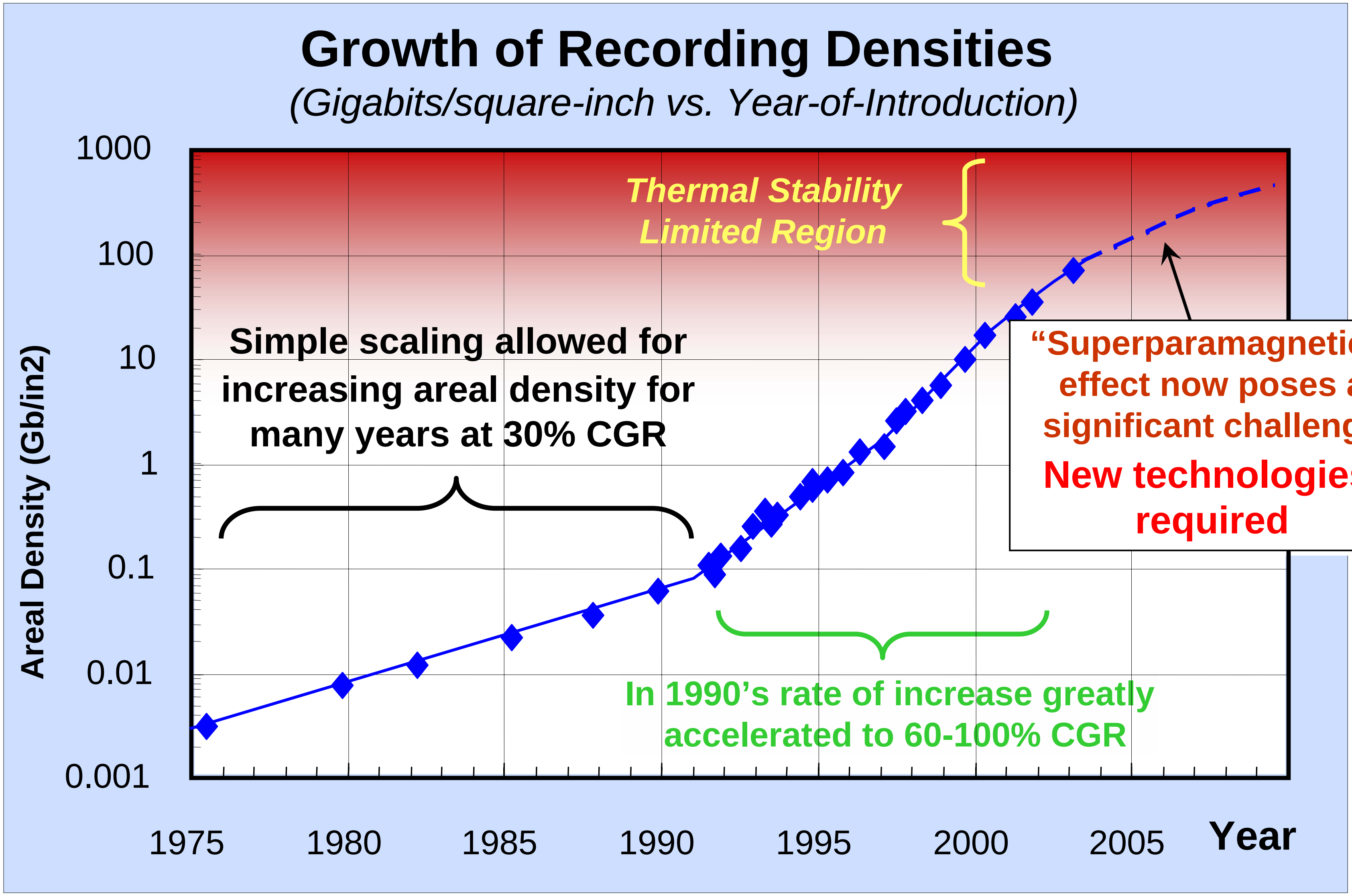


- **Disk**
  - Ultra smooth surface
  - Thin magnetic coating
  - Protective overcoat
  - Surface lubricant
- **Inductive Write Element**
  - Soft magnetic poles
  - Copper write coil
  - Alternate coil current to write magnetic transitions
- **Resistive Read Element**
  - GMR sensor to detect magnetic transitions

