# NAND Flash-based Storage

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# Today's Topics

NAND flash memory

Flash Translation Layer (FTL)

OS implications

# Flash Memory Characteristics

Flash memory

- Non-volatile, updateable, high-density
- Low cost, low power consumption, high reliability

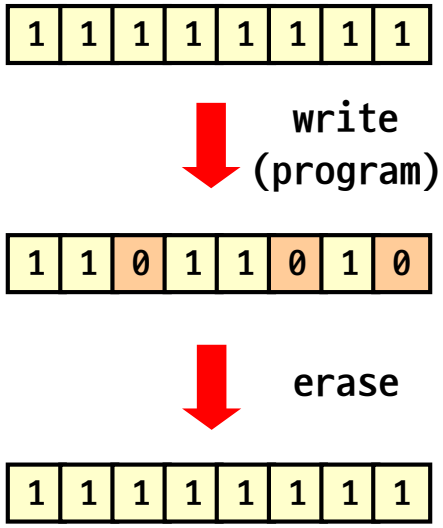
Erase-before-write

- Read
- Write(Program): 1 -> 0
- Erase: 0 -> 1

Read faster than write/erase

Bulk erase

- Erase unit: block
- Program unit: byte or word (NOR), page (NAND)



# NOR Flash

NOR flash

- Random, direct access interface
- Fast random reads
- Slow erase and write
- Mainly for code storage

- Intel, Spansion, STMicro, ...

