Challenges to Extremely High Density Magnetic Recording

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Storage Products Group

FUJITSU LIMITED

Outline

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- **History of Breakthroughs**
  - Recording Limit Predictions for HDD
- **Competition on Magnetic Recording**
  - Topics: 56Gb/in^2 demonstration
- **Magnetic Recording Technology Roadmap**
  - Media
  - Head
  - Head Disk Interface
  - Positioning
  - Performance
- **Future Prospects**

Magnetic Recording Limit Predictions

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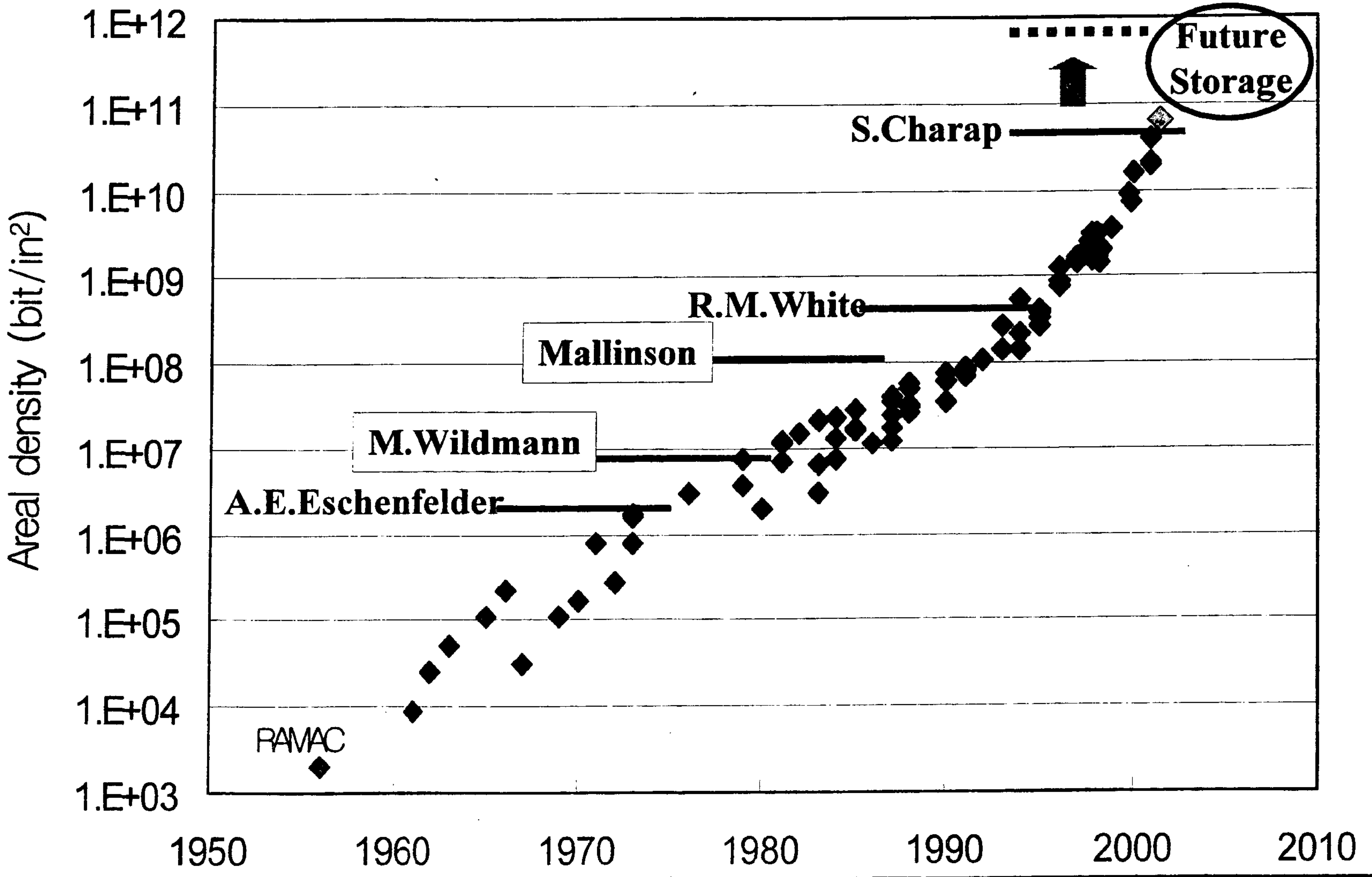

Y. Miura, 2000, Fujitsu

10th Anniversary of Korean Magnetics Society

3

Magnetic Recording Limit Predictions

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1956	RAMAC	
1970	A. E. Eschenfelder, JAP, 41 p.1372	2Mb/in^2
1974	J. Mallinson, IEEE Trans. Magn., 10 p.368 Theoretical S/N limit	100Mb/in^2
1974	M. Wildmann, IEEE Trans. Magn., 10 p.509 Mechanical limit	8Mb/in^2
1980	R. M. White, Scientific American, 243 p.138 Limit of longitudinal recording	60Mb/in^2
1994	P. Lu & S. Charap, IEEE Trans. Magn., 31 p.2767 Superparamagnetic limit	40Gb/in^2

Competitions on High Density Recording

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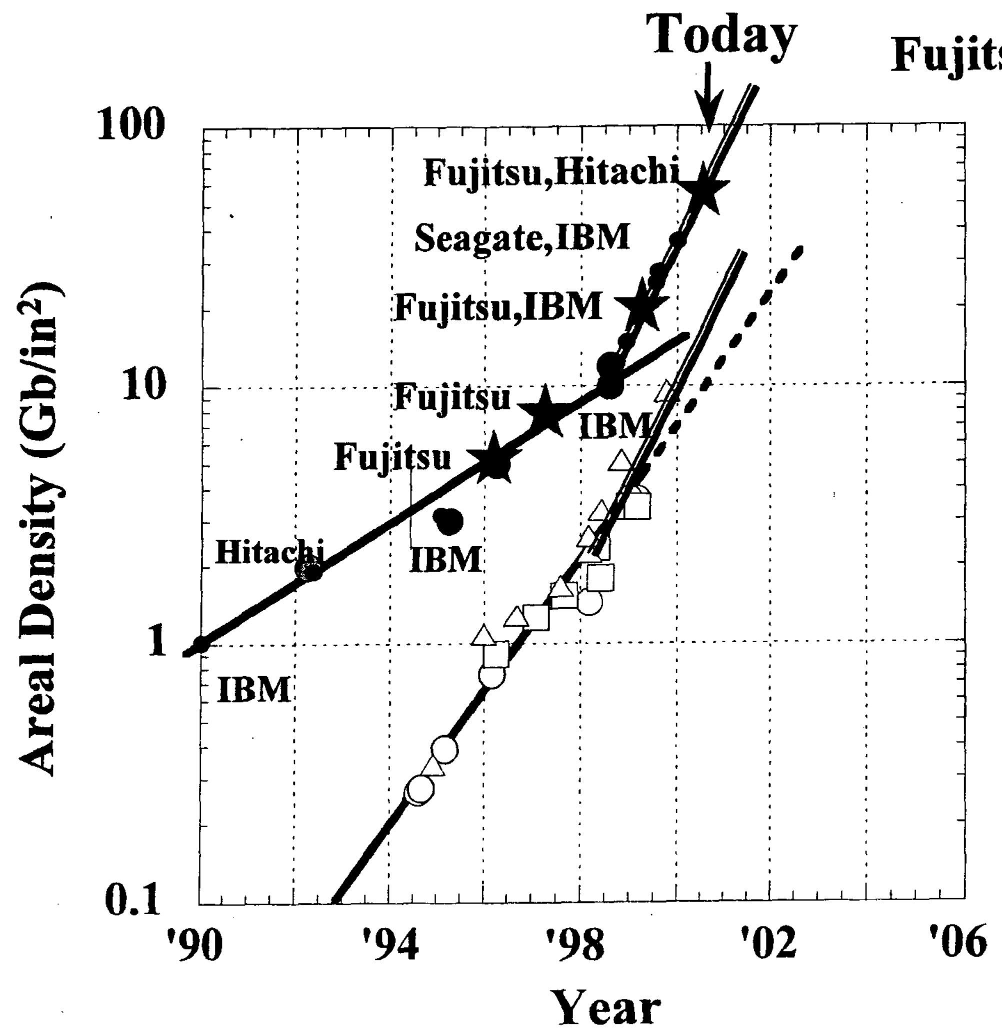

Fujitsu's Demonstration

56 Gb/in^2
82 kTPI
680 kBPI

56 Gbits/in^2 Recording Demonstration

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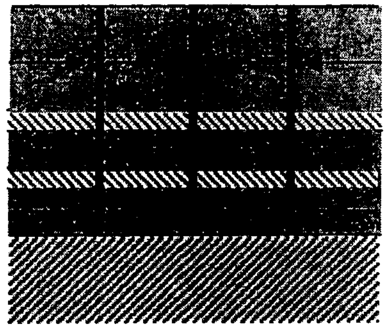


