
Magnetic Recording Beyond the First 100 Years

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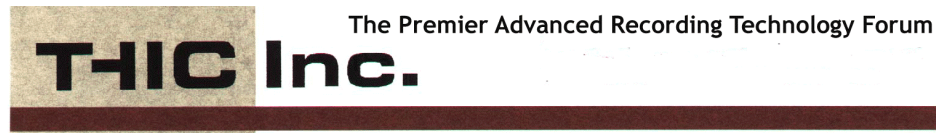
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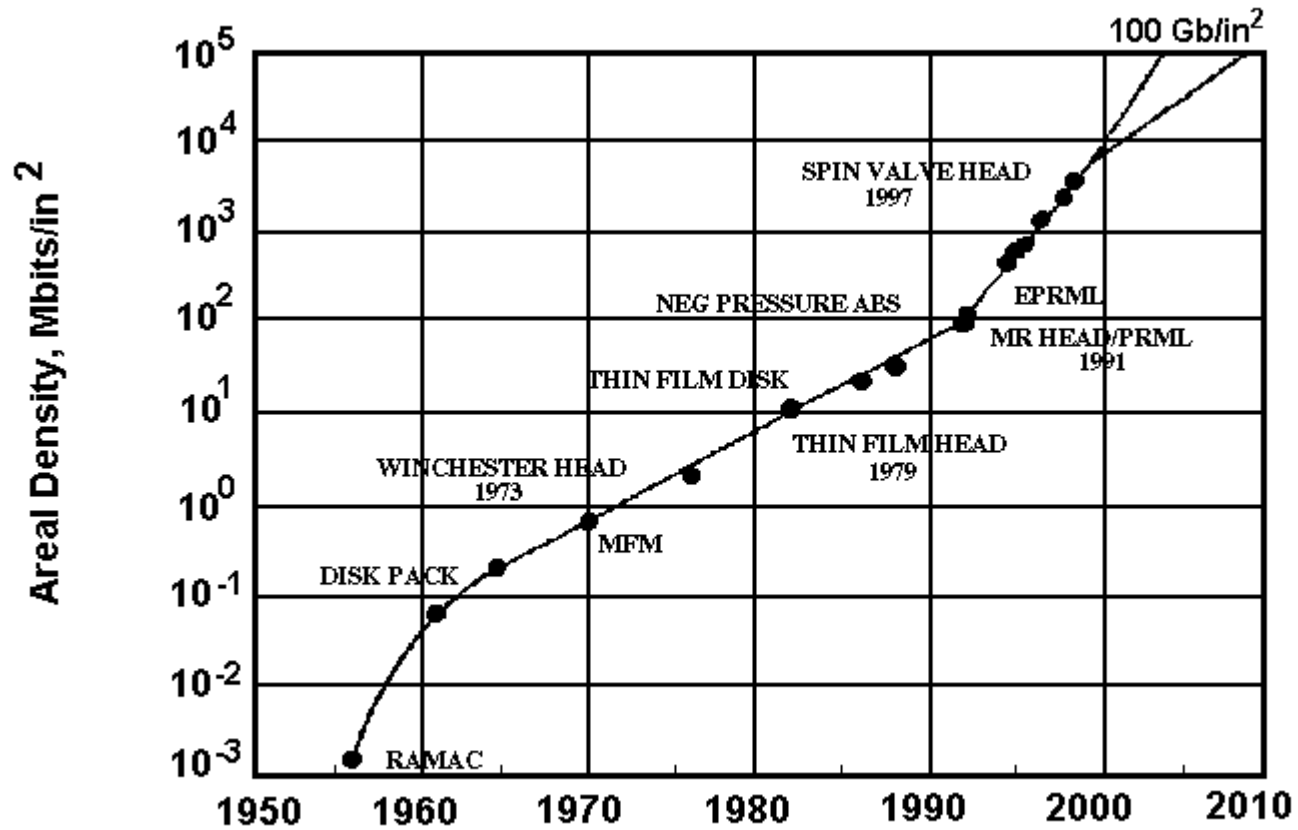
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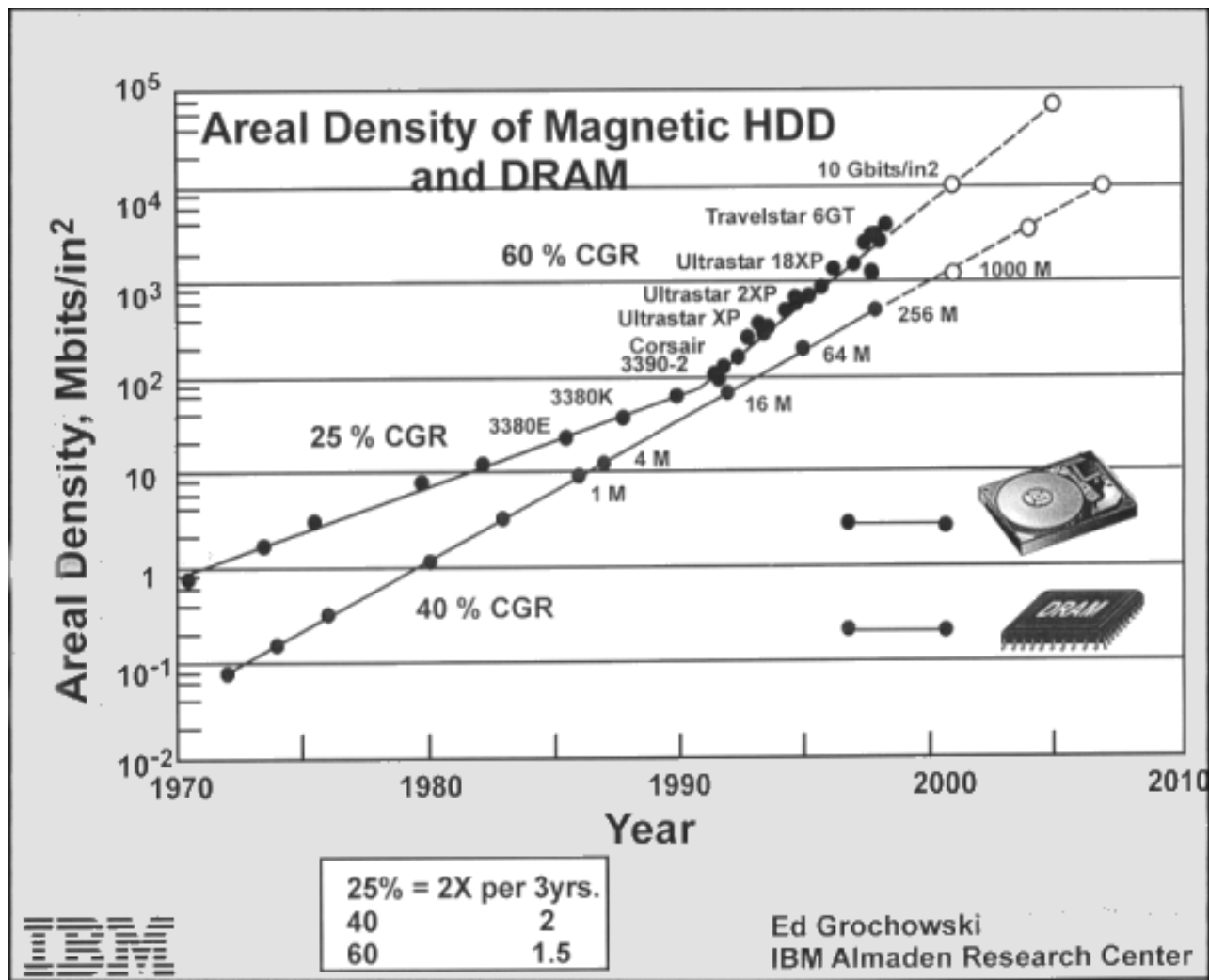


