Fifty Years of Disk Drives and The Exciting Road Ahead

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Seagate
We turn on ideas

Outline

How far we've come in 50 years – then and now

- Product and performance trends
- Metrics – old and new demands
- Technology development over time

Where we're going – now and tomorrow

- Perpendicular Recording
- Heat Assisted Magnetic Recording (HAMR)
- Bit Patterned Media (BPM)

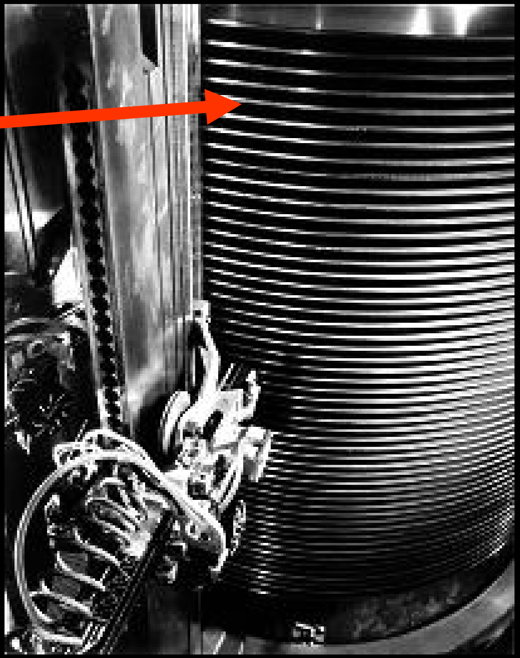
Marketplace dynamics

- Hard drives are finding their way into more devices every day.

Invention of the Disk Drive - 1956

IBM 305 RAMAC

(Random Access Method of Accounting and Control)

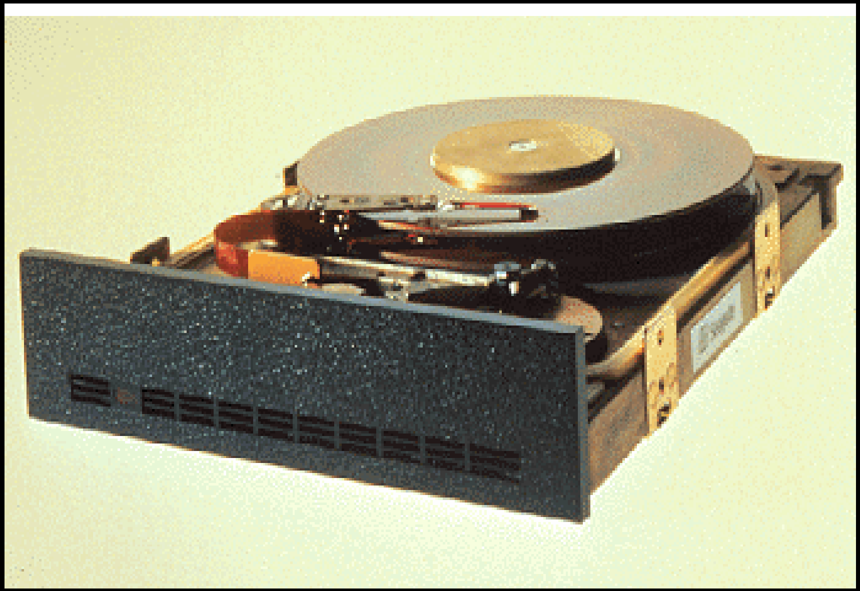


5 Megabyte Capacity
50 disks, each 24 inches in diameter
2000 bits/in^2 storage density.

This drive could store 2000 pages of text with 2500 characters per page.

Small Form Factor 5.25” Drive – 1979

Seagate ST506

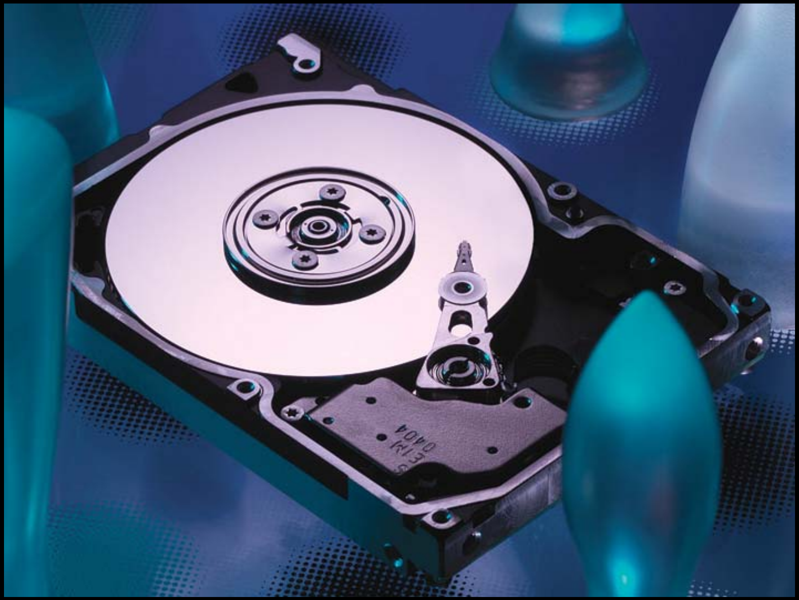


This 3,600 RPM drive has a storage capacity of 5 Mbytes

Can read or write more than 12 records, spread randomly over the disc, in less than a second

Modern 2.5” Disk Drive – 2006

Seagate Savvio 10K.2



This 10,000 RPM drive has a storage capacity of 146 Gbytes

Can read or write the complete works of Shakespeare,
15 times, in less than a second

Can read or write more than 200 records, spread randomly over the disc, in less than a second

12 GB Capacity One-Inch Hard Drive for Mobile Devices

Key Advantages

- Leading **12GB capacity** for handheld systems—delivers maximum storage for high-fidelity music, high-resolution video, and digital photos in portable music and video devices, including mobile phones
- New small footprint—**40x30x5 mm** size delivers large capacity in a tiny space, enabling smaller HDD-based systems
- Optional **drop sensor technology** improves shock tolerance to 2000 Gs by sensing and protecting against day-to-day drops and dings when properly installed in mobile devices
- **Uses 30% less power** than its predecessors
- **RunOn Technology** improves HDD performance while in a high-vibration environment such as jogging, helps prevent media skipping
- **One-second time-to-ready** helps handheld devices start up faster
- **RoHS-compliant** in line with international environmental regulations
- **Fluid dynamic bearing motors** deliver near-silent performance
- **Perpendicular recording technology** promises rapid capacity growth for years to come
- Supports **low-power modes** for increased battery life in appropriately equipped host systems

Specifications

Physical Dimensions (mm)	40x30x5
Weight (g)	14
Nonoperating Shock (Gs, 1 msec)	2000
Operating Shock (Gs, 1 msec)	2000
Power-On to Ready (sec, typical)	1.0
Write Average Current (mA)	240
Low Power Idle Average (mA)	77
Operating Temperature (°C)	0 to 70
Nonoperating Temperature (°C)	–40 to 70
Operating Humidity (%)	5 to 90
Nonoperating Humidity (%)	5 to 95