# NAND Flash

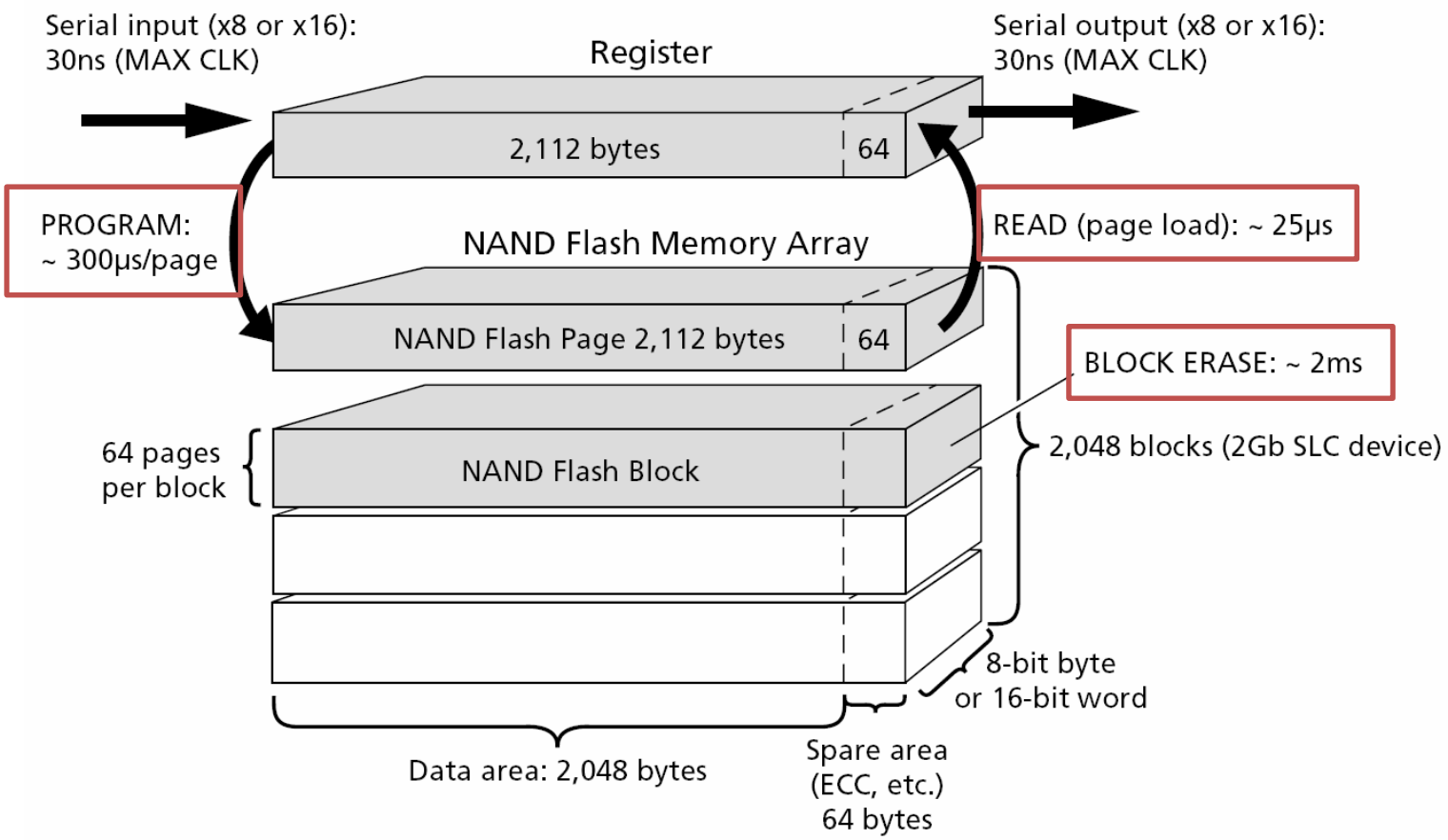
NAND flash

- I/O mapped access
- Smaller cell size
- Lower cost
- Smaller size erase blocks
- Better performance for erase and write(program)
- Mainly for data storage

- Samsung, Toshiba, Hynix, ...

# NAND Flash Architecture

## 2Gb NAND flash device organization




*Source: Micron Technology, Inc.*

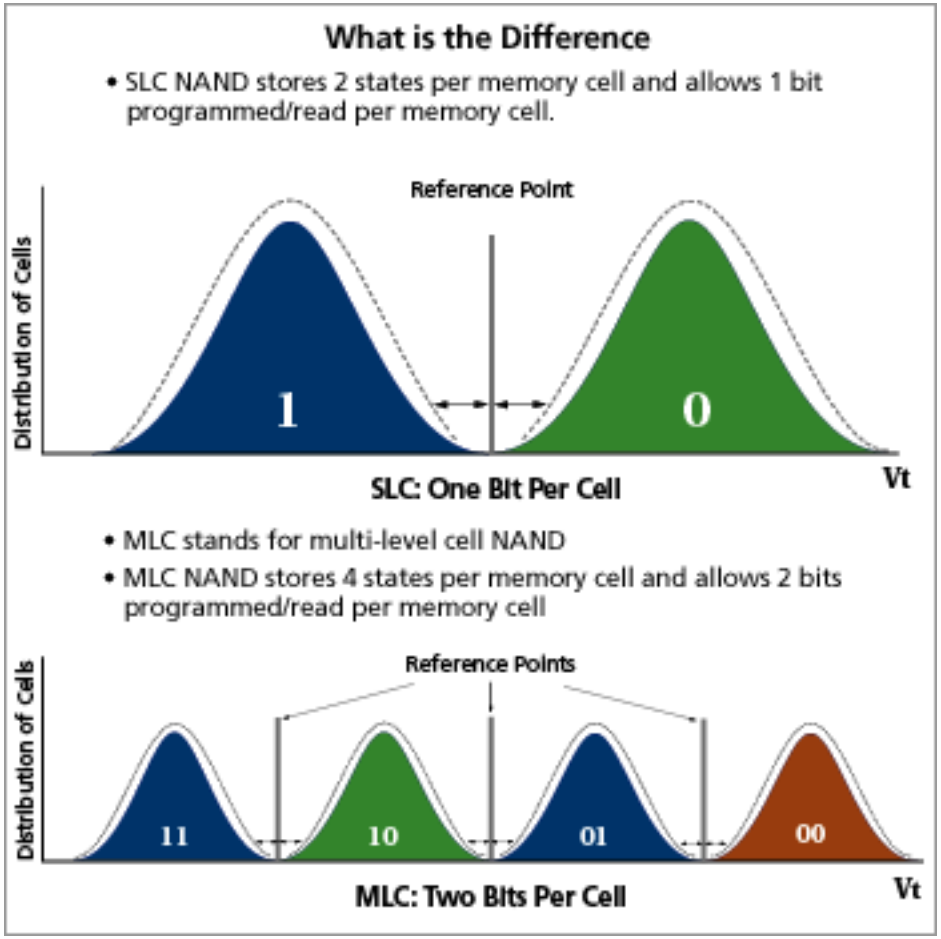
# NAND Flash Types (1)

SLC NAND Flash

- Small block (≤ 1Gb)
- Large block (≥ 1Gb)