Medium

CoCrPtB **Ferri-Coupled Structure**, Cr-based under layer,

3 nm DLC, **Hc = 3913 Oe, Mrδ = 0.39 memu/cm^2**, S' = 0.8

Write head

CoNiFe stitched pole tip

Write track-width: ***0.28 μm***

Read head

Synthetic ferrimagnet CoFeB/PdPtMn **specular spin-valve**

read track-width: ***0.21 μm***

Sensitivity: ***6 mV/μm @ Is = 3 mA,***

Channel & R/W

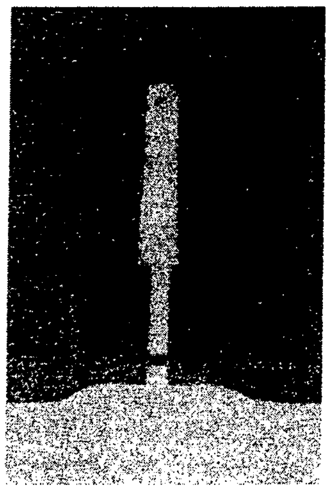
32/34 code, Marvell ME^{2}PRML

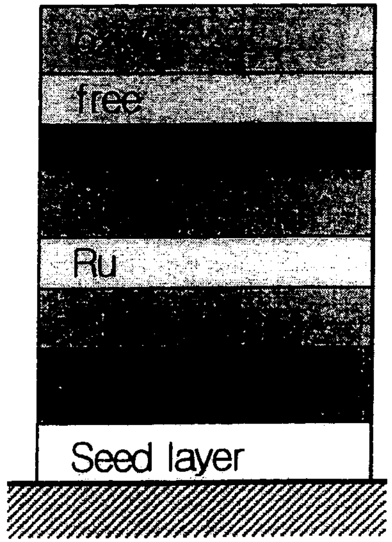
Data rate: ***17.4 MB/s***

Slider

Flying Height ***10 nm***

Magnetic Spacing: ***21 nm***





Magnetic Recording Technology Roadmap

Progress of Various Storage Devices

Trend of Bit Aspect Ratio

Media

Head

HDI

Positioning

Performance

Progress of Various Storage Devices

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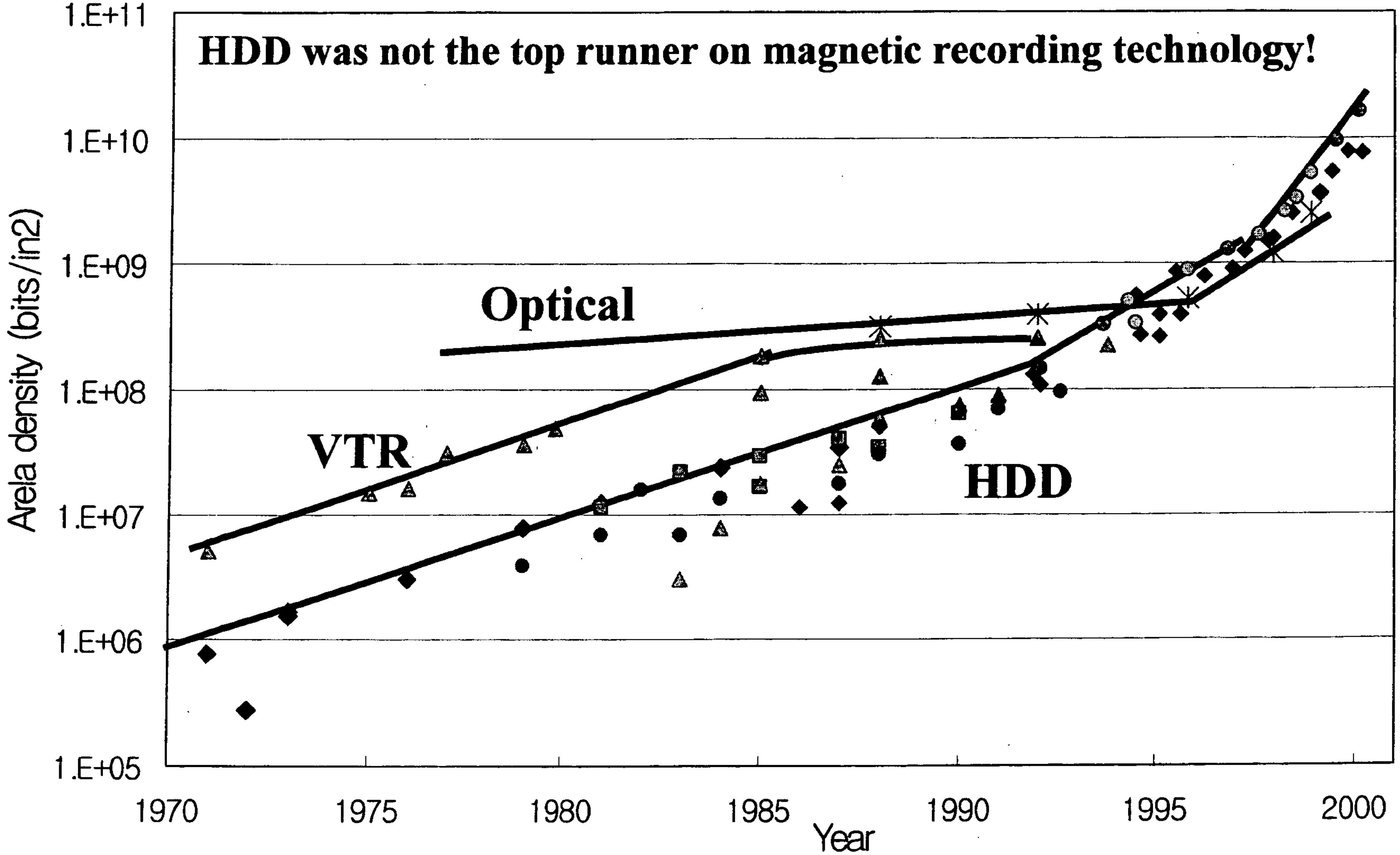

Y. Miura, 2000, Fujitsu

10th Anniversary of Korean Magnetics Society

Forecast the Trend of Bit Aspect Ratio Toward the Tbit Recording

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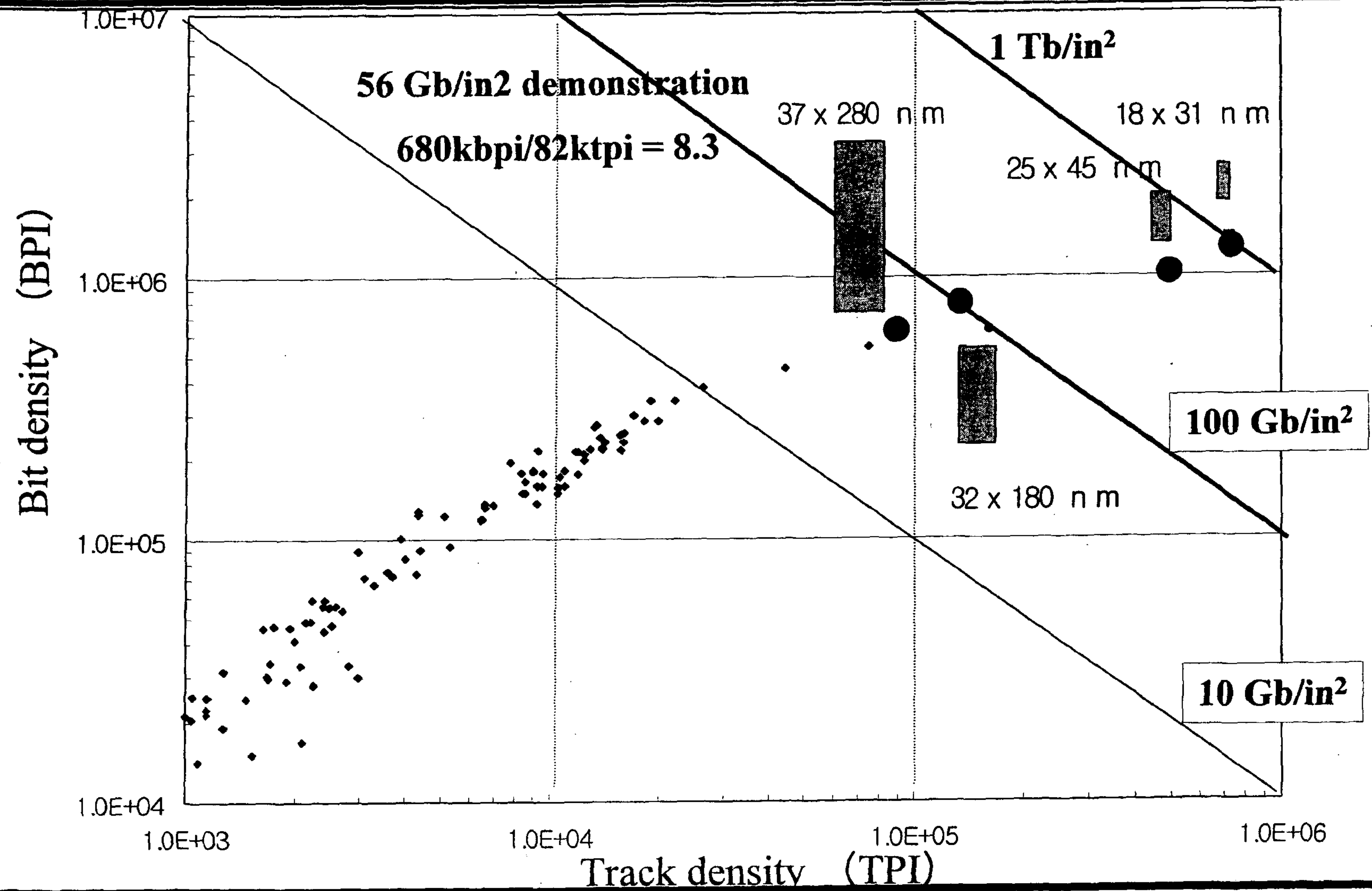

Media Road Map

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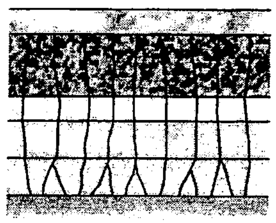
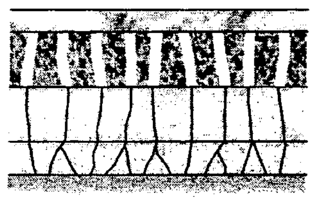
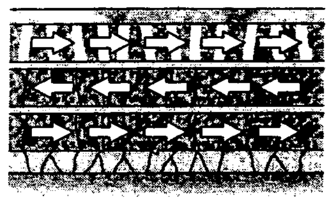
	2000	2003	2005
Areal density (Gb/in2)	15-30	100	300
Technology	Granulate Seed- layer Multi-layer	Granulate Synthetic Ferri-coupled	Perpendicular Discrete media



