Seventy Years of Disk Drives: 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
- Technology development over time

Where we're going – now and tomorrow

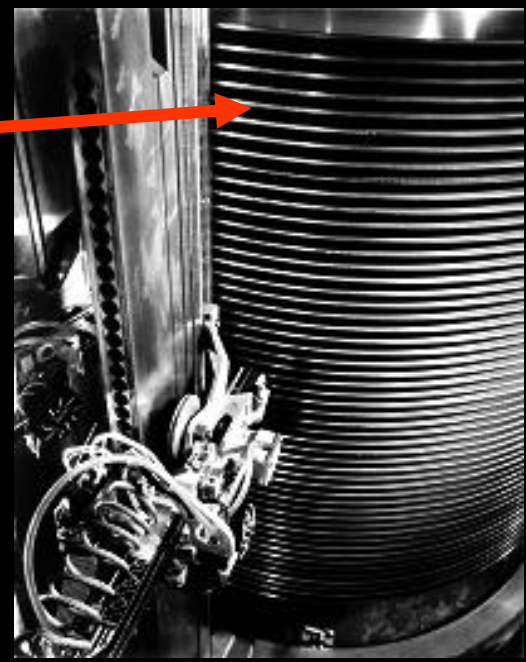
- Perpendicular Recording
- Heat Assisted Magnetic Recording (HAMR)
- Bit Patterned Media (BPM)

What this means we'll be doing in 2020.

Invention of the Disk Drive - 1956

IBM 305 RAMAC

(Random Access Method of Accounting and Control)

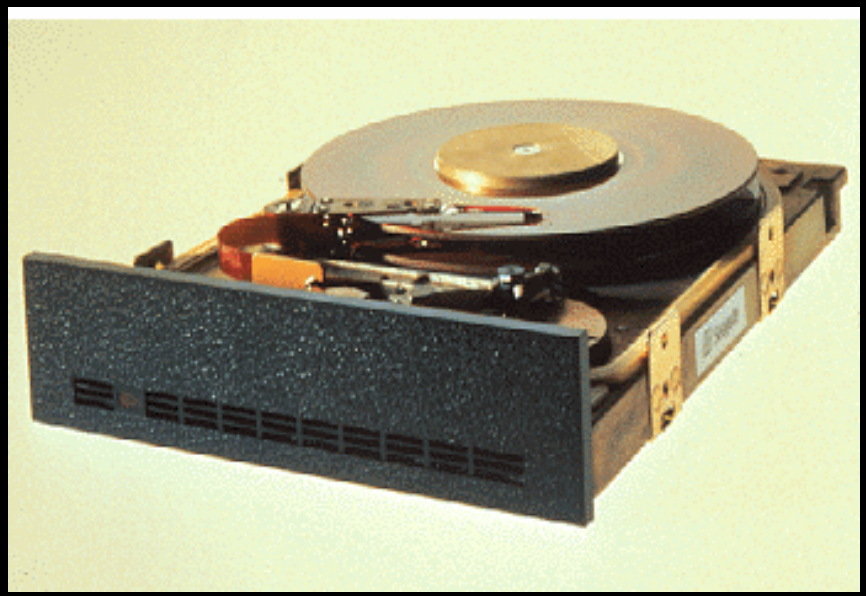


5 Megabyte Capacity
50 disks, each 24 inches in diameter
2000 bits/in^2 storage density.

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

Cheetah 15K.5

Perpendicular Recording

First 300 Gbyte 15 Krpm disk drive.

1.4 Million Hour MTBF.

Nonrecoverable Read Error Rate: 1 sector per 10e16

Average R/W time: 3.5/4.0 msec

Latency: 2 msec

125 MB/s Sustained Transfer Rate

Technical Specifications – Then and Now

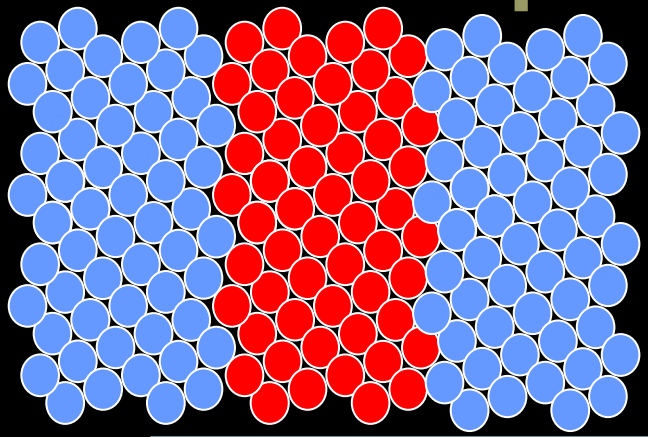
	IBM RAMAC (1956)	Seagate ST506 (1979)	Seagate Cheetah 15K.5 (2006)	Delta
Capacity	5 MB	5 MB	300 GB	60,000 X
Areal Density	2 Kbpsi	1.9 Mbpsi	108 Gbpsi	54,000,000
Discs	50 @ 24” dia.	2 @ 5.25” dia.	4 @ 3.5” dia.	
Price	$50,000	$1,500	< $1420	X/35
Price/MB	$1,000	$300	< $0.00473	X/210,000
Data Rate	10 KB/s	5 MB/s	125 MB/s	12,500 X
Power	5000 W	20 W	13.7 W	X/365
Weight	1 ton	~5 lbs	1.5 lb	X/1333
Seek Time	600 ms	85 ms	3.5/4.0 ms	X/158
Reliability	---	11K hrs	1.4M hrs	--
Spindle Speed	1,200 RPM	3,600 RPM	15,000 RPM	12.5X

Technical Specifications – Then and Now

What if automobiles had improved as much?

