iNEMI Mass Data Storage Roadmap

Outline

iNEMI Overview
Roadmap Process
Mass Data Storage Roadmap
Executive Summary

Solid State
Magnetic
Hard Disk Drive (HDD)
Tape
Optical
Storage Systems
**iNEMI Overview**

**International Electronics Manufacturing Initiative**

>60 member companies WW

**Mission:**
**To forecast and accelerate improvements in the electronics manufacturing industry for a sustainable future.**

**Technical Activities**

- Product Emulator Groups (PEG’S)
- Technical Working Groups (TWG’s)
- Technology Implementation Groups (TIG’s)
iNEMI - 2010 Roadmaps

Technical Working Groups (TWG)

- Manufacturing Technologies
- Board Assembly
- Final Assembly
- Test, Inspection & Measurement
- Component / Subsystem Technologies
- Electronic Connectors
- Energy Storage & Conversion Systems
- Interconnect Substrates – Ceramic
- Interconnect PCB - Organic
- Large-Area Flexible Electronics

**Mass Data Storage**

- MEMS / Sensors
- Optoelectronics
- Packaging & Component Substrates
- Passive Components
- Photovoltaics
- RF Components & Subsystems
- Semiconductor Technology
- Solid State Illumination
- Business Processes / Technologies
- Information Management
- Design Technologies
- Environmentally Conscious Electronics
- Modeling, Simulation & Design Tools
- Thermal Management

Product Emulator Groups (PEG)

- Aerospace / Defense
- Automotive
- Consumer / Portable
- Medical
- Netcom (Network/Datacom / Telecom)
- Office / Large Business Systems

Technical Implementation Groups (TIG)

- Board Assembly
- Board & System Mfg. Test
- Environmentally Conscious Mfg.
- Medical
- Optoelectronics
- Organic Packaging
- Organic PCB

CD-ROM with all Roadmaps
May be ordered from iNEMI.org
- $250 (NA)
- $325 (outside NA)
Mass Data Storage

2010 Contributors

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Executive Summary

Solid State
- NAND Flash Memory: Growing in importance, but will not displace HDD
- MRAM: now established, volumes may grow with ST or Thermal Switching
- Phase change yet to emerge in high volumes

Magnetic
- HDD is largest volume, continued growth expected, but rate may slow.
- Tape still plays vital archival backup role, helped by LTO standard

Optical
- Primary niche is in data transfer applications
- Holographic storage too expensive to succeed in marketplace.

Storage Systems
- Architected for cost rather than performance. Power & performance issues may enable viability of SSDs in some enterprise applications.
NAND Flash

- Playing a growing niche role in storage hierarchy
- Displaced SFF HDD’s in MP3/camera/phones
- Complementary to HDD in many applications
- Enabled the emergence of SSD & Hybrid HDD
- Multi-level packaging now broadly used
- Price decline faster than Moore’s law
  - Multi-bit cell technology improvements expected to continue
- Technology may eventually reach its scaling limits
Cross-Section of floating-gate flash memory cell

Reading

Programming

Erasing

(Source: Samsung Semiconductor Company)
## iNEMI Mass Data Storage

### NAND flash chip roadmap

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2011</th>
<th>2013</th>
<th>2016</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum Feature Size</strong></td>
<td>38nm</td>
<td>28nm</td>
<td>23nm</td>
<td>16nm</td>
<td>8.9nm</td>
</tr>
<tr>
<td><strong>Price/GB ($/GB)</strong></td>
<td>$1.16</td>
<td>$0.61</td>
<td>$0.38</td>
<td>$0.17</td>
<td>$0.052</td>
</tr>
<tr>
<td></td>
<td>@ $15/in²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average chip density</strong></td>
<td>16Gb</td>
<td>16Gb</td>
<td>32Gb</td>
<td>64Gb</td>
<td>256Gb</td>
</tr>
</tbody>
</table>

* The $15/in² number is lower than that used in the 2009 iNEMI roadmap and is more reflective of actual manufacturing costs.

