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 → 0
  - Erase: 0 → 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)

Source: Toshiba

(*)
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.
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 $\mu$s (max)</td>
<td>20 $\mu$s (max)</td>
<td>50 $\mu$s (max)</td>
</tr>
<tr>
<td>$t_{\text{PROG}}$ (program)</td>
<td>200 $\mu$s (typ)</td>
<td>200 $\mu$s (typ)</td>
<td>600 $\mu$s (typ)</td>
</tr>
<tr>
<td></td>
<td>500 $\mu$s (max)</td>
<td>700 $\mu$s (max)</td>
<td>1,200 $\mu$s (max)</td>
</tr>
<tr>
<td>$t_{\text{BERS}}$ (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>Block n-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1</td>
<td>Block 5</td>
<td>Block 9</td>
<td>Block n-3</td>
</tr>
<tr>
<td>Block 2</td>
<td>Block 6</td>
<td>Block 10</td>
<td>Block n-2</td>
</tr>
<tr>
<td>Block 3</td>
<td>Block 7</td>
<td>Block 11</td>
<td>Block n-1</td>
</tr>
</tbody>
</table>

- Plane 0
- Plane 1
- Plane 2
- Plane 3

**Multi-die**

- Chip Enable 0
- Chip Enable 1

Die 0 (Chip 0) Die 1 (chip 1)

Multi-die Chip Package

Die 0 Die 1

Multi-die Chip Package

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

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 )

'04  108MB

'05  160MB

'06  218MB

'07  310MB

'08  364MB

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™

Source: Samsung Fusion Memory