	1956 (RAMAC)	2006 (Cheetah 15K.5)
Capacity	5 people	300,000 people
Price	$2,500	$71
Price/person	$500	$0.002
Top Speed	100 mph	1,250,000 mph
0 – 60 mph	15 s	0.1 s
Gas Mileage	25 mpg	9,125 mpg
Weight	1 ton	1.5 lb

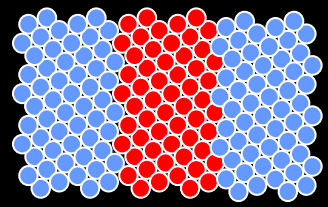
Recording Basics: Superparamagnetism



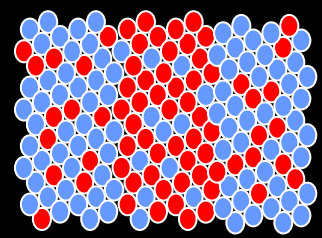
To preserve SNR, number of grains in a bit must be constant.

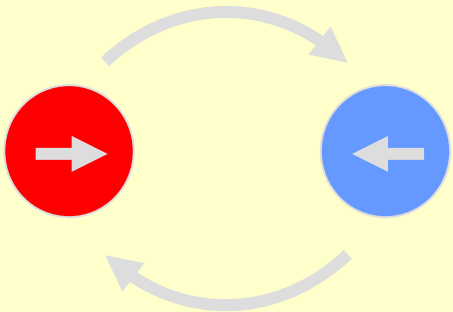
$$SNR \sim \log_{10}(N)$$

