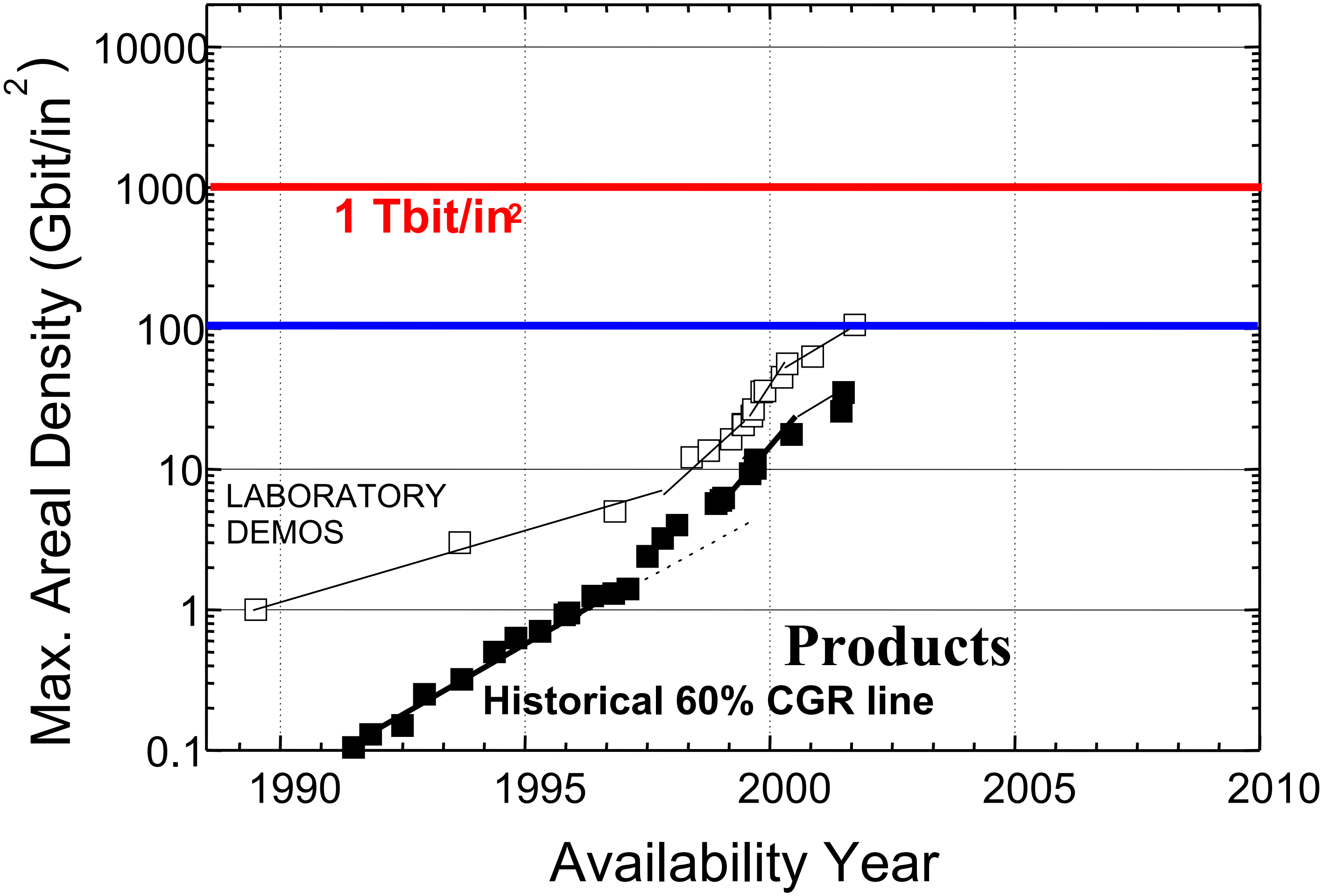
Future Magnetic Recording Technologies

Mark H. Kryder
Seagate Research

Areal Density Perspective



As of Dec., '01

Demos

~100 Gbpsi

Products:

~33 Gbpsi

40 GB per disk

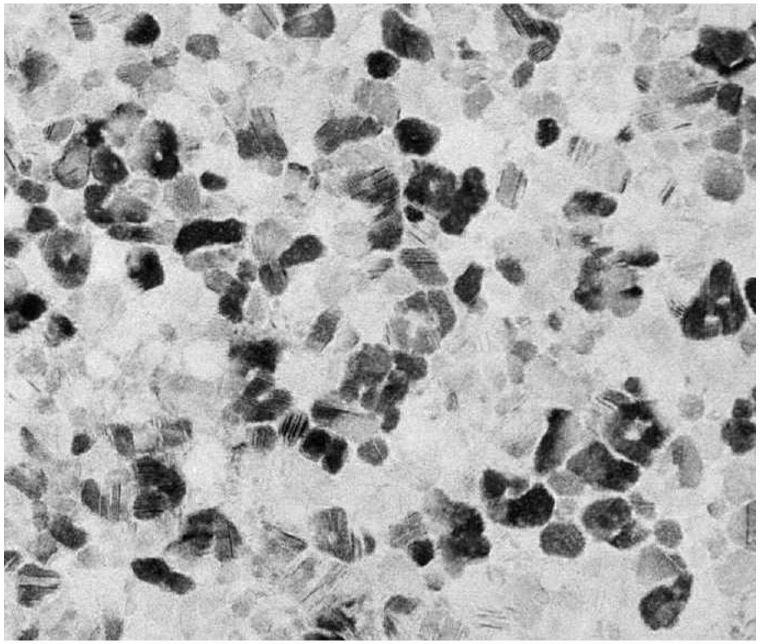
Superparamagnetic Effects

- In magnetic recording
  - **SNR** $\propto \sqrt{n}$
  - Where n = number of grains / trackwidth
- To maintain SNR as the bit size is reduced, the grain size, d_o, must be reduced.
- If d_o becomes too small, thermal energy ($K_B T$) may destabilize the magnetization and cause the recordings to decay.

45 Gbit/in^2 Demo Media (Seagate)

- 8.5 nm grains

  $\sigma_{area} \cong 0.5$



Thermal Relaxation

- Relaxation time = $\tau = 10^{-9} \exp (K_U V / K_B T)$

  τ = 72 sec for $K_U V / K_B T = 25$

  τ = 7.5 years for $K_U V / K_B T = 40$

  $\tau = 3.6 \times 10^9$ years for $K_U V / K_B T = 60$

- Demagnetizing fields in transitions shorten the relaxation time.

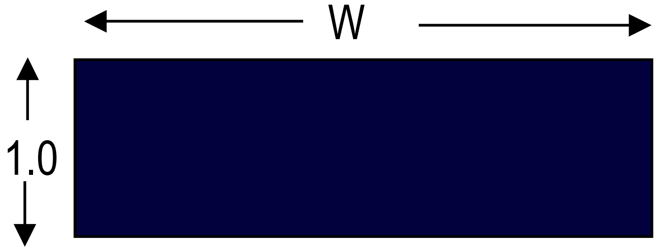
- Charap predicted that, with linear scaling, magnetic recording would reach the superparamagnetic limit at approximately 36 Gbit/in^{2}.

