A Closer Look at NAND Flash

Dean Klein
Vice President of Memory System Development
NAND World Dominance
Now, let’s be honest.

It’s not about write cycles. It’s about usage scenarios and choosing the “write” NAND for the application.
Now, let’s be brutally honest.
Micron 34nm, 32Gbit NAND

Approximately 1.6 terabytes of NAND per wafer
Rapid Scaling Driving Early Learning

Isolation

- **2004** 90nm
- **2005** 72nm
- **2006** 50nm
- **2007** 3Xnm
- **2008** 2Xnm
## Comparative Memory Cells

<table>
<thead>
<tr>
<th></th>
<th>Cell Size ($\mu^2$)</th>
<th>Tech Node (nm)</th>
<th>Cell size ($F^2$)</th>
<th>Endurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM/Infineon MRAM</td>
<td>0.74</td>
<td>130</td>
<td>44</td>
<td>Excellent</td>
</tr>
<tr>
<td>Freescale 6T-SRAM</td>
<td>0.69</td>
<td>65</td>
<td>163</td>
<td>Excellent</td>
</tr>
<tr>
<td>Intel 45nm 6T-SRAM</td>
<td>0.27</td>
<td>45</td>
<td>135</td>
<td>Excellent</td>
</tr>
<tr>
<td>Freescale TFS: Nanocrystaline</td>
<td>0.13</td>
<td>90</td>
<td>16</td>
<td>Unknown</td>
</tr>
<tr>
<td>Freescale eDRAM</td>
<td>0.12</td>
<td>65</td>
<td>28</td>
<td>Excellent</td>
</tr>
<tr>
<td>Samsung 512Mbit PRAM Device</td>
<td>0.050</td>
<td>95</td>
<td>5.5</td>
<td>Good</td>
</tr>
<tr>
<td>Micron 40-series DRAM</td>
<td>0.037</td>
<td>78</td>
<td>6</td>
<td>Excellent</td>
</tr>
<tr>
<td>Micron 60-series NAND</td>
<td>0.0046</td>
<td>34</td>
<td>4</td>
<td>Good</td>
</tr>
</tbody>
</table>
Straight Talk: Bits vs. Shrink
2 bits, 4 bits, 6 bits a dollar?
All for NAND, stand up & holler

- Scaled Cell Sizes:
  - 56nm @ 3-bits/cell = 4181nm²/bit
  - 43nm @ 2-bits/cell = 3698nm²/bit
  - 34nm @ 2-bits/cell = 2312nm²/bit
NAND Will Adapt to the Market

Source: iSuppli JAN 08
Getting dialed in on the applications

- Interfaces optimizations
- Process optimizations
- Controller optimizations
- Design optimizations
## NAND Optimizations: ONFI 2.0 HS-NAND

<table>
<thead>
<tr>
<th>Feature</th>
<th>Standard NAND</th>
<th>High Speed NAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Standard” Asynchronous Interface</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Synchronous Interface</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>tRC</td>
<td>( \geq 25\text{ns (SDR)} )</td>
<td>( 7.5\text{ns (DDR)} )</td>
</tr>
<tr>
<td>tWC</td>
<td>( \geq 25\text{ns (SDR)} )</td>
<td>( 7.5\text{ns (DDR)} )</td>
</tr>
<tr>
<td>Standardized</td>
<td>ONFI 1.0</td>
<td>ONFI 2.0</td>
</tr>
<tr>
<td>Scalable to higher performance</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Cache Mode</td>
<td>Some</td>
<td>Yes</td>
</tr>
<tr>
<td>VCCq</td>
<td>3.3V</td>
<td>1.7V to 1.95V</td>
</tr>
<tr>
<td>VCC</td>
<td>3.3V</td>
<td>2.7V to 3.6V</td>
</tr>
<tr>
<td>Parameter Page</td>
<td>Some</td>
<td>Yes</td>
</tr>
<tr>
<td>Package</td>
<td>TSOP</td>
<td>BGA</td>
</tr>
</tbody>
</table>

A natural extension to Standard NAND
## Interface Optimization: Performance Comparison