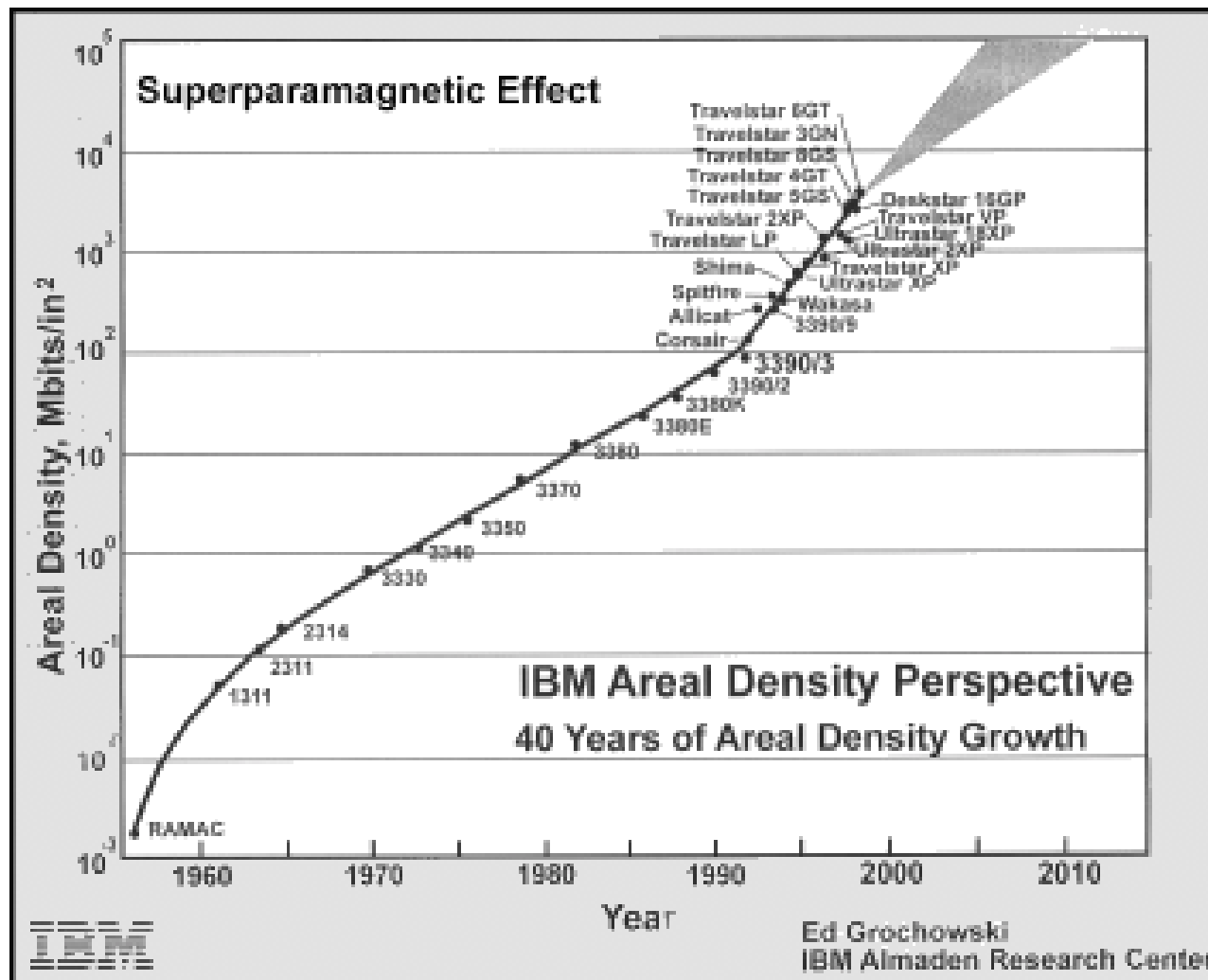
The Premier Advanced Recording Technology Forum