MLC NAND Flash

TLC NAND Flash




*Source: Micron Technology, Inc*

# NAND Flash Types (2)

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

*[1] Samsung K9F1208X0C (512Mb)* *[2] Samsung K9K8G08U0A (8Gb)* *[3] Micron Technology Inc.*

# NAND Applications

Universal Flash Drives (UFDs)

Flash cards

- CompactFlash, MMC, SD, Memory stick, …

Embedded devices

- Cell phones, MP3 players, PMPs, PDAs,
  Digital TVs, Set-top boxes, Car navigators, …

Hybrid HDDs

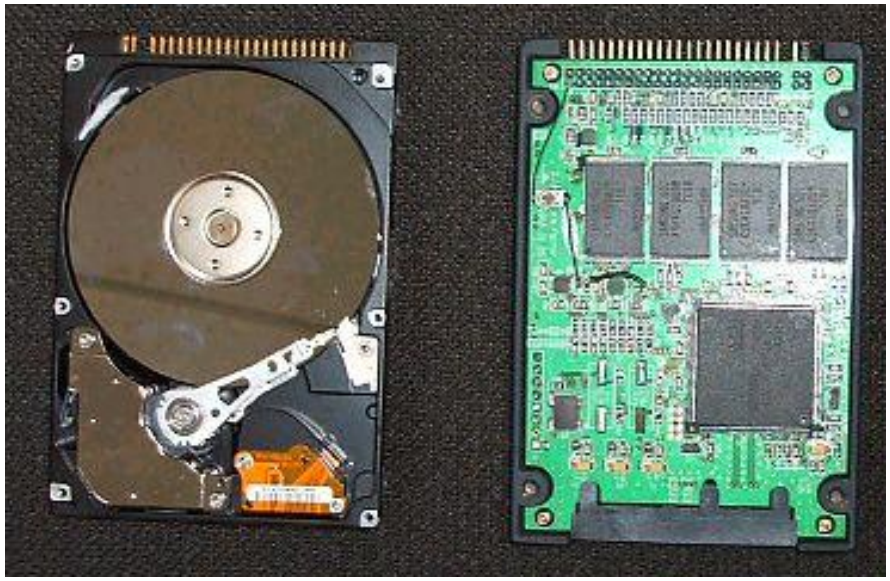
Intel Turbo Memory

SSDs (Solid-State Disks)

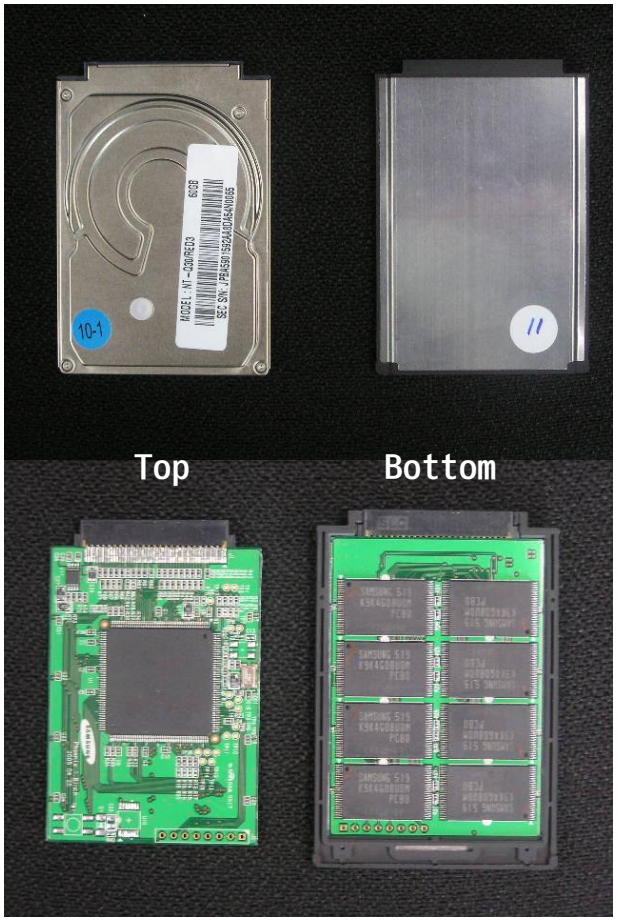

# SSDs (1)

HDDs vs. SSDs

2.5" HDD Flash SSD
(101x70x9.3mm)