- Disk rotates under a slider that has an integrated read/write head at its trailing end
- Very close slider-to-disk surface proximity critical for high resolution recording
- Information is stored in magnetic transitions written onto the disk's thin magnetic coating
- The magnetization is in the plane of the disk surface


Growth of Recording Densities
(Gigabits/square-inch vs. Year-of-Introduction)
Areal Density (Gb/in2)
1000
100
10
1
0.1
0.01
0.001
1975
1980
1985
1990
1995
2000
2005
Year
Thermal Stability Limited Region
Simple scaling allowed for increasing areal density for many years at 30% CGR
In 1990's rate of increase greatly accelerated to 60-100% CGR
"Superparamagnetic" effect now poses a significant challenge
New technologies required

Perpendicular/Longitudinal Technologies Compared

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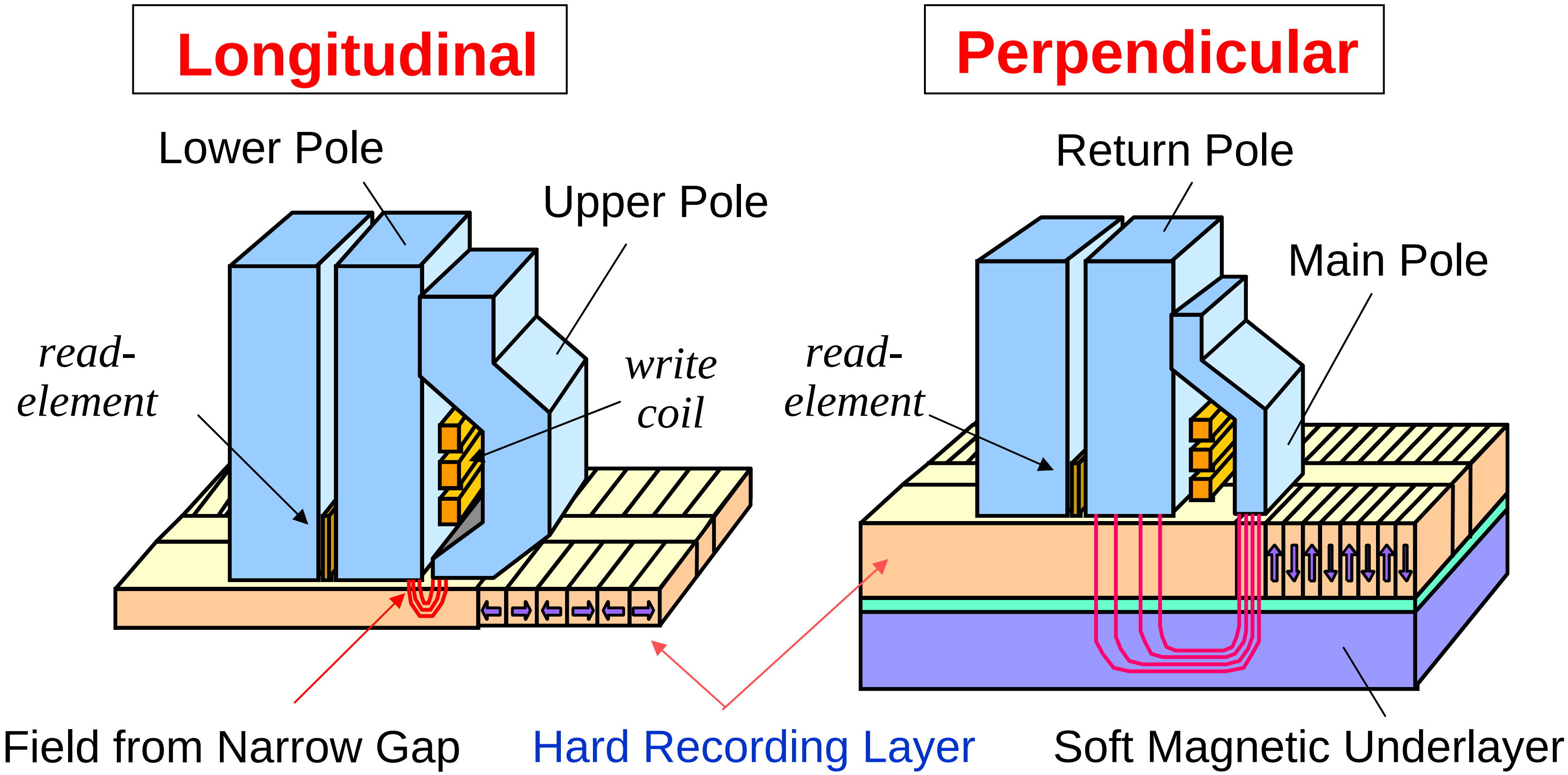
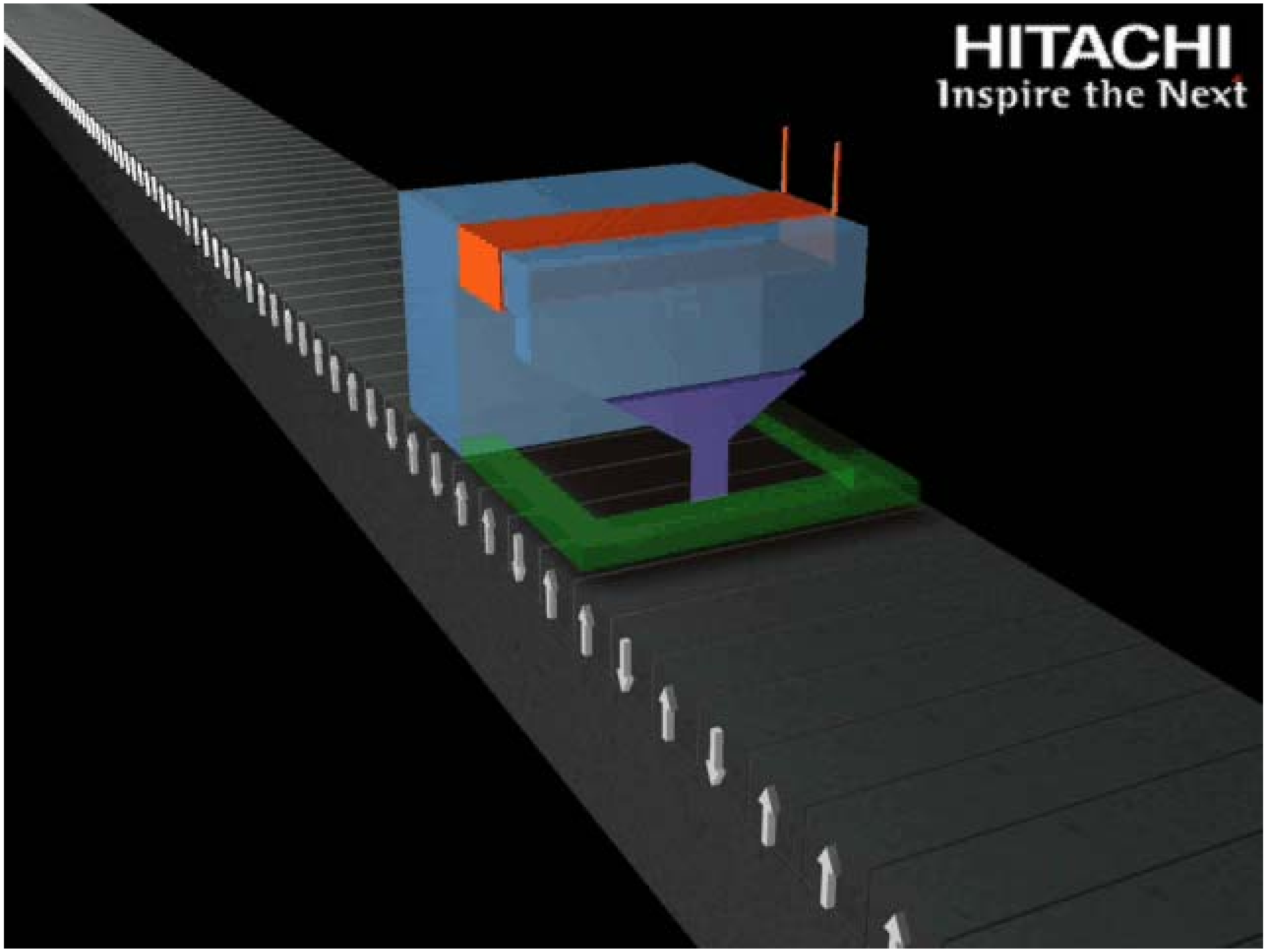