(Source: ITRS Roadmap/Objective Analysis)
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Additional Solid State Memory Technologies

- Ferroelectric RAM (FRAM or FeRAM)
  - Utilizes Perovskite crystal state change
- In marketplace > 20 yrs
- Suppliers include Ramtron, Fujitsu
- Applications: Fare cards, power meters, gaming systems, military
- Die size & mfg. cost disadvantages may be soluble
- Phase Change (PCM, PCRAM, or PRAM)
  - Utilizes Chalcogenide materials for amorph/x’tal change
  - may be scalable to 5 nm
  - being sampled for some applications
  - Numerous companies involved: Intel, Micron/Numonyx, Samsung, ST Micro, etc.
- Technology first shipped in 2006
  - Mfr’s are selling all they produce
  - Storage capacity not large, but robust in harsh environments
- A niche product
  - Requires BEOL processing
  - High Cost/Price
## Attributes of Different Memory Technologies

<table>
<thead>
<tr>
<th></th>
<th>SRAM</th>
<th>DRAM</th>
<th>Flash</th>
<th>FRAM</th>
<th>MRAM</th>
<th>PCM</th>
</tr>
</thead>
<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/Low</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>Medium</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>
</tr>
<tr>
<td>Low-Voltage</td>
<td>Yes</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Complexity</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Complex</td>
<td>Medium</td>
</tr>
</tbody>
</table>

(Source: Objective Analysis)
- HDD demand remains strong, ~650-660 M units in 2010 (563 M in 2009)
  - projected market >1B units by 2013 or 2014
  - first 1TB HDD shipped in 2007
  - 3 TB HDDs shipping today
- Volumes dominated by Desktop and Mobile segments
  - Mobile projected for highest growth
- Strong trend towards vertical integration of HDD mfr’s.
  may lead to further consolidation of suppliers
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Shipped HDD Volumes vs. Time, by Application

(Source: Coughlin Associates)
HDD Technology Advances

- Perpendicular recording & TMR head technology now shipping from all mfr’s
- Areal density will grow towards 1Tb/sq ft & push lithography limits
  - Discrete Track Recording (DTR), Bit Patterned Media (BPR), Piezo/MEMS based actuators, Heat Assisted Magnetic Recording (HAMR), CPP GMR Heads, Advanced Signal Processing
- Full disk encrypted drives improved security
- Shingled Recording & Heat Assisted Magnetic Recording may also enable areal density growth
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Form Factor</td>
<td>inches</td>
<td>3.5, 2.5, 1.8, 1.3, 1.0</td>
<td>3.5, 2.5, 1.8</td>
<td>3.5, 2.5, 1.8</td>
<td>3.5, 2.5, 1.8</td>
<td>2.5, 1.8</td>
<td>2.5, 1.8</td>
</tr>
<tr>
<td>Capacity</td>
<td>GB</td>
<td>60-2,000</td>
<td>120-4,000</td>
<td>180-10,000</td>
<td>300-10,000</td>
<td>700-30,000</td>
<td>1,500-50,000</td>
</tr>
<tr>
<td>Market Size</td>
<td>Units (M)</td>
<td>540</td>
<td>775</td>
<td>1,035</td>
<td>1,380</td>
<td>2,410</td>
<td>3,200</td>
</tr>
<tr>
<td>Cost/ GB (avg.)</td>
<td>$/ GB</td>
<td>&lt;0.15</td>
<td>&lt;0.10</td>
<td>&lt;0.05</td>
<td>&lt;0.02</td>
<td>&lt;0.01</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Design/ Performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areal Density</td>
<td>Gb/ in²</td>
<td>&gt;500</td>
<td>&gt;800</td>
<td>&gt;1,000</td>
<td>&gt;1,600</td>
<td>&gt;4,800</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>Rotational Latency</td>
<td>ms</td>
<td>2-12</td>
<td>2-12</td>
<td>2-12</td>
<td>2-12</td>
<td>2-12</td>
<td>2-12</td>
</tr>
<tr>
<td>Seek Time*</td>
<td>ms</td>
<td>3-5</td>
<td>3-5</td>
<td>3-5</td>
<td>2-5</td>
<td>1.5-5</td>
<td>1-4</td>
</tr>
<tr>
<td>RPM</td>
<td></td>
<td>4.2-15K</td>
<td>4.2-15K</td>
<td>4.2-15K+</td>
<td>4.2-15K+</td>
<td>4.2-10K+</td>
<td>4.2-10K+</td>
</tr>
<tr>
<td>Data rate</td>
<td>Mb/sec</td>
<td>10-2,200</td>
<td>10-2,500</td>
<td>12-2,800</td>
<td>14-3,200</td>
<td>20-6,400</td>
<td>40-10,000</td>
</tr>
<tr>
<td>Power</td>
<td>watts</td>
<td>2-10</td>
<td>1-10</td>
<td>1-10</td>
<td>0.7-9</td>
<td>0.5-8</td>
<td>0.3-6</td>
</tr>
</tbody>
</table>