1.8" HDD Flash SSD
(78.5x54x4.15mm)



# SSDs (2)

| Feature | SSD (Samsung) | HDD (Seagate) |
|---|---|---|
| Model | MMDOE56G5MXP (PM800) | ST9500420AS (Momentus 7200.4) |
| Capacity | 256GB<br>(16Gb MLC x 128, 8 channels) | 500GB<br>(2 Discs, 4 Heads, 7200RPM) |
| Form factor | 2.5”<br>Weight: 84g | 2.5”<br>Weight: 110g |
| Host interface | Serial ATA-2 (3.0 Gbps)<br>Host transfer rate: 300MB | Serial ATA-2 (3.0 Gbps)<br>Host transfer rate: 300MB |
| Power consumption | Active: 0.26W<br>Idle/Standby/Sleep: 0.15W | Active: 2.1W (Read), 2.2W (Write)<br>Idle: 0.69W, Standby/Sleep: 0.2W |
| Performance | Sequential read: Up to 220 MB/s<br>Sequential write: Up to 185 MB/s | Power-on to ready: 4.5 sec<br>Average latency: 4.17 msec |
| Measured performance[1]<br>(On MacBook Pro,<br>256KB for sequential,<br>4KB for random) | Sequential read: 176.73 MB/s<br>Sequential write: 159.98 MB/s<br>Random read: 10.56 MB/s<br>Random write: 2.93 MB/s | Sequential read: 86.07 MB/s<br>Sequential write: 84.64 MB/s<br>Random read: 0.61 MB/s<br>Random write: 1.28 MB/s |
| Price[2] | 583,770 won | 88,800 won |

[1] *Source: http://forums.macrumors.com/showthread.php?t=658571*

[2] *Source: http://www.danawa.com (As of Nov. 21, 2010)*

# NAND Constraints

Different read/write performance

- Sequential read: Up to 220 MB/s
- Sequential write: Up to 185 MB/s

No in-place update

- Require sector remapping (or address translation)

Bit errors

- Require the use of error correction codes (ECC)

