Why People Use Solid State Storage

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Tom Coughlin, President, Coughlin Associates is a widely respected digital storage analyst as well as business and technology consultant. He has over 37 years in the data storage industry with multiple engineering and management positions at high profile companies.

Dr. Coughlin has many publications and six patents to his credit. Tom publishes the *Digital Storage Technology Newsletter*, the *Media and Entertainment Storage Report*, the *Emerging Non-Volatile Memory Report* and other industry reports. Tom is also a regular contributor on digital storage for Forbes.com and other blogs.

Tom is the founder and organizer of the Annual Storage Visions Conference (www.storagevisions.com), a partner to the International Consumer Electronics Show, as well as the Creative Storage Conference (www.creativestorage.org). He has been the general chairman of the annual Flash Memory Summit, the world’s largest independent storage event. He is a Senior member of the IEEE and a member of the Consultants Network of Silicon Valley (CNSV). For more information on Tom Coughlin and his publications go to www.tomcoughlin.com.
Outline

• Storage Drivers, Touch Rate and Projections
• How Many IOPS are Enough?
• Non-Volatile Memory Trends
• Solid State Drive Advances
• Storage Fabrics and Memory Centric Computing
• Why Do People Use Solid State Storage?

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Storage Drivers and Touch Rate
Drivers for Storage and Memory

• Increasing storage demands—IDC 163 Zetabytes of data created by 2025 (16 ZB in 2016)
• New sources for unstructured data from media and entertainment, IoT, medicine, geo-science and big data
• Growth in local storage, storage at the edge (or the fog) and storage in large data centers (the cloud)
• There is a need for fast memory and storage to support processing and accessing this data and cheap storage to keep it for the long term

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Touch rate versus response time indicating various types of uses
Digital storage technologies regions overlaid on the Touch Rate/Response Time chart
HDD-Flash tiering/caching touch rate chart
Digital Storage Capacity Projections

- The growth and processing of data will lead to the use of many types of digital storage
- SSDs will dominate for high performance storage and higher total revenue
- HDDs will be high capacity and used for colder storage
- Magnetic tape will be used by some organizations for the lowest cost (currently <1 cent/GB)
How Many IOPS are Enough?
Our Survey
(Objective Analysis and Coughlin Associates)

• Ongoing. Take our survey at: http://TinyURL.com/IOPSsurvey

• IT participants participating
• Asks for IOPS, capacity and latency needs
  • Also their primary applications

• Some results are in a SNIA SSSI white paper
• We compared results from 2012 to those in the last few years (in 2016)
Applications: 2012

- Databases, 40%
- OLTP, 24%
- Cloud storage or services, 11%
- Scientific or Engineering, 10%
- Video Creation or Distribution, 7%
- Archiving and backup, 4%
- Mail server and mail storage, 4%
Applications: 2016

- Databases, 45%
- OLTP, 16%
- Cloud storage or services, 7%
- Video Creation or Distribution, 6%
- Scientific or Engineering, 6%
- Mail server and mail storage, 4%
- Archiving and backup, 9%
IOPS Required for Dominant Application

37% increase in median IOPS required

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Capacity Required

17% increase in mean capacity required

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Other Hardware IOPS Bottleneck

36% increase in bottleneck IOPS

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Fastest Latency the System Can Use

73% decrease in mean latency
IOPS by Form Factor

- HDD
- SATA/SAS
- NVMe/PCIe
- Memory Channel

10^2  10^3  10^4  10^5  10^6  10^7
Non-Volatile Memory Trends
iNEMI Solid State Memory Trends

• **Flash**
  - Scaling Limits lead to conversion from planar to 3D.
  - Market moving from displacement (i.e. photographic film) to new applications (SSDs in PC and servers)

• **MRAM**
  - Evolution of Next Generation to spin torque switching
  - Growth of Applications
  - New players, partnerships and Everspin IPO

• **Phase Change**
  - Newly-defined application creates 3D Xpoint

• **RRAM**
  - Some positioning as competing against 3D XPoint
  - Otherwise viewed as an eventual NAND replacement
<table>
<thead>
<tr>
<th>Year</th>
<th>SLC/MLC</th>
<th>Planar Process</th>
<th>3D Layers</th>
<th>3D Process</th>
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<tbody>
<tr>
<td>2013</td>
<td>64G/128G</td>
<td>18nm</td>
<td>16-32</td>
<td>64nm</td>
</tr>
<tr>
<td>2015</td>
<td>128G/256G</td>
<td>15nm</td>
<td>16-32</td>
<td>54nm</td>
</tr>
<tr>
<td>2017</td>
<td>256G/512G</td>
<td>13nm</td>
<td>32-64</td>
<td>45nm</td>
</tr>
<tr>
<td>2019</td>
<td>512G/1T</td>
<td>11nm</td>
<td>48-96</td>
<td>30nm</td>
</tr>
<tr>
<td>2021</td>
<td>9nm</td>
<td>8nm</td>
<td>64-128</td>
<td>28nm</td>
</tr>
<tr>
<td>2023</td>
<td>8nm</td>
<td>8nm</td>
<td>96-192</td>
<td>27nm</td>
</tr>
<tr>
<td>2025</td>
<td>8nm</td>
<td>8nm</td>
<td>192-384</td>
<td>25nm</td>
</tr>
<tr>
<td>2028</td>
<td>8nm</td>
<td>8nm</td>
<td>192-384</td>
<td>22nm</td>
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</table>