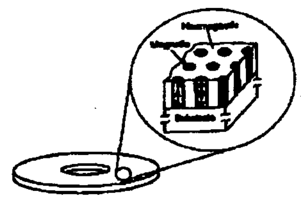


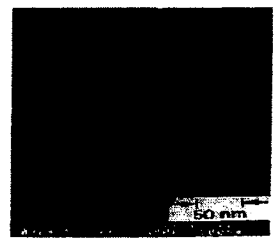
Low Noise



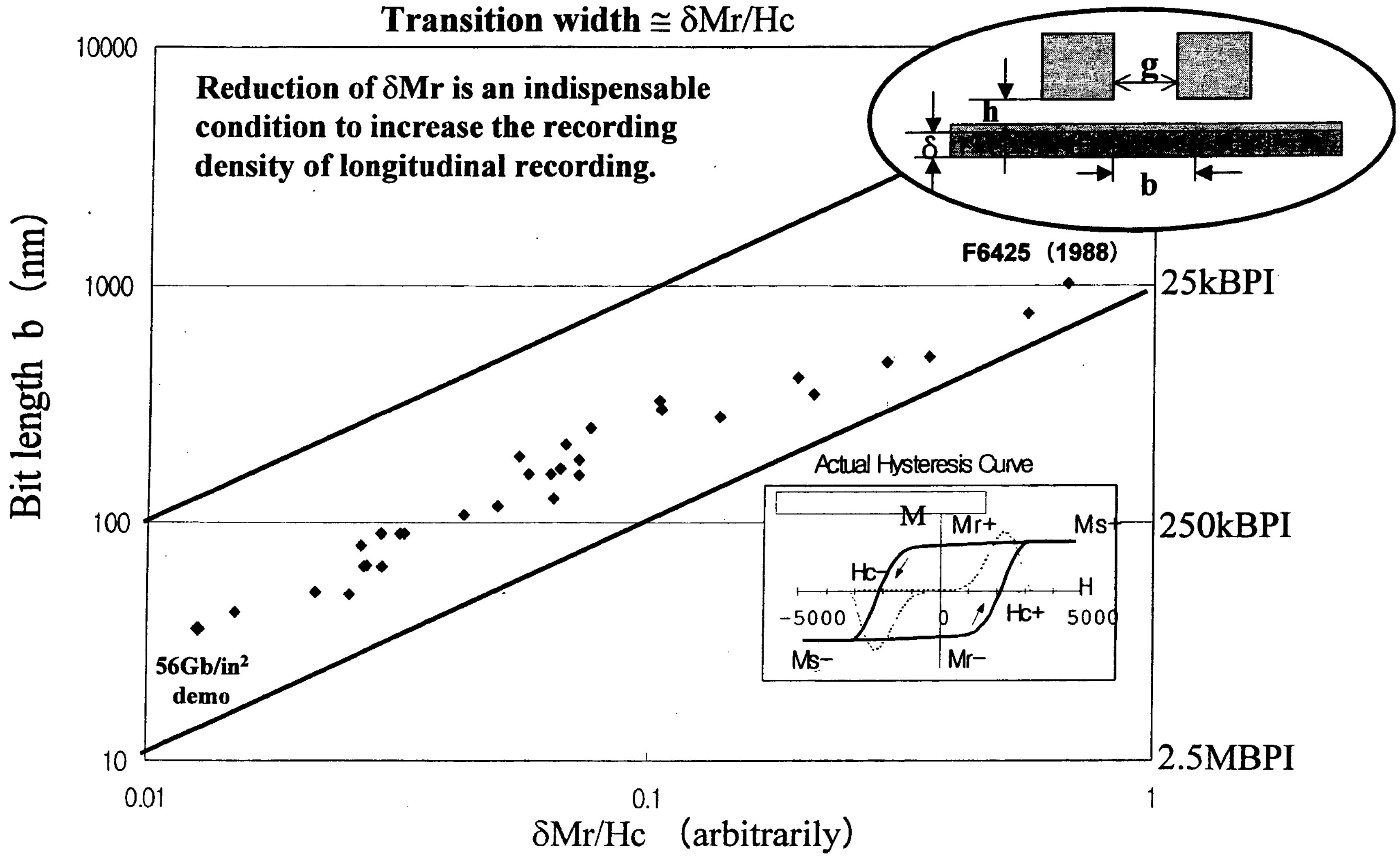
Thermal Stability

Signal decay





Relation between recording density versus $\delta Mr/Hc$ of magnetic media



Design Concept of Recording Media

Approach to high density recording media

Reduce the exchange interaction

Reduce the magnetic grain size

⇓ Issues

Thermal decay

⇓ Improvement

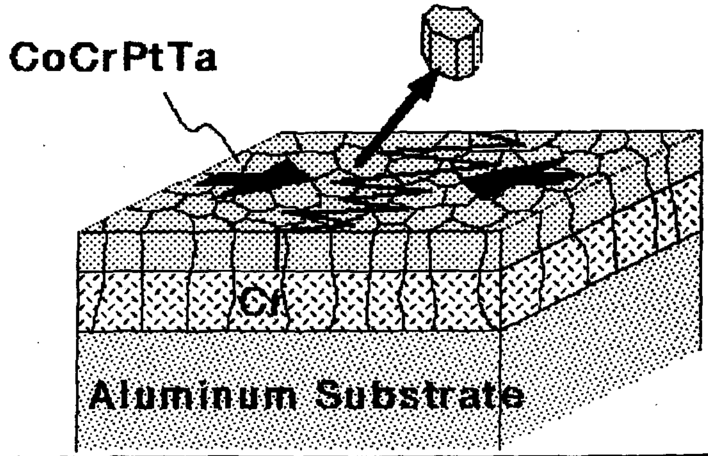
- Higher magnetic orientation
  - Homogenize the grain
  - Increase the magnetic anisotropy energy
- Stabilize with layer coupling

⇐ Reduce the media noise

Thermal relaxation $\propto K_u V / k_\beta T$

V : Volume of a grain

K_u : Magnetic anisotropy energy



Media Structures for Stabilization

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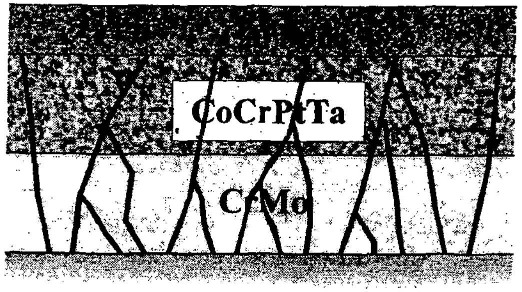
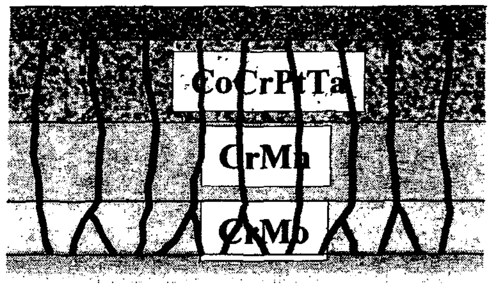
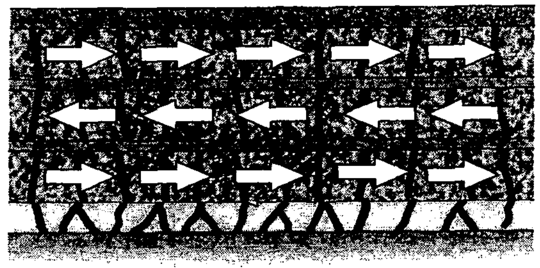


a) Conventional media

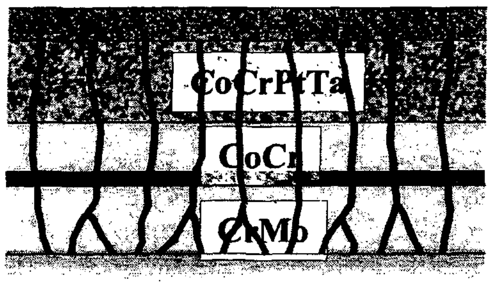


b) Stabilized media with **AFM** (antiferromagnetic) underlayer



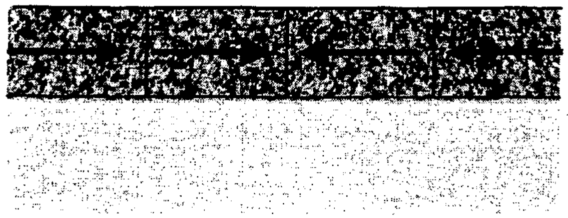
d) Stabilized media with synthetic **Ferri coupled layer**

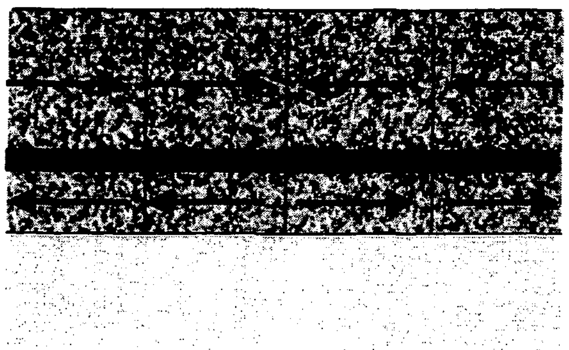
U. S. Patent No. 5,701,223.

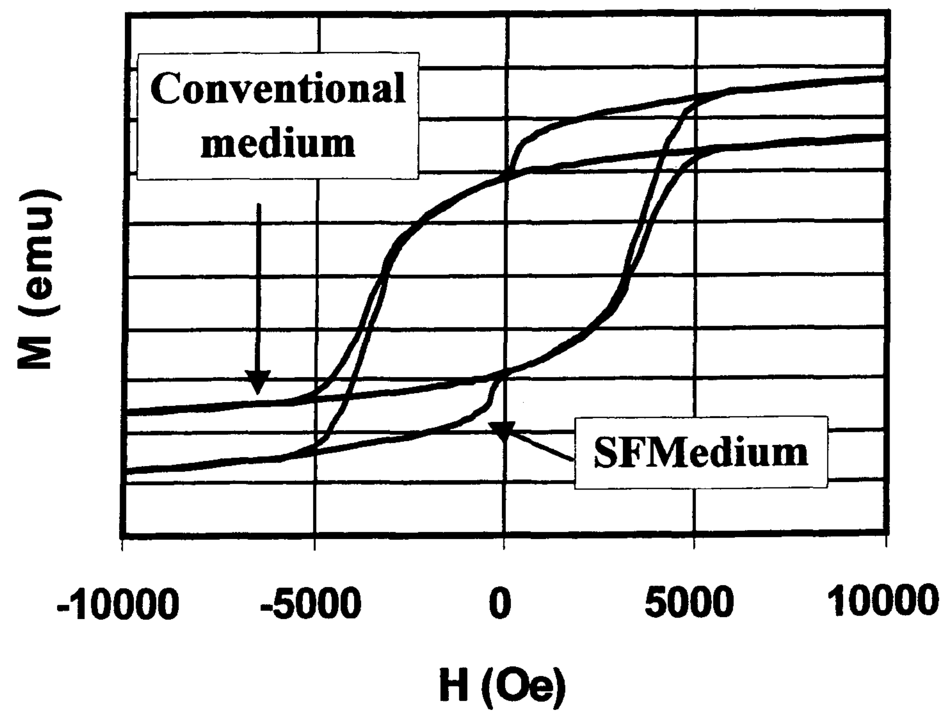


c) Stabilized media with **Keeper** (softmagnetic) underlayer

Synthetic Ferri-coupled (SF) Media







Signal degradation (300 kfci)

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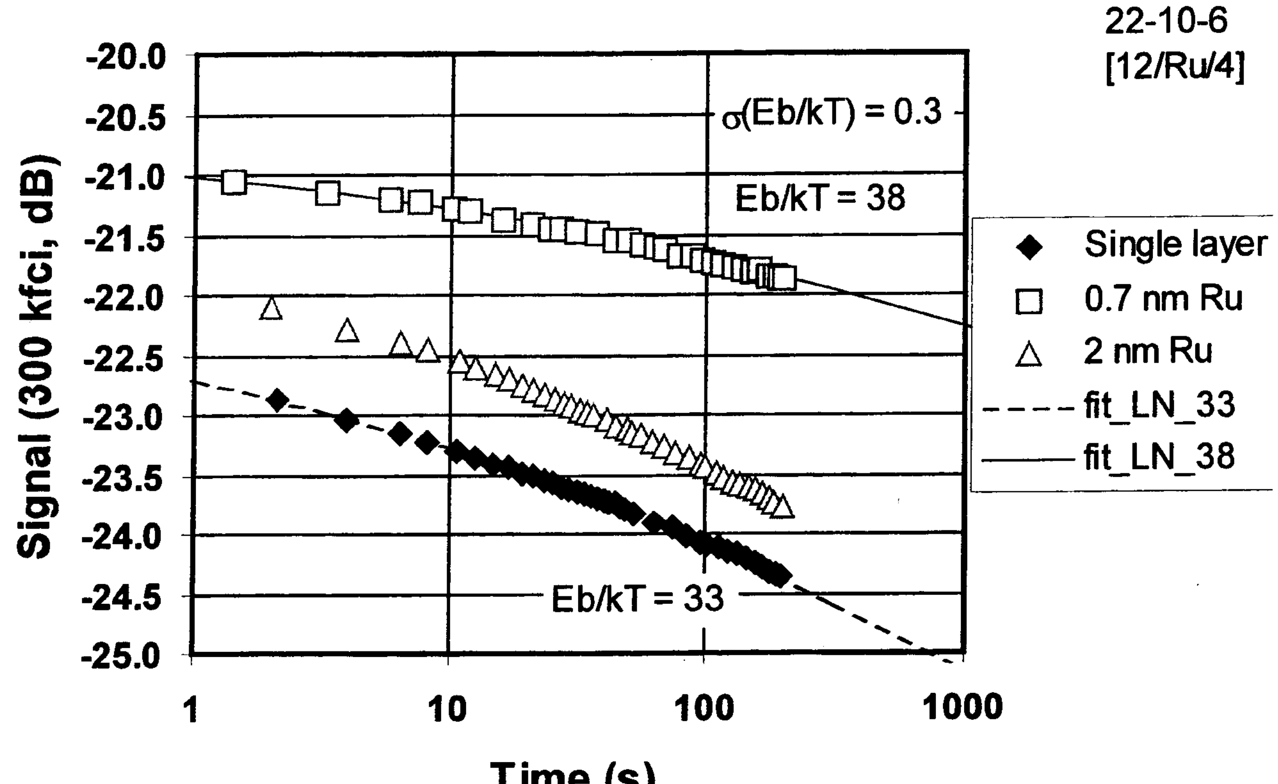