- **Disk material can be thicker, which makes small grains more resilient to superparamagnetic effect**
- **Soft underlayer allows head to provide stronger field to make it possible to write on media with higher stability**
- **Adjacent perpendicular bits stabilize one another**

Video:



Hitachi's 230 Gbits/in^2 Perpendicular Achievement

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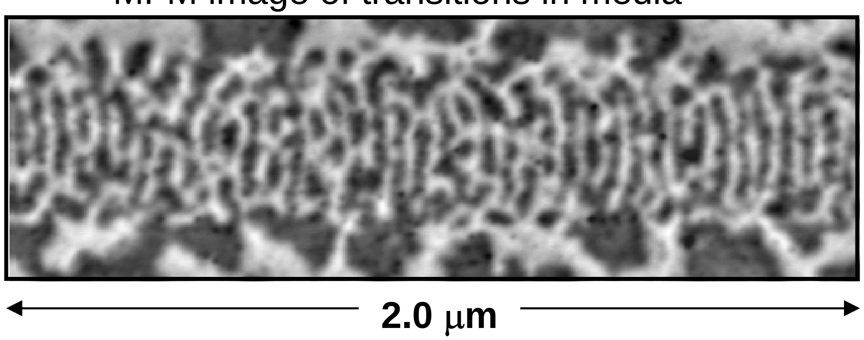
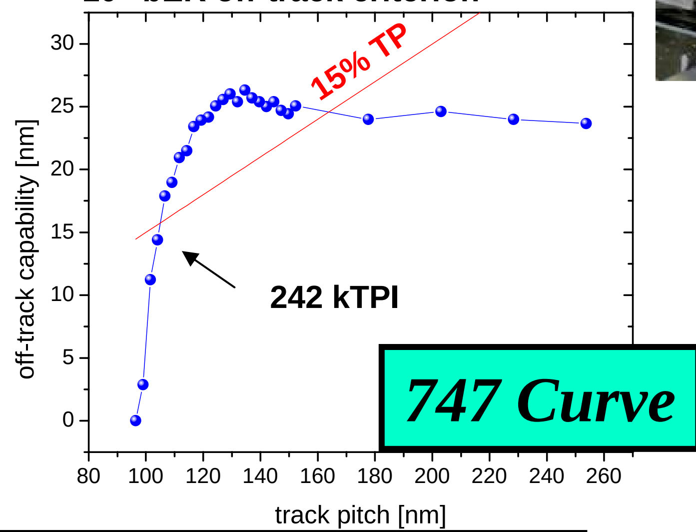
- March 2005 laboratory spin-stand demonstration of 233 Gb/in^2
  - 965,000 bits/inch x 242,000 tracks/inch = 233 Gbits/inch^2
- Requires major changes in Media, Head, and R/W electronics
  - Employed single pole and trailing shield write heads and CoPtCr-oxide media with SUL

MFM image of transitions in media



945 kbpi with 10^{-5} on-track bER
10^{-3} bER off-track criterion



This areal density will enable 20 GB 1-inch Microdrive or 1 terabyte 3.5-inch desktop drive