*Note: Seek Time* includes both rotational latency and seek time.
Tape Storage

-LTO (= Linear Tape-Open) “Ultrium”
  the industry wide system archival tape storage standard
-Consortium established by HP, IBM, & Seagate
-Drop-in replacement for DLT, based on ½” tape
-An Ultrium drive can:
  - read data from a cartridge in its own generation and at least the two prior generations.
  - write data to a cartridge in its own generation and to a cartridge from the immediate prior generation in the prior generation format
iNEMI Mass Data Storage
Tape Storage Roadmap

Eight-Generation Roadmap

<table>
<thead>
<tr>
<th>Year</th>
<th>Generation 1</th>
<th>Generation 2</th>
<th>Generation 3</th>
<th>Generation 4</th>
<th>Generation 5</th>
<th>Generation 6</th>
<th>Generation 7</th>
<th>Generation 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 GB</td>
<td>400 GB</td>
<td>800 GB</td>
<td>1.6 TB</td>
<td>3.2 TB</td>
<td>6.4 TB</td>
<td>12.8 TB</td>
<td>64 TB</td>
</tr>
<tr>
<td></td>
<td>200 GB</td>
<td>800 GB</td>
<td>1.5 TB</td>
<td>3.2 TB</td>
<td>6.4 TB</td>
<td>12.8 TB</td>
<td>64 TB</td>
<td>256 TB</td>
</tr>
<tr>
<td></td>
<td>up to 40 MB/s</td>
<td>up to 160 MB/s</td>
<td>up to 240 MB/s</td>
<td>up to 320 MB/s</td>
<td>up to 520 MB/s</td>
<td>up to 780 MB/s</td>
<td>up to 1180 MB/s</td>
<td>up to 472 MB/s</td>
</tr>
<tr>
<td></td>
<td>up to 20 MB/s</td>
<td>up to 80 MB/s</td>
<td>up to 120 MB/s</td>
<td>up to 210 MB/s</td>
<td>up to 315 MB/s</td>
<td>up to 472 MB/s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Compressed capacities for generations 1-5 assume 2:1 compression. Compressed capacities for generations 6-8 assume 2.5:1 compression (achieved with larger compression history buffer).
Source: The LTO Program. The LTO Ultrium roadmap is subject to change without notice and represents goals and objectives only.
Linear Tape-Open, LTO, the LTO logo, Ultrium, and the Ultrium logo are registered trademarks of HP, IBM and Quantum in the US and other countries.
### iNEMI Mass Data Storage