<table>
<thead>
<tr>
<th></th>
<th>High Speed NAND</th>
<th>Traditional SLC NAND</th>
<th>MLC NAND</th>
<th>MLC NOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Read Performance</strong></td>
<td>200 MB/sec</td>
<td>40 MB/sec</td>
<td>33 MB/sec</td>
<td>103 MB/sec</td>
</tr>
<tr>
<td><strong>Write Performance</strong></td>
<td>100 MB/sec</td>
<td>15 MB/sec</td>
<td>3.5 MB/sec</td>
<td>&lt; 1 MB/sec</td>
</tr>
<tr>
<td><strong>Erase Performance</strong></td>
<td>1.5 ms</td>
<td>1.5 ms</td>
<td>2 ms</td>
<td>900 ms</td>
</tr>
</tbody>
</table>
Solid State Drives
Gartner’s Hype Cycle for PC Technologies 2007

- SSD’s

- Technology Trigger
- Peak of Inflated Expectations
- Trough of Disillusionment
- Slope of Enlightenment
- Plateau of Productivity

Years to mainstream adoption:
- ○ less than 2 years
- ● 2 to 5 years
- ● 5 to 10 years
- ▲ more than 10 years
- ● obsolete

As of July 2007
Gartner’s Hype Cycle for PC Technologies 2008

SSD’s

Technology Trigger

Peak of Inflated Expectations

Trough of Disillusionment

Slope of Enlightenment

Plateau of Productivity

Years to mainstream adoption:

- less than 2 years
- 2 to 5 years
- 5 to 10 years
- more than 10 years
- obsolete before plateau

As of June 2008
SSD Cost Parity?

- 1.8" HDD
- 2.5" HDD
- SSD

$/Gb vs. Year

Why SSD’s?

• Performance
SSD – Performance
The Storage Gap

The CPU - Storage Gap

- CPU
- HDD

1988
2008
### SSDs in Computing

**NAND Flash Closes the Latency Gap**

<table>
<thead>
<tr>
<th></th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Latency</td>
<td>Relative Cost/bit</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>L1 Cache</td>
</tr>
<tr>
<td>2.5</td>
<td>L2 Cache</td>
</tr>
<tr>
<td>1,200</td>
<td>DRAM</td>
</tr>
<tr>
<td>25,000</td>
<td>SSD</td>
</tr>
</tbody>
</table>

Cost/bit Data as of November 2007
Why SSD’s?

• Performance
• Power
SSD – Energy
A recent editorial review highlighted that power consumption increases when solid state drives are used in today’s notebook computers.
Notebooks: SSD’s *Can* Improve Battery Life

A recent editorial review highlighted that power consumption **decreases** when solid state drives are used in today’s notebook computers.
Notebooks: SSD’s *Can* Improve Battery Life

- **Requirements:**
  - A well-designed SSD
    - Efficient Wear Management Algorithms
    - An Efficient Controller
  - Notebook Optimizations for SSD’s
  - Operating System Improvements
    - New SATA commands: ID and Trim
    - Disable Defrag
SSD: Power and Performance

SSDs do more with less power

Power Profile

Watts

Time

HDD
SSD
Why SSD’s?

- Performance
- Power
- Reliability
SSD – Reliability
Cost of Ownership Analysis from SSDs in Notebooks

Notebooks at Micron: 2000 units
Avg lifespan of notebook: 36 months

% of employees w/notebook that would benefit from an SSD: 75%

IT hours to repair HDD failure: 5 hours
IT hours to recover from HDD fatal error: 5 hours

HDDs with fatal error per annum: 15 units

Number of hours employee is idle as a result of HDD repair: 5 hours

Higher Reliability $208,300
Increased User Productivity $415,775
Increased Battery Efficiency $151,260
Additional Cost for SSDs $300,000

= $475,335 net savings
SSD’s are not just for Notebooks

- Industrial Applications
- VOD and IPTV
- Enterprise
HDD & SSD in the Enterprise Server Market
HDD & SSD in the Enterprise Server Market

SSD Drive
High-performance SSDs do more using less space and less power.

<table>
<thead>
<tr>
<th>Power</th>
<th>Capacity</th>
<th>IOPS</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD</td>
<td>SSD</td>
<td>HDD</td>
<td>SSD</td>
</tr>
</tbody>
</table>

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Making SSD’s Enterprise-Ready

• Performance
• Power
• Reliability
• Endurance
Endurance: Wear Leveling
“The brightest flashes in the world of thought are incomplete until they have been proved to have their counterparts in the world of fact.”

— John Tyndall, Scientific Materialism
NAND: by far the most exciting technology you will ever see

aNANDconvenienttruth

NAND: A NON-REVOLVING Revolution

NAND: now playing in select systems