Perpendicular Recording Possibilities

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- **First products near 150 Gbits/inch^2 (2005 – 2006)**
  - Enables 160 GB mobile drive and 15 GB Microdrive
- **Perpendicular magnetic recording will be ubiquitous by 2008**
- **230 Gbits/inch^2 (2007 – 2008)**
  - Enables 1 TB desktop drive and 20 GB Microdrive
- **Theory shows that perpendicular can be extended to about 500 Gbits/inch^2**
  - Enables ½ TB 2.5-inch drive and 40 GB Microdrive
- **Extensions to perpendicular recording -- patterned media and thermally assisted recording -- enable data densities well in excess of 1 Tbit/inch^2**
  - Enables multi-TB mobile drives and >100 GB Microdrive
    - Entire HDTV video libraries in a compact set top box
    - Thousands of hours of music and multiple movies in a mobile phone

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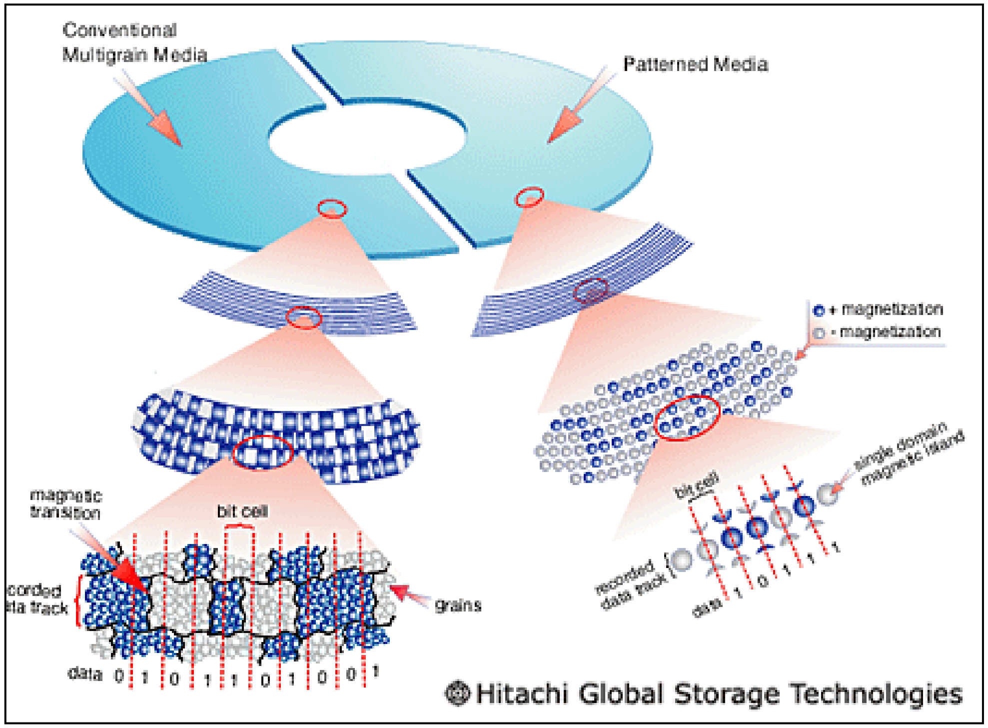
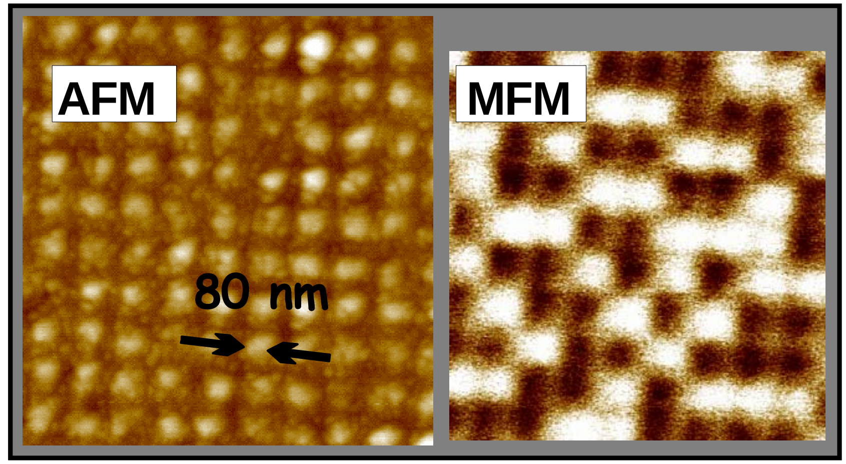
Patterned Media -- Very Small Bits