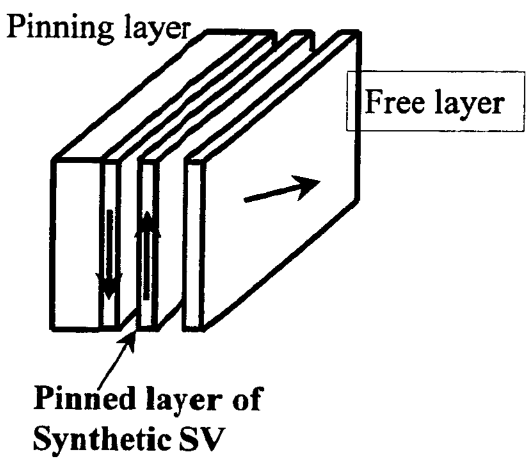
Layer exchange essential in enhanced thermal stability:

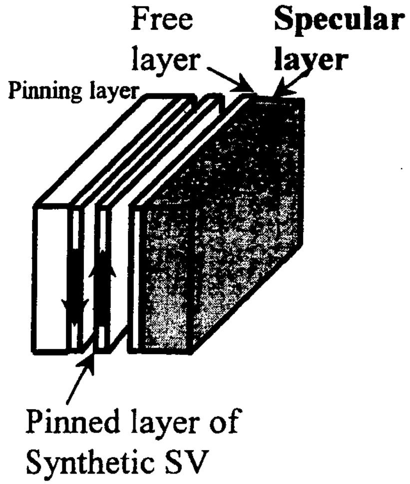
⇒ increased effective volume; 15% Eb/kT increase (vol. increase 33%)

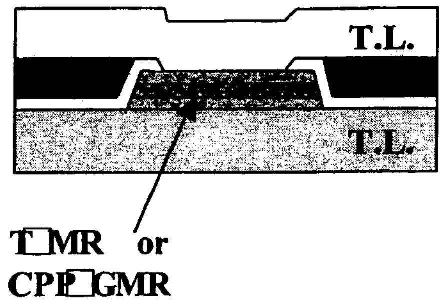
⇒ not magnetic anisotropy increase in top layer.

Head & R/W Roadmap

	2000	2003	2005
Areal density (Gb/in2)	15-30	100	300
Head Technology	Synthetic Ferri-SV	Specular Spin-Valve	Tunneling-MR CPP-MR
	2V/μm	6V/μm	10V/μm
Coding	MEEPRML	ME^nPRML / LDPC / Turbo	







Principle of Spin-Valve Movement

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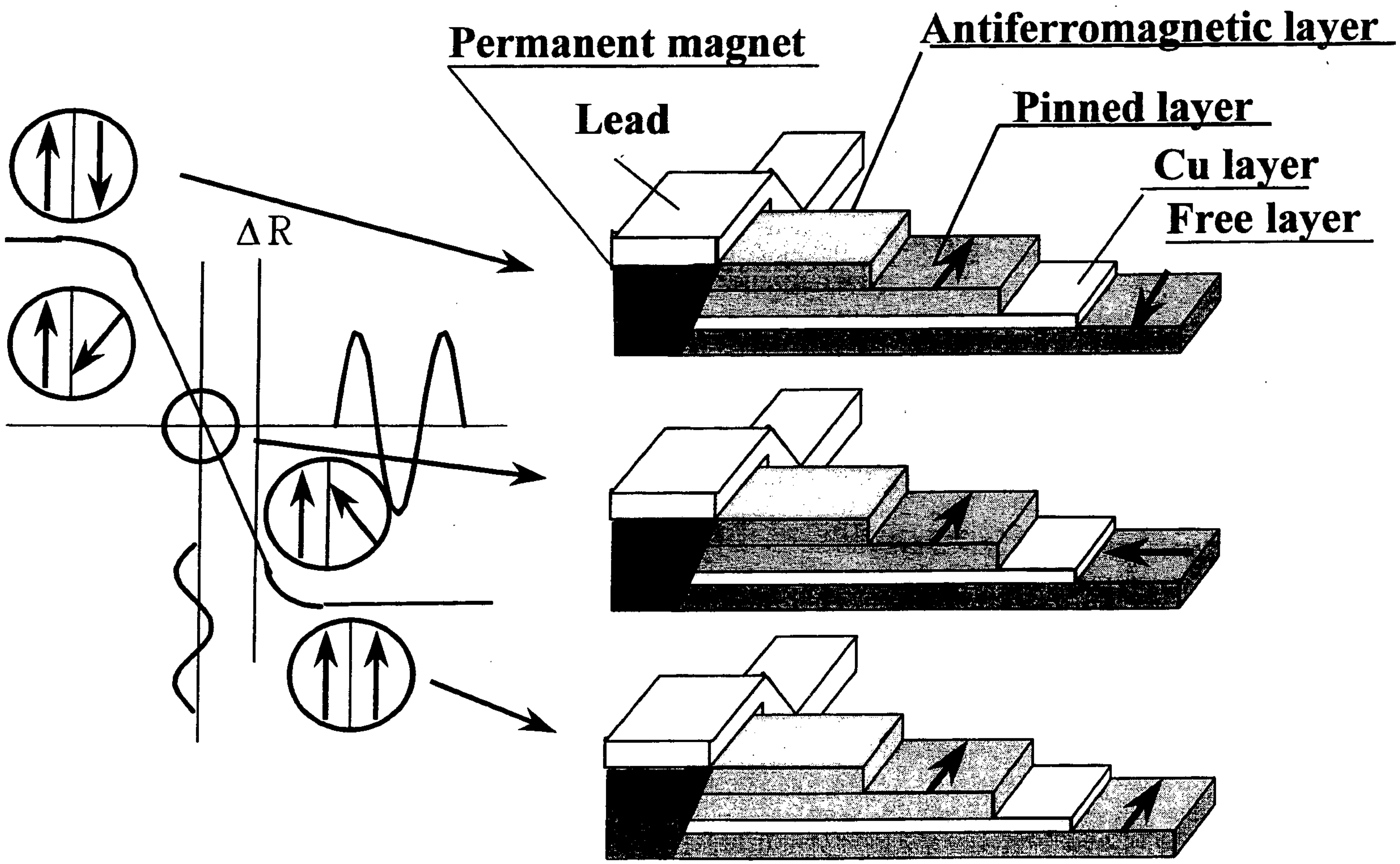

Spin Valve GMR Head: Robust design

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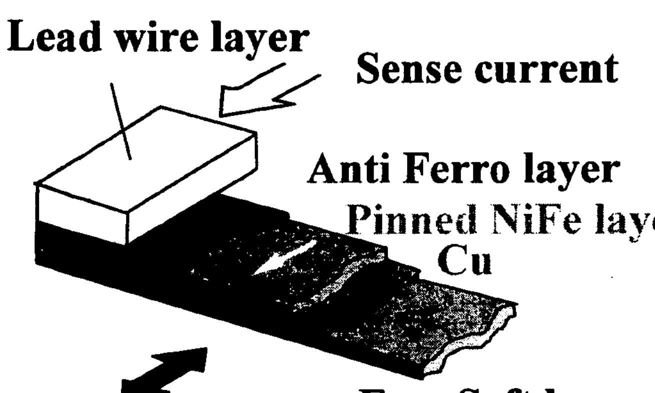
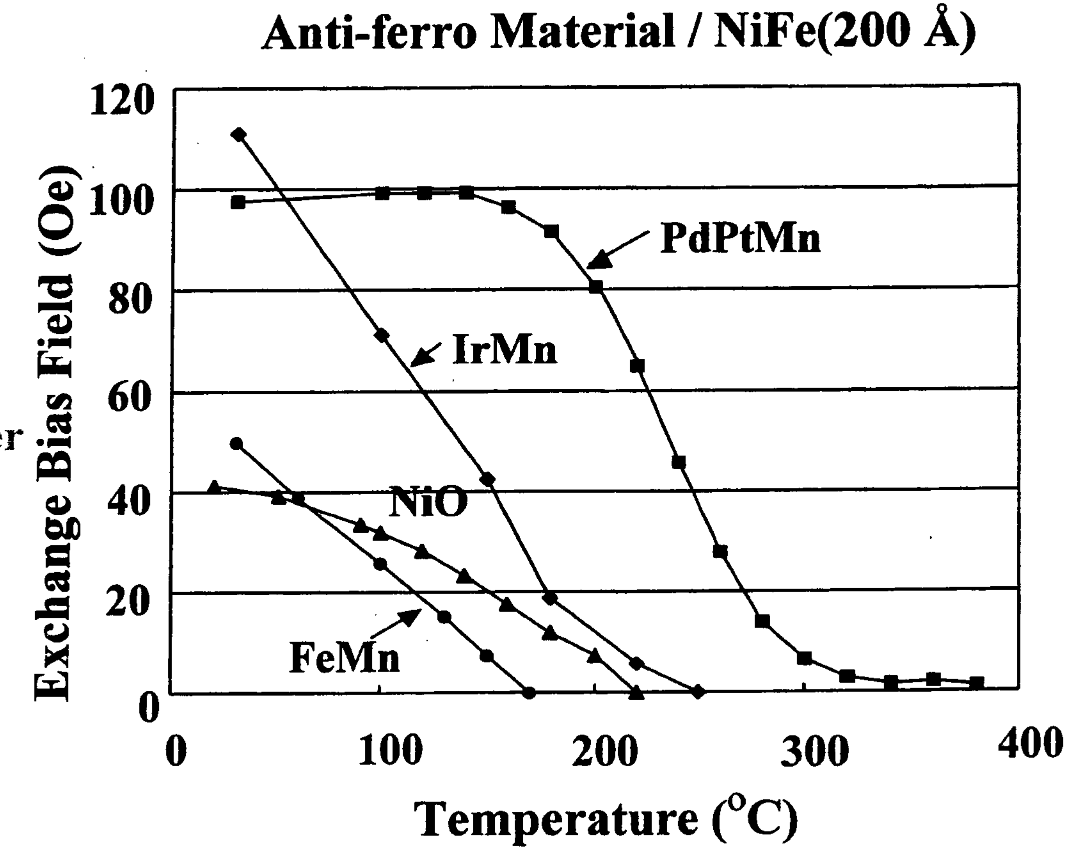
Anti-ferro Material Selection





Output of MR/GMR Head

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$$V \propto \frac{I\,W\,\Delta\rho}{h\,t}\;\frac{Mr\delta}{Ms\,t}\;\exp(2\pi d/\lambda)$$