Therefore higher densities require smaller grains



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



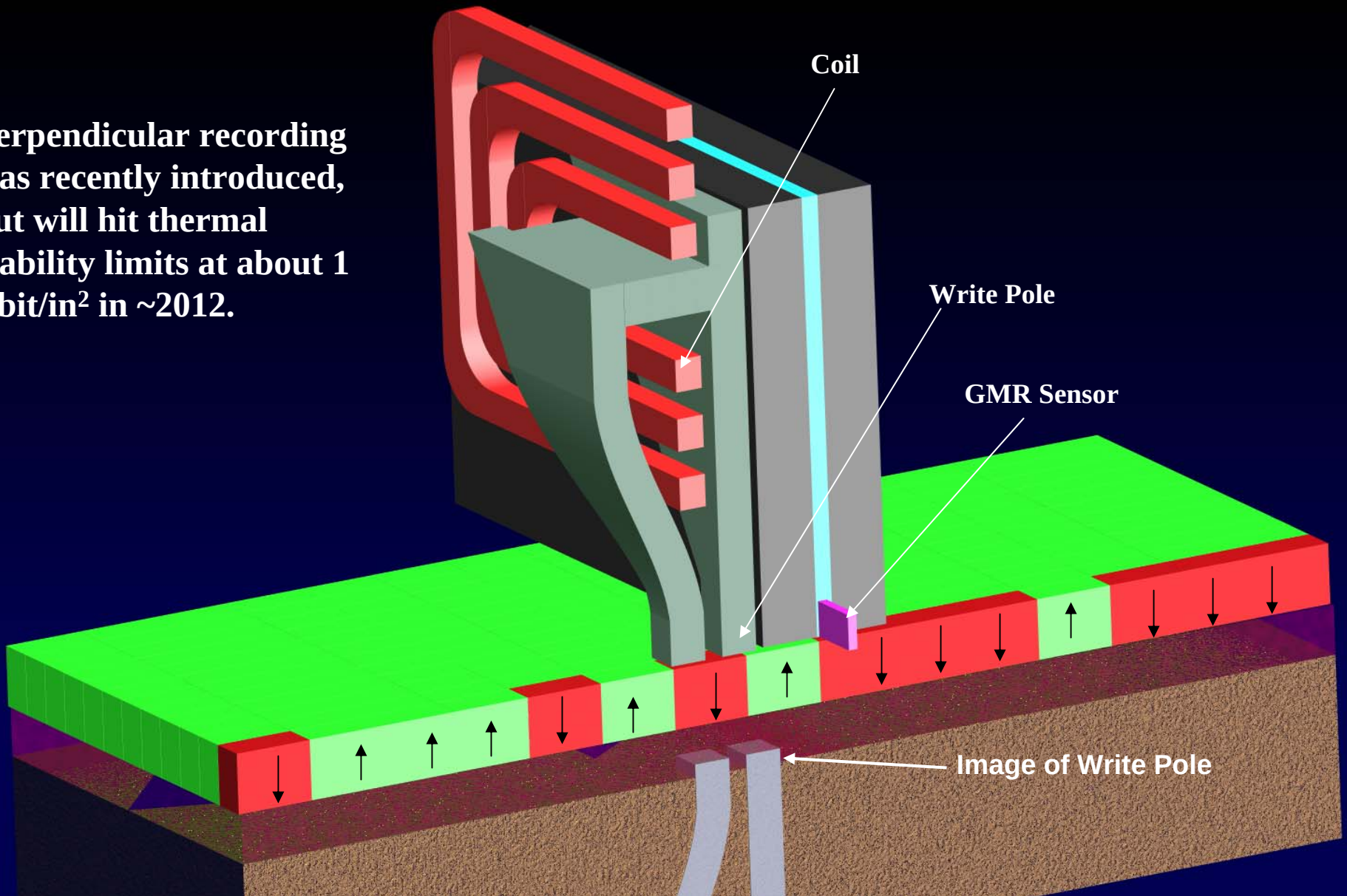


High areal density means small volume

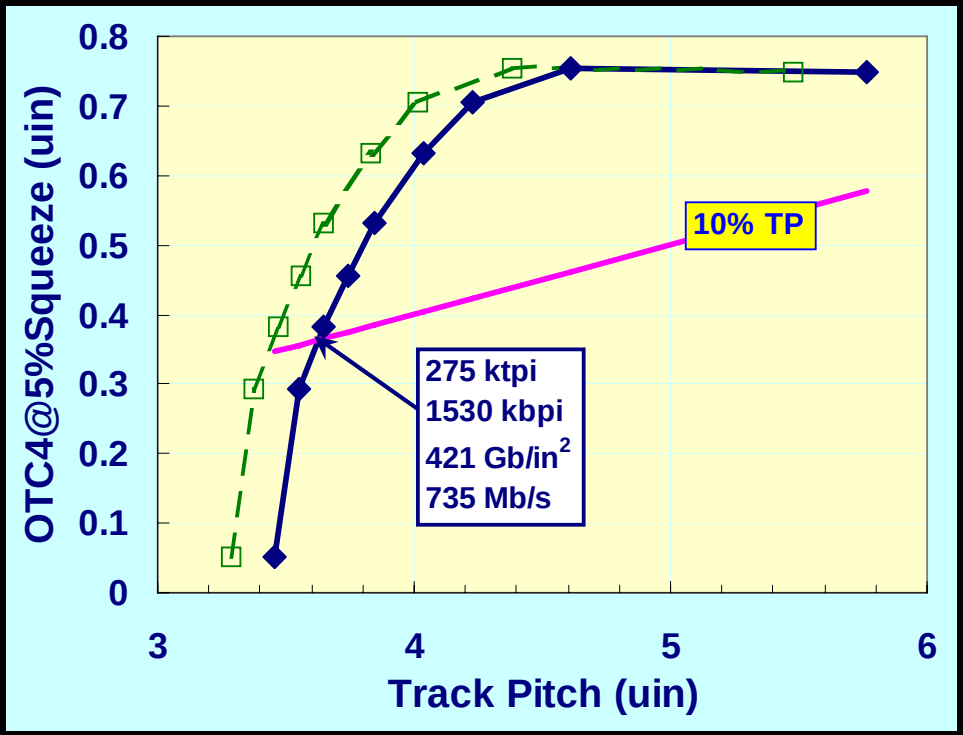
$$\tau = \frac{1}{f_0} e^{\frac{K_u V}{k_B T}}$$

Perpendicular Recording

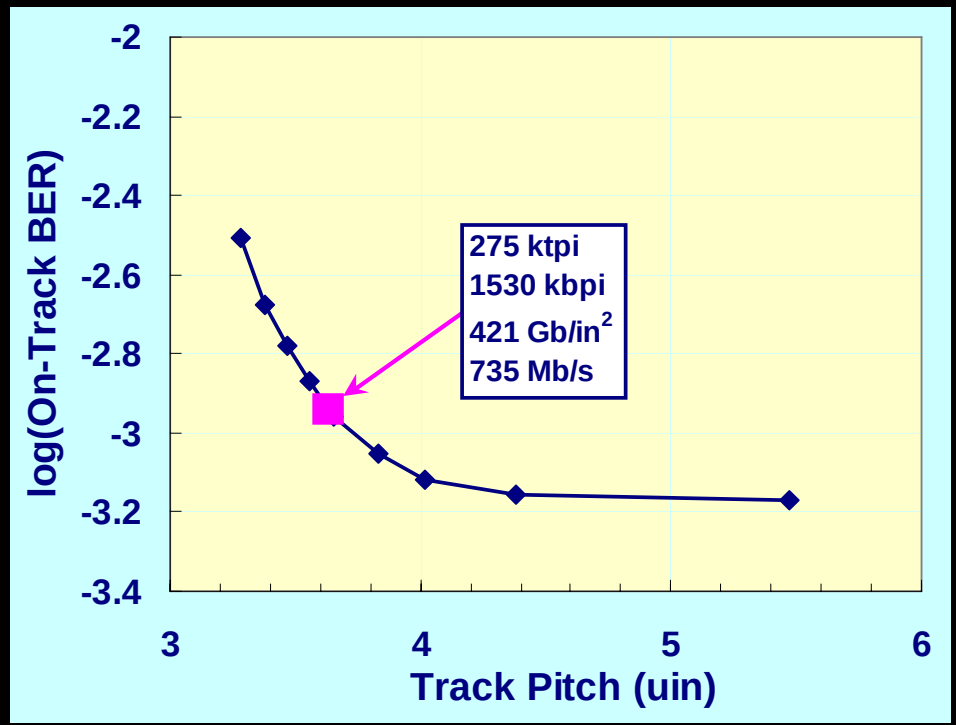
Perpendicular recording was recently introduced, but will hit thermal stability limits at about 1 Tbit/in^2 in ~2012.



