Magnetic Recording Beyond the First 100 Years

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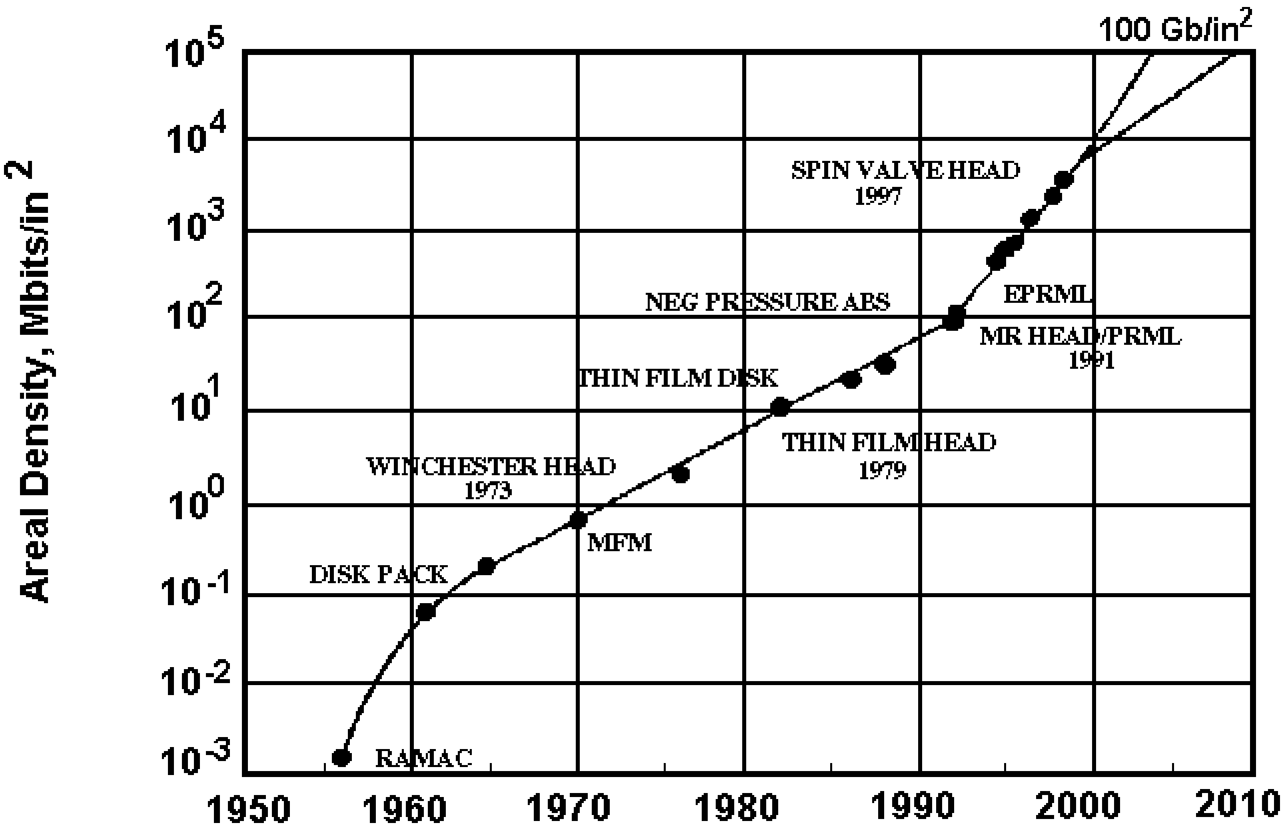