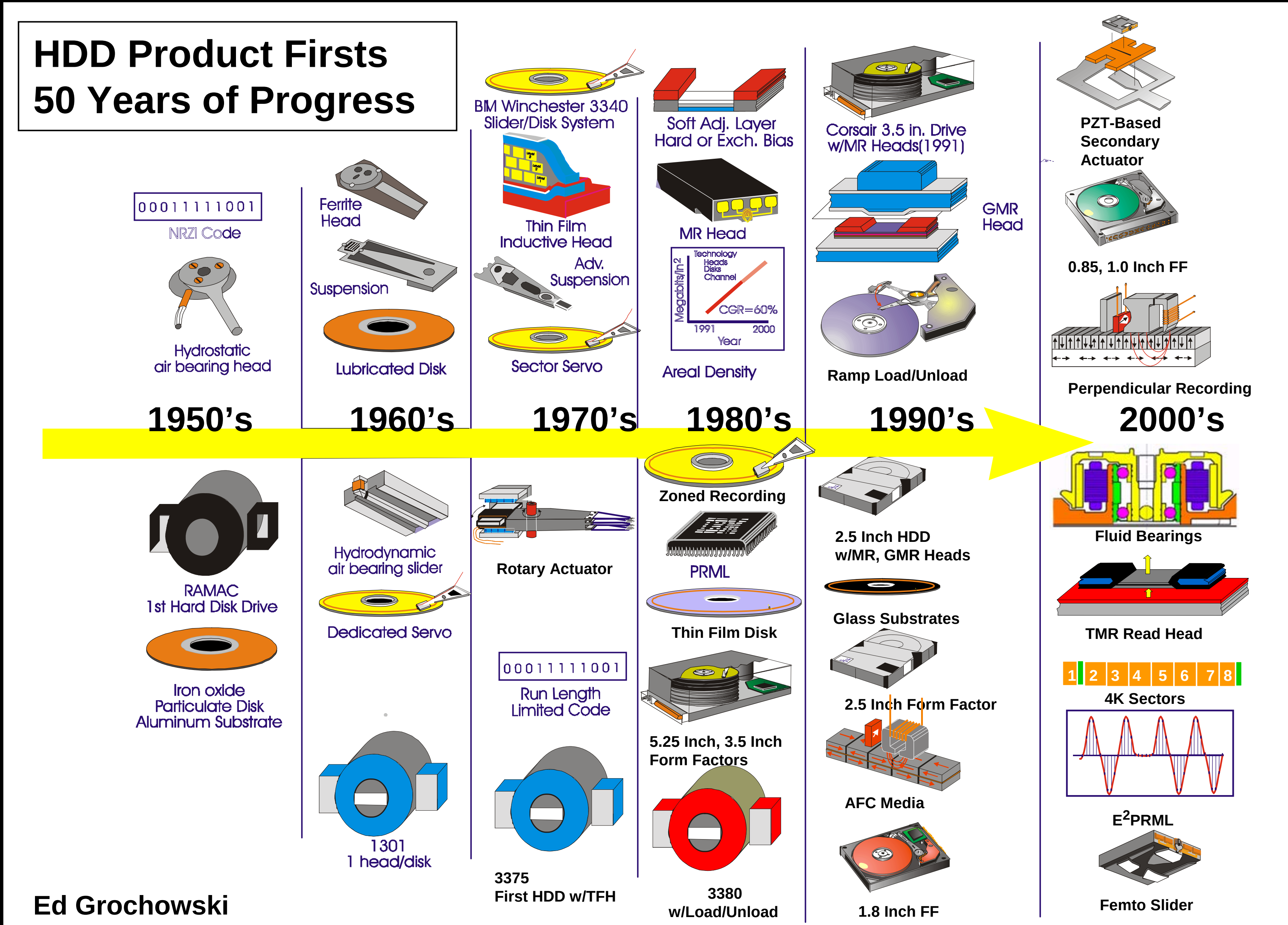
Technical Specifications – Then and Now

	IBM RAMAC (1956)	Seagate ST506 (1979)	Seagate Savvio 10K2 (2006)	Delta
Capacity	5 MB	5 MB	146 GB	29,800 X
Areal Density	2 Kbpsi	1.9 Mbpsi	136 Gbpsi	68,000,000
Discs	50 @ 24” dia.	2 @ 5.25” dia.	2 @ 2.5” dia.	
Price	$50,000	$1,500	< $300	X/170
Price/MB	$1,000	$300	< $0.002	X/500,000
Data Rate	10 KB/s	5 MB/s	85 MB/s	8,500 X
Power	5000 W	20 W	5 W	X/1,000
Weight	1 ton	~5 lbs	0.5 lb	X/4,000
Seek Time	600 ms	85 ms	3.8 ms	X/158
Reliability	---	11K hrs	1.6M hrs	--
Spindle Speed	1,200 RPM	3,600 RPM	10,000 RPM	8.3X

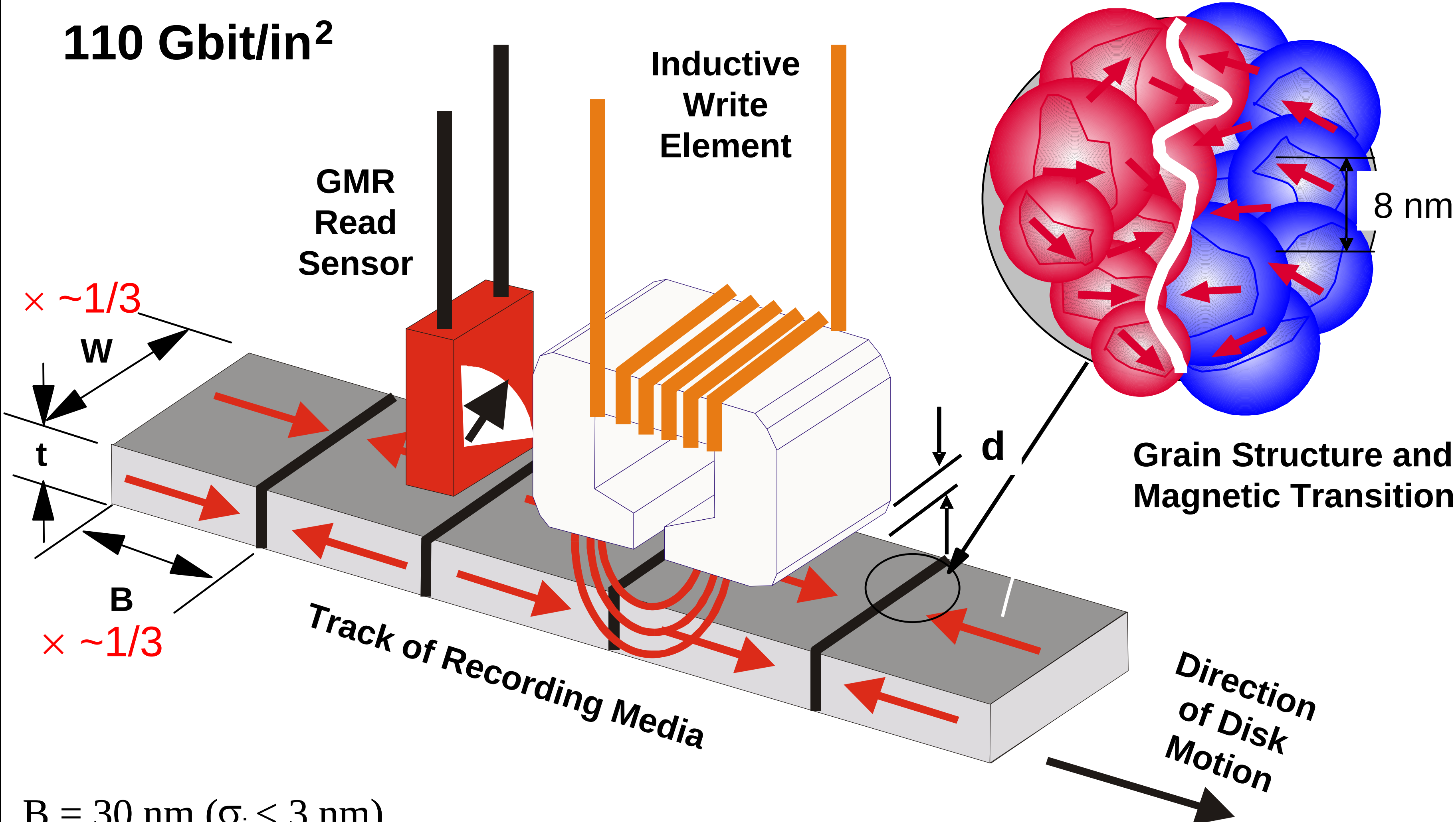
Technical Specifications – Then and Now

What if automobiles had improved as much?