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

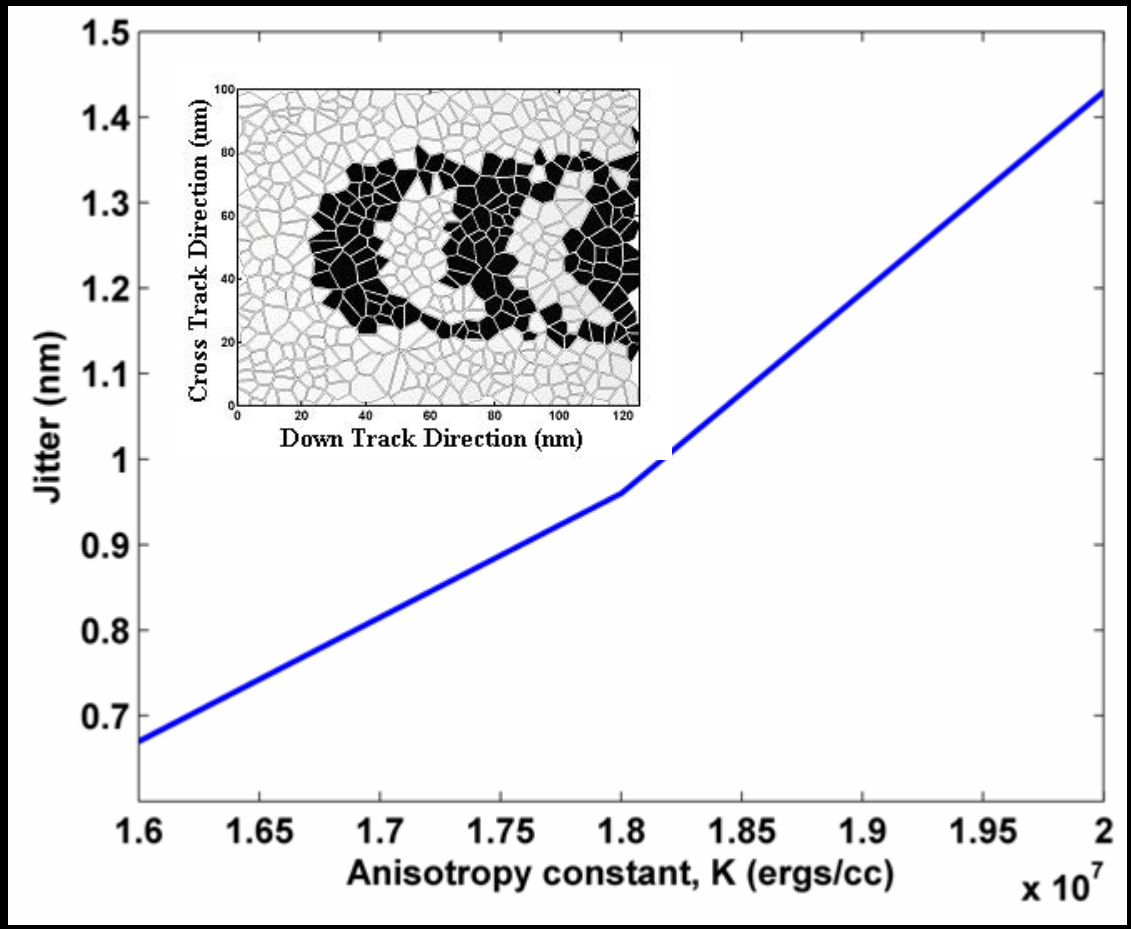


- Using OTC-w3GI criteria, areal density of 421 Gb/in^2 was achieved. On-track BER at nominal TP is $10^{-2.94}$ with no parity. PE Error Floor is $10^{-3.17}$ with no parity and $10^{-3.71}$ with parity. BAR = 5.6



R. Victora et al., U. of Minnesota

Jitter: Recording at Tbit/in2



Media Parameters

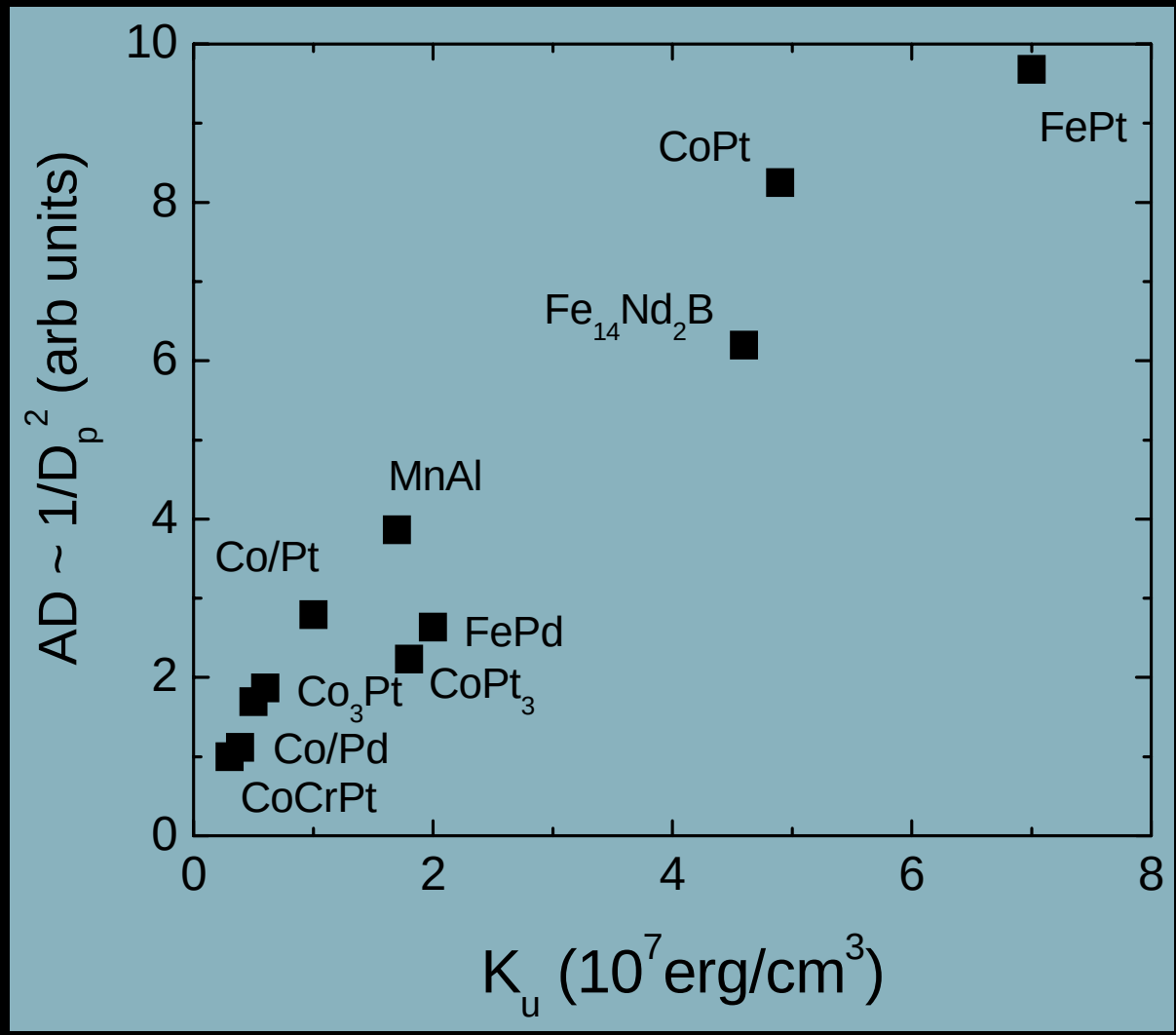
- Optimized ECC grain
- 3° Easy Axis Cone
- Bit length is 10 nm.
- K uniformly distributed with 5% stdev.