Source: ITRS, 2013

Figure 4. Cross-Section of planar floating-gate flash memory cell
Left: Reading, Middle: Programming, Right: Erasing
(Source: Samsung Semiconductor Company)
### Table 6. Attributes of Different Memory Technologies

<table>
<thead>
<tr>
<th>Attribute</th>
<th>SRAM</th>
<th>DRAM</th>
<th>Flash</th>
<th>FRAM</th>
<th>MRAM</th>
<th>ReRAM</th>
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<tbody>
<tr>
<td>Read Speed</td>
<td>Fast</td>
<td>Medium</td>
<td>Medium</td>
<td>Fast</td>
<td>Fast</td>
<td>Medium</td>
</tr>
<tr>
<td>Write Speed</td>
<td>Fast</td>
<td>Medium</td>
<td>Slow</td>
<td>Fast</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Array Efficiency</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Scalability</td>
<td>Good</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>Cell Density</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Volatile?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Endurance</td>
<td>Infinite</td>
<td>Infinite</td>
<td>Limited</td>
<td>Limited</td>
<td>Infinite</td>
<td>Limited</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>Low/High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Low-Voltage</td>
<td>Yes</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Process Complexity</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Complex</td>
<td>Medium</td>
</tr>
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</table>

(Source: Objective Analysis)
# MRAM Roadmap

<table>
<thead>
<tr>
<th>Metric</th>
<th>2013</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2023</th>
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<tr>
<td>density (Mbit)</td>
<td>16</td>
<td>64</td>
<td>256</td>
<td>1024</td>
<td>4064</td>
</tr>
<tr>
<td>technology</td>
<td>toggle</td>
<td>STT, in-plane</td>
<td>STT, in-plane</td>
<td>STT, perpendicular</td>
<td>STT, perpendicular</td>
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<tr>
<td>die size (cm²)</td>
<td>0.58</td>
<td>0.58</td>
<td>0.58</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>density (Mbit/cm²)</td>
<td>28</td>
<td>110</td>
<td>441</td>
<td>1138</td>
<td>4064</td>
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<tr>
<td>array efficiency</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>array element size (μm²)</td>
<td>1.577</td>
<td>0.394</td>
<td>0.099</td>
<td>0.059</td>
<td>0.018</td>
</tr>
<tr>
<td>cell efficiency (F^2)</td>
<td>38</td>
<td>22</td>
<td>22</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>required litho resolution (nm)</td>
<td>102</td>
<td>67</td>
<td>33</td>
<td>29</td>
<td>17</td>
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<tr>
<td>wafer size (mm)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>450</td>
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<tr>
<td>dice/wafer</td>
<td>2316</td>
<td>2316</td>
<td>2316</td>
<td>1492</td>
<td>3022</td>
</tr>
<tr>
<td>wafer cost ($)</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>4000</td>
</tr>
<tr>
<td>est. production cost/die ($)</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
<td>2.01</td>
<td>1.32</td>
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<tr>
<td>est. production cost/Gbit ($)</td>
<td>46.96</td>
<td>11.74</td>
<td>2.94</td>
<td>1.77</td>
<td>0.33</td>
</tr>
</tbody>
</table>

## Performance

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write / read time (ns)</td>
<td>25</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Data rate (write or read limit) (MHz)</td>
<td>150</td>
<td>400</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Energy to write 1 bit (picojoule)</td>
<td>200</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Energy to read 1 bit (picojoule)</td>
<td>100</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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Solid State Drive Advances
From the 2017 Flash Memory Summit
The move to Non-Volatile Storage

• NVMe PCIe-based storage interfaces avoid much of the overhead of hard disk drives—designed for fast solid state storage

• 2D to 3D manufacturing transition is underway with 3D yields improving and achieving cost parity with 2D by 2018

• 3D flash fab investments are over $10 B US per plant-many being build—now at 96 layers

• Shortage of flash memory throughout 2017 and into 2018 is due to yield issues with the 3D flash transition
3D Flash

- Shipments up to 64 layer—common by end of year
- Announcements up to 96 layers—1 Tb per die
- Technology projections of hundreds of layers
- Announced quad-level cells for higher density
Introducing the 9200 NVMe™ SSD
Where Capacity Meets Tenacity

High-performance NVMe SSD; designed for data ingest, OLTP, caching

First mainstream, Micron NVMe SSD to deliver greater than 10TB

The 11TB 9200 ECO SSD is 45% faster than a competing NVMe SSD

Be Revolutionary. Be SOLID.
Intel Dual Port NVMe SSDs
1U Form Factor NVMe SSDs
New technologies