Bad blocks

- Factory-marked & run-time bad blocks
- Require bad block remapping

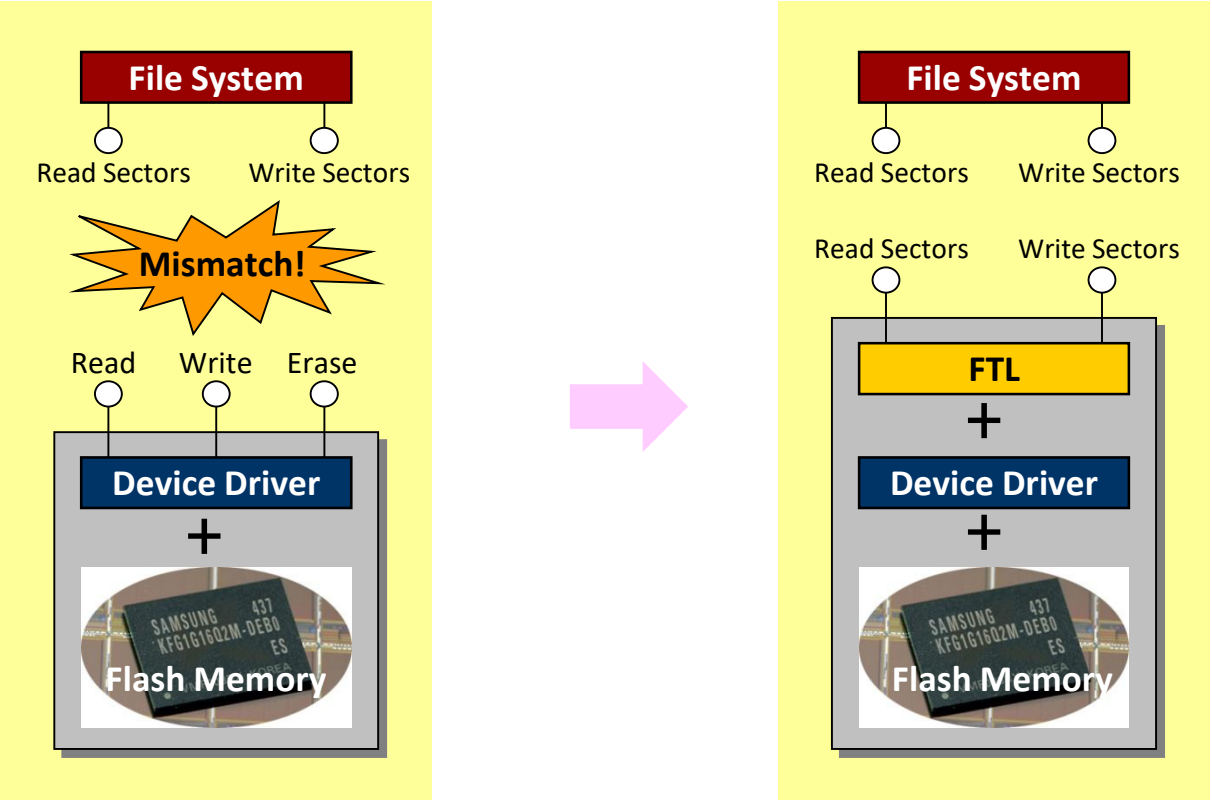
Limited program/erase cycles

- < 100K for SLCs
- < 10K for MLCs
- Require wear-leveling

# FTL (1)

What is FTL?

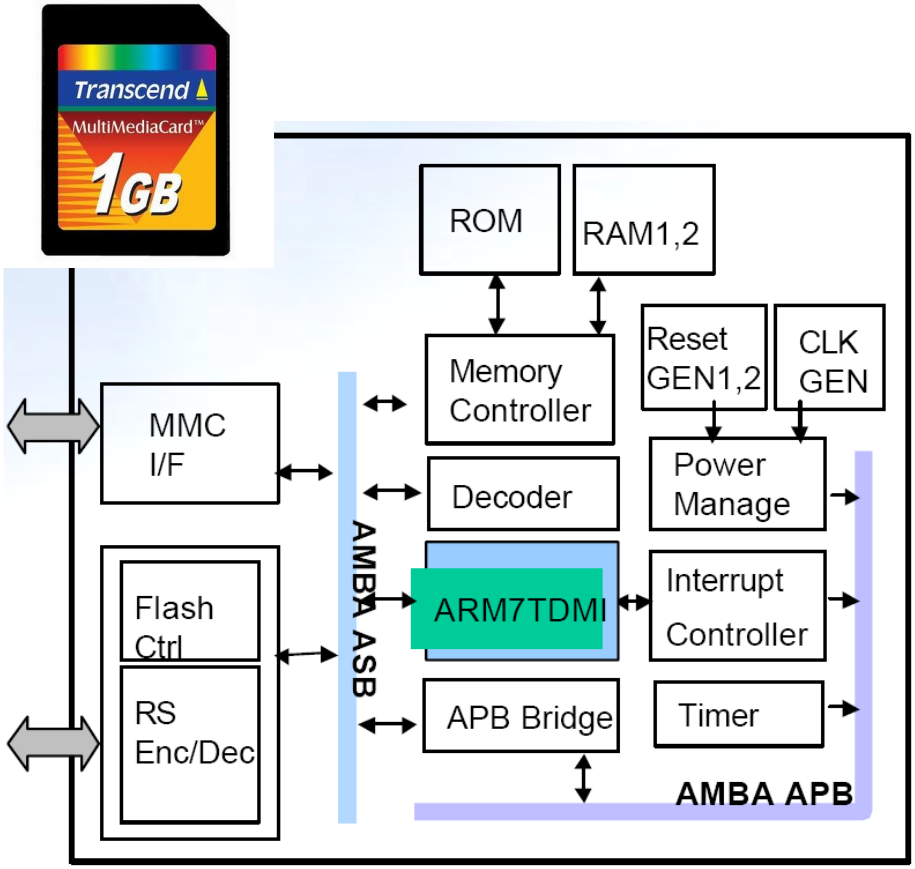
- Flash translation layer
- A software layer to make NAND flash fully emulate traditional block devices (e.g., disks).