Seagate Demo of 101 Gb/in^2

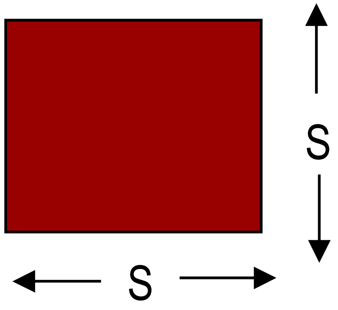
- 149 ktpi; 680 kbpi; 101 Gb/in^2
- BAR = 4.6
- RW ~ 3.75 uin; WW ~ 4.9 uin
- AFC media
- Napa channel @ 256 Mb/s
- On-Track BER = $5 X10^{-5}$
- OTC=10%TP; 5% squeeze; BER of $1X 10^{-4}$

The Importance of Being Square*

Rectangular Bit



Square Bit



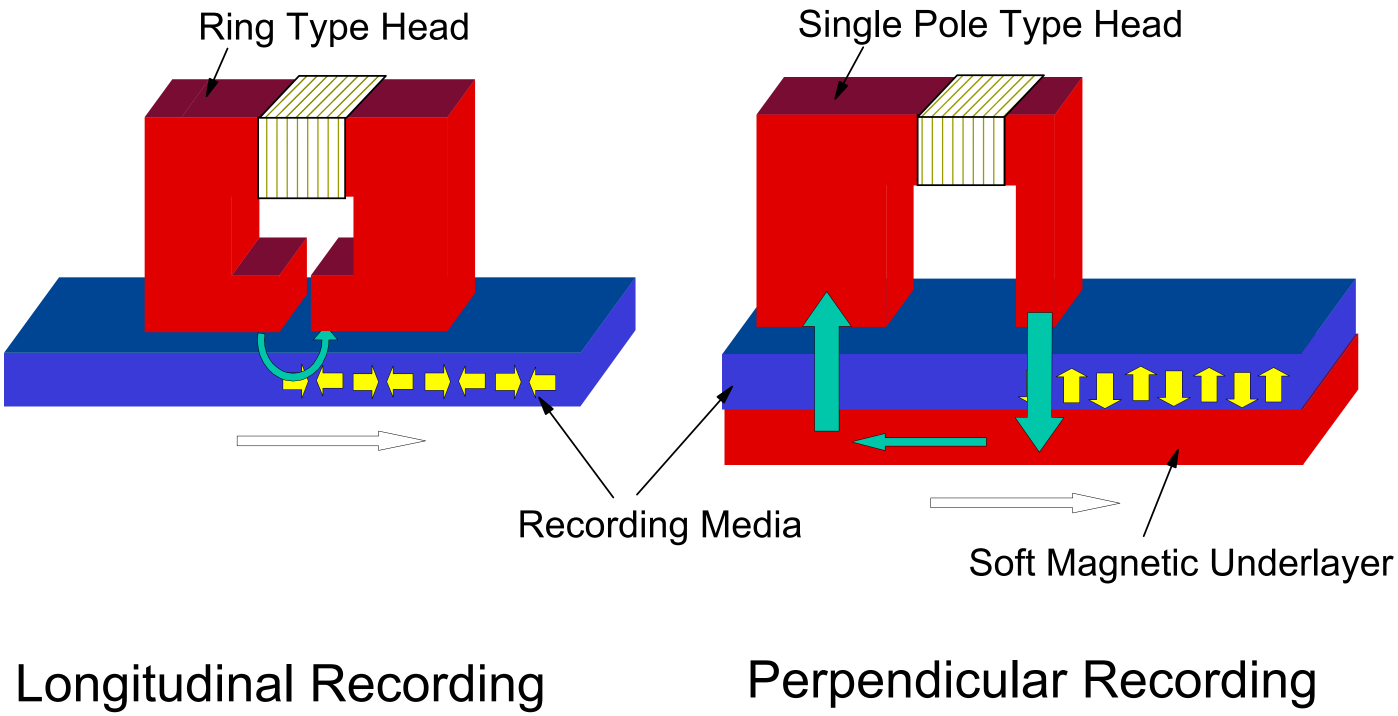
Under conditions of constant decay rate (grain volume and demag field constant) and constant transition noise jitter:

$$\text{Gain} = \frac{\text{Square Bit Density}}{\text{Rectangular Bit Density}} = \frac{1/S^2}{1/W} = 2^{2/3} \bullet W^{5/9}$$

If W = 20, Gain = 8.4

This is undoubtedly more areal density gain than can be achieved, but does indicate that more square bits are desirable.

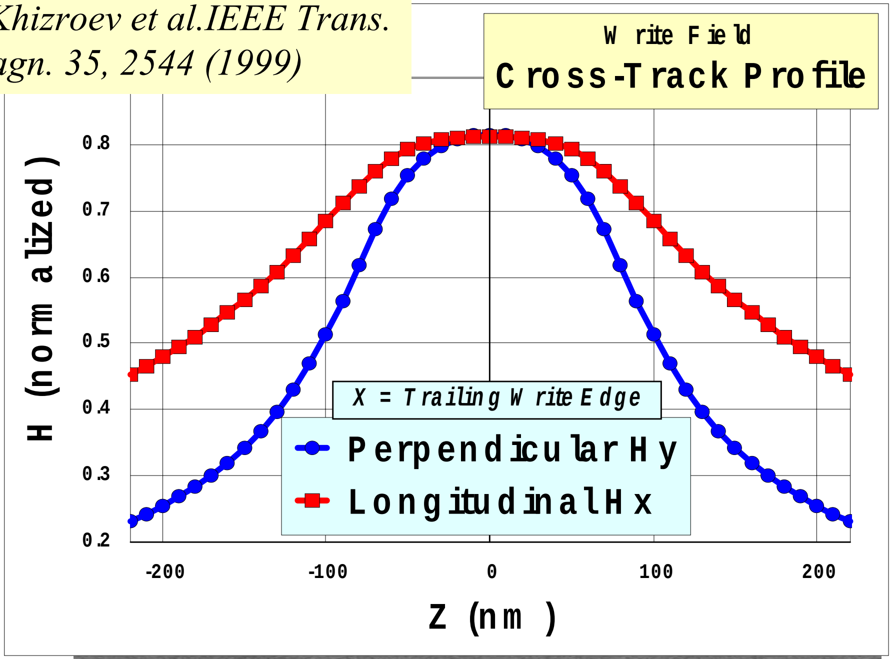
Longitudinal and Perpendicular Recording

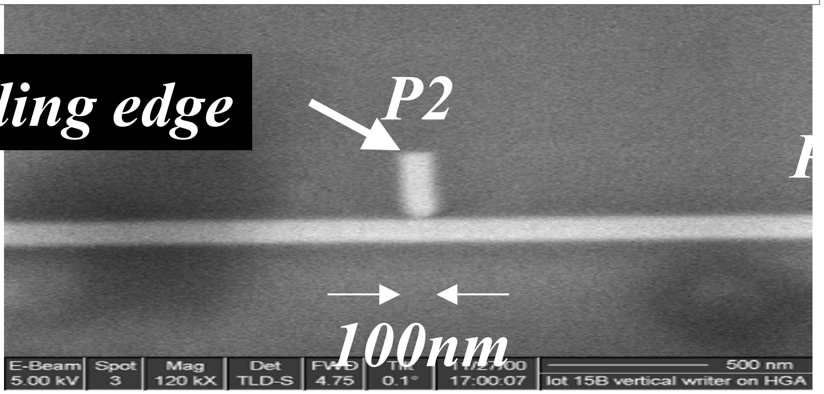


- ***Smaller side fringing fields***
- ***Potential increase in the magnitude of the write fields***
- ***Potential increase in media thickness***
- ***→ Higher BPI and Areal Density with Thermal Stability***