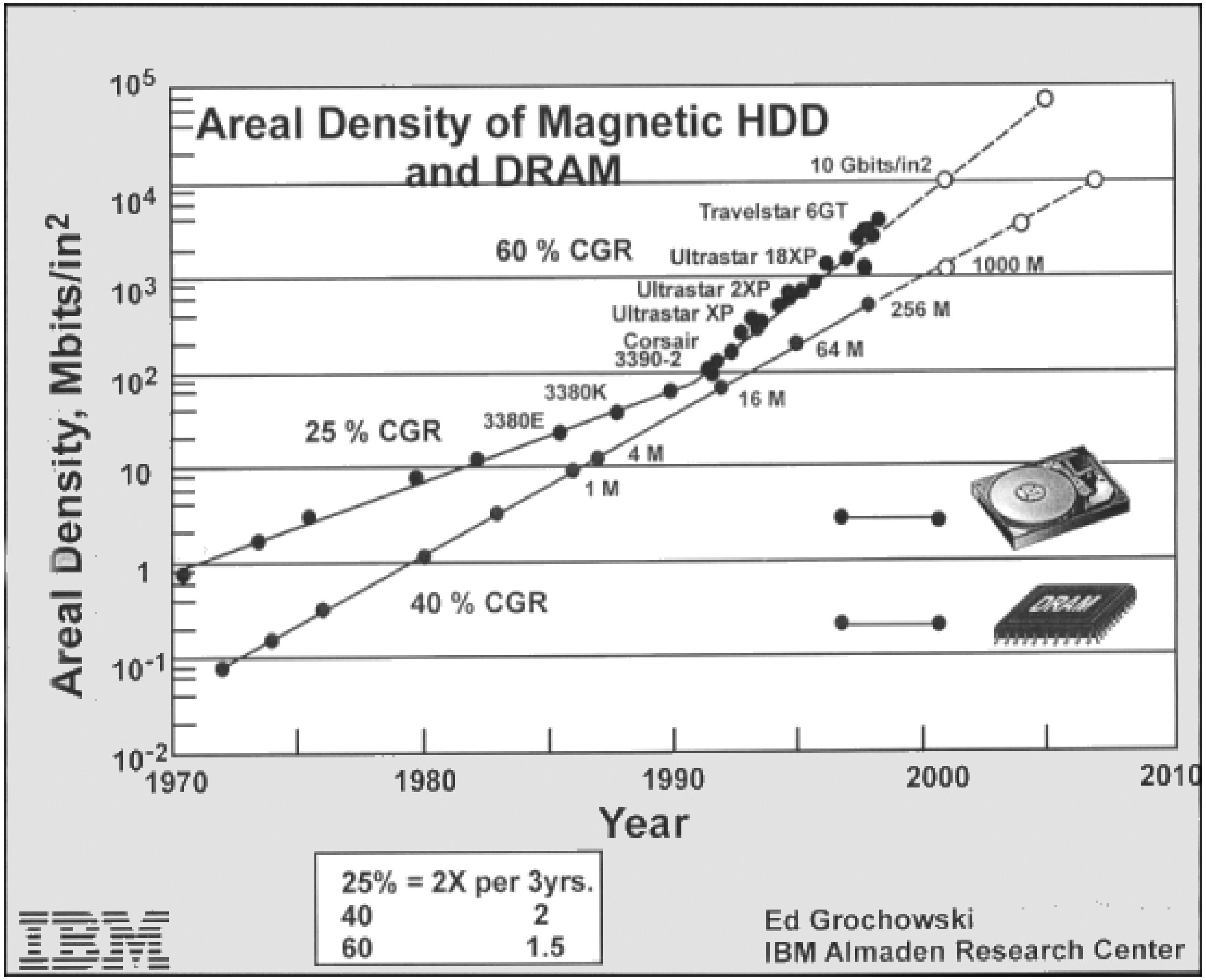
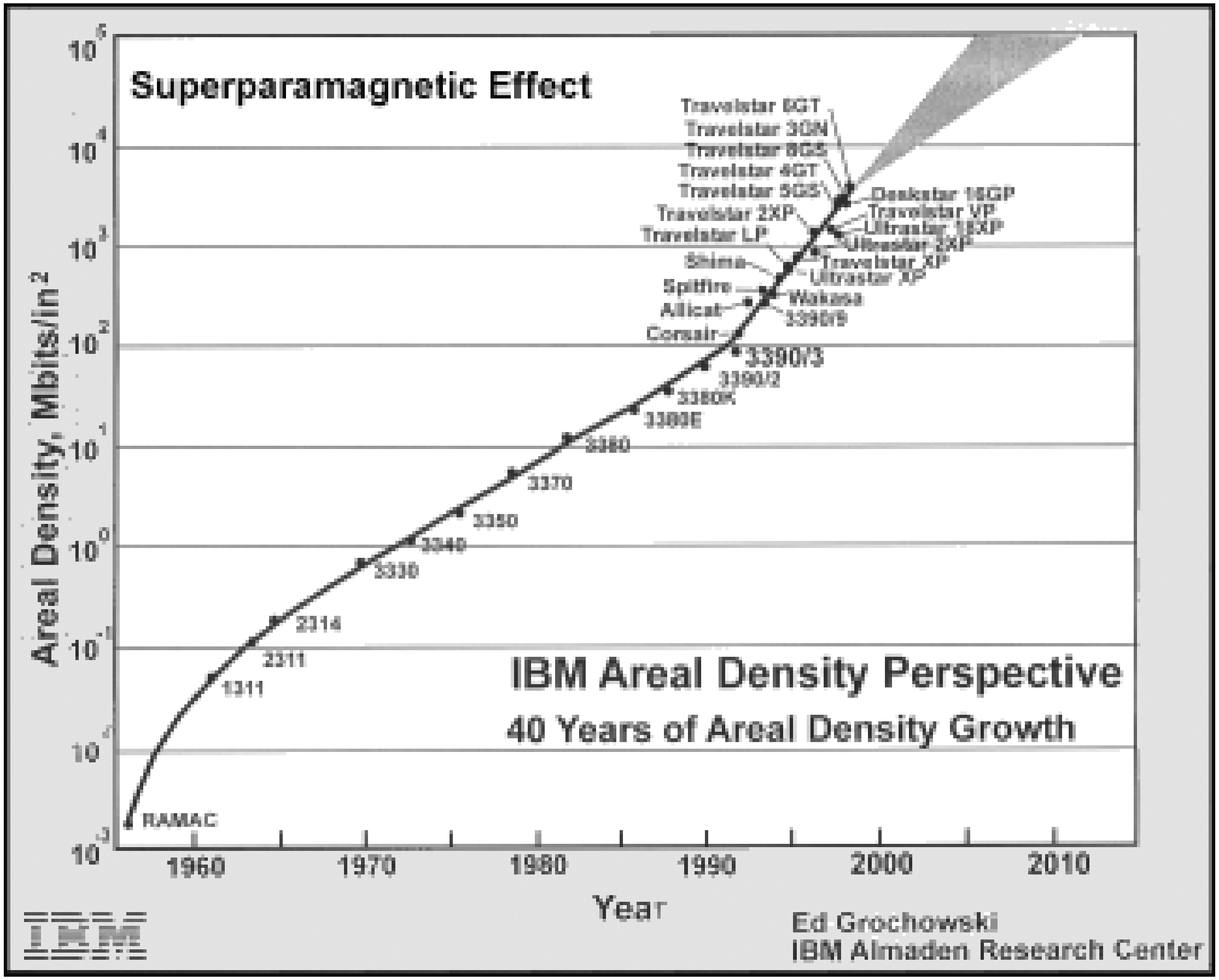
The Premier Advanced Recording Technology Forum