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.

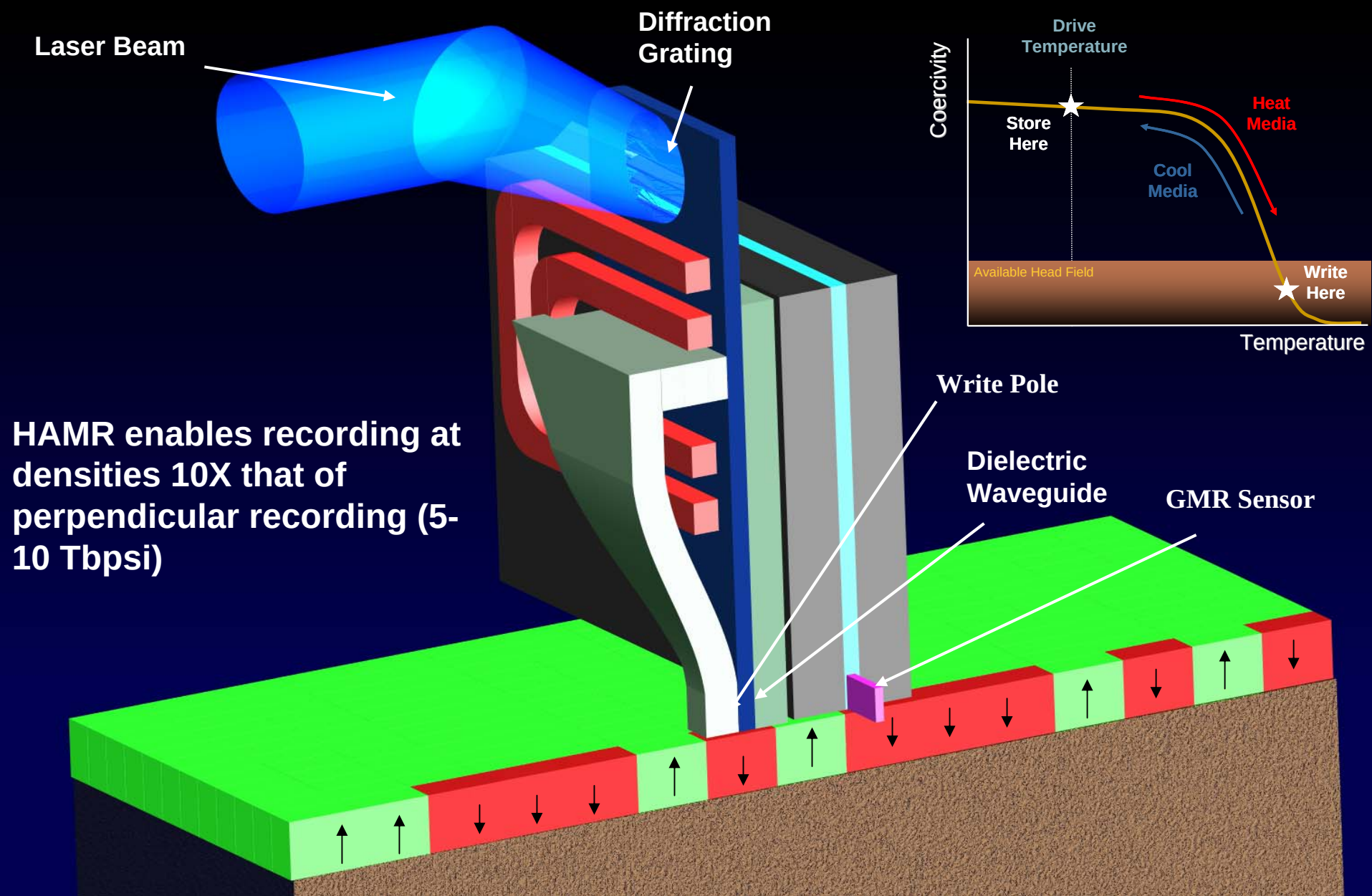
Areal Density Potential of Media Candidates

FePt and other high anisotropy materials offer areal density potential 10X that of CoCrPt materials used in perpendicular recording.

