Quick Review over the Last Lecture

Optical recording:

- Initial phase
- Written phase
- Writing
- Reading

Laser spot

Written data bits


Magneto-optical recording:


08  Flash Memory

- NOR flash
- NAND flash
- TSV
- Multiple value
- SONOS

Performance Gap between HDD and DRAM

* http://www.theregister.co.uk/2013/06/25/wd_shingles_hamr_roadmap/*
In 1980, Fujio Masuoka invented a NOR-type flash memory:

![Flash Memory Diagram]

**Flash Memory**

**NOR-Flash Writing and Erasing Operation**

**Writing operation:**

**Erasing operation:**

* http://nikunabi-next.yahoo.co.jp/tech/docs/ct_s03600.jsp?p=000500;
** http://www.wikipedia.org/
In 1986, Fujio Masuoka invented a NAND-type flash memory:

* http://www.wikipedia.org/

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**NAND-Flash Writing and Erasing Operation**

**Writing operation:**

- Control gate
- Floating gate
- Source
- Drain
- Potential voltage
- Insulating layer

**Erasing operation:**

- Control gate
- Floating gate
- Source
- Drain
- Ground
- Positive

* http://www.tdk.co.jp/techmag/knowledge/200705/index2.htm
Reading Operation

“0” state:

- Gate Voltage (Low)
- Current
- No electrons have accumulated at floating gate
- Low resistance between source and drain
- Current flows when gate voltage is low

“1” state:

- Gate Voltage (High)
- Current
- Electrons have accumulated at floating gate
- High resistance between source and drain
- Current flows when gate voltage is high

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents05.htm

Cells, Pages and Blocks

Flash memory blocks:

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents06.htm
Flash Memory Integration

NOR or NAND?

Solid State Drive with Flash Memory

Solid state drive (SSD) started to replace HDD:

- pureSi introduced 2.5” 1-TB SDD in 2009:

  ✓ Data transfer speed at 300 MB/s
  ✗ Slow write speed

  For example, a system with a units of 2kB for read / out and 256 kB for erase:

  in order to write 1 bit, the worst case scenario is
  - 128 times read-out
  - 1 time flash erase
  - 128 times re-write

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents04.htm

* http://www.tdk.co.jp/techjournal_e/vol01_ssd/contents02.htm
Fabrication of Flash Memory

* https://www.youtube.com/watch?v=M-wNC3Z3ZX4

HDD vs Flash Memory

Demand for flash memories:

Price of flash memories:

* http://www.manifest-tech.com/ce_products/flash_revolution.htm
Flash Memory Development

Intel flash memories:

- 130 nm (128 MB) in 2003
- 90 nm (512 MB) in 2005
- 50 nm (1 GB) in 2007
- 34 nm (4 GB) in 2009
- 25 nm (8 GB):

  [Image: Flash Memory Diagram]


* https://www.techinsights.com/blog/techinsights-memory-technology-update-iedm18

For Higher Recording Density ...

Through Silicon Vias (TSV):

- Samsung demonstrated 16 GB flash.

  [Image: Samsung TSV Diagram]

Stacked flash:

- Toshiba also demonstrated 16 GB flash.

  [Image: Toshiba TSV Diagram]

* http://www.semiconductorjapan.net/serial/lesson/13.html;

Latest Flash Memory

32 1-TB flash modules:

V-NAND architecture: 16 layers of flash memories to achieve 512Gb


Latest Flash Memory

Grade 3: -40°C ~ 85°C
Grade 2: -40°C ~ 105°C
compatible with 64 layers

* https://car.watch.impress.co.jp/docs/news/1148730.html
Bit Cost vs Recording Capacity

Simple memory stack and BiCS memory:


**Bit Cost Scalable (BiCS)**

BiCS memory design:

Multiple-Valued Flash Memory

Multiple electrons can be stored in the floating gate:

![Diagram showing cell distributions and memory cell read-out threshold](image)

SONOS

Si / SiO₂ / SiN / SiO₂ / poly-Si (SONOS):

By replacing the poly-Si floating gate with SiN, *i.e.*, Si₉N₁₀, unbound dangling bonds can trap more electrons.

![Image of SONOS structure](image)

* http://www.semiconductorjapan.net/serial/lesson/13.html

3-Dimensional Integration with Higher Density

Max Shulaker (MIT) proposed monolithic architecture:

Integration of Functionality

3D monolithic can be advantageous over TSV etc.

* https://sense.mit.edu/people/max-shulaker
## Flash Memory vs DRAM

Comparisons between flash memory and DRAM:

<table>
<thead>
<tr>
<th>Principles</th>
<th>DRAM</th>
<th>Flash memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transistor</td>
<td>Condenser</td>
<td>Tunnel barrier Floating gate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Writing operation</th>
<th>DRAM</th>
<th>Flash memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>Electron charges are stored in the condenser.</td>
<td>On</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data volatility</th>
<th>DRAM</th>
<th>Flash memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage from the condenser.</td>
<td>Electrons cannot tunnel through the barriers.</td>
<td></td>
</tr>
</tbody>
</table>

* http://pc.nikkeibp.co.jp/article/NPC/20061228/257976/

## Flash Memory vs HDD – Configurations

Comparisons between flash memory and HDD:

- **HDD 3.5”**
  - Platters
  - Spindle
  - R/W Head
  - Actuator Arm
  - Actuator Axis
  - Actuator
  - Shock resistant up to 350g/2ms

- **SSD 2.5”**
  - Cache
  - NAND Flash Memory
  - Controller
  - Shock resistant up to 1500g/0.5ms

* https://www.enterprisestorageforum.com/storage-hardware/ssd-vs-hdd.html
## Flash Memory vs HDD - Performance

Comparisons between flash memory and HDD:

<table>
<thead>
<tr>
<th>SSD</th>
<th>HDD</th>
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</thead>
<tbody>
<tr>
<td><strong>Access Times</strong></td>
<td><strong>Energy Savings</strong></td>
</tr>
<tr>
<td>SSDs deliver at least 6000 io/s</td>
<td>SSDs consume between 2 and 5 watts</td>
</tr>
<tr>
<td>SSDs have a failure rate of less than 0.5%</td>
<td>HDDs consume between 6 and 15 watts</td>
</tr>
<tr>
<td>SSDs have an average I/O wait of 1%</td>
<td>SSDs have an average I/O wait of 7%</td>
</tr>
<tr>
<td>The average service time for an I/O request while running a backup remain below 20 ms</td>
<td>The I/O request time with HDDs during backup rises up to 400-500 ms</td>
</tr>
<tr>
<td>SSD backups take about 6 hours</td>
<td>HDD backups take up to 20-24 hours</td>
</tr>
</tbody>
</table>

### Random I/O Performance
- SSDs are at least 15 times faster than HDDs

### Reliability
- This makes SSDs 4-10 times more reliable

### Input/Output Request Times
- SSDs allow for much faster data access

### Backup Rates
- SSDs allow for 3-5 times faster backup for your data

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* [https://www.enterprisestorageforum.com/storage-hardware/ssd-vs-hdd.html](https://www.enterprisestorageforum.com/storage-hardware/ssd-vs-hdd.html)