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>2009</th>
<th>2010</th>
<th>2012</th>
<th>2019</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Form Factor</strong></td>
<td>inch</td>
<td>5.25 FH,</td>
<td>5.25 FH,</td>
<td>5.25 FH,</td>
<td>5.25 HH,</td>
<td>5.25 HH,</td>
</tr>
<tr>
<td>F/HH=Full/Half Height</td>
<td>HH,3.5</td>
<td>5.25</td>
<td>5.25</td>
<td>5.25</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Longitudinal Tape</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Volumetric Density</strong></td>
<td>GB/in³</td>
<td>100</td>
<td>200</td>
<td>400</td>
<td>2,000</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Cartridge capacity</strong></td>
<td>GB/TB</td>
<td>800 GB</td>
<td>1,500 GB</td>
<td>3-4 TB</td>
<td>12-24 TB</td>
<td>24-48 TB</td>
</tr>
<tr>
<td><strong>Areal Density</strong></td>
<td>Gb/in²</td>
<td>1.2</td>
<td>2.0</td>
<td>3.0-3.5</td>
<td>5-10</td>
<td>10-20</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td>MB/s/drive</td>
<td>120</td>
<td>160-180</td>
<td>200-280</td>
<td>400-800</td>
<td>800-1,200</td>
</tr>
<tr>
<td><strong>Tape Speed (for data)</strong></td>
<td>meters/sec</td>
<td>6-8</td>
<td>8-10</td>
<td>10-12</td>
<td>12-15</td>
<td>12-15</td>
</tr>
<tr>
<td><strong>Head tracking precision required</strong></td>
<td>+/- µm</td>
<td>0.5</td>
<td>0.35</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td><strong>Key Requirements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heads</strong></td>
<td>type</td>
<td>MR</td>
<td>MR</td>
<td>MR</td>
<td>MR/GMR</td>
<td>GMR/TMR</td>
</tr>
<tr>
<td><strong>Number of data channels</strong></td>
<td>Number</td>
<td>16-24</td>
<td>16-24</td>
<td>16-24</td>
<td>16-32</td>
<td>16-32</td>
</tr>
<tr>
<td><strong>Detection channel</strong></td>
<td>type</td>
<td>E PRML</td>
<td>E PRML</td>
<td>E PRML, LDPC</td>
<td>E PRML, LDPC</td>
<td>E PRML, LDPC</td>
</tr>
<tr>
<td><strong>Magnetic film</strong></td>
<td>type</td>
<td>dual-layer metal particle</td>
<td>multi-layer metal particle</td>
<td>multi-layer metal particle</td>
<td>multi-layer metal particle</td>
<td>multi-layer metal particle</td>
</tr>
<tr>
<td><strong>Tape/media thickness</strong></td>
<td>µm (micron)</td>
<td>6</td>
<td>5</td>
<td>4.5</td>
<td>&lt;4</td>
<td>&lt;4</td>
</tr>
<tr>
<td><strong>media substrate material</strong></td>
<td>type</td>
<td>PEN Aramid*/adv. polymer</td>
<td>PEN Aramid*/adv. polymer</td>
<td>PEN Aramid*/adv. polymer</td>
<td>Aramid*/adv. polymer</td>
<td>Aramid*/adv. polymer</td>
</tr>
</tbody>
</table>
Optical

- Optical storage has evolved primarily into a data storage transfer technology
  - Software delivery
  - Digital AV
- Diverse set of technologies (CD, DVD, DVD-R, DVD-RW, Blue-ray, MO, Holographic, 2-photon etc.)
- Standard Blu-ray growth may be hampered by direct download to HDD technology
- May need to increase capacity & lower cost to meet challenge of Flash SSD
# Mass Data Storage

## Optical Storage Market Segments

<table>
<thead>
<tr>
<th>Market Segment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer Electronics (CE)</td>
<td>CD-DA, DVD-Video, DVD+/-R, DVD+/-RW, DVD-RAM, Mini-Disc, &amp; BD/HD DVD.</td>
</tr>
<tr>
<td>PC Workstation</td>
<td>All non-application specific CD/DVD storage and 3.5” MO (5.25” MO was sometimes used for archival storage in medical image processing workstations and similar applications, but the volume is very low).</td>
</tr>
<tr>
<td>Professional</td>
<td>UDO and Sony’s Professional Disc for DATA (both are &quot;blue laser&quot; technologies); 3.5” MO is sometimes used by this segment, but penetration is relatively low. 5.25” MO no longer in production.</td>
</tr>
<tr>
<td>Data Center (Enterprise)</td>
<td>Legacy 5.25” MO, 12”/14” WORM, &amp; Sony’s Professional Disc for DATA. Only UDO has ongoing sales. Much greater emphasis on optical disc library (ODL) solutions &amp; more rugged drives.</td>
</tr>
</tbody>
</table>
Blu-ray disc won the HD optical format war
## Mass Data Storage