- Individual magnetic islands can be created on the disk
- Each island would represent a single bit of information





Isolated physical islands (AFM) produce single domain magnetic islands (MFM)

$1000\ Gb/in^2 = 1Tb/in^2$

5 TB 3.5-inch drive

1.2 TB 2.5-inch drive

80 GB 1-inch drive

- **Patterned media will extend magnetic recording to > 1 Tb/in^2**

Patterned Media Challenges

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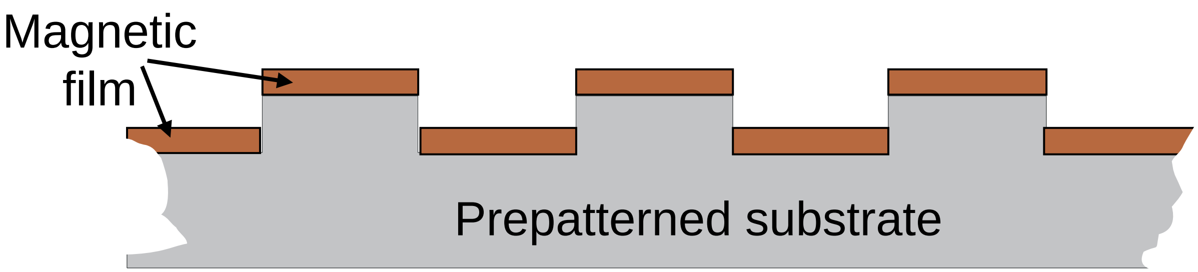
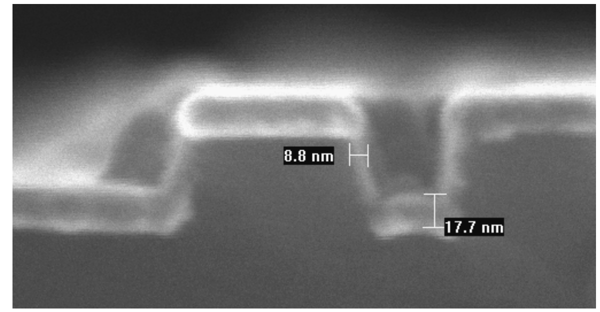
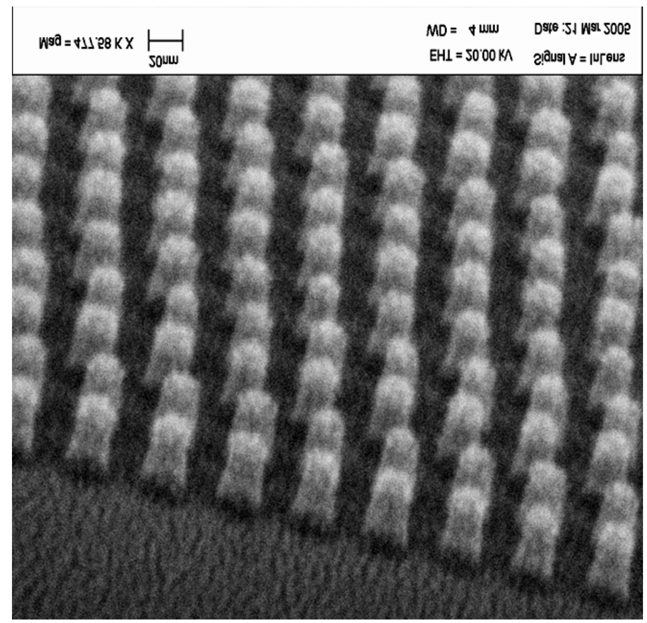