Fastest & highest capacity SSD
64TB NVMe SSD
Over 13,000 MB/s of throughput

Seagate Nytro Q-Boost™ features

IO Determinism

Nytro Q-Boost Demo

Multi-Stream

Nytro Q-Boost Demo

- 7x reduced average read latency
- 16x reduced max read latency
- 4x improved WAF & NAND endurance
- 3x Faster performance
Samsung’s 128 TB SSD

• Samsung’s latest V-NAND chip is a 1Tb V-NAND chip, available next year.
• This will enable 2TB of memory in a single V-NAND package by stacking 16 1Tb dies
• Using 32-die stack of 1 Tb QLC NAND the company was showing a 2.5” form factor 128 TB SSD.
Samsung Z-NAND

• Samsung introduced its Z-SSD technology at FMS 2016.
• In 2017, its first product, the SZ98 Z-SSD (15 microseconds of read latency)
• The Z-SSD is intended for data centers and enterprise systems dealing with extremely large, data-intensive tasks
• Samsung says that at the application level, the use of Samsung’s Z-SSDs can reduce system response time by up to 12 times, compared to using NVMe SSDs.
Key Value SSD

• Samsung introduced a Key Value SSD. KVS is a way to organize data in storage for more rapid access that is commonly used in object storage systems.

• Samsung’s Key Value assigns a ‘key’ or specific location to each “value,” or piece of object data – regardless of its size, enabling direct addressing of a data location.

• Samsung’s Key Value technology enables SSDs to scale-up (vertically) and scale-out (horizontally) in performance and capacity.

When data is read or written, a Key Value SSD can reduce redundant steps, which leads to faster data inputs and outputs, as well as increasing TCO and significantly extending the life of an SSD.
More Generations of V-NAND

• Samsung was presented their V-NAND roadmap showing—at least 5 more generations of V-NAND beyond their announced 5th generation.

• These higher capacity products will leverage three technological developments.

• These include continued vertical stacks (more 3D layers), lateral shrink (smaller features) and cell over peripheral (building the cell layers over the supporting CMOS logic).
Storage Fabrics and Memory Centric Computing
Insistence on Data Persistence
Bringing Memory & Storage Closer to Compute

Cost

Latency

Nanoseconds

Performance Optimized Persistent Memory
NVDIMM-N (DRAM/NAND) 35ns
RDIMM/LRDIMM (DRAM) 35ns
3D XPoint™ 100ns

Microseconds

NVMe™ SSD (NAND) 100µs
SATA/SAS SSD (NAND) 100µs

Milliseconds

10K SAS HDD (Spinning Media) 2.9ms
NVMe over Fabric

• Mellanox announced their BlueField SoC for accelerating NVMe over Fabrics (200 Gb/s of throughput and more than 10 million IOPS in a single SoC device)

• A French company, Kalray said that it has released a high-performance NVMe-oF target controller for enabling NVMe-based (JBOF) array boxes.
MRAM and PRAM

**MRAM**
- Everspin shipped over 70 M MRAM Chips. Company has partnership with Global Foundries, who is building 300 mm wafers and targeting embedded memory applications
- Samsung—plans to ship STT MRAM product samples by 2018.
- Seagate was showing an Everspin MRAM boot SSD at the 2017 FMS

**PRAM**
- Intel says their Optane NVMe products will ship this year.
- Micron planning to introduce DIMM-based 3D XPoint product
PM Needs New Software

• Move away from “Storage vs. Memory” approach
  • Store at the byte level, not blocks
  • Avoid the storage stack
  • Avoid things like flash translation
The SNIA Persistent Memory Programming Model

• [https://www.snia.org/PM](https://www.snia.org/PM)
Memory-centric Computing

For many emerging challenges, memory capacity, memory access latency and memory bandwidth are more constrained than compute resources

- Memory Disaggregation
  Remove memory from behind the processor

- Memory Pooling & Sharing
  Enable efficient use of memory. Address new class of problems with large memory footprint

- Heterogeneous Compute
  Enable multi-vendor heterogeneous compute (e.g. ML accelerators)
Why People use Solid State Storage?

• It is robust—so good in mobile consumer devices
• It is fast—so people like it in some enterprise applications and client computers
• NVMe and NVMe-oF allow building storage devices and network storage without restrictions from HDD interfaces
• The groundwork is being laid for memory centric computing
• There will be many types of storage technology used for several more years
Dr. Tom Coughlin is a highly respected technology and market analyst and author and the Founder and Chairman of the Storage Visions Conference.

Storage Growth!

16ZB → 163ZB

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- Video (M&E and Surveillance)
- Medical and Genomic Data
- Cloud and Fog Computing Solutions
- In Memory Processing
- Exabyte Video Projects
- Artificial Intelligence
- Internet of Things
- Big Science
- New Memory/Storage
- Hyperscale
- Gb/s Cars

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• Touch Rate: A metric for analyzing storage system performance, Steven Heltzer and Tom Coughlin, 2015, http://www.tomcoughlin.com/techpapers.htm