Future Magnetic Recording Technologies

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Seagate Research
As of Dec., ‘01
Demos: ~100 Gbpsi
Products: ~33 Gbpsi
40 GB per disk
In magnetic recording

- $\text{SNR} \propto \sqrt{n}$
- Where $n = \text{number of grains / trackwidth}$

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/in² Demo Media (Seagate)

- 8.5 nm grains
  \[ \sigma_{\text{area}} \approx 0.5 \]
Thermal Relaxation

- Relaxation time $\tau = 10^{-9} \exp \left( \frac{K_U V}{K_B T} \right)$
  - $\tau = 72$ sec for $K_U V / K_B T = 25$
  - $\tau = 7.5$ 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/in²

- 149 ktpi; 680 kbpi; 101 Gb/in²
- BAR = 4.6
- RW ~ 3.75 uin; WW ~ 4.9 uin
- AFC media
- Napa channel @ 256 Mb/s
- On-Track BER = 5 \times 10^{-5}
- OTC=10\%TP; 5\% squeeze; BER of 1X 10^{-4}
The Importance of Being Square*

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

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

If \( W = 20 \), \( \text{Gain} = 8.4 \)  

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

Longitudinal Recording

- Smaller side fringing fields
- Potential increase in the magnitude of the write fields
- Potential increase in media thickness
- \[ \rightarrow \ \text{Higher BPI and Areal Density with Thermal Stability} \]

Perpendicular Recording
Narrow Track Recording


Track width

- 100 nm
- 250 nm
- 500 nm

Cross-Track Profile

$X = \text{Trailing Write Edge}$

$H_{\text{perpendicular}}$ and $H_{\text{longitudinal}}$

Write Field

Trailing edge

P2

100 nm

Seagate

Information the way you want it
Field Amplitude / Sensitivity to Spacings

Down Track Vertical Write Field vs. HSS

much better heads available

P1

P2

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 = 17.4 dB + 13.34 dB (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/mm²)  
*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: Hₖ=12,000 Oe (1 MA/m); Mₛ=6360 Gauss (510 EMU/cc)  
Thickness = 0.36 microinches (9 nm); Mₘ=0.45 mEMU/cm²  
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: Bₛ = 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), GF2¹⁰, overhead = 35%

R. Wood, NSIC
Particle Size Distributions

3D

Mean: 6.3571 nm  StDev: 0.3172

5% StDev

D. Weller, E. Svedberg

2D

Mean: 8.17 nm  StDev: 0.76

9.3% StDev
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

- Ring Head
- Isotherms
- Laser Spot
- Magnetic film
- Media
- $H(x,y,z)$
- $T(x,y,z,t)$
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"

Wing length, \( l \)
Light Transmitted Through Array of 50 nm Holes

Incident power density: 0.14 mW/mm²
Ave. transmitted power density/hole:
0.87 mW/mm² at resonance

W. Challener
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 Tbps, 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)$_5$ $\Delta$, -CO

Pt(acac)$_2$ $\rightarrow$ $+ 2e^-$

Modeling: $D = 4.8$ nm, $K_u = 4.9 \times 10^7$ erg / cm$^3$, exch = 0.2

650$^\circ$C, 30 minutes

$\leftarrow\text{L}1_0\rightarrow$

H$_c$ = 1.2T

298 K

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 Tbps!
Conclusions

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