Narrow Track Recording

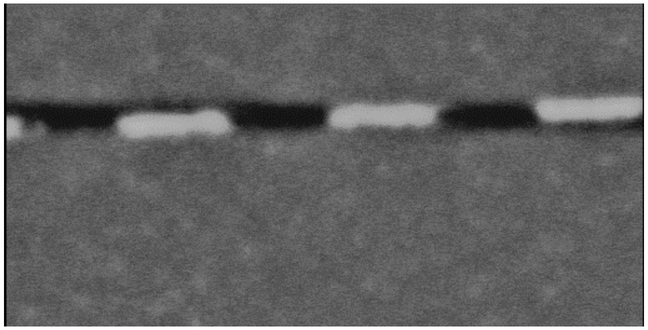
S. Khizroev et al.IEEE Trans. Magn. 35, 2544 (1999)



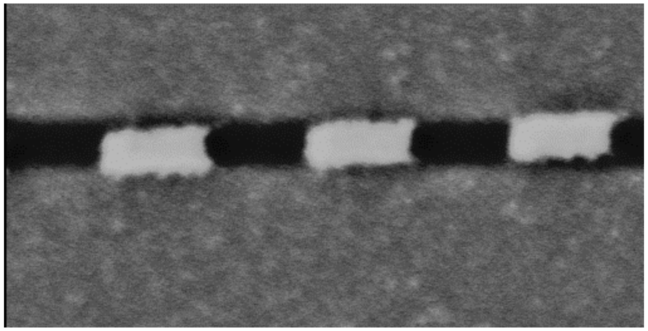


Track width

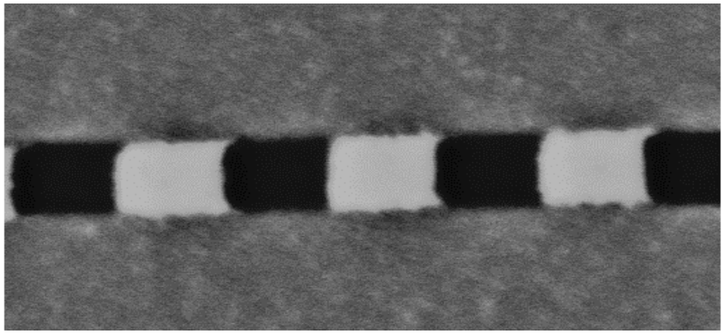
100 nm



250 nm

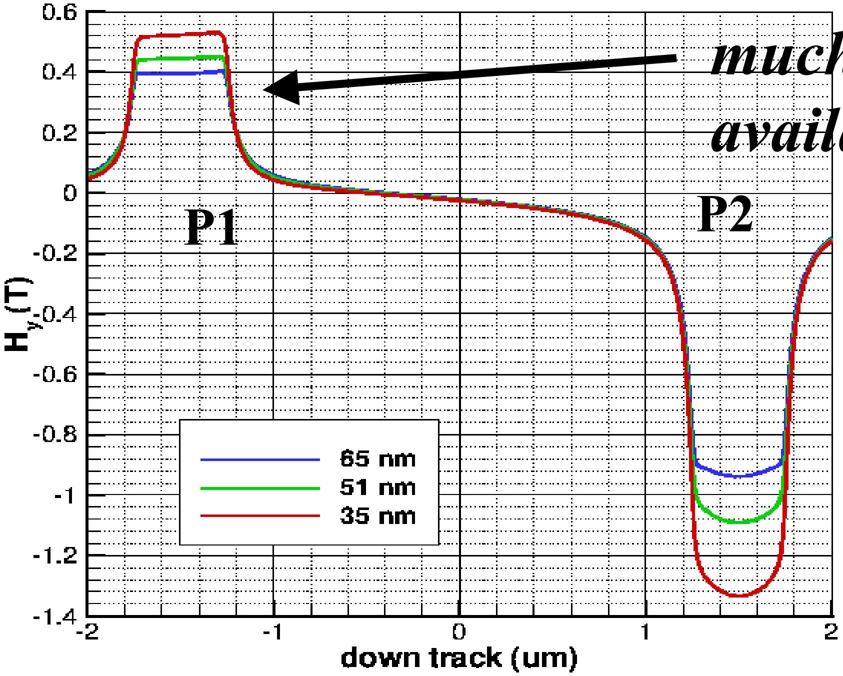


500 nm

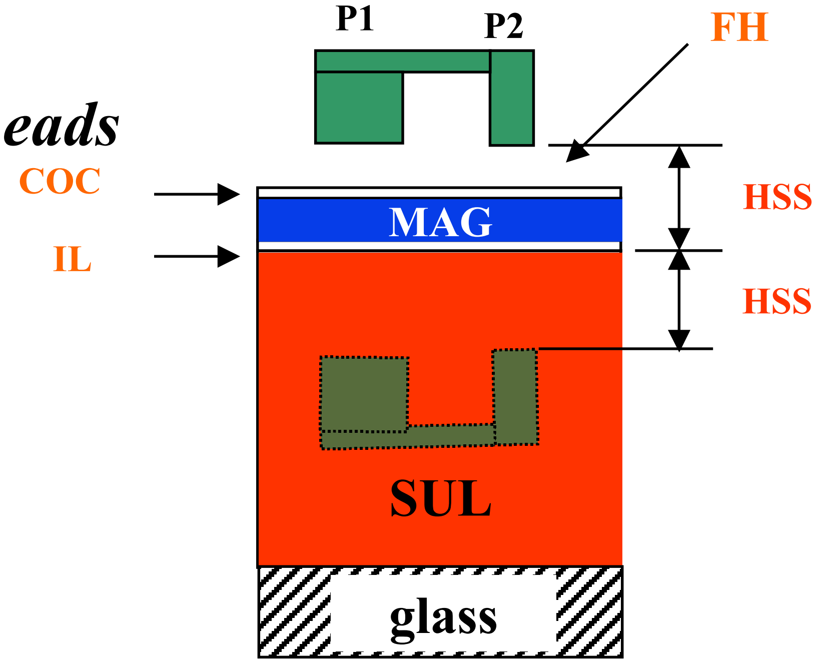


Field Amplitude / Sensitivity to Spacings

Down Track Vertical Write Field vs. HSS



much better heads available



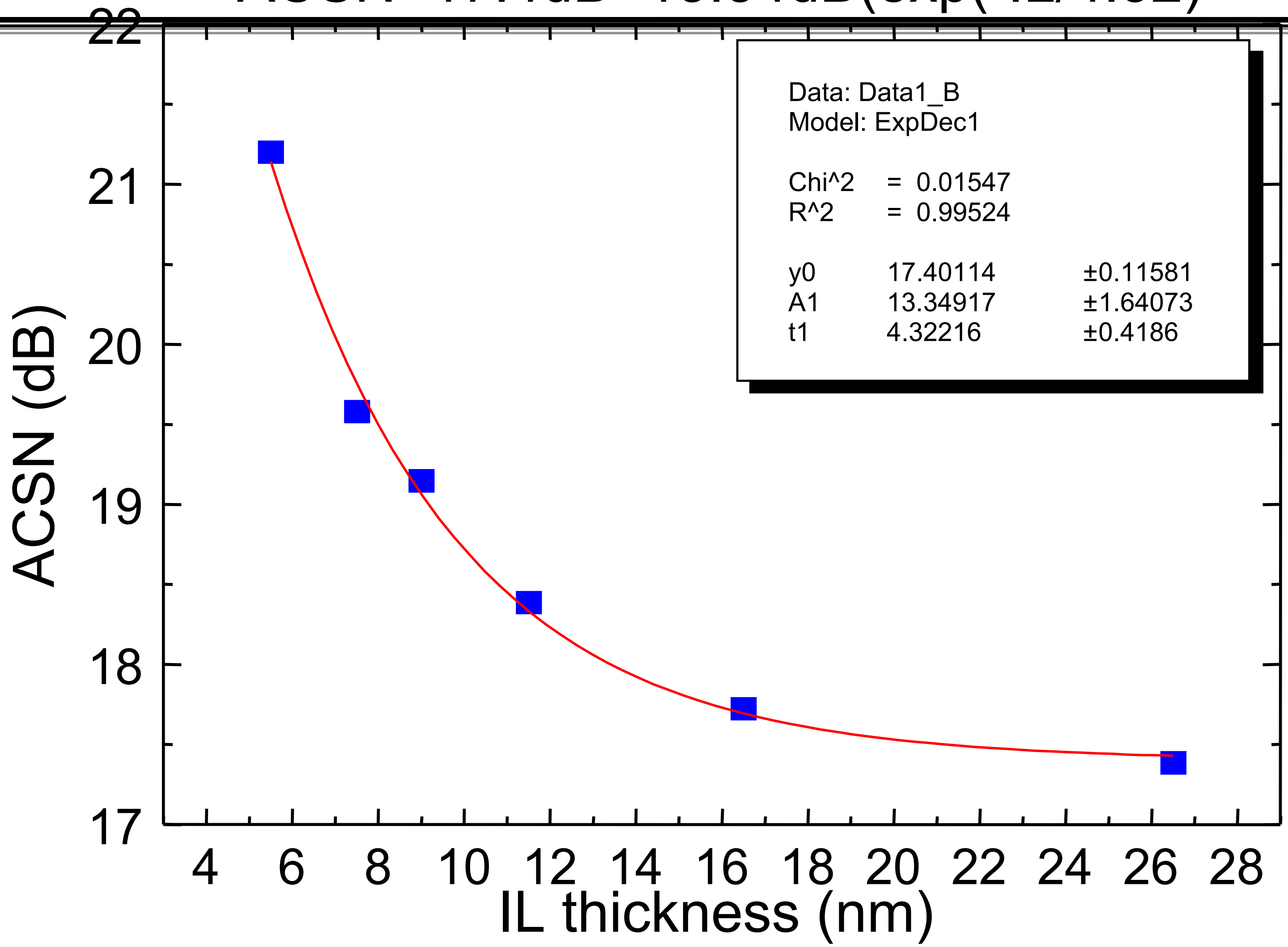
HSS=65 nm   H up to 9000 Oe

HSS=51 nm   H up to 11000 Oe

HSS=35 nm   H up to 13500 Oe

Head to Soft Underlayer Spacing is critical

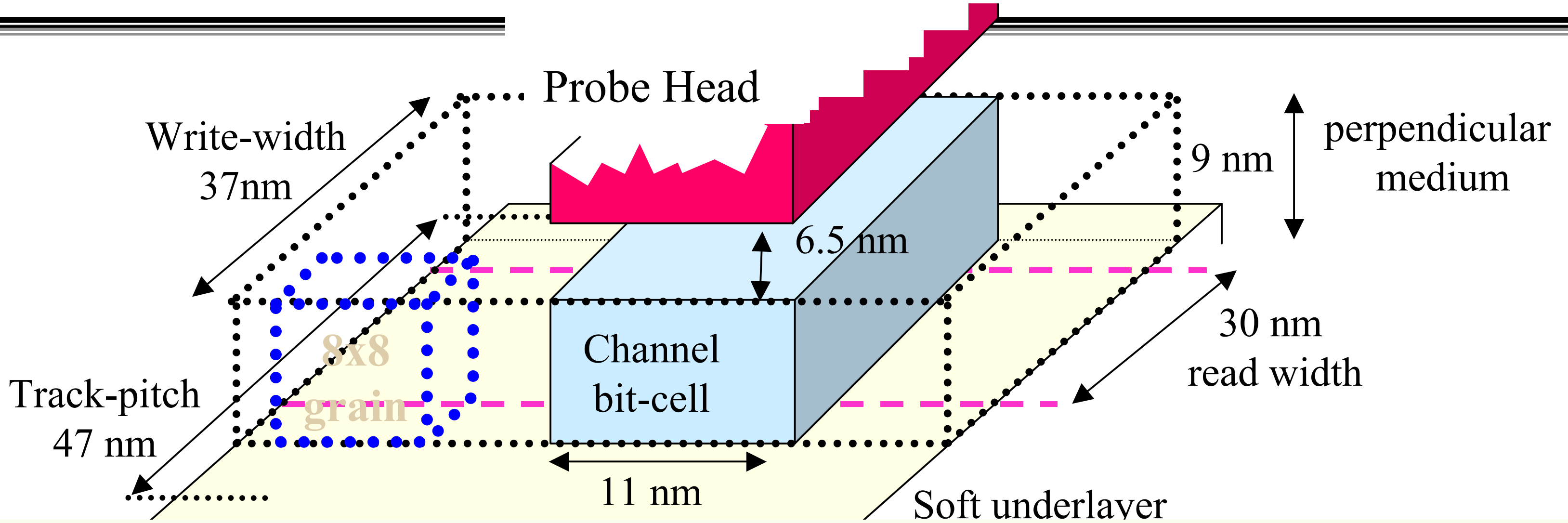
ACSN=17.4dB+13.34dB(exp(-IL/4.32)



Reducing IL thickness from 26.5 to 5 nm improves **+4 dB** in ACSN

Y. Kubota et al.
NAPMRC

Perpendicular System at 1 Terabit/sq.in. (650 Gbpsi User Density)