	1956 (RAMAC)	2006 (Savio 10K.2)
Capacity	5 people	146,800 people
Price	$2,500	$15
Price/person	$500	$0.001
Top Speed	100 mph	940,000 mph
0 – 60 mph	15 s	0.1 s
Gas Mileage	25 mpg	36,000 mpg
Weight	1 ton	0.25 lb


HDD Product Firsts
50 Years of Progress
00011111001
NRZI Code
Hydrostatic air bearing head
Ferrite Head
Suspension
Lubricated Disk
BM Winchester 3340 Slider/Disk System
Thin Film Inductive Head
Adv. Suspension
Sector Servo
Soft Adj. Layer Hard or Exch. Bias
MR Head
Technology
Heads
Disks
Channel
Megabits/in2
CGR=60%
1991
2000
Year
Areal Density
Corsair 3.5 in. Drive w/MR Heads(1991)
GMR Head
Ramp Load/Unload
PZT-Based Secondary Actuator
0.85, 1.0 Inch FF
Perpendicular Recording
1950's
1960's
1970's
1980's
1990's
2000's
RAMAC 1st Hard Disk Drive
Iron oxide Particulate Disk Aluminum Substrate
Hydrodynamic air bearing slider
Dedicated Servo
1301 1 head/disk
Rotary Actuator
00011111001
Run Length Limited Code
3375 First HDD w/TFH
Zoned Recording
PRML
Thin Film Disk
5.25 Inch, 3.5 Inch Form Factors
3380 w/Load/Unload
2.5 Inch HDD w/MR, GMR Heads
Glass Substrates
2.5 Inch Form Factor
AFC Media
1.8 Inch FF
Fluid Bearings
TMR Read Head
1 2 3 4 5 6 7 8
4K Sectors
E2PRML
Femto Slider
Ed Grochowski

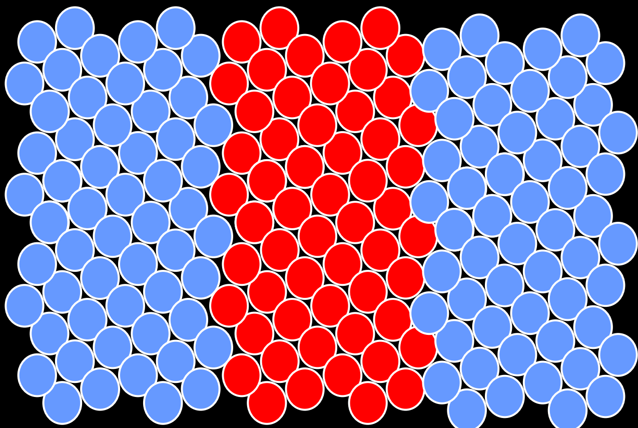
Recording Basics – Some Dimensions



B = 30 nm (σ_j < 3 nm)
W=194 nm, t = 15 nm, d= 10 nm

Need σ_j~ 1nm at Tbpsi Densities

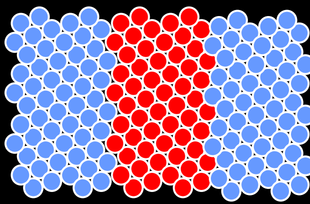
Superparamagnetism



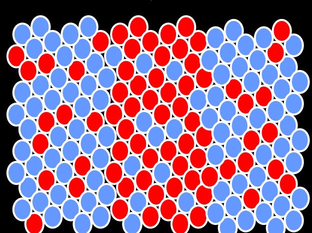
To preserve SNR, number of grains in a bit must be constant.