*Source: Zeen Info. Tech.*

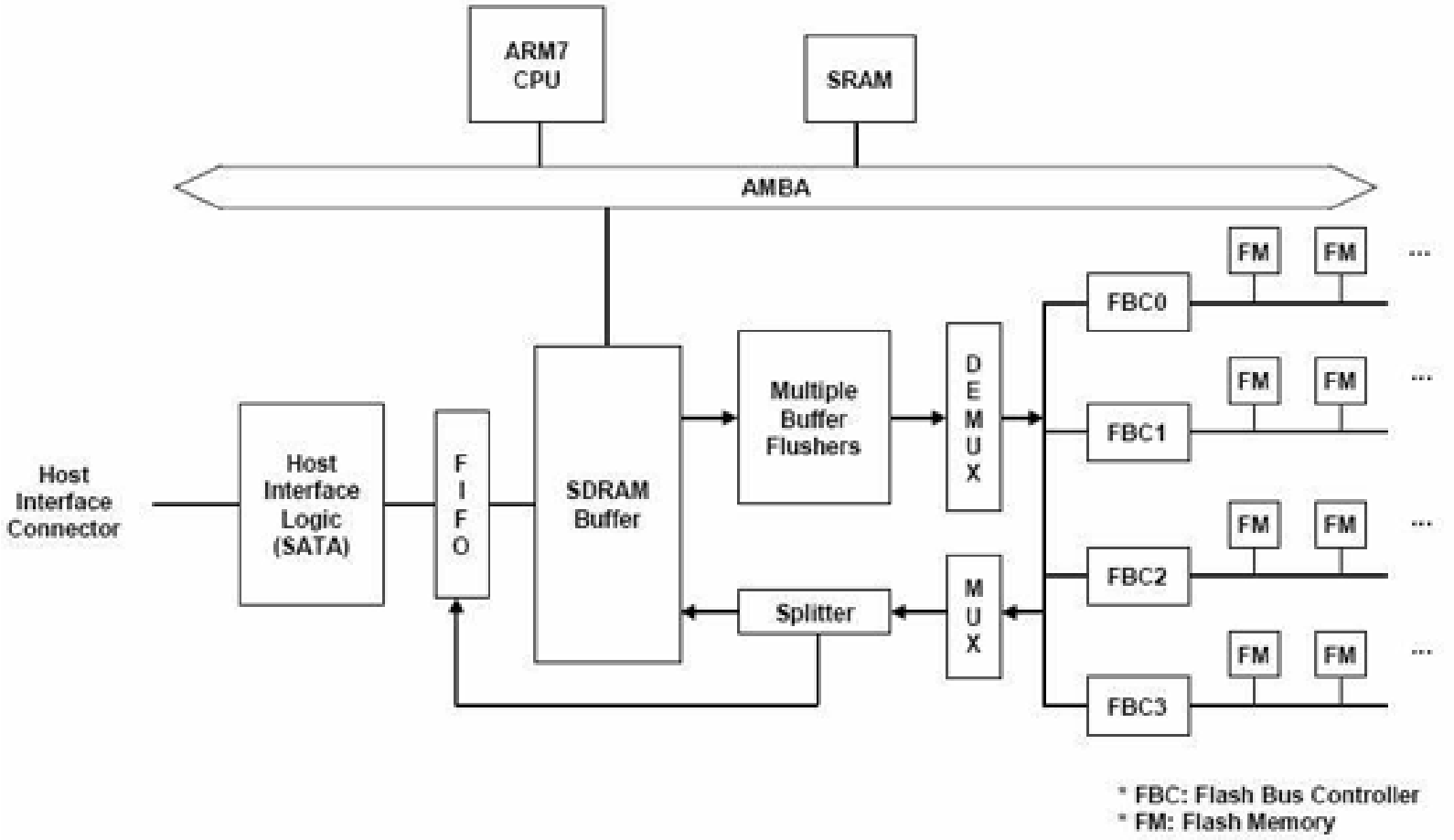
# FTL (2)