Areal Density: 1 Terabit/sq.in. (1.6 Gbit/mm^2) *(including Channel overhead; excluding ECC overhead)*

= 1.85 Mbits/inch (73 Kbits/mm) x 540 Ktracks/inch (21 Ktracks/mm)

(Bit aspect ratio is 3.5:1; required racking accuracy =0.3 μ" (7 nm) 3σ-2pass)

Medium: Perpendicular with soft underlayer: H_c=12,000 Oe (1 MA/m); M_r=6360 Gauss (510 EMU/cc)
Thickness = 0.36 microinches (9 nm); $M_r t$ = 0.45 mEMU/cm^2
Grain-diameter: 8 nm ± 1nm (1-sigma) *- random position and size distribution*

Read Head: Read-width: 1.2 microinches (30 nm), Sensitivity:1 mV peak-peak; Resistance: 50 ohms

Write Head: Write-width: = 1.5 microinches (37nm); Saturation: B_s = 20,000 Gauss (2 T)

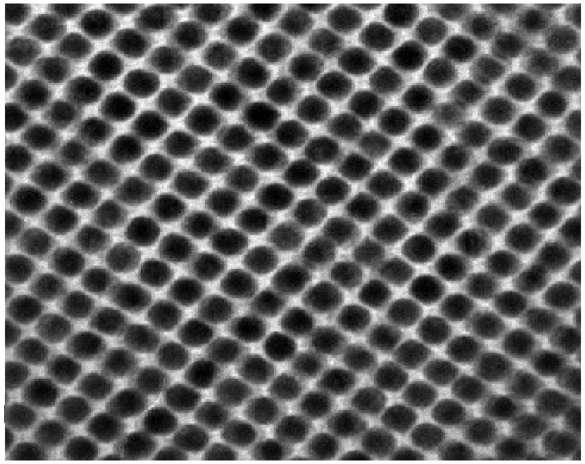
Head/Disk Interface: Magnetic Spacing: 0.26 microinch (6.5nm) to top of medium; 1600 inches/s (40 m/s) max.