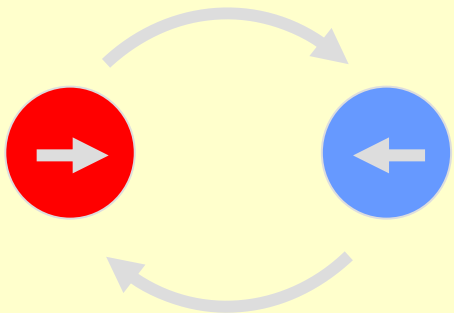
$$SNR \sim \log_{10}(N)$$

Therefore higher densities require smaller grains



The smaller bits have a higher probability of flipping and the data is unstable

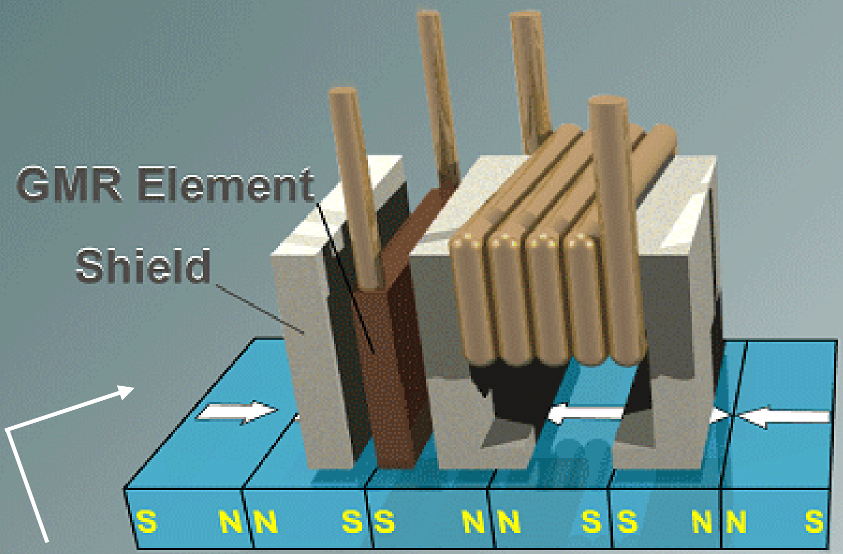




High areal density means small volume

$$\tau = \frac{1}{f_0} e^{\frac{K_u V}{k_B T}}$$

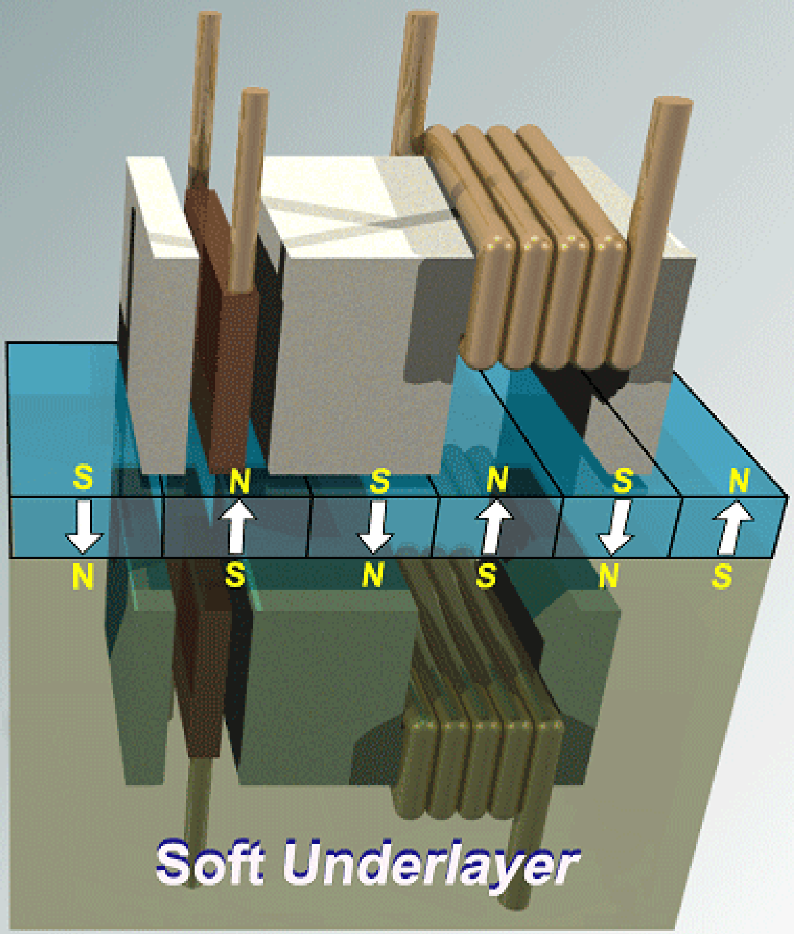
Longitudinal Recording



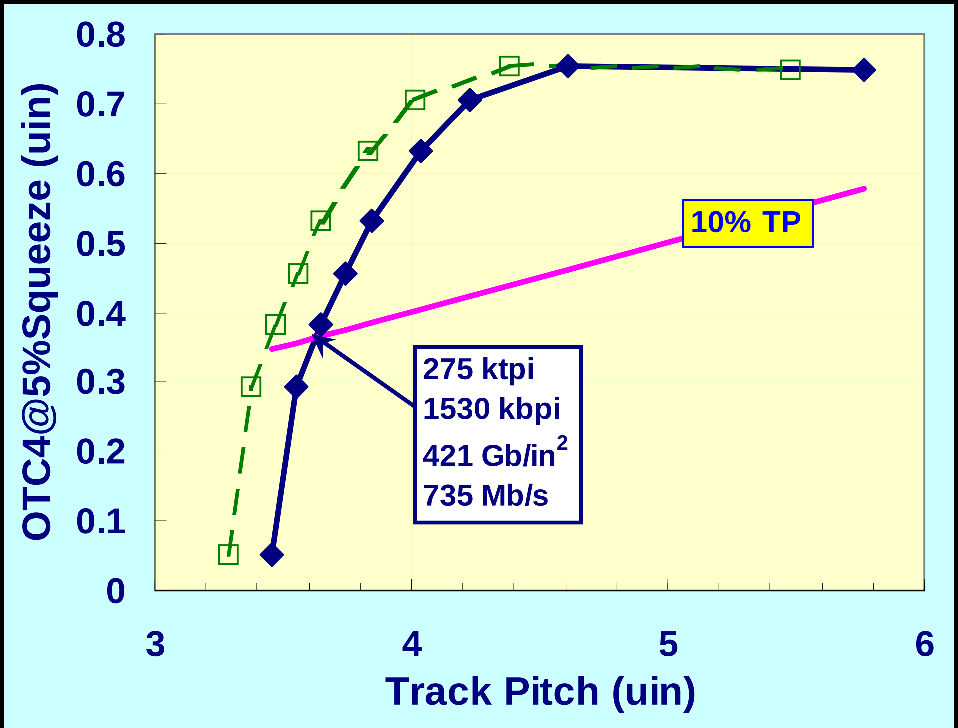
Magnetic domains oriented in the direction of travel of the head.

Soft underlayer "mirrors" write head and makes it possible to write domains much closer together.