### Major Optical Storage Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD/DVD</td>
<td>95% of Market; Mature Technology, SW/AV Dist., +R/+RW, DVD-ROM &lt; 10% pf DVD media repl.</td>
</tr>
<tr>
<td>Blue-Laser Disk (BD)</td>
<td>Video recording, PC/Workstation app’s., RO, R(WO), RE(RW), Blu-ray is format winner, HD-DVD discon. in 2008</td>
</tr>
<tr>
<td></td>
<td>BDXL – High capacity recordable/rewriteable 4 layers – 100-128 GB</td>
</tr>
<tr>
<td></td>
<td>IH-BD (intra-Hybrid), 2-25 GB BD layers</td>
</tr>
<tr>
<td>Versatile Mini-Disc (VMD)</td>
<td>EVD (Enhanced Versatile Disc) – proposed in 2005 by New Media Enterprises – 5 GB capacity</td>
</tr>
<tr>
<td></td>
<td>VMD= 8 layers = 40GB capacity for HDTV</td>
</tr>
<tr>
<td>Magneto-Optic</td>
<td>Sony Mini-Disc, 2.5” FF, 1GB capacity for Audio recorder, sold mostly in Japan.</td>
</tr>
<tr>
<td>Holography</td>
<td>In-Phase now out of business. Following was their goal:</td>
</tr>
<tr>
<td></td>
<td>Target: 300GB disk $150 @ 715 GB/in² Drive ~$1800. Reliable/Affordable over long term? Mfg. High capacity &amp; throughput achievable?</td>
</tr>
</tbody>
</table>
## iNEMI Mass Data Storage

### Storage Systems

<table>
<thead>
<tr>
<th>Area</th>
<th>Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise</td>
<td>Shipped capacity to 53,000PB by 2013 (44% CAGR), Revenue flat @$30Bn, migration from performance to capacity/cost optimization, HDD cost 10X&lt;SSD Flash. 15% of HDD, &lt; 5% of Flash revenues</td>
</tr>
<tr>
<td>Cloud</td>
<td>Impact of Cloud storage services yet to be seen. Communication line speed may be bottleneck. i.e. LTO-5 (1.5TB) would take 5 hrs @ 1Gb/sec. Lossless compression may help.</td>
</tr>
<tr>
<td>Consumer</td>
<td>Cost the key driver. Data compression widely used. SSD can provide rapid startup and performance, but costly. Backups use HDD, DVD, &amp; CD.</td>
</tr>
</tbody>
</table>
- $55B capital to replace all 2009 HDD enterprise capacity with NAND Flash

- Error rate behavior for NAND Flash more complicated than for HDD’s
  - dependent on write cycle count & age of data:

![Example Error Rate Surface](image)

NAND Flash Raw Error Rate Behavior

## Average Electrical Power usage in Data Centers

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chillers</td>
<td>33%</td>
</tr>
<tr>
<td>UPS</td>
<td>18%</td>
</tr>
<tr>
<td>AC</td>
<td>9%</td>
</tr>
<tr>
<td>Other (lights, surveillance, PDAs...)</td>
<td>10%</td>
</tr>
<tr>
<td>Non-IT equipment total electricity</td>
<td>70%</td>
</tr>
<tr>
<td>IT equipment averages</td>
<td>30%</td>
</tr>
<tr>
<td>Total IT electrical consumption</td>
<td>30%</td>
</tr>
<tr>
<td>Servers</td>
<td>35%</td>
</tr>
<tr>
<td>Storage</td>
<td>30%</td>
</tr>
<tr>
<td>Networks</td>
<td>23%</td>
</tr>
<tr>
<td>Other</td>
<td>12%</td>
</tr>
</tbody>
</table>
iNEMI Mass Data Storage

Summary

Solid State

NAND Flash Memory: Growing in importance, but will not displace HDD
MRAM: now established, volumes may grow with ST or Thermal Switching
Phase change yet to emerge in high volumes

Magnetic

HDD is largest volume, continued growth expected, but rate may slow.
Tape still plays vital archival backup role, helped by LTO standard

Optical

Primary niche is in data transfer applications
Holographic storage too expensive to succeed in marketplace.

Storage Systems

Architected for cost rather than performance. Power & performance issues may enable viability of SSDs in some enterprise applications.
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Thank you!