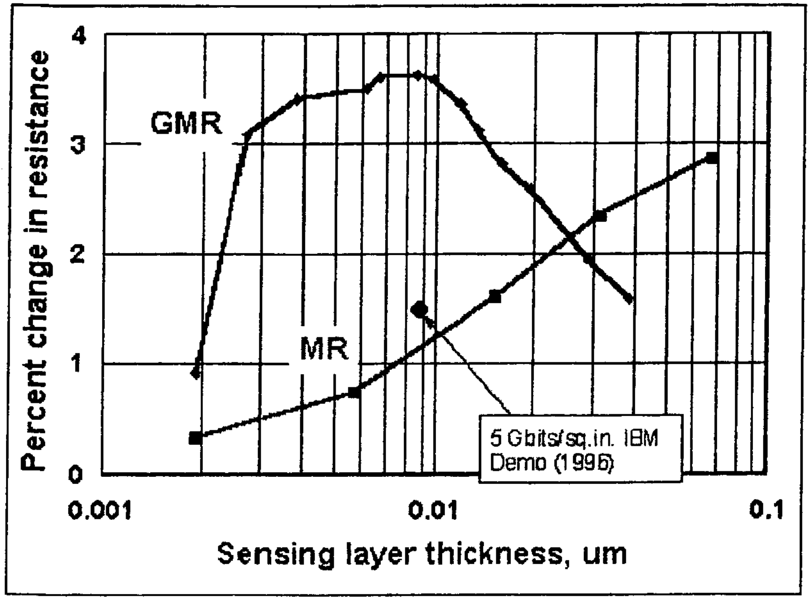
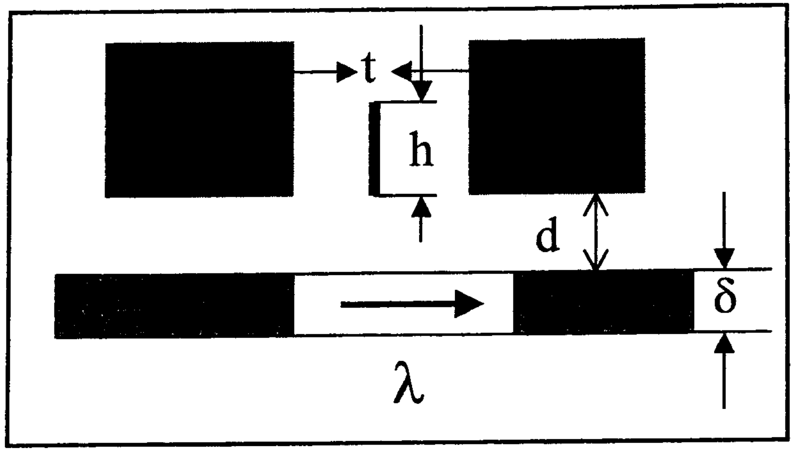


Figure 4. Percent change in resistance of MR and GMR sensors

Source: IBM



I = read head current
W = width of read sensor
Δρ = magnetoresistive coefficient
h = height of read sensor
Ms = saturation magnetization of the sensor
t = thickness of read sensor
Mr = remanent magnetization of media
δ = thickness of magnetization media
d = effective magnetic spacing

Spin Valve Head Roadmap

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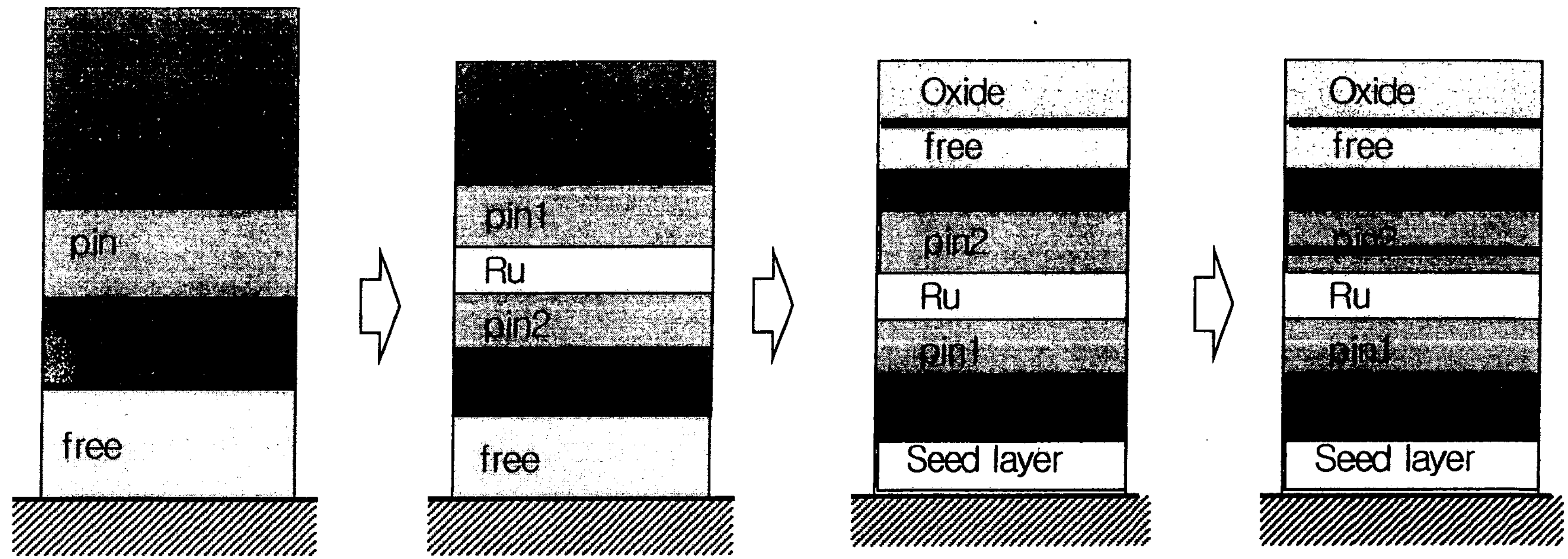
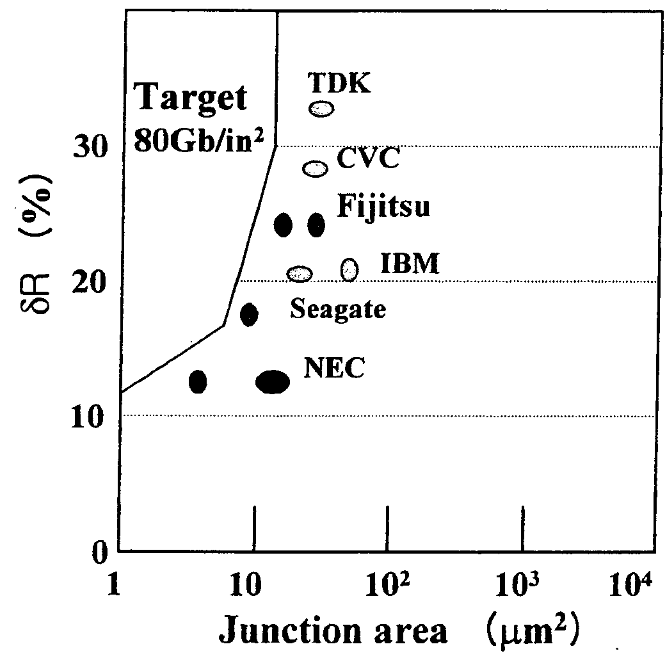
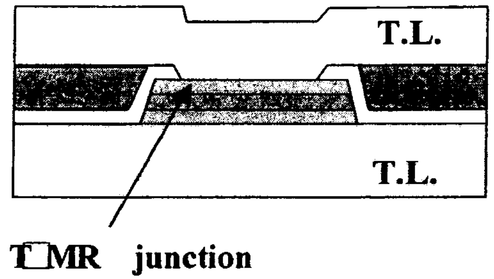


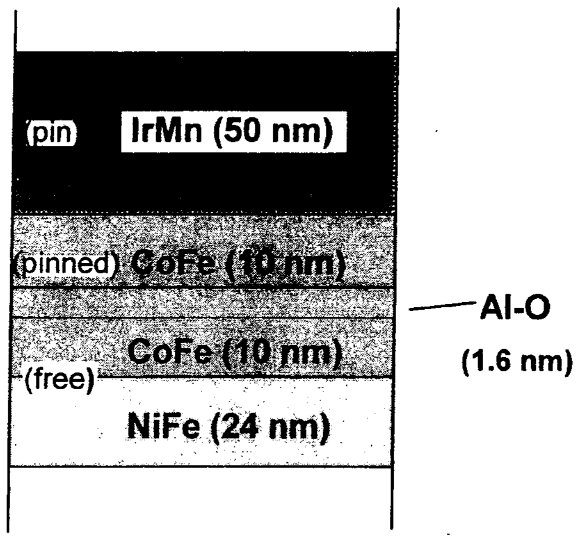
a) Conventional b) Ferri-Pinned c) Specular d) Double-specular

- Enhanced specularity: Increased **mean free path** of electron
- Controllable interlayer coupling: Less shunt through Cu spacer
- Oxygen control through **CuO_x**: Improved soft magnetic properties

Tunneling MR







H. Kikuchi, K. Kobayashi and M. Sato

Write Head Issues

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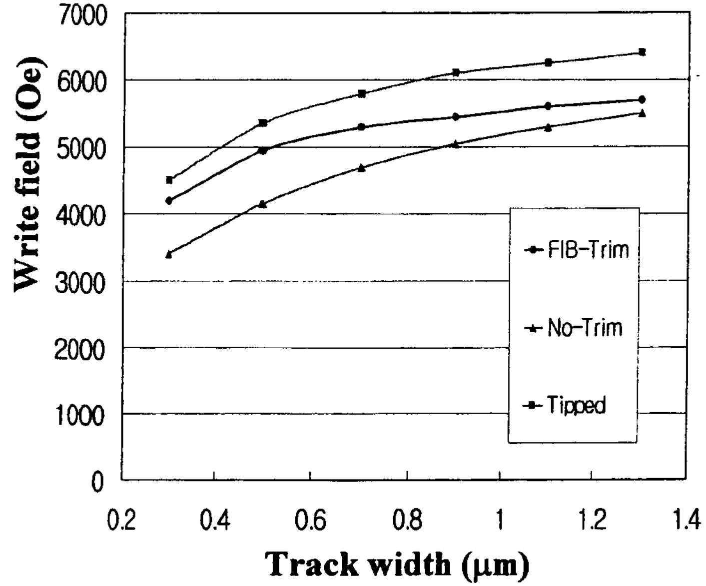
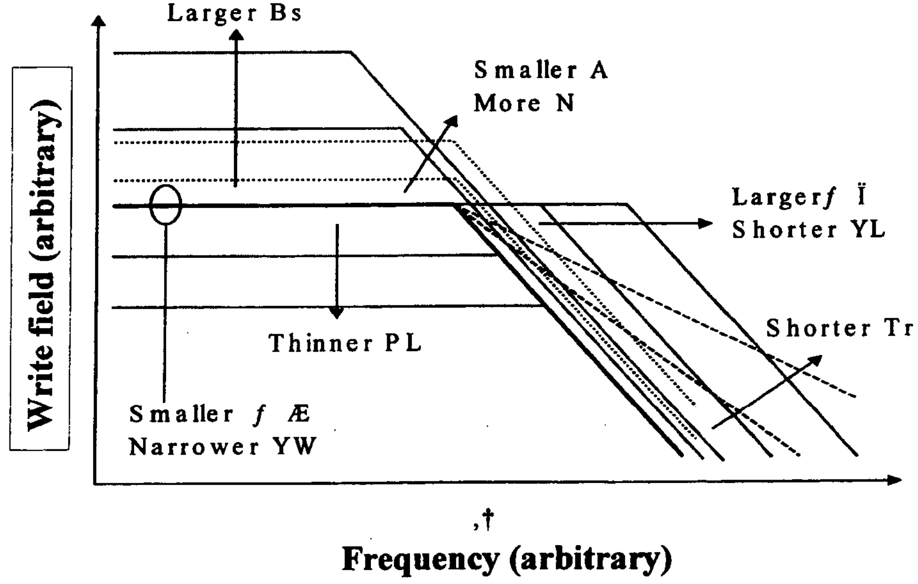
Narrow Track Performance