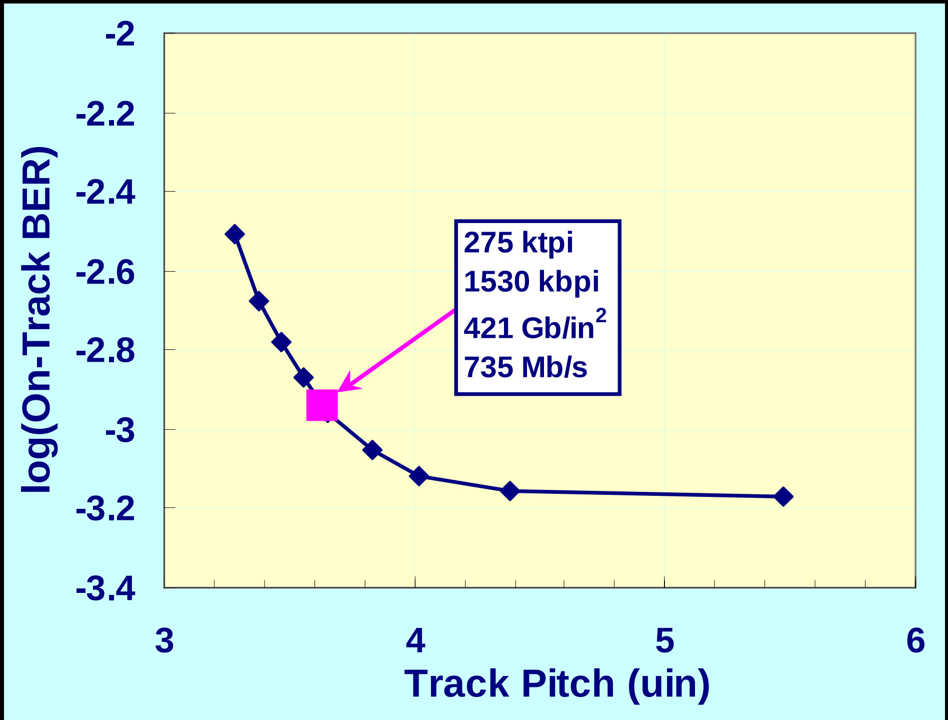
Perpendicular Recording



421 Gb/in^2 Areal Density Demo at OTC-w3GI

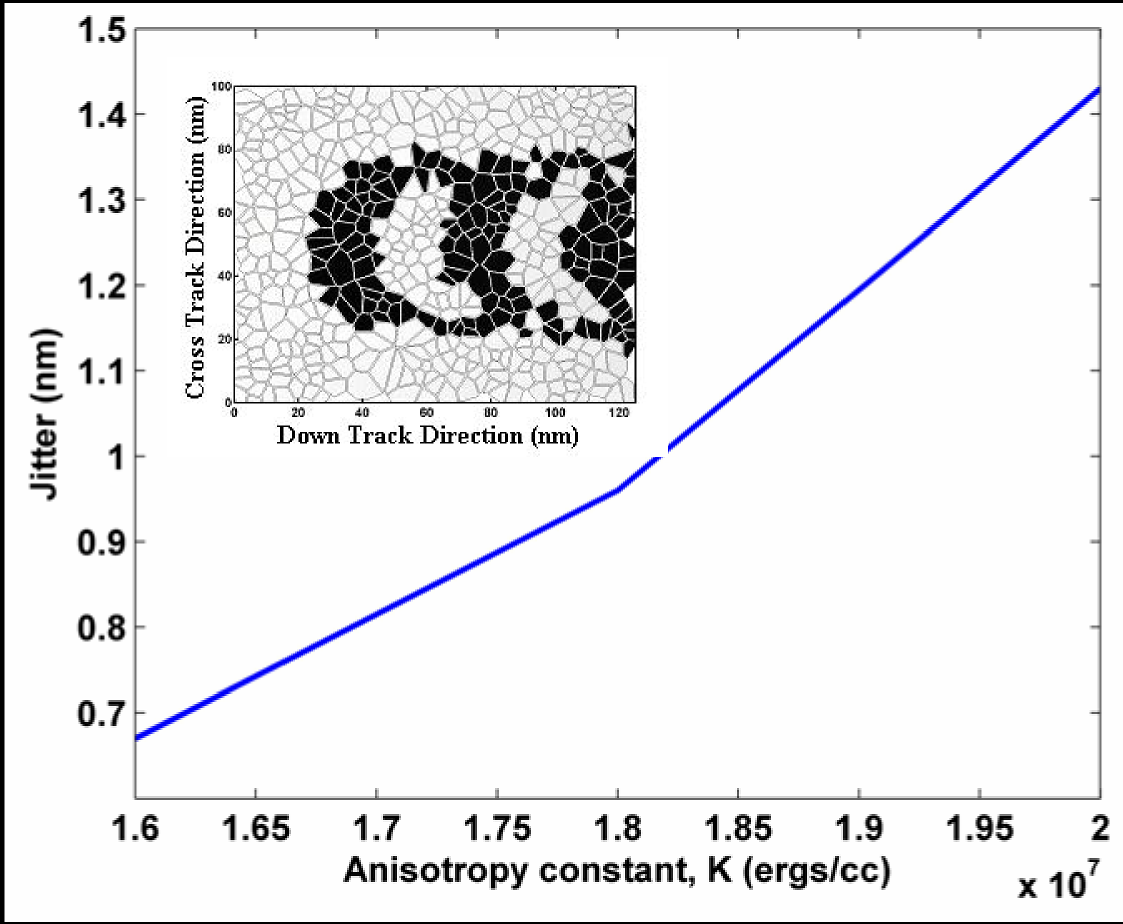


- Using OTC-w3GI criteria, areal density of 421 Gb/in^2 was achieved. On-track BER at nominal TP is $10^{-2.94}$ with no parity. PE Error Floor is $10^{-3.17}$ with no parity and $10^{-3.71}$ with parity. BAR = 5.6



R. Victora et al., U. of Minnesota

Jitter: Recording at Tbit/in2

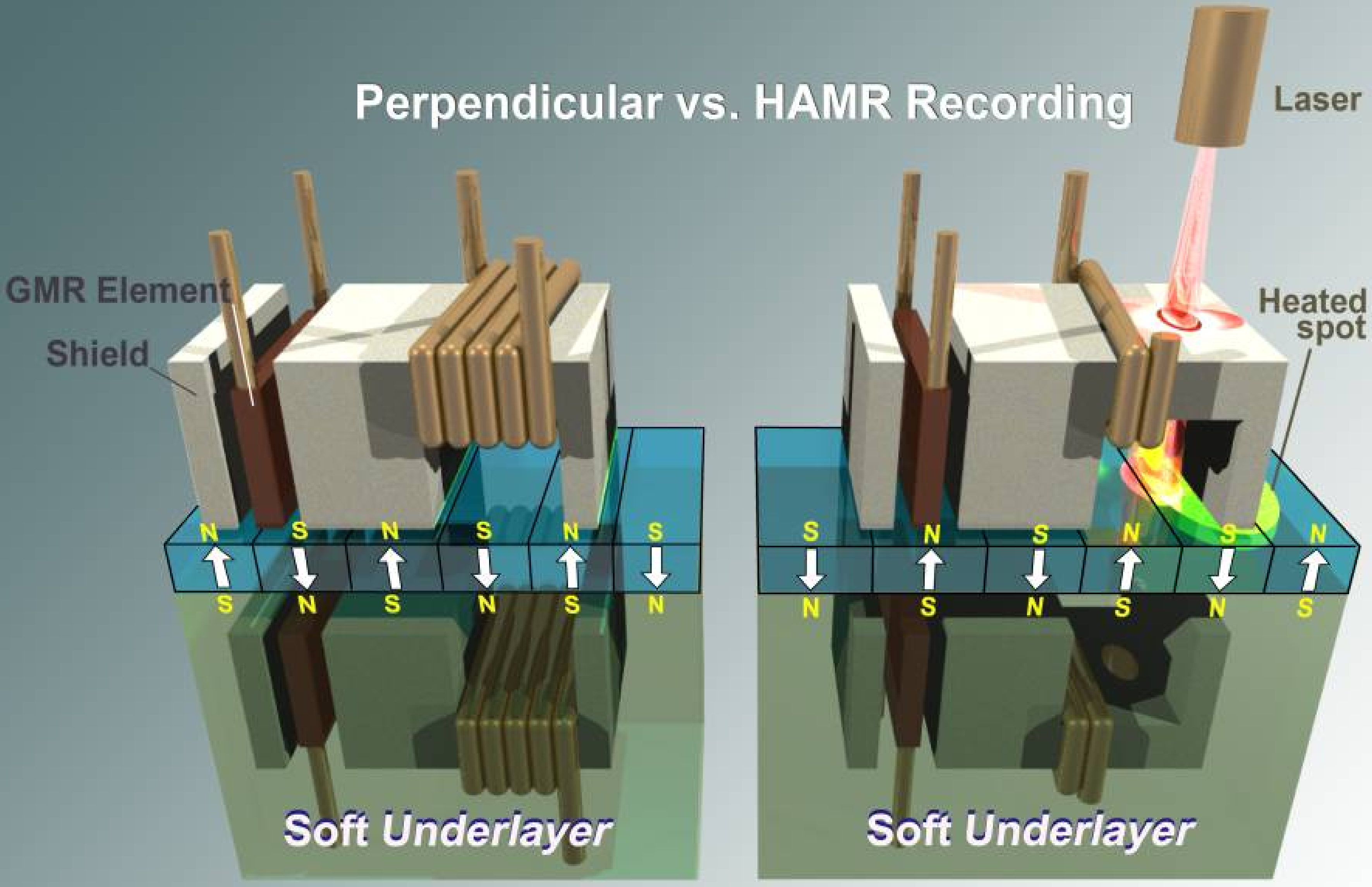


Media Parameters

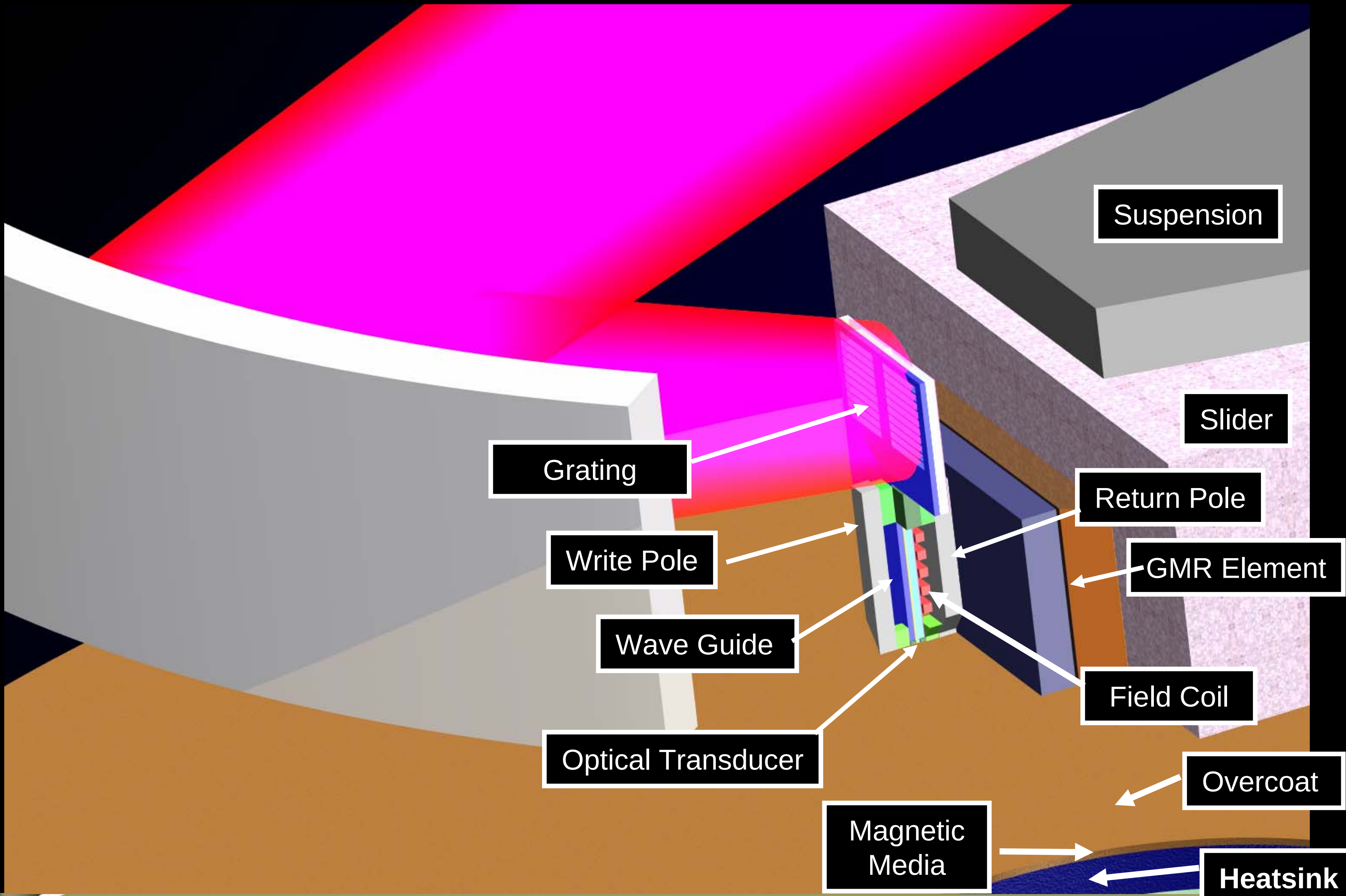
- Optimized ECC grain
- 3° Easy Axis Cone
- Bit length is 10 nm.
- K uniformly distributed with 5% stdev.

