NAND Flash Memory

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Flash Memory
**Memory Types**

**FLASH**
- High-density
- Low-cost
- High-speed
- High reliability

**EPROM**
- Non-volatile
- High-density
- Ultraviolet light for erasure

**EEPROM**
- Non-volatile
- Lower reliability
- Higher cost
- Lowest density
- Electrically byte-erasable

**DRAM**
- High-density
- Low-cost
- High-speed
- High-power

**ROM**
- High-density
- Reliable
- Low-cost
- Suitable for high production with stable code

Source: Intel Corporation.
Flash Memory Characteristics

- **Erase-before-write**
  - Read
  - Write or Program: $1 \rightarrow 0$
  - Erase: $0 \rightarrow 1$

- **Bulk erase**
  - Program unit:
    - NOR: byte or word
    - NAND: sector or page
  - Erase unit: block
NOR Flash

- Random, direct access interface
- Fast random reads
- Slow erase and write
- Mainly for code storage
- Intel, Spansion, STMicro, ...
NAND Flash

- I/O mapped access
- Smaller cell size
- Lower cost
- Smaller size erase blocks
- Better performance for erase and write
- Mainly for data storage
- Samsung, Toshiba, Hynix, ...
NOR vs. NAND (1)

(*):
Dependant on how memory is used. NOR is typically slow on writes and consumes more power than NAND. NOR is typically fast on reads, which consume less power.

Source: Toshiba
NOR vs. NAND (2)

Mass Storage-NAND

- Memory Cards (mobile computers)
- Solid-State Disk (rugged & reliable storage)
- Digital Camera (still & moving pictures)
- Voice/Audio Recorder (near CD quality)

- **Low Cost** and High Density
- **Good P/E Cycling Endurance**

Code Memory-NOR

- BIOS/Networking (PC/router/hub)
- Telecommunications (switcher)
- Cellular Phone (code & data)
- POS / PDA / PCA (code & data)

- **Fast Random Access**
- **XIP**

Source: Samsung Electronics
NAND Flash Memory
NAND Technology (1)

- Hwang’s law
  - The density of the top-of-the-line flash memory chips will double every 12 months
NAND Technology (2)

- Density growth

Source: Samsung Electronics
NAND Technology (3)

- Cost trends

Source: IEEE Computer, 2011
NAND Flash Architecture

- **2Gb NAND flash device organization**

Source: Micron Technology, Inc.
NAND Flash Types (1)

- **SLC NAND flash**
  - Small block (≤ 1Gb)
  - Large block (≥ 1Gb)

- **MLC NAND flash**
  - 2 bits/cell

- **TLC NAND flash**
  - 3 bits/cell

Source: Micron Technology, Inc.
## NAND Flash Types (2)

<table>
<thead>
<tr>
<th></th>
<th>SLC NAND(^1) (small block)</th>
<th>SLC NAND(^2) (large block)</th>
<th>MLC NAND(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page size (Bytes)</td>
<td>512+16</td>
<td>2,048+64</td>
<td>4,096+128</td>
</tr>
<tr>
<td>Pages / Block</td>
<td>32</td>
<td>64</td>
<td>128</td>
</tr>
<tr>
<td>Block size</td>
<td>16KB</td>
<td>128KB</td>
<td>512KB</td>
</tr>
<tr>
<td>(t_R) (read)</td>
<td>15 μs (max)</td>
<td>20 μs (max)</td>
<td>50 μs (max)</td>
</tr>
<tr>
<td>(t_{PROG}) (program)</td>
<td>200 μs (typ)</td>
<td>200 μs (typ)</td>
<td>600 μs (typ)</td>
</tr>
<tr>
<td></td>
<td>500 μs (max)</td>
<td>700 μs (max)</td>
<td>1,200 μs (max)</td>
</tr>
<tr>
<td>(t_{BERS}) (erase)</td>
<td>2 ms (typ)</td>
<td>1.5 ms (typ)</td>
<td>3 ms (typ)</td>
</tr>
<tr>
<td></td>
<td>3 ms (max)</td>
<td>2 ms (max)</td>
<td></td>
</tr>
<tr>
<td>NOP</td>
<td>1 (main), 2 (spare)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Endurance Cycles</td>
<td>100K</td>
<td>100K</td>
<td>10K</td>
</tr>
<tr>
<td>ECC (per 512Bytes)</td>
<td>1 bit ECC</td>
<td>1 bit ECC</td>
<td>4 bits ECC</td>
</tr>
<tr>
<td></td>
<td>2 bits EDC</td>
<td>2 bits EDC</td>
<td>5 bits EDC</td>
</tr>
</tbody>
</table>

\(^1\) Samsung K9F1208X0C (512Mb)  \(^2\) Samsung K9K8G08U0A (8Gb)  \(^3\) Micron Technology Inc.
NAND Flash Types (3)

- Chip configuration

**Multi-plane**

<table>
<thead>
<tr>
<th>Block 0</th>
<th>Block 4</th>
<th>Block 8</th>
<th>(\cdots)</th>
<th>Block 1</th>
<th>Block 5</th>
<th>Block 9</th>
<th>(\cdots)</th>
<th>Block 2</th>
<th>Block 6</th>
<th>Block 10</th>
<th>(\cdots)</th>
<th>Block 3</th>
<th>Block 7</th>
<th>Block 11</th>
<th>(\cdots)</th>
<th>Block (n-1)</th>
</tr>
</thead>
</table>

**Multi-die**

- Chip Enable 0
- Chip Enable 1

Source: Zeen Info. Tech.
NAND Flash Types (4)

- Samsung OneNAND™

Source: Samsung’s OneNAND ebrochure
NAND Flash Types (5)

- Samsung Flex-OneNAND™

Source: Samsung Fusion Memory
NAND Applications
USB Flash Drives (UFDs)
Flash Cards

- CompactFlash, MMC, SD/miniSD, Memory Stick, xD, ...
Mobile Handset

- UMTS Phone (~2003)
  - WCDMA (UMTS) (2Mbps)
- 3D Game Phone (2004)
- Slim Phone (2005)
- DMB Phone (2006)
- WiBro Phone (2007)
  - Fusion Ubiquitous Mobile Handset? (3D + DMB + WiBro + PMP + ...)

- NOR Flash: CAGR 7%
- NAND Flash: CAGR 88%
- Mobile DRAM: CAGR 56%

(3G Phone, Source: Samsung)
CE Devices

- MP3 players
- PMPs
- PDAs
- Smartphones
- Digital TVs
- Set-top boxes
- Car navigation & entertainment systems
- ...

Hybrid HDDs

- Reduce power consumption
- Faster boot and resume
- Higher reliability

- Support in Windows Vista/7
- Seagate Momentus XT

Add a non-volatile cache

ATA Interface

Seagate Momentus XT
Intel Turbo Memory

- Non-volatile HDD cache
- Mini PC-express memory card

- Supported by
  - Microsoft ReadyBoost
  - Microsoft ReadyDrive
Solid-State Drives (SSDs)

- High performance
  - Sequential read: > 200 MB/s
  - Sequential write: > 150 MB/s

- Reliable and robust: no mechanical parts

- Small, light-weight, low power

- Netbooks, notebooks, desktop & servers
Embedded MMC (e-MMC)

- Samsung MovinAND™