THIC Inc.

Hard Disk Drive Technological Milestones




Areal Density of Magnetic HDD and DRAM
Areal Density, Mbits/in2
Year
10 Gbits/in2
Travelstar 6GT
Ultrastar 18XP
Ultrastar 2XP
Ultrastar XP
Corsair
3390-2
3380K
3380E
60 % CGR
25 % CGR
40 % CGR
1000 M
256 M
64 M
16 M
4 M
1 M
DRAM
25% = 2X per 3yrs.
40 2
60 1.5
IBM
Ed Grochowski
IBM Almaden Research Center


Superparamagnetic Effect
IBM Areal Density Perspective
40 Years of Areal Density Growth
Areal Density, Mbits/in2
Year
Ed Grochowski
IBM Almaden Research Center
RAMAC
1311
2311
2314
3330
3340
3350
3370
3380
3380E
3380K
3390/2
3390/3
3390/9
Corsair
Allicat
Spitfire
Wakasa
Shima
Ultrastar XP
Travelstar XP
Travelstar LP
Travelstar 2XP
Ultrastar 2XP
Ultrastar 18XP
Travelstar VP
Deskstar 16GP
Travelstar 5GS
Travelstar 4GT
Travelstar 8GS
Travelstar 3GN
Travelstar 6GT
1960
1970
1980
1990
2000
2010

Scaling has been the principal path to higher areal densities.

- **Reduction in line widths and device dimensions in semiconductor devices.**

- **Reduction in head-to-media spacing, magnetic film thickness, head dimensions, and magnetization transition length in magnetic devices.**

Ultimate Limits May Be:

- <u>Fundamental limits</u> due to the atomic nature of matter which may impose ultimate physical bounds to nanofabrication and miniaturization.