Thermal stability requires K= $2x10^7$ ers/cc. Therefore, this head and media combination requires signal processing to accommodate 14% jitter for Terabit/in^2.

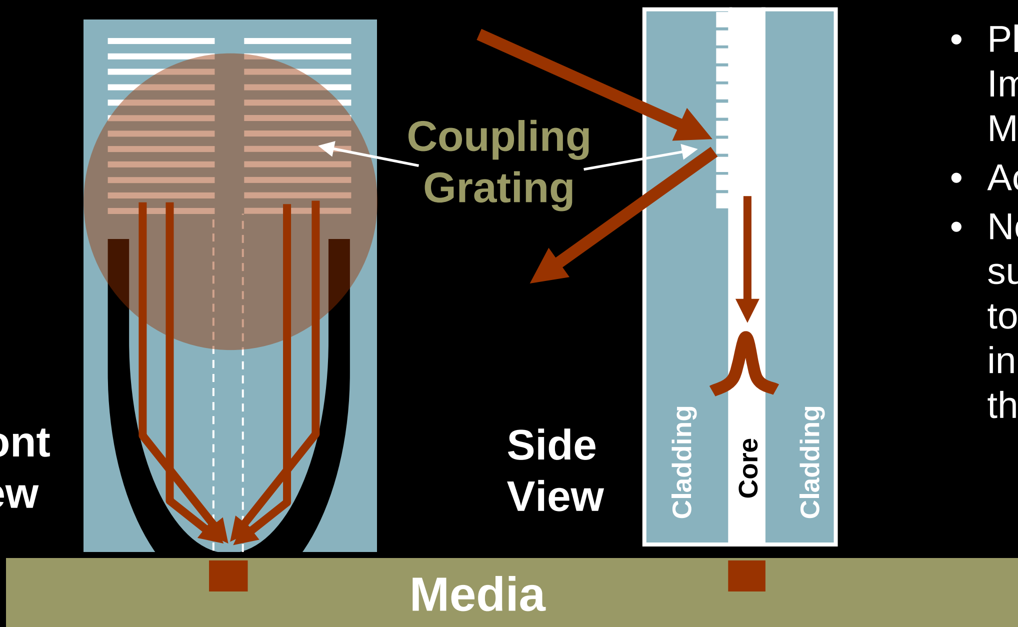
Perpendicular vs. HAMR Recording



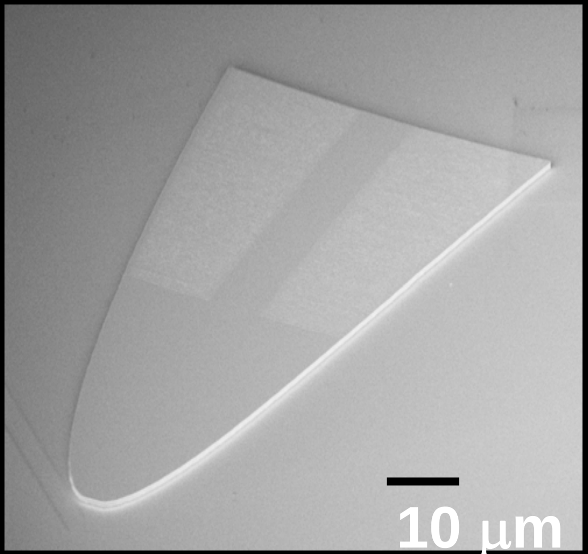
HAMR Recording System



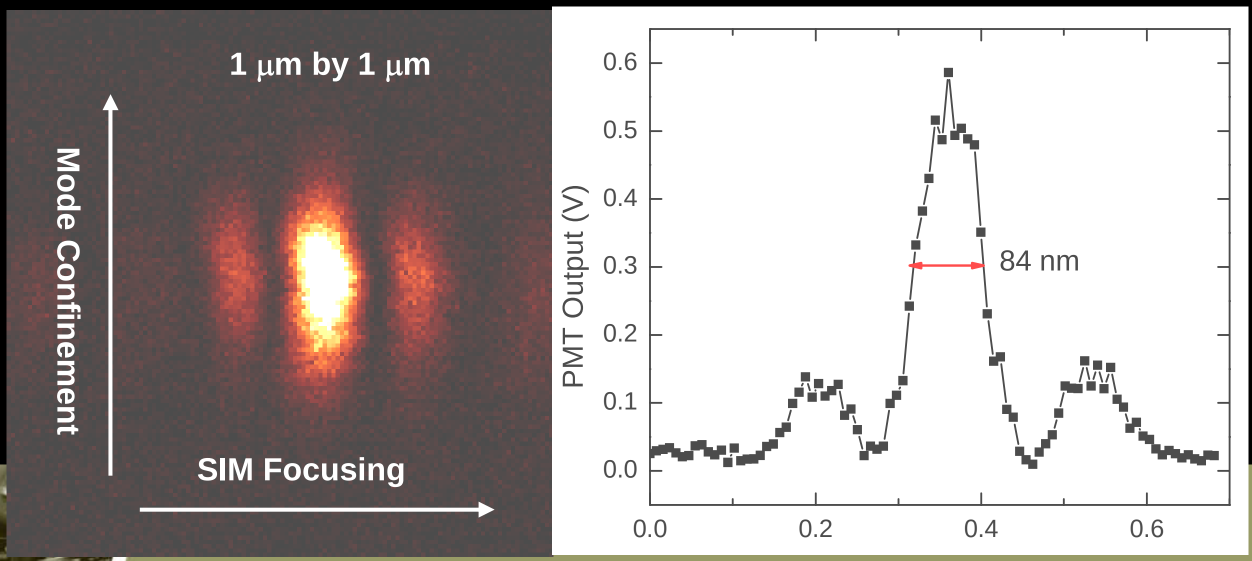
Near-Field Optical Waveguide



- Planer Solid Immersion Mirror (SIM)
- Achromatic
- Not susceptible to variations in film thickness