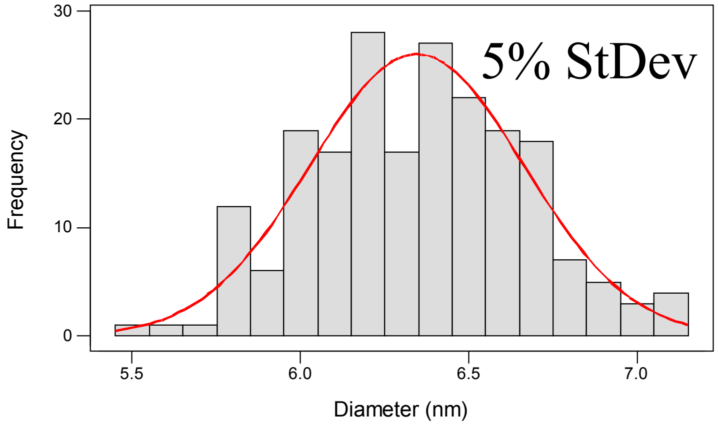
Read Channel: Detector SNR: 9.5 dB (rms/rms) allowing ~ 3dB system margin; Max. data-rate = 3 Gbit/s;
Channel: 5/6-rate simple parity; ECC: RS(556, 410), $GF2^{10}$, overhead = 35%

R. Wood, NSIC

Particle Size Distributions

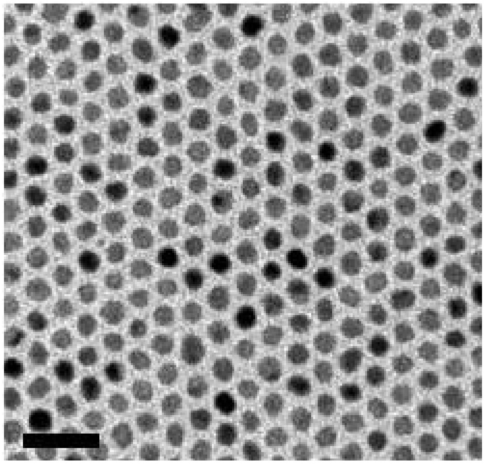
3D

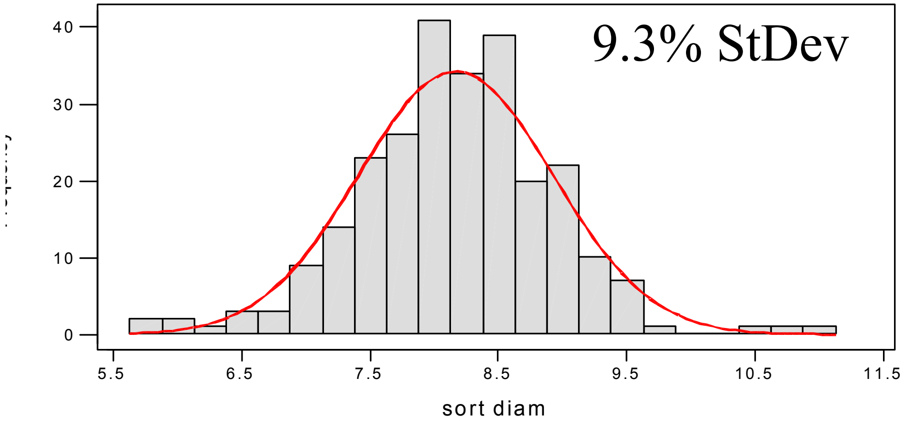




Mean: 6.3571 nm StDev: 0.3172

2D





Mean: 8.17 nm StDev: 0.76

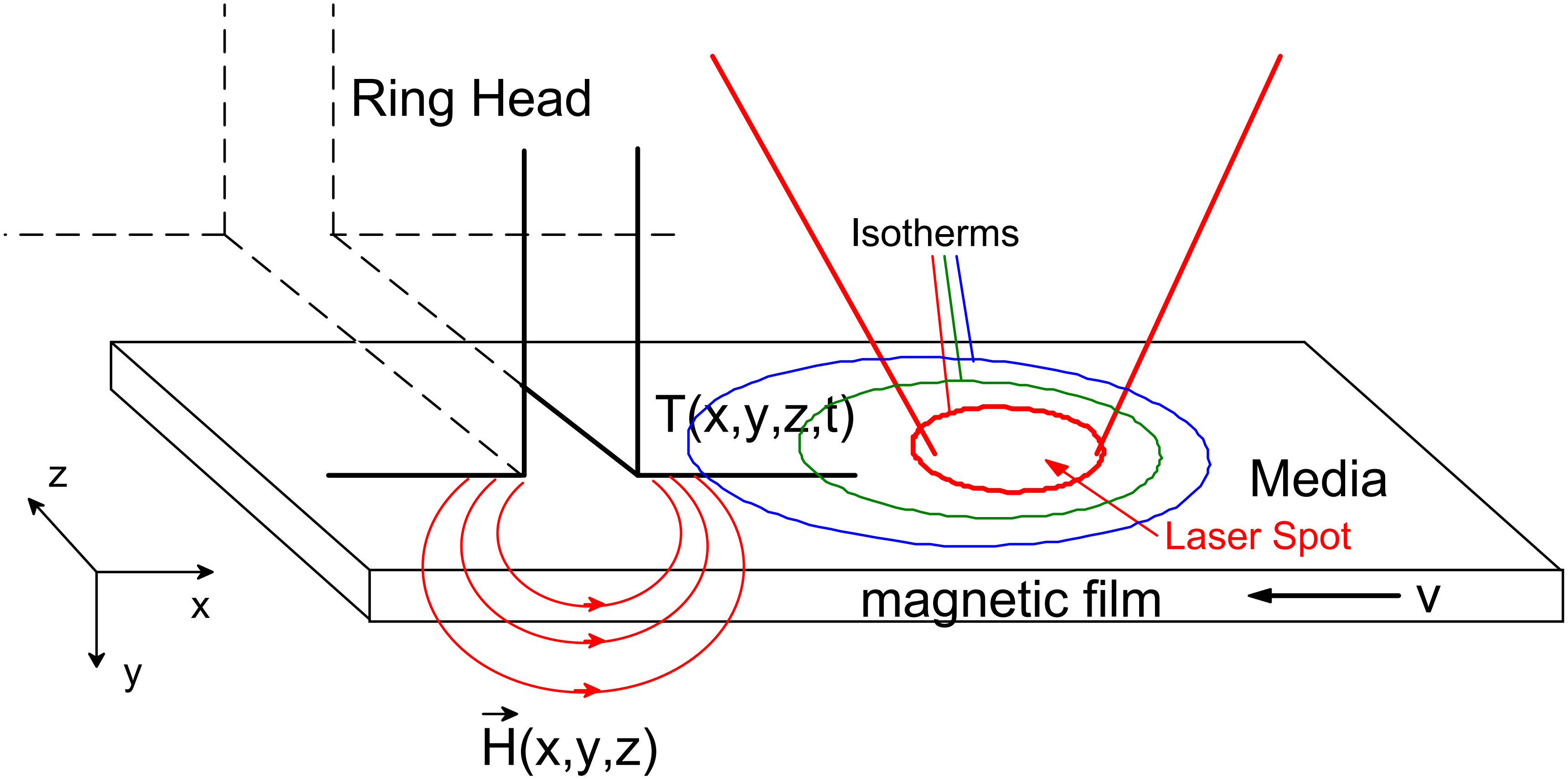
D. Weller, E. Svedberg

Perpendicular Recording Density Potential

- 1 Tbpsi perpendicular recording proposal is challenging!
  - User density is really 650 Gbpsi
  - Grain size dispersion is much less than we know how to achieve with polycrystalline media.
    - Self-Ordered Magnetic Arrays might be a solution.
  - Media anisotropy/coercivity is at the limit of what can be written with conventional head materials/structures.