High Frequency Performance



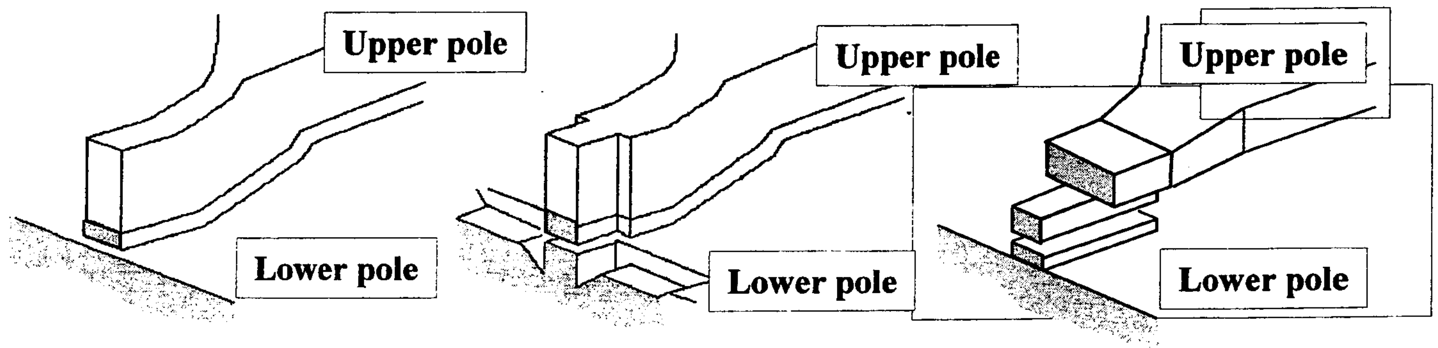


Photo Lithograph Roadmap

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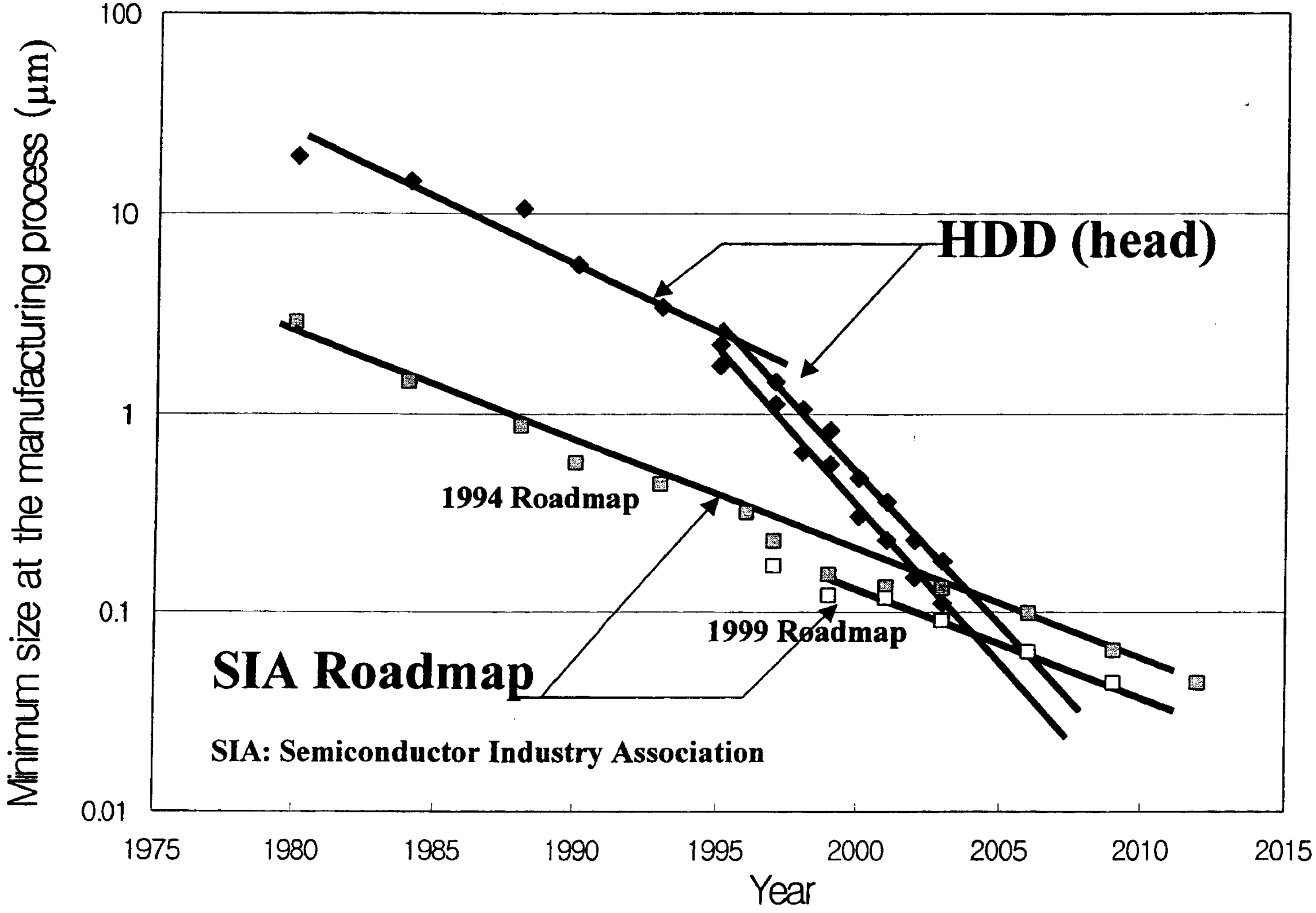

Head Disk Interface

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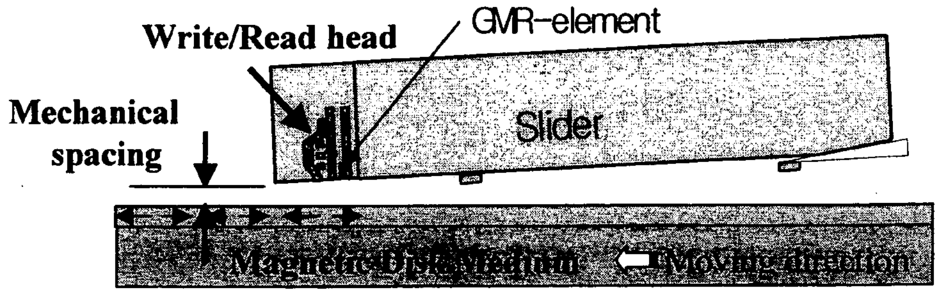
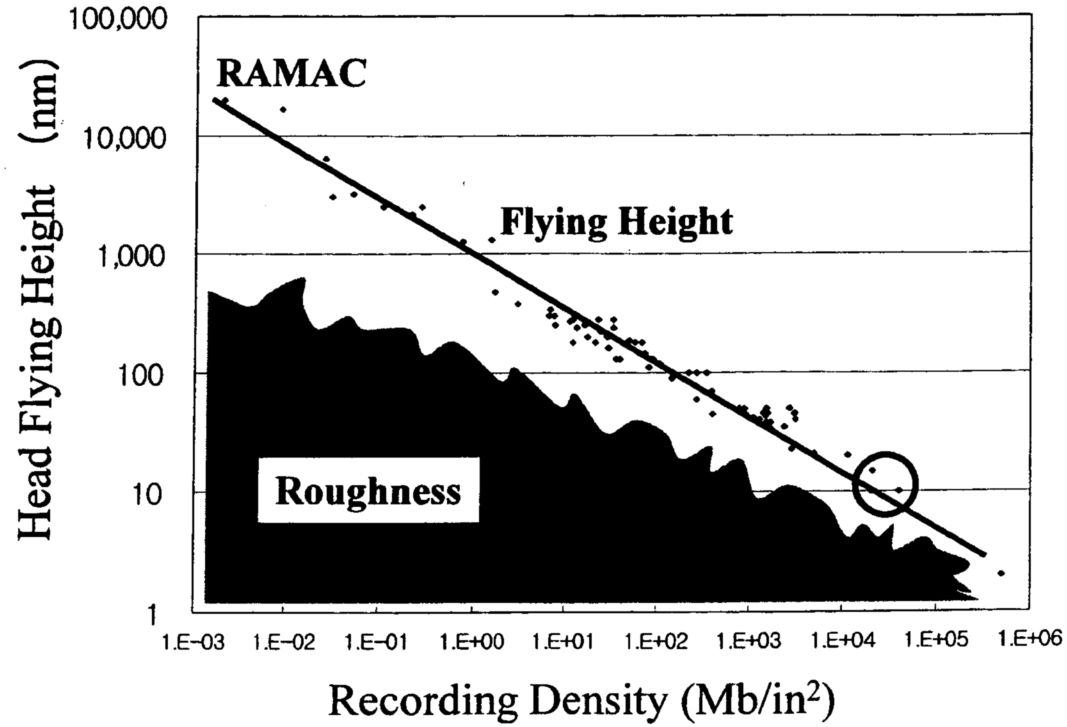
High density magnetic recording achieved, if only head to medium spacing could reduce.