Solid Immersion Mirror

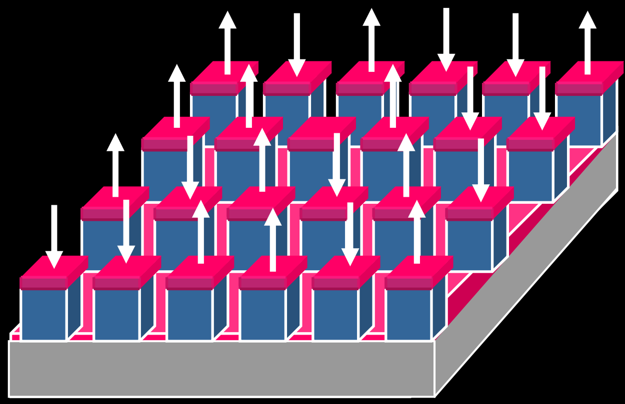


- Tantalum core layer sandwiched between two alumina cladding layers
- SNOM scans over focal plane
- At blue light (413 nm), full-width-half-max focused spot size < 90 nm

Seagate

Bit Patterned Media
Lithography vs. Self Organization

Lithographically Defined

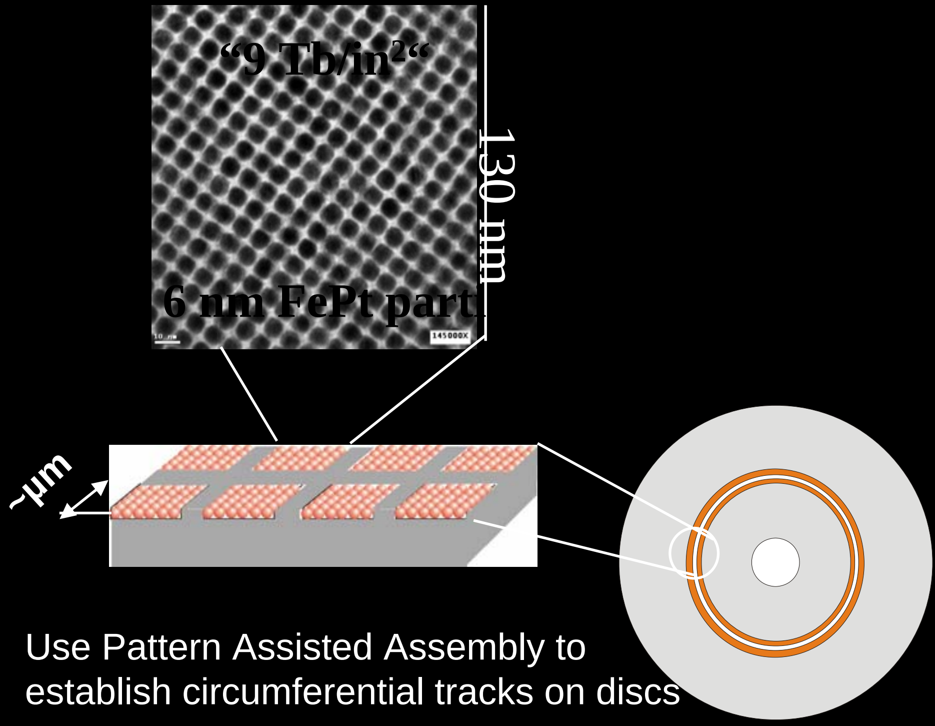


Direct E-Beam Write or Di-Block Co-Polymer

Major obstacle is finding low cost means of making media

- At 1 Tbpsi, assuming a square bit cell and equal lines and spaces, 12.5 nm lithography would be required
- Semiconductor Industry Association roadmap does not provide such linewidths within the next decade

FePt Self-Organizing Media



Use Pattern Assisted Assembly to establish circumferential tracks on discs

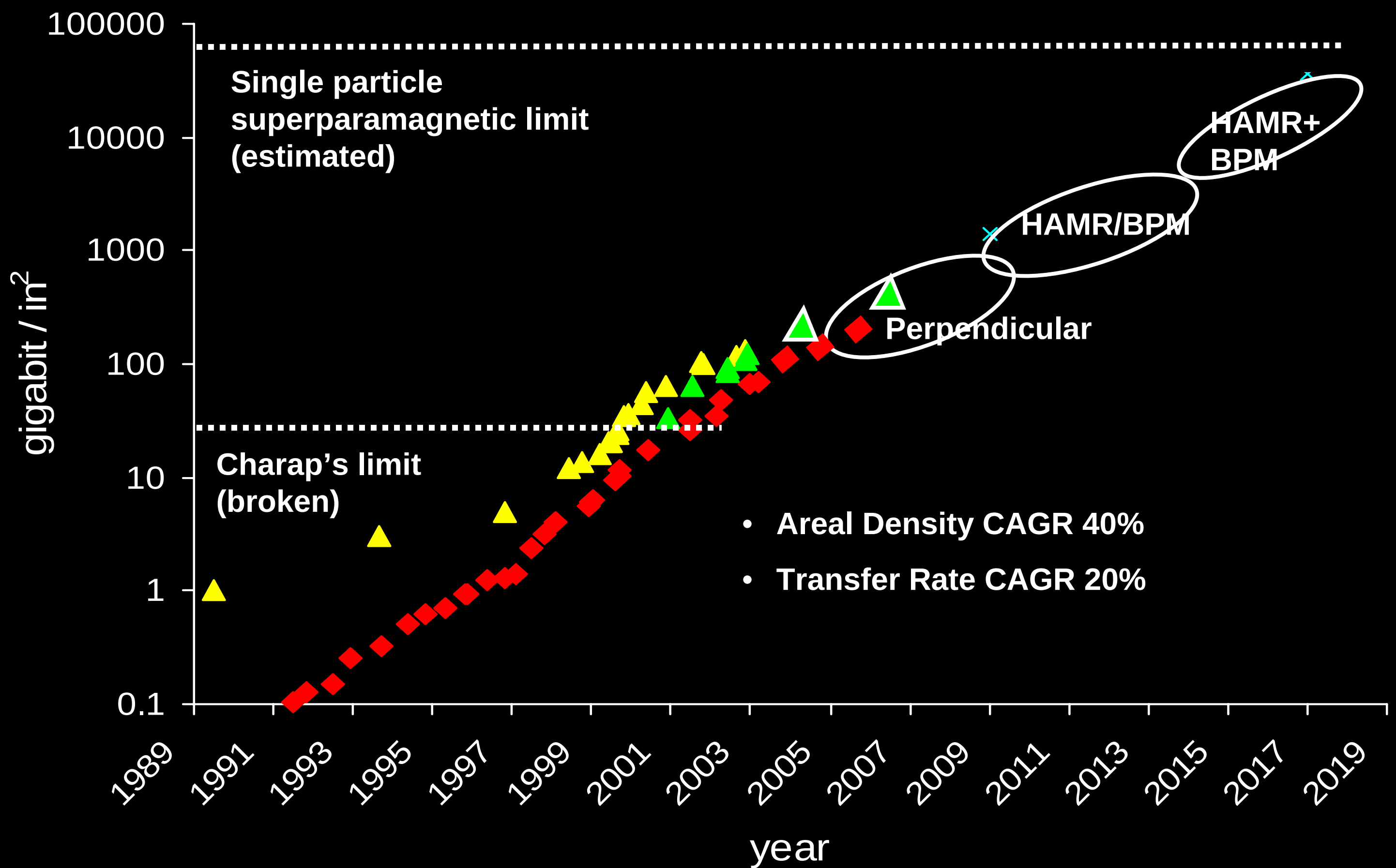
Single particle FePt density limit: 50-100 Tbpsi