- <u>Practical limits</u> arising from the fact that the cost of fabricating even higher density and more powerful memory modules will become prohibitive.

Areal Density Limitations

- Magnetic relaxation (superparamagnetic limit)
- Head-to-medium separation
- Write head saturation
- Read head sensitivity
- Servo tracking bandwidth

Data Rate Limitations

- Switching speed of media
- Switching speed of heads
- Electronics and signal processing limits

Relaxation Time:

$$\tau = 10^{-9} \exp(KV/kT)$$

K: Uniaxial anisotropy of grain

V: Volume of grain

<u>Examples</u>:

For $KV/kT = 25$, $\tau = 1$ min.

For $KV/kT = 40$, $\tau = 7.5$ years

For $KV/kT = 60$, $\tau = 10^9$ years

Beyond Conventional Longitudinal Recording

<u>a) Very high anisotropy media</u>:

- **CoSm**
- **CoPt**
- **FePt**
- **Other alloys**

Beyond Conventional Longitudinal Recording

b) Oxide Media

- Very low media noise as a result of the oxygen superlatice
- Ease of obtaining high anisotropies and adjusting the value of M_s/H_k to an optimal level to reduce thermal instabilities
- Total immunity to corrosion
- A better tribological interface which may eliminate the need for carbon overcoats
- Easily extendable to perpendicular recording

Perpendicular Recording

- Minimization of the demagnetizing fields at extremely high recording densities
- Larger grain size supportable by the greater magnetic layer thickness permissible with perpendicular media
- Improved media yields because the recording layer does not have to be extremely thin as in the case for longitudinal recording
- Doubling of the effective writing field
- Greater remanent magnetization
- Higher useable perpendicular coercivity

Perpendicular Recording

Compared with Longitudinal, Perpendicular Recording allows for:

- **Sharper writing field gradient**
- **Higher useable coercivity**
- **Greater remanent magnetization**
- **Greater anisotropy**

A Break-Through Technology: Patterned Media

- Oriented single domain nanoparticles can be thermally stable down to 10nm or even smaller areal densities of greater than 1Tbits/in^2.
- The switching of the single domain nanoparticles does not require that the writing field extend over the entire particle.
- The single domain nature of the particles precludes any partial switching or erasing, minimizing the effects of fringing fields from the writing head.
- Very low media noise, since there are no zig-zag magnetization transitions and fluctuations in the magnetization of the nanoparticles.

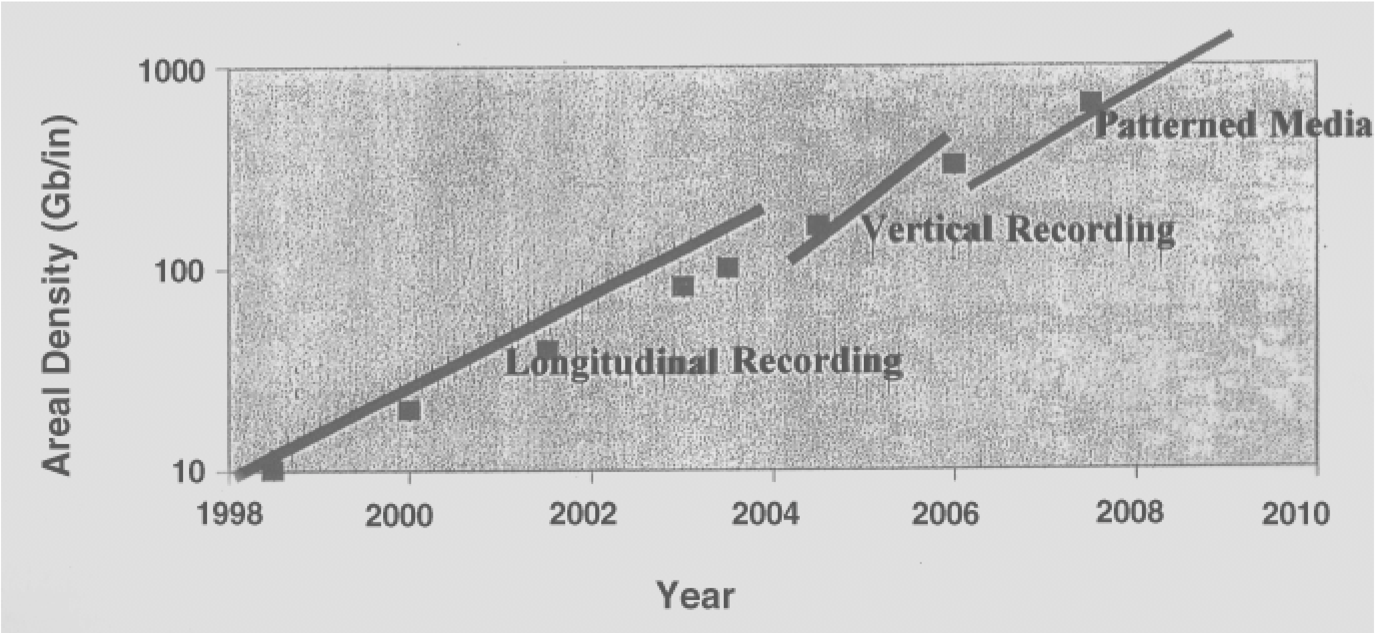
A Break-Through Technology: Patterned Media