## Flash cards internals

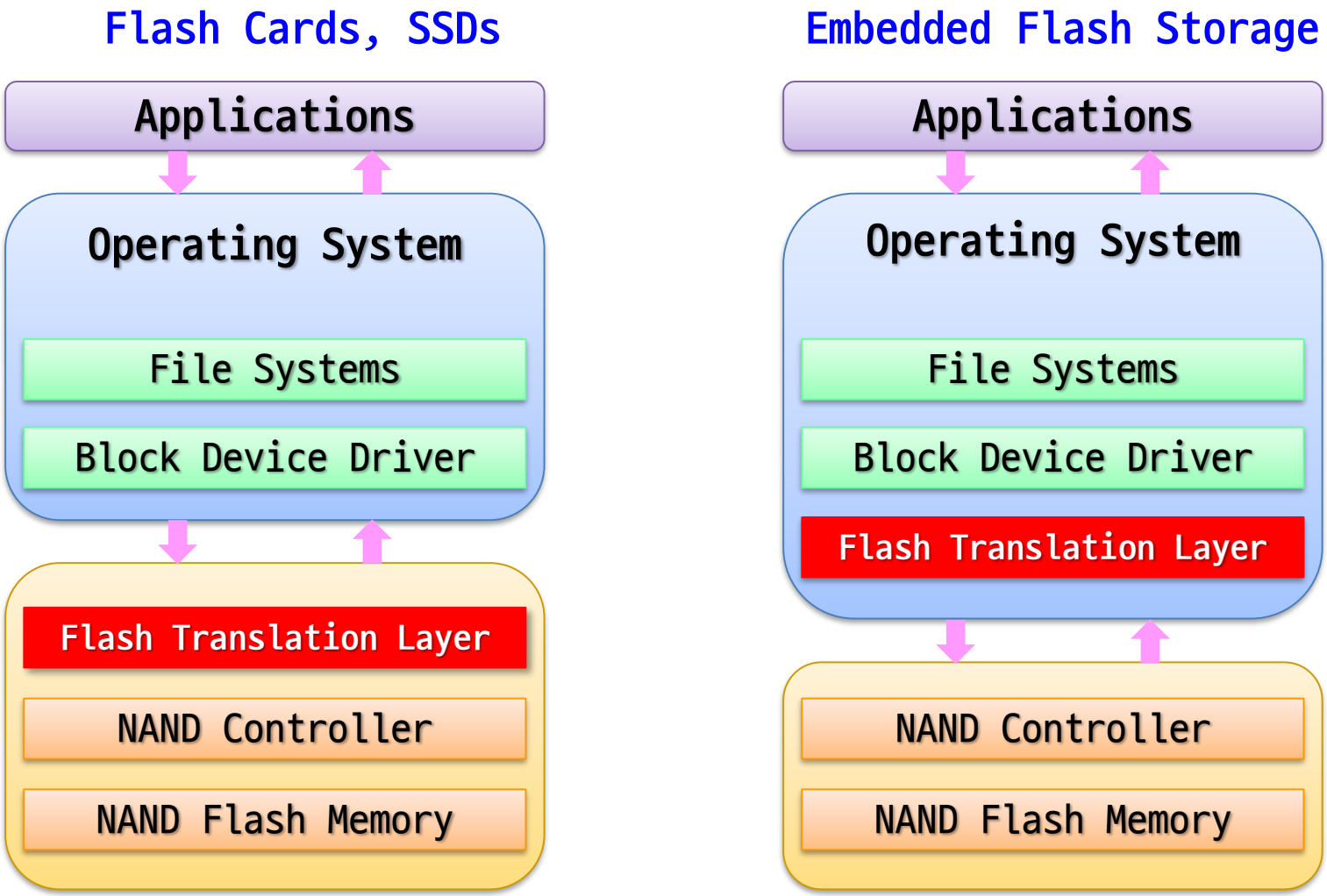
# FTL (3)

SSDs internals




*Source: Mtron Technology*

# FTL (4)


Flash Cards, SSDs
Applications
Operating System
File Systems
Block Device Driver
Flash Translation Layer
NAND Controller
NAND Flash Memory
Embedded Flash Storage
Applications
Operating System
File Systems
Block Device Driver
Flash Translation Layer
NAND Controller
NAND Flash Memory

# FTL (5)

For performance

- Address translation
- Garbage collection
- Hot/cold data identification/separation
- Interleaving over multiple channels & flash chips
- Request scheduling
- Buffer management

# FTL (6)

For reliability

- Bad block management
- Wear-leveling
- Power-off recovery
- Error correction code (ECC)