HDD Performance Trends

3.5 inch Consumer	2006 (Perp)	2010 (Perp)	2014 (HAMR/BPM)
Drive Capacity (GB)	750	3,000	12,000
Number of Discs	4	4	4
Capacity (GB/disc)	187	750	3000
Product Areal Density (Gbpsi)	133	500	2000
Transfer Rate (Mb/sec)	930	2,000	4,000
RPM	7,200	7,200	7,200
3.5 inch Enterprise	**2006 (Perp)**	**2010 (Perp)**	**2014 (HAMR/BPM)**
Drive Capacity (GB)	300	1200	5,000
Number of Discs	4	4	4
Capacity (GB/disc)	75	300	1,200
Product Areal Density (Gbpsi)	108	400	1,600
Transfer Rate (Mb/sec)	975	2,000	4,000
RPM	15,000	15,000	15,000
1.0 inch Handheld	**2006 (Perp)**	**2010 (Perp)**	**2014 (HAMR/BPM)**
Drive Capacity (GB)	12	50	200
Number of Discs	1	1	1
Capacity (GB/disc)	12	50	200
Product Areal Density (Gbpsi)	133	500	2,000
Transfer Rate (Mb/sec)	145	300	750
RPM	3,600	4,200	5,400

Areal Density Growth

- **Late 1990s – super paramagnetic limit demonstrated through modeling**
- **Longitudinal recording reaching areal density limits**
- **Perpendicular expected to extend to 0.5-1 Tb/in^2**
- **Additional innovations required at that point:**
  - **Heat-Assisted Magnetic Recording (HAMR)**
  - **Bit Patterned Media (BPM) recording**



Marketplace Dynamics

Disc Drives Today Cover the Widest Range of Users and Systems Ever

Drive Industry Dynamics – Dynamic, Emerging Markets Outside of Traditional Compute Space

- 212 million PC's and laptops were sold in 2005.
- 380 million hard disk drives were sold in 2005.
  - More than 1 million disk drives produced every day.
- 168 million drives didn't go into PC's and laptops.
  - They went into servers, DVRs, handheld digital audio players, game boxes, cell phones, digital cameras, automotive
- This gap has been growing and is expected to widen over the next several years.

	2002	2006	2009
HDD PC/Server Market ($B)	**16**	**19**	**21**
Total HDD Market ($B)	**19**	**31**	**46**
	84%	**61%**	**46%**

Summary and conclusions

- Dramatic changes in HDD performance, form-factor and cost over last 50 years.
- Areal density growth on track at 40% per year
  - Perpendicular recording extensible to 500-1000 Gbpsi.
  - HAMR extensible by an additional order of magnitude.
  - Bit patterned media/SOMA, combined with HAMR could, in principle, extend the areal density to perhaps 50 Tbpsi.
- Major market growth opportunities exist. Dynamic, emerging markets outside of traditional computing.

Questions?

Backup

Recent Perpendicular Products

Product Name	Application	Disc Diameter (in.)	Areal Density (Gb/In^2)	Linear Density (Kbpi)	Track Density (Ktpi)	Drive Capacity (GB)	Disc Capacity (GB)
ST1.3	Handheld	1	133	940	140	12	12
Barracuda 7200.10	Consumer	3.5	133.3	939	142	750	187.5
Momentus 5400.3	Notebook	2.5	130.5	870	150	160	80
Cheetah 15K.5	Enterprise	3.5	108	865	125	300	75

Technical Specifications – Then and Now

	IBM RAMAC (1956)	Seagate ST506 (1979)	Seagate Savvio 10K2 (2006)	Seagate ST1.3 (2006)
Capacity	5 MB	5 MB	146 GB	12 GB
Areal Density	2 Kbpsi	1.9 Mbpsi	136 Gbpsi	130 Gbpsi
Discs	50 @ 24” dia.	2 @ 5.25” dia.	2 @ 2.5” dia.	1 @ 1” dia.
Price	$50,000	$1,500	< $300	$75
Price/MB	$1,000	$300	< $0.002	$0.006
Data Rate	10 KB/s	5 MB/s	85 MB/s	10 MB/s
Power	5000 W	20 W	5 W	<1 W
Weight	1 ton	~5 lbs	0.5 lb	14g
Seek Time	600 ms	85 ms	3.8 ms	20 ms
Spindle Speed	1,200 RPM	3,600 RPM	10,000 RPM	3,600 RPM

Technical Specifications – Then and Now

	IBM RAMAC (1956)	Seagate ST1.3 (2006)	Delta
Capacity	5 MB	12 GB	2400 X
Areal Density	2 Kbpsi	130 Gbpsi	65,000,000X
Discs	50 @ 24” dia.	1 @ 1” dia.	
Price	$50,000	$75	X/670
Price/MB	$1,000	$0.006	X/170,000
Data Rate	10 KB/s	10 MB/s	1,000 X
Power	5000 W	<1 W	X/5,000
Weight	1 ton	14g	X/76,000
Seek Time	600 ms	20 ms	X/30
Spindle Speed	1,200 RPM	3,600 RPM	3X

Longitudinal vs. Perpendicular Recording

2.5 inch Momentus Notebook Drive

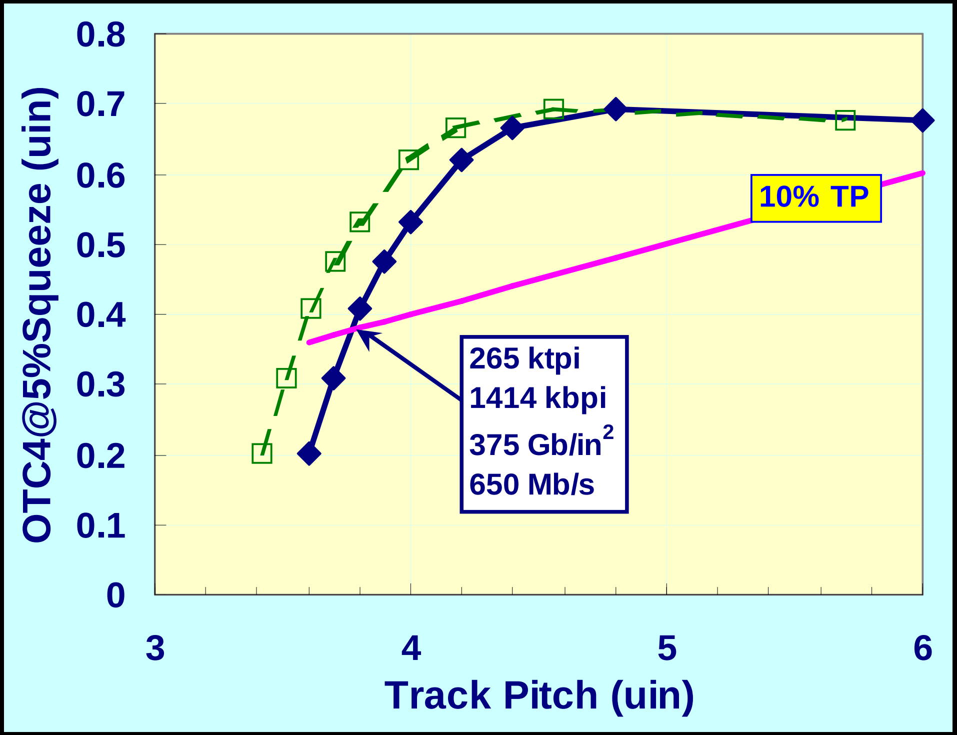
Longitudinal

Drive Capacity (GB)	**120**
Number of Discs	2
Capacity (GB/disc)	60
KTPI (avg)	123
KBPI (nom)	780
Product Areal Density	**95.9**
Transfer Rate (MB/sec)	460
RPM	5400
Seek Time (ms)	
Average Read	12.5
Average Write	14

Perpendicular

Drive Capacity (GB)	**160**
Number of Discs	2
Capacity (GB/disc)	80
KTPI (avg)	147
KBPI (nom)	885
Product Areal Density	**130.1**
Transfer Rate (MB/sec)	520
RPM	5400
Seek Time (ms)	
Average Read	10
Average Write	11

375 Gb/in^2 Areal Density Demo at OTC4



- Using OTC4 criteria, areal density of 375 Gb/in^2 was achieved. On-track BER at nominal TP is $10^{-4.83}$. PE Error Floor is $10^{-5.16}$. BAR = 5.3