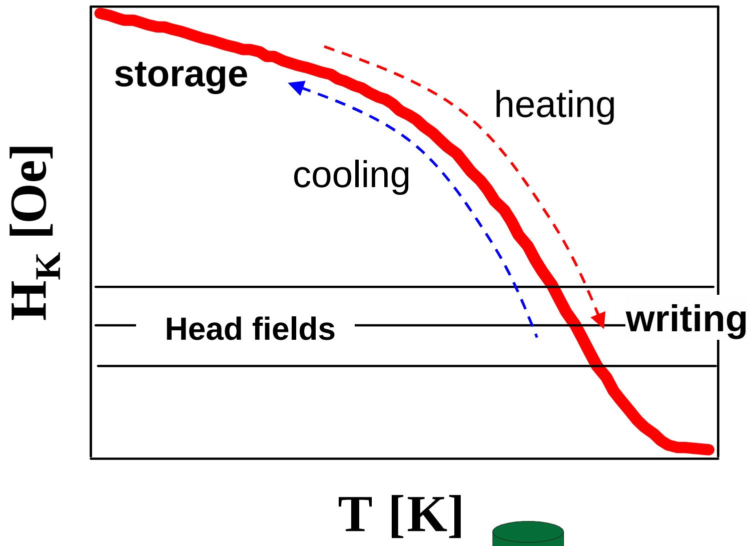


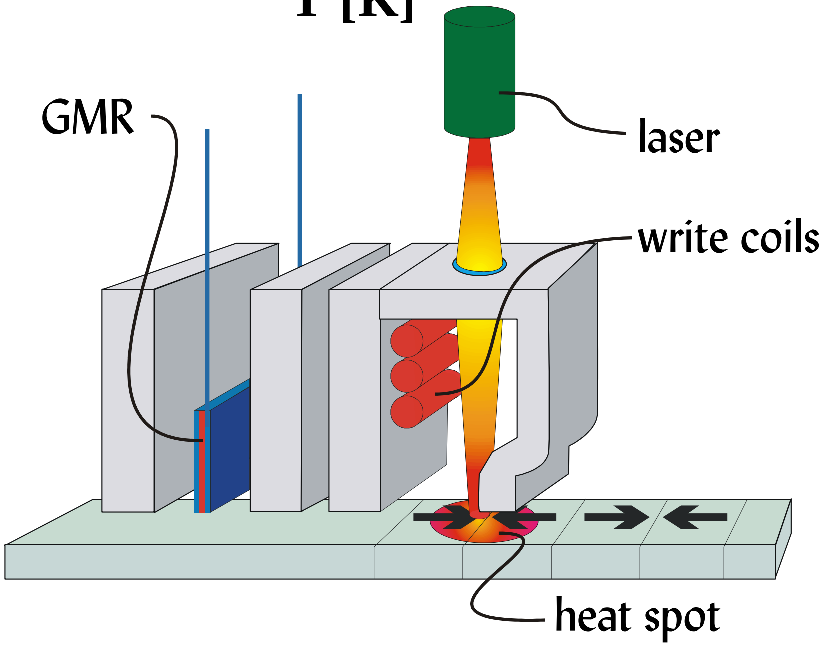


- **Must use lithography with feature resolution ~ 20 nm**
- **Most viable approach may be nano-imprint lithography**
- **Major changes required in drive architecture**
  - **Bit aspect ratio ~1 : head design, servo**
  - **Bit locations determined by disk : write synchronization**
  - **HDI on non-homogeneous surface**

Thermally-Assisted Recording

- Employ temperature dependence of media coercivity to meet simultaneous demands of
  - low coercivity for writing, and
  - high coercivity for stable storage
- Requires small spot heating source with <10 ns response time aligned to write head
- Likely to be used in combination with patterned media
- Combination of temperature-assist and patterned media could extend areal density beyond 10 Tb/in^2





