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&lt;sup&gt;1&lt;/sup&gt; (small block)</th>
<th>SLC NAND&lt;sup&gt;2&lt;/sup&gt; (large block)</th>
<th>MLC NAND&lt;sup&gt;3&lt;/sup&gt;</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&lt;sub&gt;R&lt;/sub&gt; (read)</td>
<td>15 μs (max)</td>
<td>20 μs (max)</td>
<td>50 μs (max)</td>
</tr>
<tr>
<td>t&lt;sub&gt;PROG&lt;/sub&gt; (program)</td>
<td>200 μs (typ) 500 μs (max)</td>
<td>200 μs (typ) 700 μs (max)</td>
<td>600 μs (typ) 1,200 μs (max)</td>
</tr>
<tr>
<td>t&lt;sub&gt;BERS&lt;/sub&gt; (erase)</td>
<td>2 ms (typ) 3 ms (max)</td>
<td>1.5 ms (typ) 2 ms (max)</td>
<td>3 ms (typ)</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 2 bits EDC</td>
<td>1 bit ECC 2 bits EDC</td>
<td>4 bits ECC 5 bits EDC</td>
</tr>
</tbody>
</table>

<sup>1</sup> Samsung K9F1208X0C (512Mb)  
<sup>2</sup> Samsung K9K8G08U0A (8Gb)  
<sup>3</sup> Micron Technology Inc.
NAND Flash Types (3)

- Chip configuration

Multi-plane

![Multi-plane diagram]

Multi-die

![Multi-die diagram]

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

- Samsung OneNAND™

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

- Samsung Flex-OneNAND™
NAND Applications
USB Flash Drives (UFDs)
Flash Cards

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

UMTS Phone ~2003

3D Game Phone 2004

Slim Phone 2005

DMB Phone 2006

Wibro Phone 2007

Fusion Ubiquitous Mobile Handset?
(3D + DMB + Wibro + PMP + ...)

WCDMA (UMTS) (2Mbps)

S-DMB (JP)

T-DMB (KR)

HSDPA (KR, JP)

DVB-H (EU)
WiBro (KR)

(MByte/Sys)

108MB 160MB 218MB 310MB 364MB

'04 '05 '06 '07 '08

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
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™
UFS

- Universal Flash Storage
  - Next generation flash storage that provides the low power of eMMC with the high performance of SCSI SSD
  - JEDEC Standard JEDS220