Technical Issues

- Surface Roughness
  - Precision machining
- Stiction
  - Stiction free techniques
- Outgas & Contamination
  - Outgas free component
  - Environment cleanliness
- Overcoat & Lublicant
  - Thin film < 3 nm
  - Corrosion protection
- Thermal Asperity



HDI Roadmap

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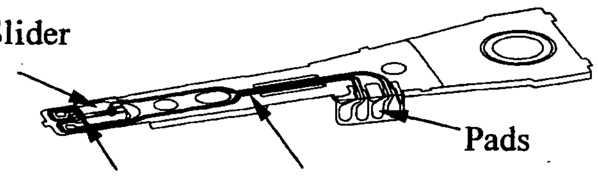
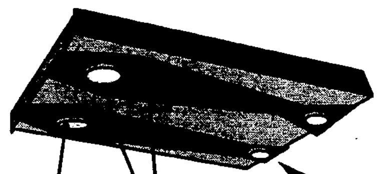
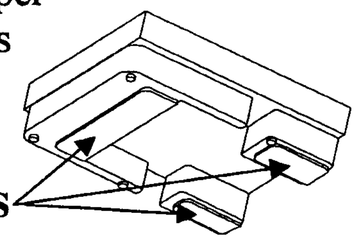
	2000	2003	2005
Areal density (Gb/in^2)	15-30	100	300
Load/Unload	Load/Unload CAPS		
Suspension	High Stiffness CAPS		
Slider	SFS	New Trini SFS	



CAPS
(Cable Patterned Suspension)



Guppy slider



Trini-Slider

Roughness vs Stiction on SFS

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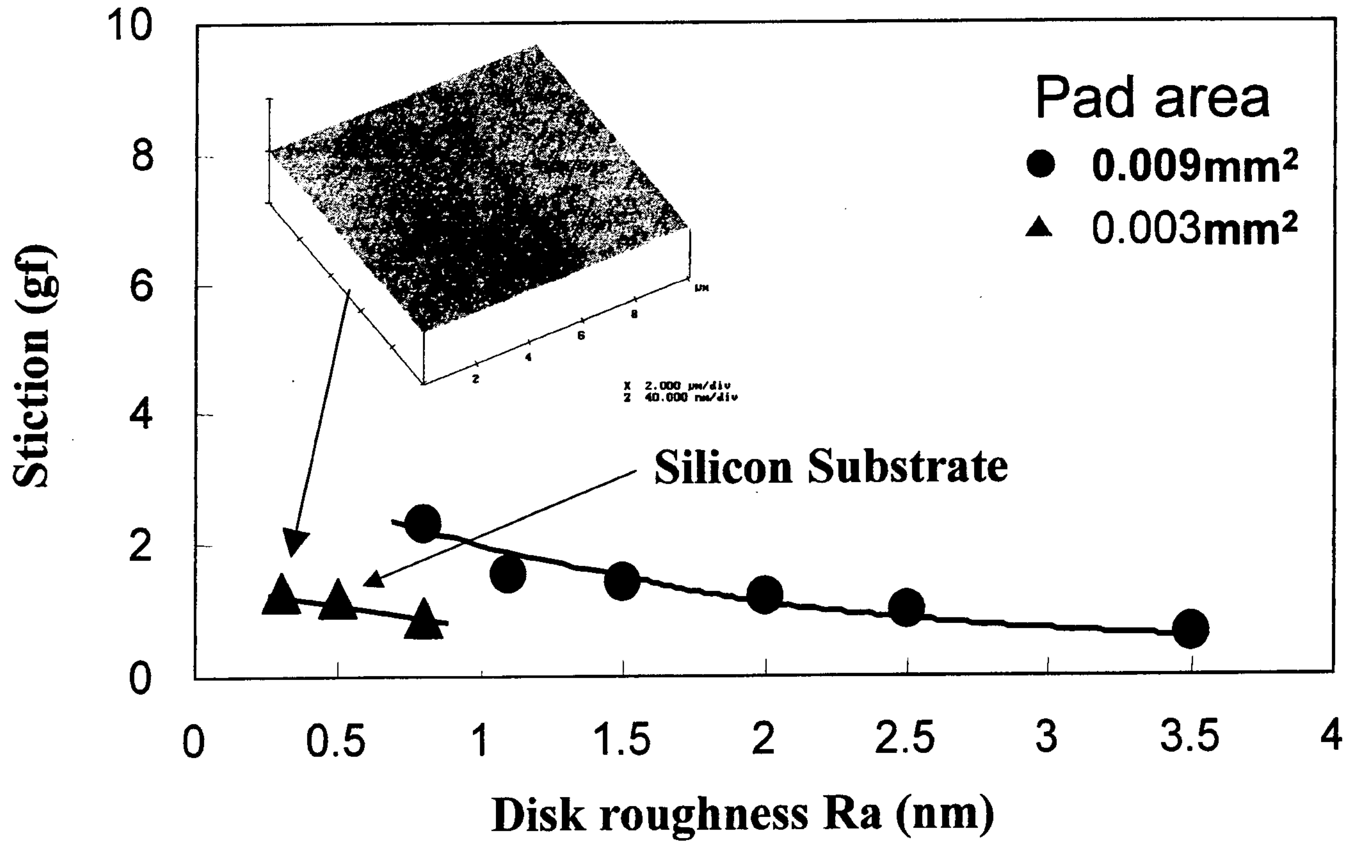
Why Stiction Free Slider?

Smoother disks without stiction

No Loading/Unloading Zone = No data zone loss



Head Positioning Roadmap

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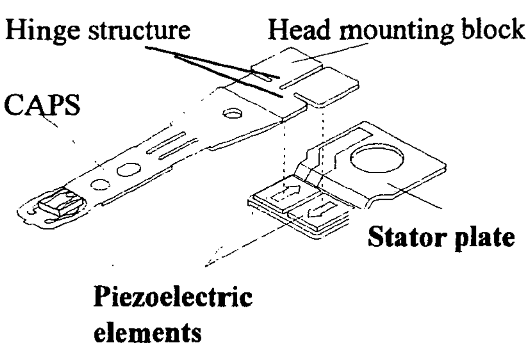
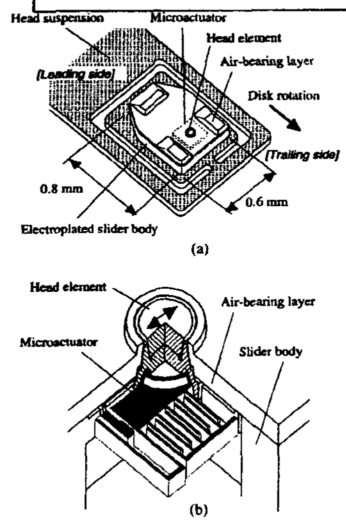
	2000	2003	2005
Areal density (Gb/in^2)	15-30	100	300
Track Width (μm)	0.5	0.25	0.15
Servo signal	STR		Pre Grooved
Actuator	VCM	Piezo actuator	

Piezoelectric actuator



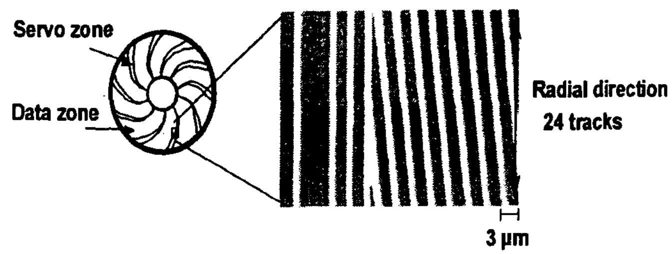
Micromachined actuator



ESPAR

Pre-grooved substrate

(Embedded Servo PAttem under Recording layer)



Head Positioning Technology

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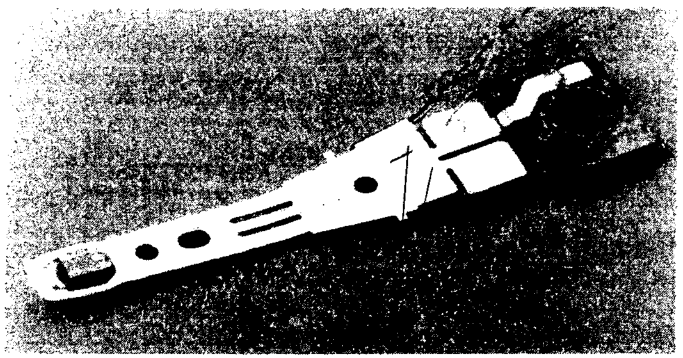
Actuator

Voice Coil Motor
Piezoelectric actuator
Micromachined actuator

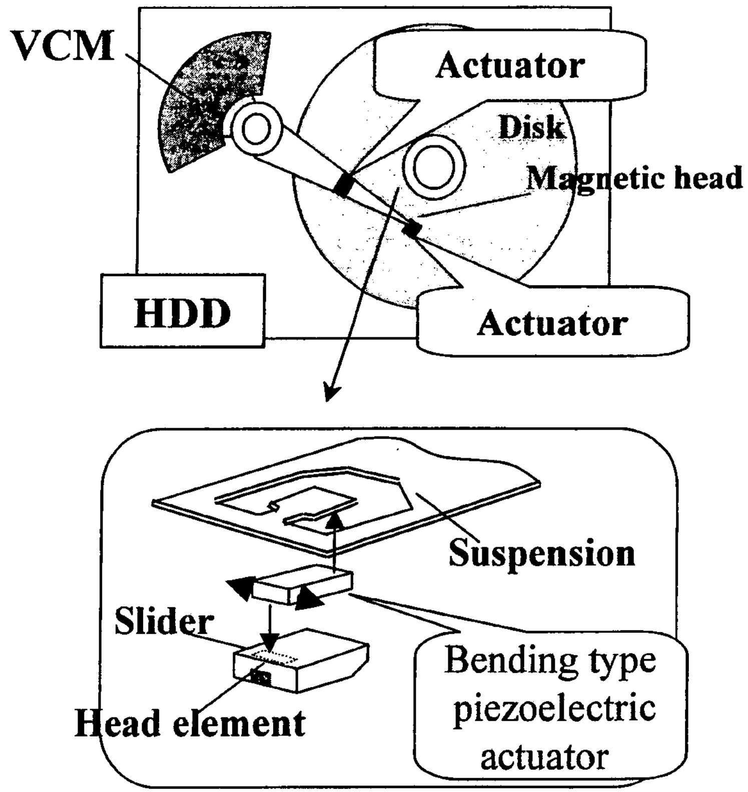
Position signal

Servo Track Writer
Pre embossed disk



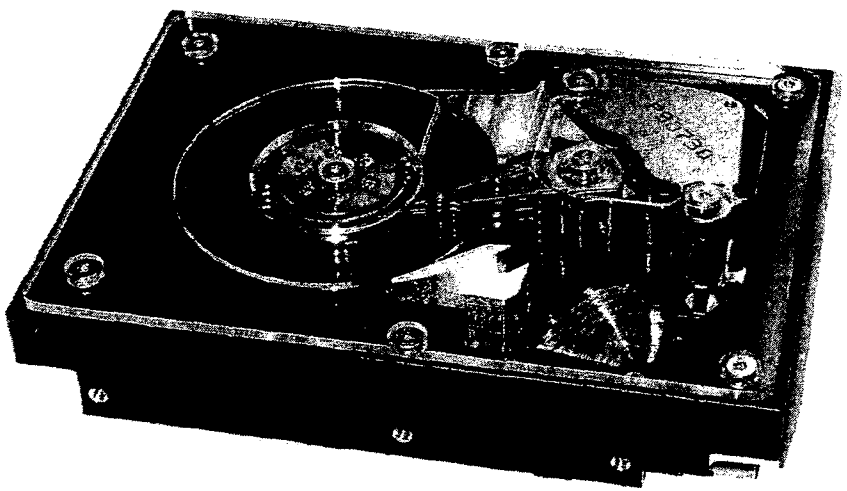
hinges

•Micro actuator for HDD

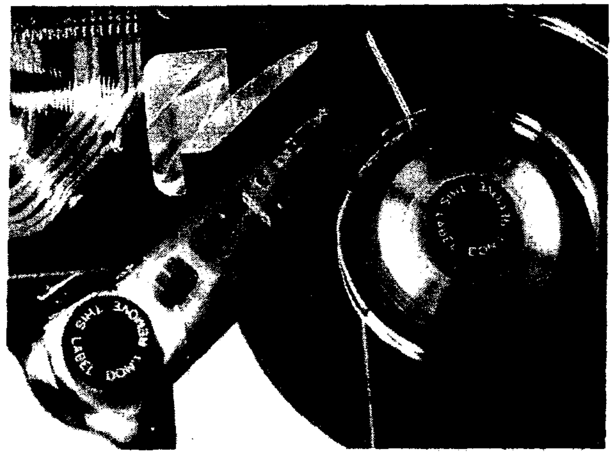


Performance Roadmap 1

	2000	2003	2005
Areal density (Gb/in^2)	15-30	100	300
Rotational speed (rpm)	10,000	15,000	20,000
Data transfer rate (Mbps)	500	1,250	2,000
Disk diameter (inch)	3	2.75	2.5