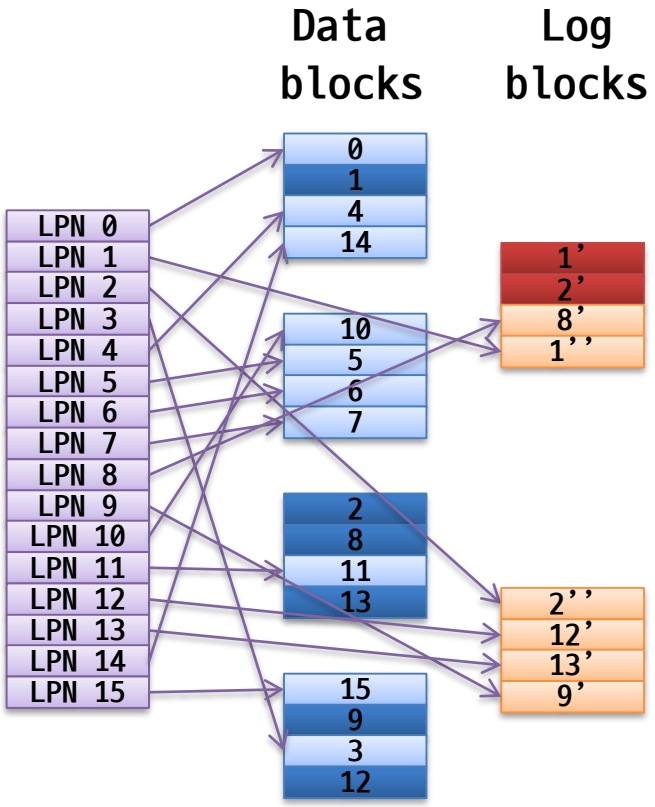
Other features

- Encryption
- Compression
- Deduplication

# Sector Mapping (1)

General page mapping

- Most flexible
- Efficient handling of small writes
- Large memory footprint
  - One mapping entry per page:
    32MB for 32GB MLC (4KB page)
  - Bitmap for page validity
  - Per-block invalid page counter
- Sensitive to the amount of reserved blocks
- Performance affected as the system ages




invalid in data block

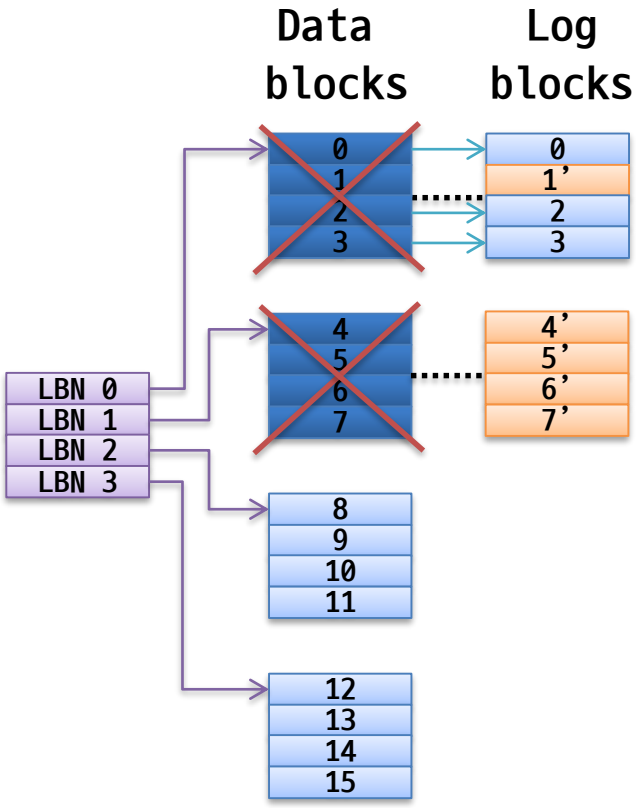
invalid in log block

W = <1, 2, 8, 1, 2, 12, 13, 9>

# Sector Mapping (2)

Naïve block mapping

- Each table entry maps one block
- Small RAM usage
- Inefficient handling of small writes




W = <4, 5, 6, 7, 1>

# OS Implications (1)

NAND flash has different characteristics compared to disks

- No seek time
- Asymmetric read/write access times
- No in-place-update
- Good sequential read/sequential write/random read performance
- But bad random write performance
- Wear-leveling

- Traditional operating systems have been optimized for disks

# OS Implications (2)

SSD support in Microsoft Windows 7

- Turn off "defragmentation" for SSDs
- New "TRIM" command
  - Remove-on-delete
- Align file system partition with SSD layout
- Larger block size proposal (4KB)

# Beauty and the Beast

NAND Flash memory is beauty

- Small, light-weight, robust, low-cost, low-power non-volatile device

NAND Flash memory is a beast

- Much slower program/erase operations
- No in-place-update
- Erase unit > write unit
- Limited lifetime (10K~100K program/erase cycles)
- Bad blocks

Software support for NAND flash memory is very important for performance & reliability

=> FTL is crucial for performance and reliability