How to write on them?

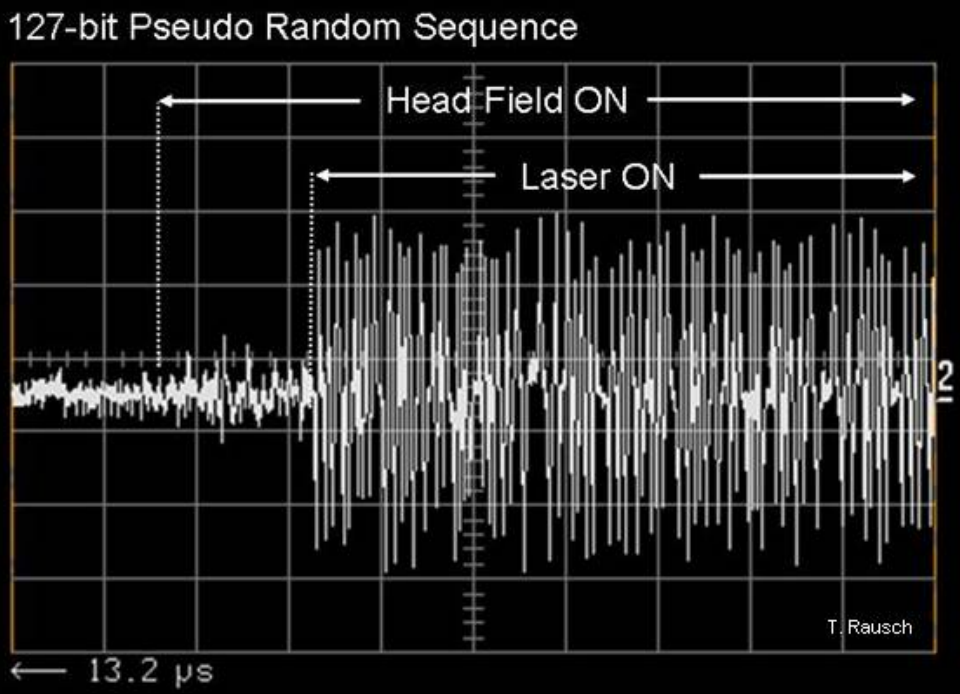


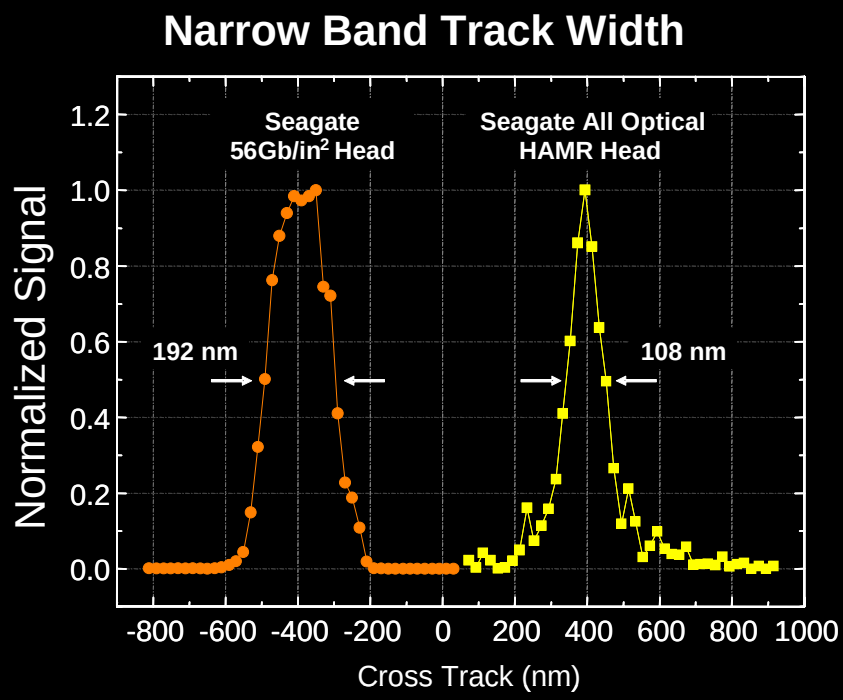
Heat Assisted Magnetic Recording (HAMR)



HAMR enables recording at densities 10X that of perpendicular recording (5-10 Tbpsi)

Spin Stand Recording – HAMR





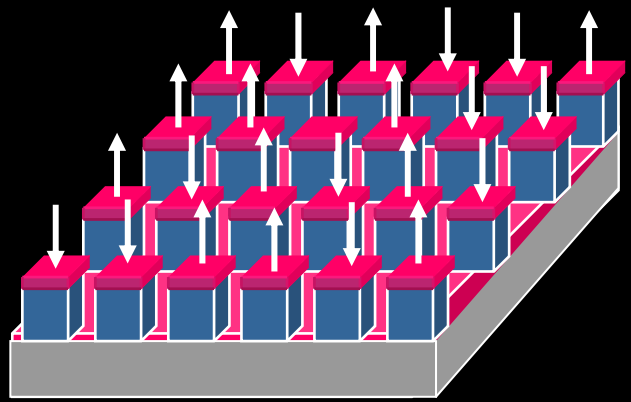
Recorded and Read back using typical recording conditions