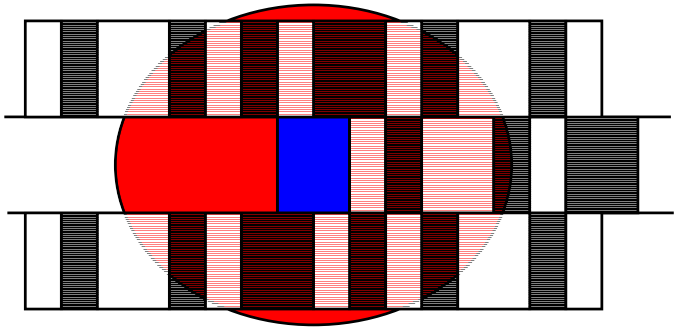
Heat-Assisted Magnetic Recording (HAMR)

Hybrid Recording Using Light

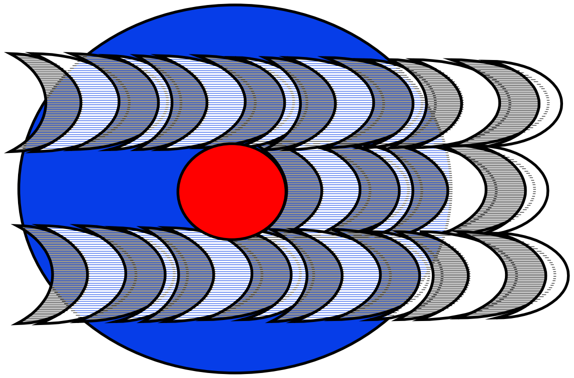


Different Approaches to HAMR

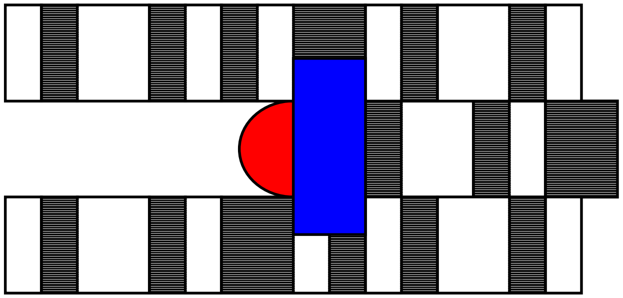
Far Field Light Delivery System:



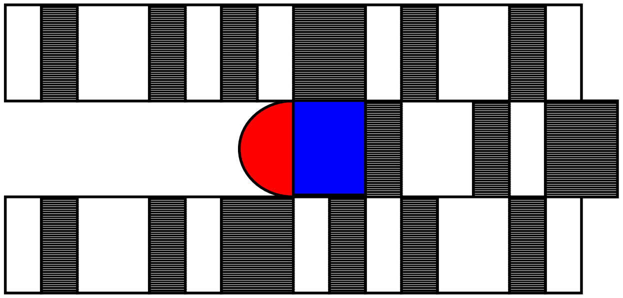
Near Field Light Delivery System with Global Magnetic Field:



Near field light delivery system defines track-width; magnetic head defines bit length:

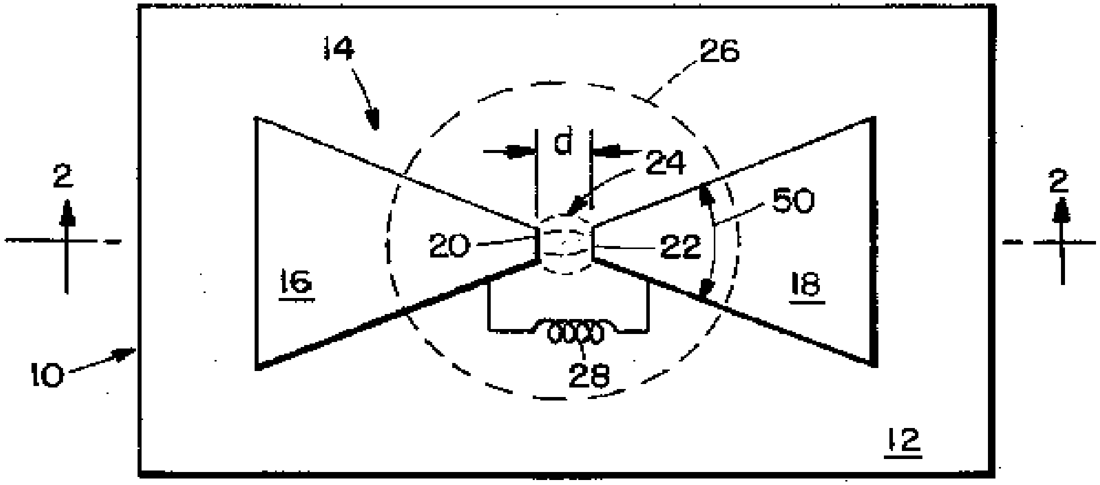


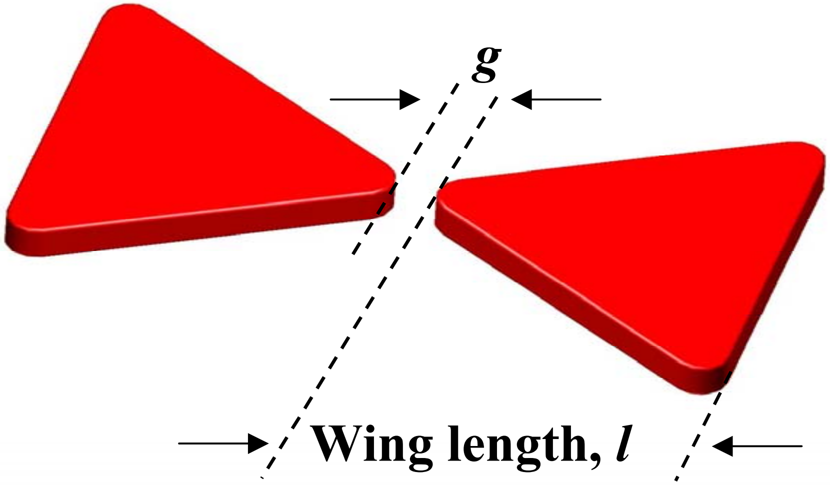
Near field light delivery system and magnetic head co-located to define bit and track:



