Quick Review over the Last Lecture

Energy assisted magnetic recording : *
HAMR (heat-assisted magnetic recording) : **

MAMR (microwave-assisted magnetic recording) : **

* http://www.tagen.tohoku.ac.jp/labokitakamii/research_j/research_j.html
06 HDD Media

- Grain-size control
- 2-dimensional magnetic recording
- Shingled write recording
- Bit patterned media
- Other efforts

Precise Grain-Size Control

Grain-size reduction from 7 ~ 8 nm down to ~ 5 nm:

* http://www.toshiba.co.jp/*
In 2008, Roger Wood et al. proposed 2-dimensional magnetic recording (TDMR): *

![Example diagram of 2-Dimensional Magnetic Recording (TDMR)]

TDMR simulations: *

![TDMR simulation diagram showing readback and 2D read waveform (grain-outlines superimposed)]

Toshiba has been developing shingled write recording:

- Writing:
- Reading:

- ✓ Large track width
- ✓ Large writing field
- ✓ Higher areal density (~ 30 %)
- ✓ No cross-talk between tracks
- ✗ Write-in / read-out time
- ✗ Data re-write mechanism
- ✗ No improvement in TPI
- ✗ No improvement in SNR


Shingled Write Recording in HDD

Western Digital Continues Enterprise-Capacity HDD Leadership

New 15TB Ultrastar DC HC620 HDD Leverages SMR Technology to Improve Areal Density and Lower TCO for Scale-out Cloud and Enterprise Data Center Customers

Western Digital 15TB Ultrastar DC HC620 host-managed SMR Hard Disk Drive (Photo: Business Wire)

Shingled Recording Projection

Shingled recording technology:


Bit Patterned Media (BPM)

* http://news.cnet.com/2300-1008_3-6108692.html
**Patterning Process**

![Diagram of the patterning process](http://spie.org/x33843.xml)

1. **Dispense imprint resist by scanning inkjet head**
2. **Position imprint template**
3. **Contact drops of imprint resist**
4. **Liquid resist fills topography as template conforms**
5. **UV illuminate through template to cure resist**
6. **Final imprinted disk after removing the template**

* http://spie.org/x33843.xml

**Bit Patterned Media (BPM)**


Bit Patterned Media (BPM)

HGST demonstrated 10-nm bit patterns using self-organisation and nano-imprint:

Discrete Track Media

Tracks can be confined to reduce noise at bit boundaries:

- Noise reduced
- Pre-patterned servo pattern
- Aligned bits along rotation direction
- Low areal density

* http://www.hgst.com/

* http://www.tdk.co.jp/
Discrete Tracks for BPM

Defined tracks can align patterned bits:

![Image of platter and nano-holes]

Conventional BPM

Discrete tracks for BPM

Fabrication of Discrete Tracks

Discrete tracks are flattened by sputtering and dry etching processes:

![Images of flattened media surface and cross-section of ferromagnetic layer]

* http://www.tdk.co.jp/
**Bit-Error Rate with Discrete Tracks in BPM**

Significant improvement in bit-error rates:

* http://www.hgst.com

**Dual Stage Actuator**

Precise head positioning can be achieved by two-step actuator:

Multi-Actuator Operation

Seagate plans to introduce a new HDD with multi-actuator technology:


Head Suspension Projection

Head suspension technology:

Minimisation of Vibration

Entire HDD is simulated using fluid dynamics modelling:


**Helium-Sealed HDD**

In 2012, HGST introduced a He-sealed HDD to reduce the head-media distance:

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In the diagram, the **Sealed Platform: How It Works** is explained. The gas exchange from Air to Helium reduces mechanical power dissipated in air shear, allowing platters to be placed closer together enabling more capacity. The diagram also highlights a 49% reduction in Watts/TB.

* http://www.hgst.com/
Helium-Sealed HDD

He-sealed HDD can achieve the following features:

- **More Robust**
  - Hermetically sealed HDD is cleaner across broader environments

- **Quieter**
  - Less air resistance → less noise
  - 0.9 dBs lower during idle

- **Same Form Factor**
  - More platters in traditional 1" form factor

**Comparison between air- and He-sealed HDD:**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Air</th>
<th>Helium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Dynamic viscosity (kg/m·s)</td>
<td>1.9608×10⁻⁵</td>
<td>2.0939×10⁻⁵</td>
</tr>
<tr>
<td>Kinematic viscosity (kg/m·s)</td>
<td>1.79947×10⁻⁵</td>
<td>1.3844×10⁻⁴</td>
</tr>
</tbody>
</table>

**Velocity distribution of He-sealed HDD:**

* [Tawinprai et al., IOP Conf. Ser.: Earth Environ. Sci. 113, 012200 (2018)].
HDD and DRAM

Performance Gap between HDD and DRAM

* http://www.theregister.co.uk/2013/06/25/wd_shingles_hamr_roadmap/