Hard Disk Drive Technological Milestones







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:

- **Fundamental limits** due to the atomic nature of matter which may impose ultimate physical bounds to nanofabrication and miniaturization.
- **Practical limits** 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

Examples:

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

a) Very high anisotropy media:

- CoSm
- CoPt
- FePt
- Other alloys



Beyond Conventional Longitudinal Recording

b) Oxide Media

- Very low media noise as a result of the oxygen superlattice
- 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/in².**
- **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.**



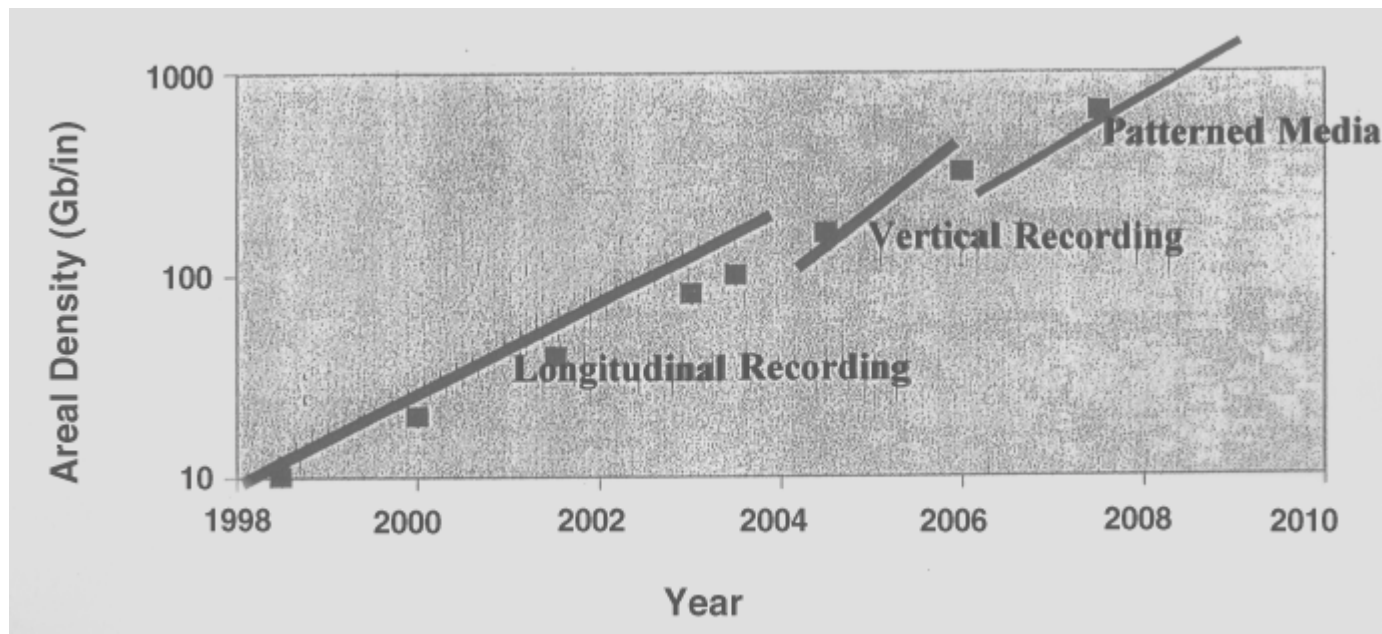
A Break-Through Technology: Patterned Media

- 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/in² Magnetic Recording

1 Tb/in² 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/in²

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_rt = 0.3 memu/cm²

Write Head: Write-width = 38nm

B_s = 2 T

SNR at the detector: 9 dB rms/rms

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



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.



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.**