Bowtie antenna

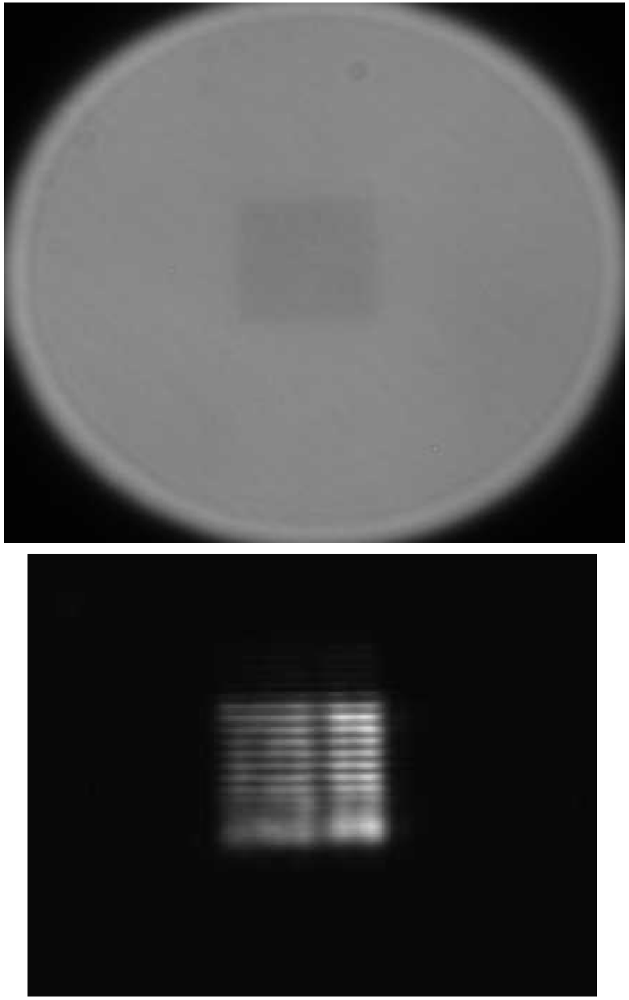
U.S. Patent 5,696,372
R.D. Grober et.al., Dec. 9, 1997

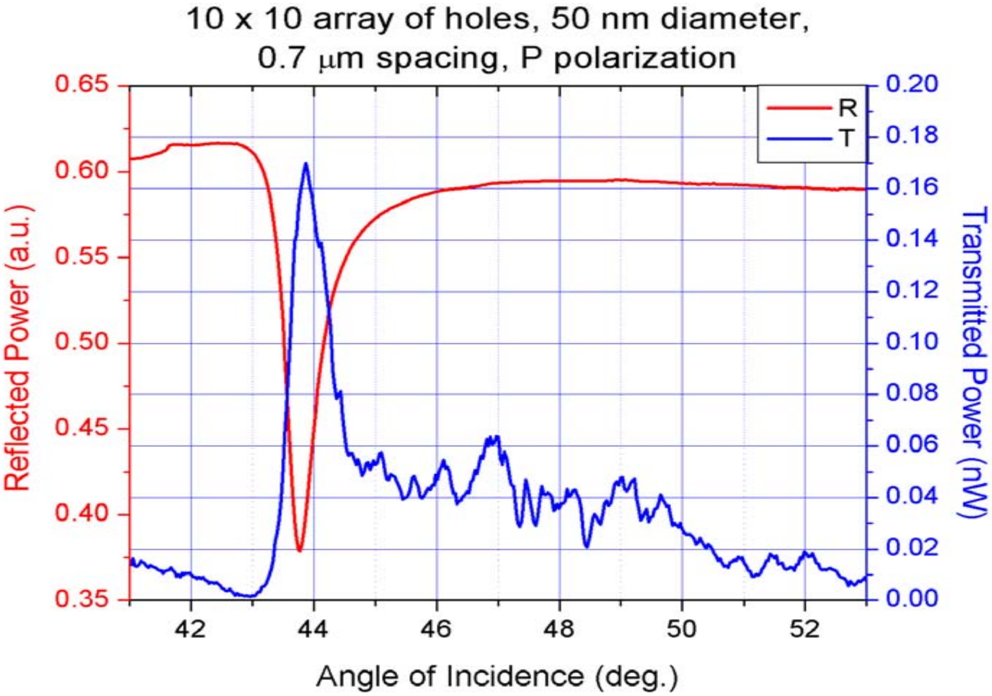




"High Efficiency **Near-Field Electromagnetic Probe Having a Bowtie Antenna Structure"**

Light Transmitted Through Array of 50 nm Holes





Incident power density: 0.14 mW/mm^2

Ave. transmitted power density/hole:

0.87 mW/mm^2 at resonance

W. Challener

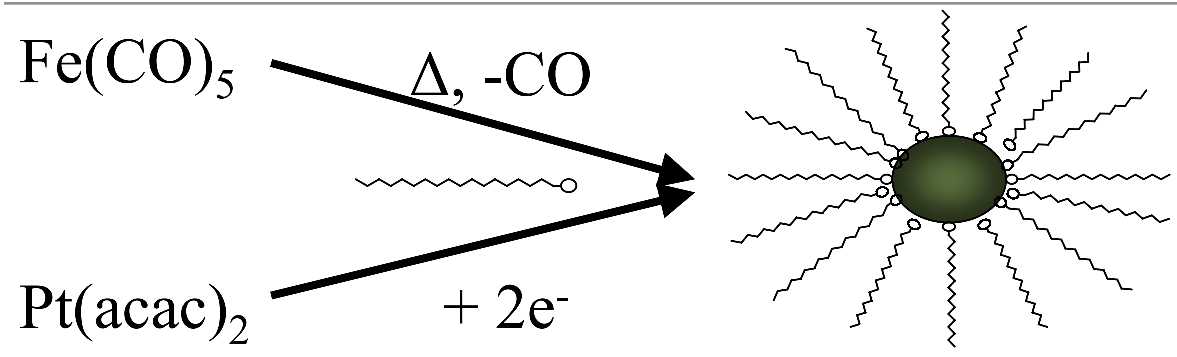
Heat Assisted Magnetic Recording

- What areal density might be achieved with HAMR?
  - HAMR could make it possible to use the smallest possible thermally stable grain, irrespective of the anisotropy/coercivity.
    - In FePt, this is about 3 nm.
  - If perpendicular recording can achieve 500 Gbpsi with 8 nm grains, then HAMR should be able to achieve about 10X higher density.

Patterned Media Recording

- 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 gives no hope of achieving such linewidths within the next decade.
  - E-beam and X-ray lithography have been around for over 30 years, but during that time, there has been little progress on the minimum producible feature size.
- Numerous systems issues also exist.