HDD Performance Trends: Short Term

3.5 inch Consumer	2006 (Perp)	2010 (Perp)	2014 (HAMR)
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)**
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)**
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

Bit Patterned Media
Lithography vs. Self Organization

Lithographically Defined

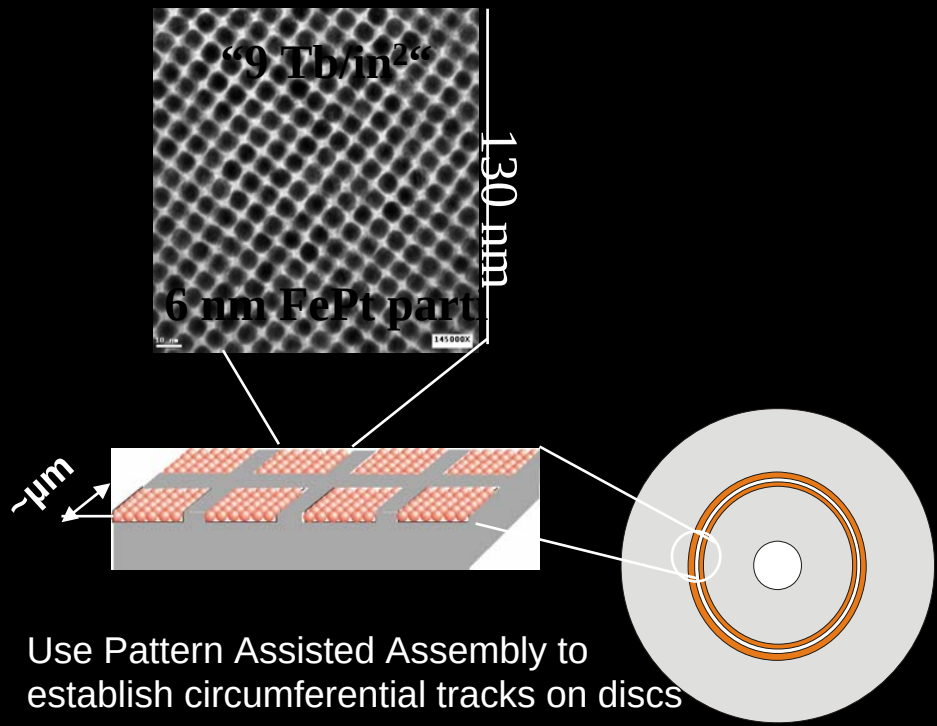


Direct E-Beam Write or Di-Block Co-Polymer

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

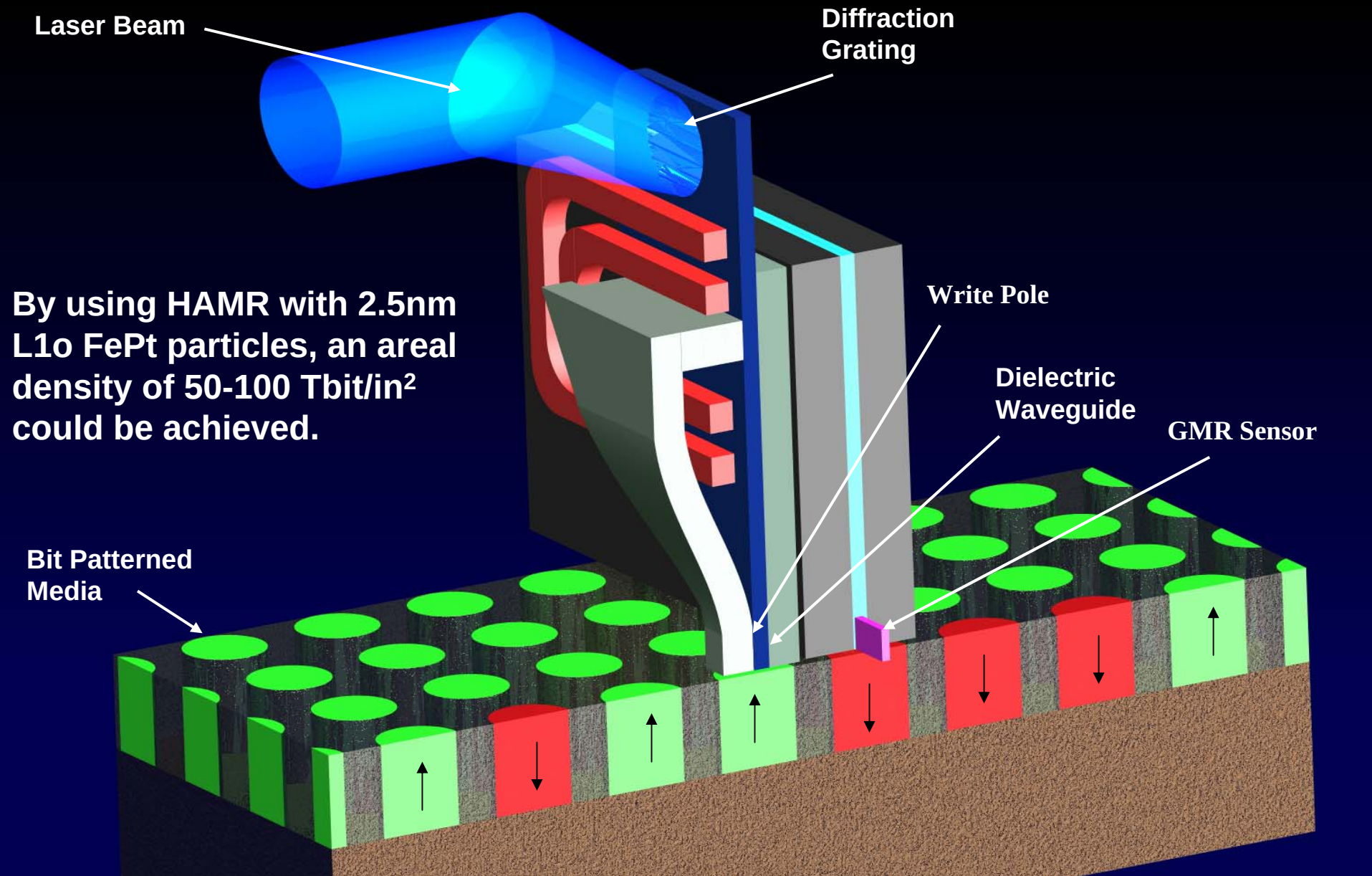
FePt Self-Organizing Media



Use Pattern Assisted Assembly to establish circumferential tracks on discs

Single particle FePt density limit: 50-100 Tbpsi

