Quick Review over the Last Lecture

LTO Storage:
- 12.65 mm wide tape / tracks
- Track width: \( \mu \text{m} \)
- Length: m
- < \( \mu \text{m} \) left / right distributions
- < nm surface roughness

\* http://home.jeita.or.jp/
04 Development of Hard Disk Drives

- Design
- Write / read operation
- MR / GMR heads
- Longitudinal / perpendicular recording
- Recording media
- Bit size
- Areal density
- Tri-lemma

Where Can We Find a Hard Disk Drive (HDD)?

PC
Hard disc recorder
Data storage
Video game
PDA
GPS navigation
mp3 player
Digital camera
Video camera
Mobile phone

Most popular recording media now:

. . .
How to Access HDD?

Open your computer ...

This is a HDD!

HDD Shipments

Worldwide unit shipments of hard disk drives (HDD) from 1976 to 2025 (in millions):

Do NOT Try This at Home!

Open a metal frame of HDD ...

- Arm is operated by a linear motor with a very strong permanent magnet.
  - Arm moves ~ times/sec.
  - Platter records data.
  - Platter rotates rpm.

HDD Operation

HDD Writing / Reading Operation

HDD writing operation : *
HDD reading operation : *

1 0 0 1 1 1 0 1

Increase in Recording Density of Hard Disk Drives

Similar to Moore’s law:

* [http://dspace.wul.waseda.ac.jp/dspace/bitstream/2065/28765/6/Honbun-4557_03.pdf](http://dspace.wul.waseda.ac.jp/dspace/bitstream/2065/28765/6/Honbun-4557_03.pdf)
Anisotropic magnetoresistance (AMR) :

Anisotropic magnetoresistance (AMR) is a phenomena where a change in magnetic field affects the electrical resistance of a material. The main sensing material used for AMR is permalloy (Ni$_{80}$Fe$_{20}$), which has been in use since 1991.

Areal density in a HDD increased by 60% per year (from 25% per year).

Mainly permalloy (Ni$_{80}$Fe$_{20}$) alloys have been used as a sensing layer since 1991 by replacing ferrite bulk heads.

Giant magnetoresistance (GMR) :

Giant magnetoresistance (GMR) is a phenomenon where the resistance of a material changes significantly in response to a magnetic field. The GMR ratio is given by the change in resistance divided by the resistance at zero magnetic field.

For example, the GMR ratio of a [3 nm Fe / 0.9 nm Cr] layer is 60%.

MR Ratio

50% resistance change at 4.2 K

Discovery of Giant Magnetoresistance

Giant magnetoresistance (GMR):

[3 nm Fe / 0.9 nm Cr] × 60

MR

Magnetic field (kG)

50% resistance change at 4.2 K

Giant Magnetoresistive Head

Giant magnetoresistance (GMR) :

After GMR implementation by IBM and Toshiba independently, areal density increased % per year (1998 ~).

Miniaturisation in Head Design

Size evolution of a recording head in HDD :
Longitudinal Recording Technology

Longitudinal recording:

- From Computer Desktop Encyclopedia
  ©2006 The Computer Language Company Inc.

~ 2005.

Perpendicular Recording Technology

Perpendicular recording:

- Originally proposed by Shun-ichi Iwasaki in
  Toshiba introduced in

* http://www.hitachigst.com/
Development of HDD

Recording density increases at 100% / year:

First HDD in the world:
RAMMAC 305 (1956, IBM)
60 cm platter \times 50 = \text{Mbit / inch}^2

Current HDD:
MK2035GSS (2006, Toshiba)
6.4 cm platter \times 2 = \text{Gbit / inch}^2

Recording Media

Polycrystalline recording media:

* http://dspace.wul.waseda.ac.jp/dspace/bitstream/2065/28765/6/Honbun-4557_03.pdf
**Bit Sizes of Recording Media**

Required bit sizes for higher-density recording:

<table>
<thead>
<tr>
<th>Areal density (Gb/in²)</th>
<th>Typical one bit size</th>
<th>Number of grains (assumed φ8 nm/grain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>803 nm</td>
<td>80 nm</td>
</tr>
<tr>
<td>100</td>
<td>120 x 16 nm</td>
<td>~1280 grains</td>
</tr>
<tr>
<td>200</td>
<td>125 x 25 nm</td>
<td>~130 grains</td>
</tr>
<tr>
<td>500</td>
<td>80 x 16 nm</td>
<td>~65 grains</td>
</tr>
<tr>
<td>1000 (1 Tbit/in²)</td>
<td>36 x 18 nm</td>
<td>~26 grains</td>
</tr>
<tr>
<td></td>
<td>(25 x25 nm)</td>
<td>~13 grains</td>
</tr>
</tbody>
</table>

* http://dspace.wul.waseda.ac.jp/dspace/bitstream/2065/28765/6/Honbun-4557_03.pdf

**Aerial Density Increase by TMR Head Introduction**

Aerial density growth of hard disk drives:

Requirements for higher-density recording:

- **Writability of bits** ($H_{\text{write}}$): $H_{\text{write}}$ to reduce noise.
- **Signal-to-noise ratio** $\propto \text{(number of grains)}^{1/2}$: Noise by a stray field to increase $H_{\text{write}}$.
- **Thermal stability of bits** $K_u V \approx 60 k_B T$: $K_u$ to reduce $V$.

- $K_u$ to reduce $H_{\text{write}}$.
- $K_u$ to reduce $V$.
- $V$ to reduce $K_u$. 

**Explanation:**

- The signal-to-noise ratio depends on the number of grains to the power of $1/2$.
- Thermal stability is closely related to the size of the grains and external fields.
- Writability of bits is influenced by the magnetic fields applied during recording.

**Diagram Notes:**

- Red arrows indicate dependencies to reduce $H_{\text{write}}$.
- Blue arrows indicate dependencies to increase $K_u$.
- Green arrows indicate the relationship with the signal-to-noise ratio.

**Key Points:**

- Reducing $H_{\text{write}}$ helps in reducing noise.
- Increasing $K_u$ helps in reducing the voltage $V$.
- Larger $K_u$ and smaller $H_{\text{write}}$ are beneficial for thermal stability.

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**References:**

- Tri-Lemma in HDD: [Source](https://example.com/tri-lemma-hdd)
- Requirements for higher-density recording: [Source](https://example.com/high-density-recording)