Solid State Drives

By: Amar Bhatt and Mateo Diz
Agenda

- Overview
- History
- Technology
- Performance Limitations
- Solutions to Limitations
- Current Applications
- Future Research
Overview

- Solid state drives are the newest solution to fast, high-capacity storage
- Reliable
- One of the fastest growing research fields in the last decade
- Popular choice among laptop and mobile device manufacturers
History

- Used initially to improve boot-time on a machine
- Created as an alternative to solve memory problems caused by moving parts on a Hard Disk Drive
- Increased popularity among mobile device manufacturers
Leaders in manufacturing

- **2003**
  - Samsung controlled 60% of the SSD market in their sole production of SLC-SSD
  - Toshiba controlled 30% of the SSD market in the production of SLC and 2X MLC

- **2008**
  - Samsung controlled 40% of market
  - FlashVision, Hynix, IM Flash
    - Manufacturers for SanDisk, Toshiba, Intel, Micron
Cost Overtime

- As time goes on, SSDs become exponentially cheaper
- 2004 8GB SLC-SSD, $4,000
- 2009 16GB MLC-SSD, $200

How it works

- NAND-Based Architecture
- Bits per cell
  - Single-Level Cell
  - Multi-Level Cell
  - Triple-Level Cell
NAND-Based Architecture

- Cheaper to manufacturer
- Non-volatile memory
- Parallel architecture suitable for storing and executing code (unlike NOR-based architectures)
- Durable, shock-resistant
- Low Power Consumption
Workings of a Flash Cell

- Cell value is obtained by using a test voltage
- Setting a cell
  - Programming Voltage - sets cell to logic 0
  - Erasure Voltage - sets cell to logic 1
  - Higher than test voltage because they need to force electrons over an oxide substrate between two gates
Inside of a Flash Cell

- Floating Gate Transistor
- Bitline connected to Source
- Word line connected to gate
- Voltage on the gate allows for reading a value
- At threshold voltage, gate is used to program/erase a cell

Programming vs. Erasing

Types of SSDs

- Single-Level Cell (SLC)
  - Stores one bit \{0,1\}
  - Expensive to make
  - Fast read times

- Multi-Level Cell (MLC)
  - Stores two bits \{00,01,10,11\}
  - Cheaper to make
  - Most used in retail SSDs
  - Slower read times
Types of SSDs (cont...)

- **MLC-1**
  - Can act as an SLC to trade off capacity for performance

- **Triple-Level Cell (TLC)**
  - Stores three bits \{000,001,010, ..., 110, 111\}
  - Slowest read times
  - Newest to the market
Technology Growth of SSDs

- NAND technology density is exceeding at a faster rate than Moore’s law
- SLC-SSD components are at 64 Gb using stacked monolithic die
- New packaging techniques allow MLC capacities to be between 512 GB - 1 TB
- Closing in on HDD capacity
## Performance

<table>
<thead>
<tr>
<th></th>
<th>Solid State Drive</th>
<th>Hard Disk Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start-up time</strong></td>
<td>few milliseconds</td>
<td>seconds</td>
</tr>
<tr>
<td><strong>Random Access Time</strong></td>
<td>&lt; 0.1 ms</td>
<td>2.9 - 12ms</td>
</tr>
<tr>
<td><strong>Data transfer rates</strong></td>
<td>100 MB/s - 600 MB/s</td>
<td>140 MB/s</td>
</tr>
<tr>
<td><strong>Defragmentation</strong></td>
<td>Not needed</td>
<td>Needed</td>
</tr>
<tr>
<td><strong>Noise (sound)</strong></td>
<td>No moving parts</td>
<td>Moving parts</td>
</tr>
<tr>
<td><strong>Temperature limit</strong></td>
<td>High Temperatures</td>
<td>&lt; 131°F</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>1.8-3.5”</td>
<td>3.5”</td>
</tr>
<tr>
<td><strong>Life Expectancy</strong></td>
<td>Limited based on usage</td>
<td>9 - 11 years</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>2 TB</td>
<td>8 TB</td>
</tr>
</tbody>
</table>
Performance Goals

- Larger Capacity
- Smaller Area
- Better reliability

Is it practical?
Capacity

- As capacity increases, latency and instability increase, read bandwidth decreases
- Unstable around 16TB, stops scaling at ~4.6TB
- By 2024 (when 16TB is achieved)
  - Latency will increase 2.5x
  - SSDs will no longer be a speed advantage
SSDs degrade in performance at smaller sizes

The threshold voltage needed for programming/erasing becomes too close to the reading voltage and degrade the oxide layer

Currently the limit is at 6.5nm silicon
Multiple writes and erases break down the oxide barrier, making it harder to keep a charge.

- MLC endurance is 10,000 erase cycles
- SLC endurance is 100,000 erase cycles
- As usage increases, the endurance decreases
Limitation Solutions

- **Wear-leveling**
  - Spread data evenly across SSD
  - Static wear leveling
    - Operating System, look-up tables, executables
  - Block Erasing Table (BET)
  - Evenness-Aware Algorithm
  - Dual-Pool Algorithm
Error Correction Codes (ECC)
  ○ Trade off between number of bits corrected, controller cost, complexity, and performance
  ○ Limited by how many bytes from NAND architecture are dedicated to ECC
    ■ Usually 16 bits of ECC data for every 512-byte sector
  ○ Properties
Current Applications

- Ultrathin Laptops (MacBook Air)
- Database Transactions
- Fast-Changing Data Platforms
  - Takes advantage of short-term reliability
- High Quality Video Streaming
Future Research

- 3D Memory
- Planar Memory Cells
- SAS Interface
References