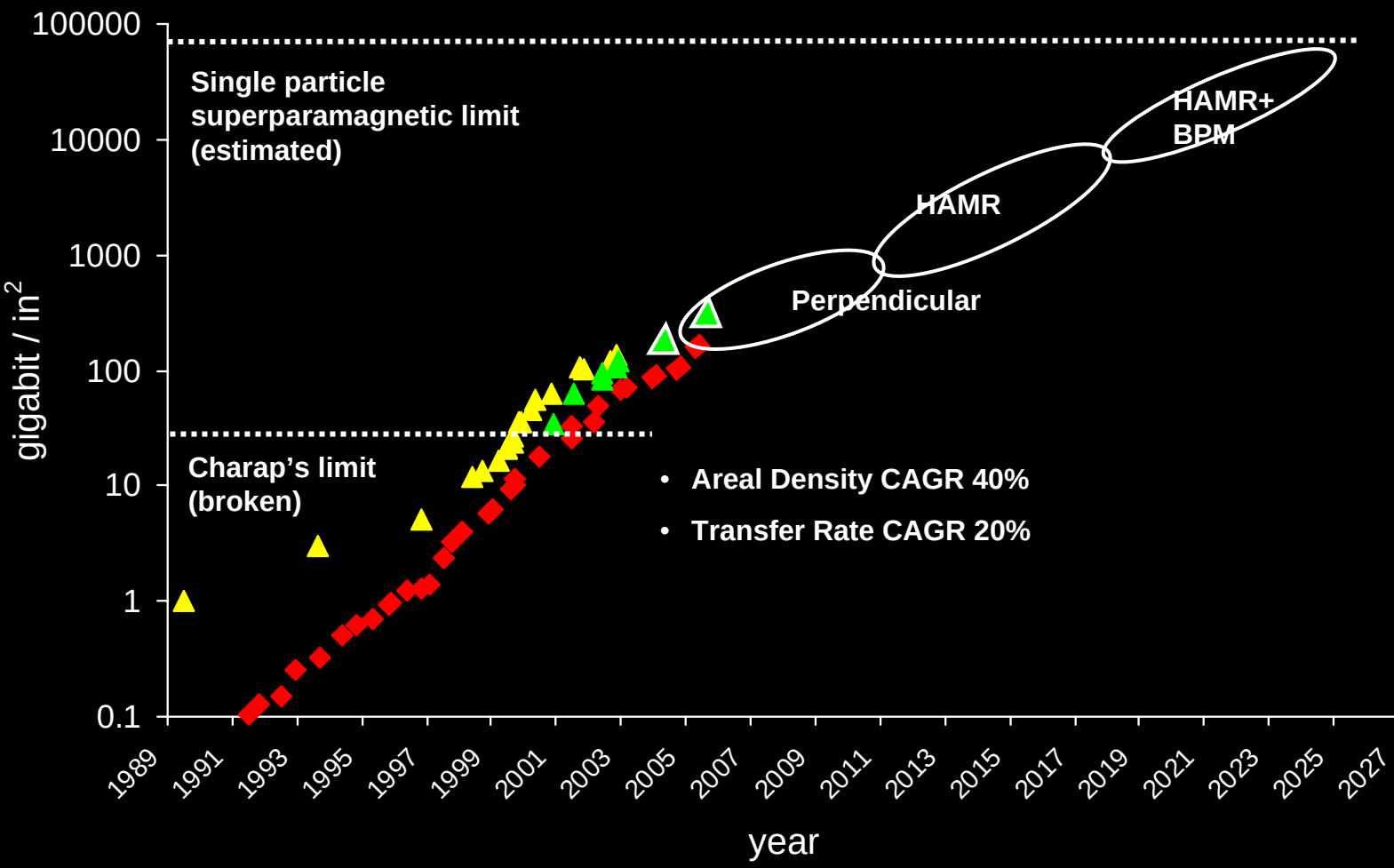
HAMR on Bit Patterned Media (BPM)



By using HAMR with 2.5nm L1o FePt particles, an areal density of 50-100 Tbit/in² could be achieved.

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



Enterprise Drive in 2020

Capacities: 10, 20 TBytes

Areal Density: 14 Tbit/in^2

Sustained Data Rate: 1.4 GByte/sec

Seek Time: 3.5/4.0 msec

Latency: 2 msec

MTBF: 20 million hours

Price: $300

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 promise to extend the areal density to perhaps 50 Tbpsi.
- Prediction: In 2020, storage will utilize HAMR with BPM at an areal density of 14 Tbit/in^2.
  - 2.5” drives with 20 Tbyte capacity.

Questions?