Self-Ordered Magnetic Arrays (SOMA) of FePt



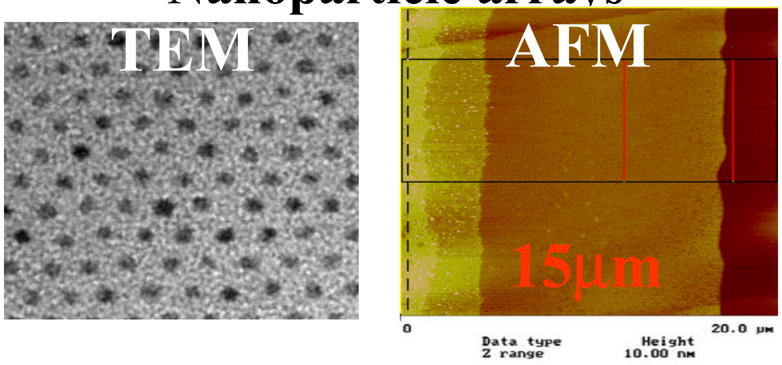
$Fe(CO)_5$

Δ, -CO

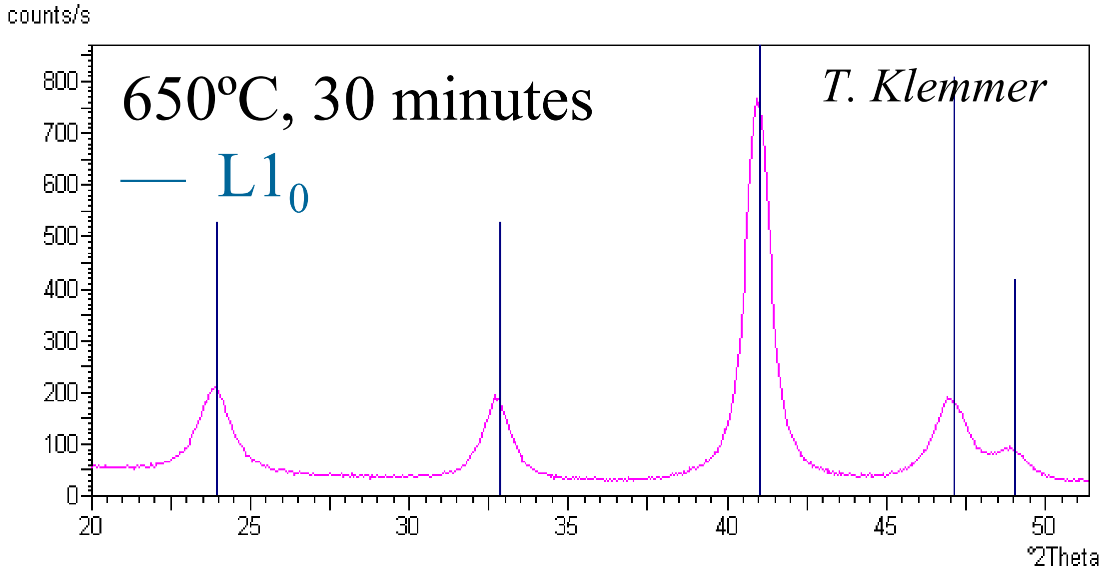
$Pt(acac)_2$

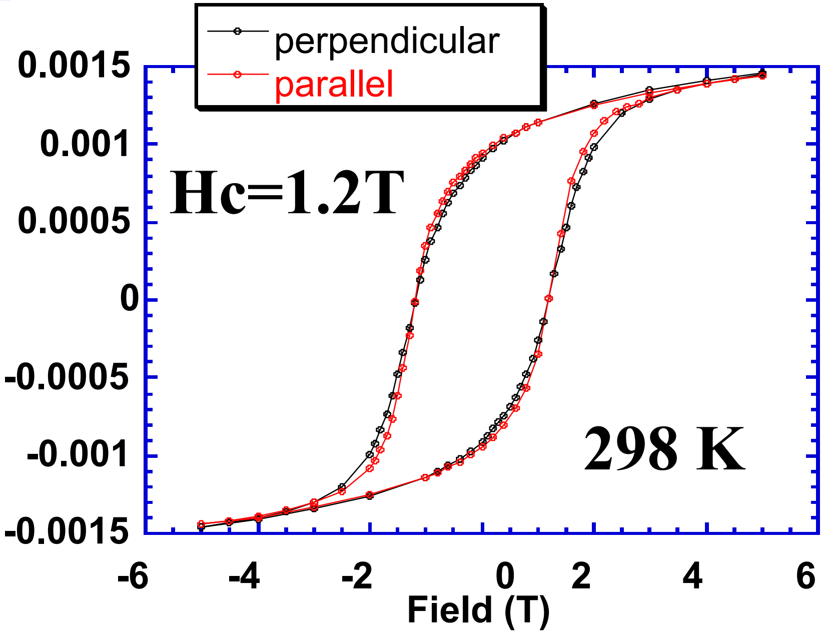
$+ 2e^-$

~3-5 nm Dia FePt Nanoparticle arrays



Modeling: D = 4.8 nm, Ku = 4.9 x 10^7 erg / cm^3, exch = 0.2





Shukla, Liu, Wu, Klemmer, Chantrell, Lu, Ahner, Weller (to be published)

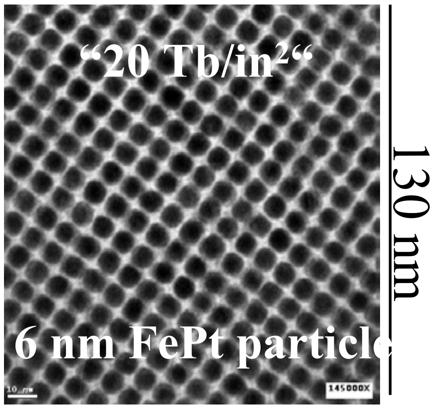
SOMA Media - Obstacles to Overcome

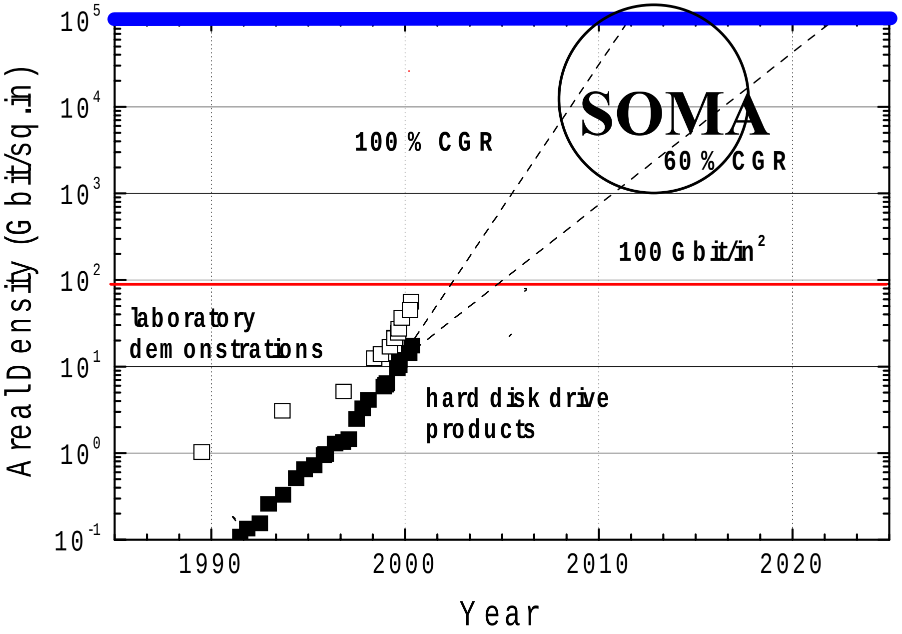
- SOMA do not form in concentric tracks.
- To achieve the highest areal density, we will still need improved means of writing.

HAMR with SOMA Media: The Ultimate Potential?

- HAMR could make it possible to write on FePt.
- With single particle/bit recording, and 3nm stable particles, the potential is over 50 Tbpsi!

Naturally Patterned SOMA Structure (nm scale)





Conclusions

- Longitudinal recording is expected to approach limits somewhere beyond 100 Gbpsi.
- Perpendicular recording appears promising for extending the areal density progression -- perhaps to 1 Tbpsi.
- Heat assisted magnetic recording could extend the areal density to 5 Tbpsi.
- SOMA media, in combination with HAMR offer an ultimate areal density of 50 Tbpsi.