15krpm HDD



Seeking in average
access time of 4.0ms

Performance Roadmap 2

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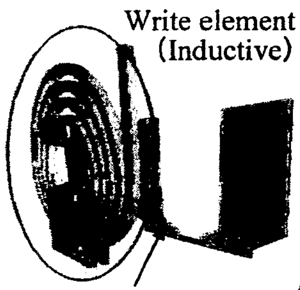
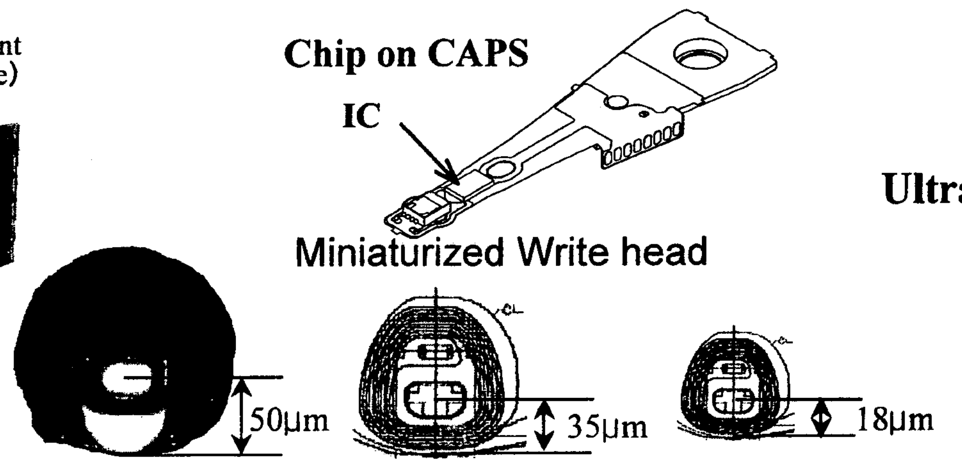
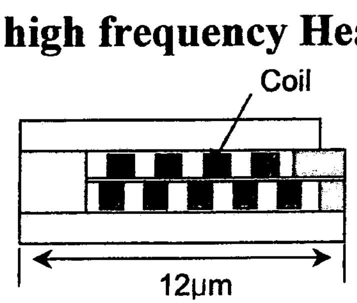
	2000	2003	2005
Areal density (Gb/in^2)	15-30	100	300
Data transfer rate (Mbps)	500	1,250	2,000
Write:York length (μm)	18	12	10
Read: GMR	Synthetic Ferri-SV	Specular Spin-Valve	Tunneling-MR CPP-MR







Prospect of Information Storage Technology

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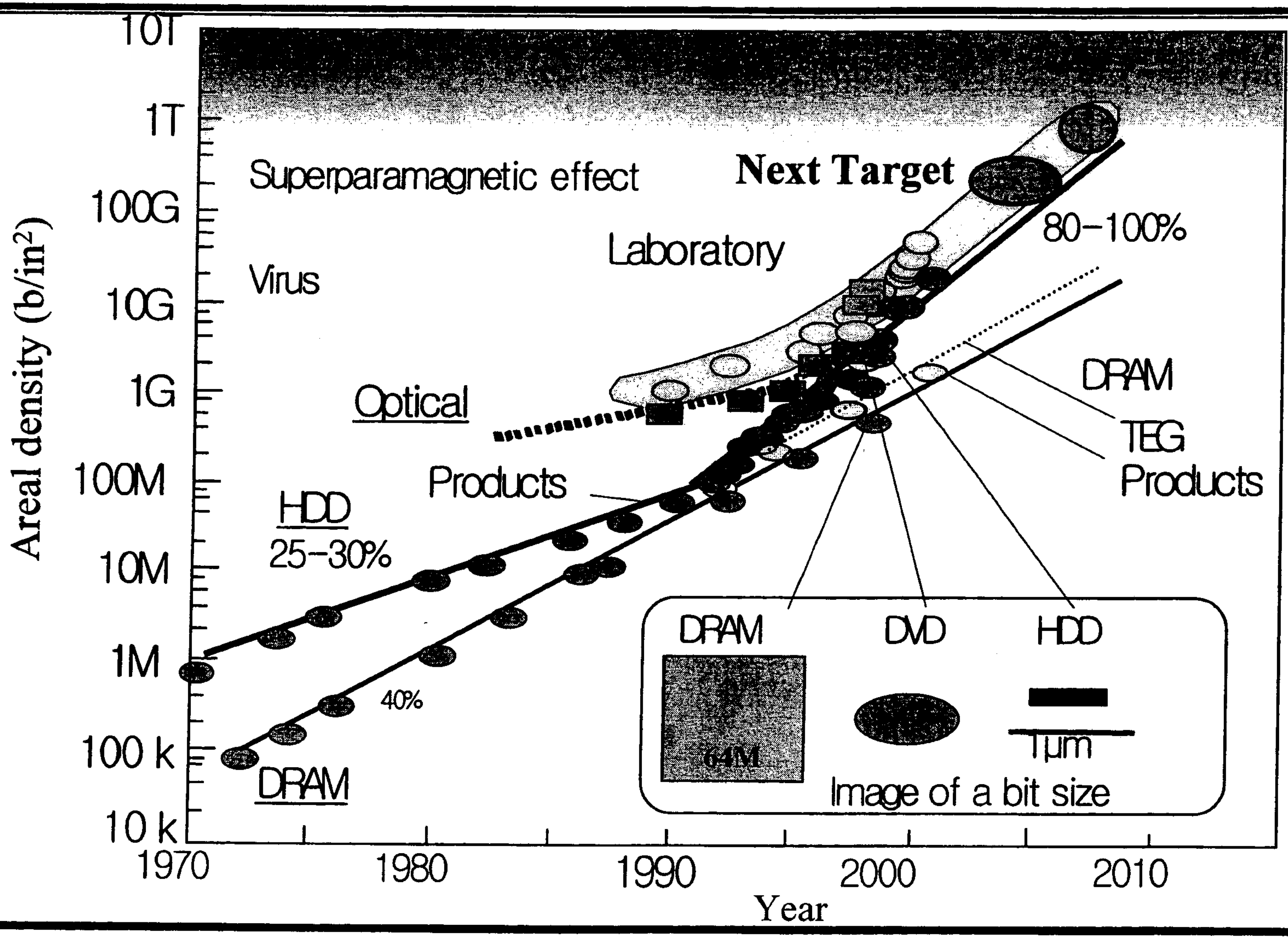

Typical Breakthroughs for HDD

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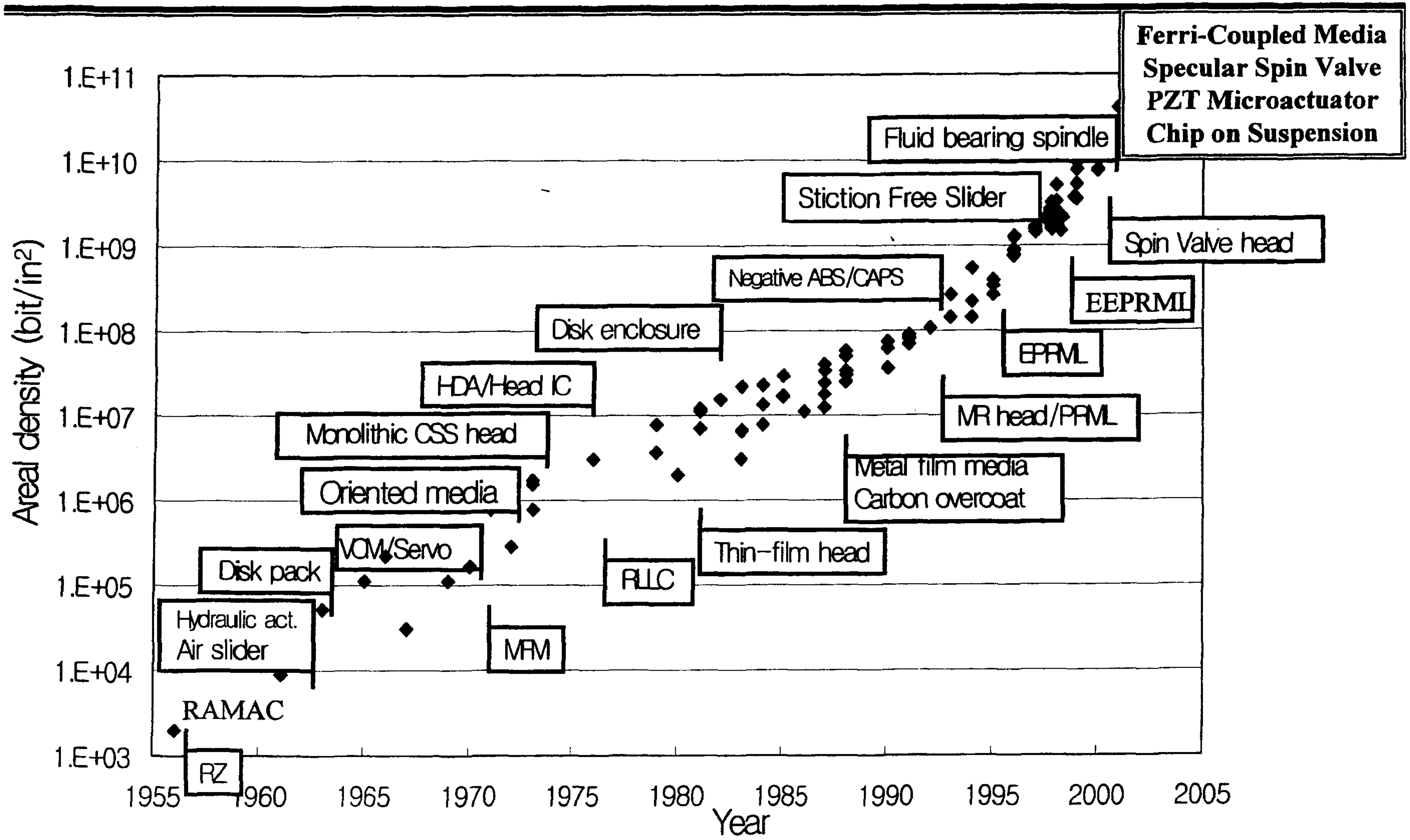

Magnetic Recording will Keep on Providing Key Technologies for High Performance HDDs up to 300 $Gbit/in^2$

• Head technology	Specular GMR / TMR
Head	
• Media technology	High Energy Media (SFM)
• Servo technology	Piezo Actuator
• Performance technology	Chip on CAPS
	Ultra high frequency Head