- Interactions between bits can be controlled and minimized by adjusting the spacing between the nanoparticles and their magnetization.

- The discreteness, uniformity and precision of these single domain nanoparticle arrays can provide the platform for tracking extremely high track densities.

Media Technology vs. Year

Areal Density vs. Year



Toward 1 Tb/in^2 Magnetic Recording

1 Tb/in^2 System Specification (Perpendicular Magnetic Recording)

Capacity: 1 TeraByte (8 Terabits)

Disks: 8 disks of 1.4” diameter

RPM: 25,000 (average latency: 1.2 ms)

Access-Time: 2.3 ms average access time

Data-Rate: 3 Gbits/s

Areal Density: 1 Tb/in^2

Linear Density: 1730 kBPI

Track Density: 577 kTPI

Magnetic Spacing: 3nm

Media: 2-layer perpendicular (with soft underlayer)

H_c = 12,000 Oe

M_r = 340 emu/cc

Thickness = 9 nm

$M_r t$ = 0.3 memu/cm^2

Write Head: Write-width = 38nm

Bs = 2 T

SNR at the detector: 9 dB rms/rms

R. Wood: Abstract of TMRC’99, Paper A7 (1999.08.09)

TECHNOLOGIES

A Big Step *Forward*

- Replace the electromechanical access by electronic access, but without resorting to discreteness of the bits or any discrete wiring paths which usually imply higher cost.
- Requires an “inertialess” energy beam (light, electrons, and maybe ion) which can be focused into a small spot, and which can be deflected electronically to access a large area.

Semiconductor Main Memories: Attributes

- Discrete bits
- Discrete wired access to each bit
  - electronic access
- High performance
  - fast access, high throughput
- Relatively high cost per bit

Semiconductor Main Memories: Attributes

- Discreteness of the bits and of the wired paths to the bits are major contributors to the cost.
- The same attributes are responsible for the high performance.

TECHNOLOGIES

Peripheral Magnetic Storage: Attributes

- Homogeneous storage media
- Electromechanical access
- Lower performance
- Lower cost per bit

Peripheral Magnetic Storage: Attributes

- **Cost per bit is reduced by utilizing homogeneous storage media.**
- **Sharing the cost of write-read-signal processing electronics with billions of bits through electromechanical accessing which in part “brings the bits to the sensor” and in part “brings the sensor to the bits”.**

Other Peripheral Storage Technologies

The attractive attributes of conventional peripheral magnetic storage also apply to:

- **Near Field Optical (NFR)**
- **Magnetic Super Resolution (MSR)**
- **Holographic**
- **Probe**

Problems with Beam Memories

- Depth of focus
- Depth of field
- High overhead cost for beam:

  generation,

  polarization,

  focusing,

  deflection,

  modulation,

  possible vacuum environment
- Economics for 2D beam storage not favorable but 3D becomes attractive

3D Beam Storage

- The media must not be overly absorptive or excessively scattering.

- 3D Holographic
  - Needs improved materials

- 2 Photon
  - Needs improved materials

Quantum Storage

- Manipulation of nuclear spins similar to the NMR processes used in Magnetic Resonance Imaging (MRI).
- Potential of performing logic and memory in the same system of quantum states without requiring sophisticated nanotechnology fabrication.
- Can achieve massive parallelism by being in multiple states at once and acting on all of them simultaneously.