Thermally-Assisted Recording Challenges

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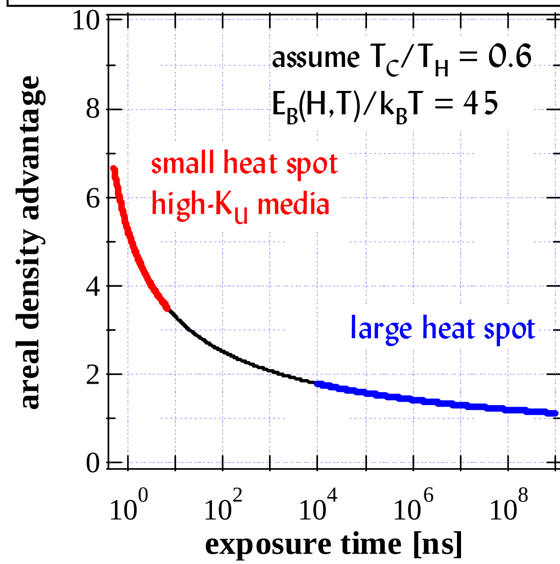
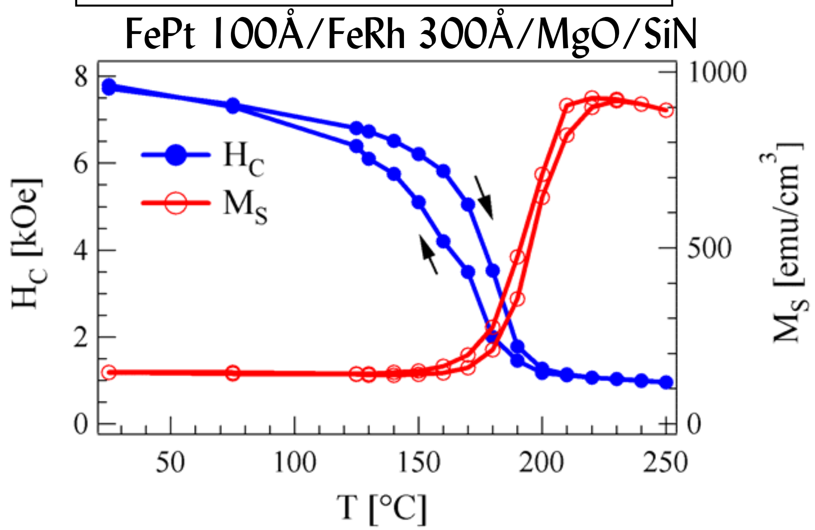
- Requires integration of efficient, very small spot optics with conventional magnetic recording head
- Media must be heated and cooled several 100 °C in less than 10 ns
- Must develop new high-Ku media with low noise and proper thermal properties
- Must maintain HDI reliability

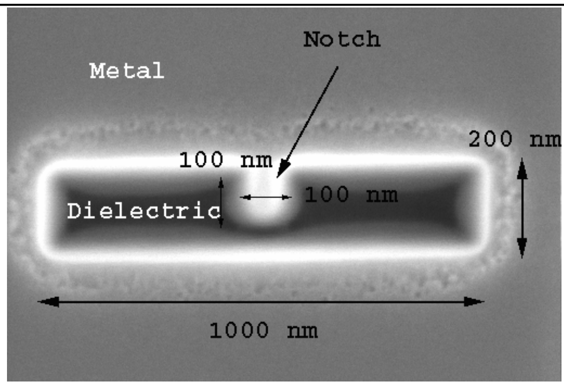
Largest gains only come with very small heating spot and high Ku materials



May be possible to make alloys with steep dH/dT at modest Tc



Integrated optics and novel near-field optical apertures required



I will record all relevant information I see & hear ….

- **Every picture I've ever taken**
- **Every song I want to hear**
- **Every movie I want to save**
- **Every TV show I want to see**
- **Every street I want to walk on**
- **Every newspaper I want to read**
- **Every sports event I want to recall**
- **Every medical record I've ever had**
- **Every memory of my life**

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