Future Technology Challenges For NAND Flash And HDD Products

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1. Analyze Storage Technology Trends For Flash And HDD
2. Project Where These Principal Storage Technologies Will Evolve
3. Project Data Density Growth, Costs Per Gigabyte
4. Discuss Reliability And Endurance Issues
5. Analyze Lithography Challenges
6. Future Designs For Flash/HDD
7. Discuss Competitive Non Volatile Alternative Technologies
HDD and Flash Byte Ships

HDD (Ref. Coughlin/Grochowski 2012 Report)
Flash (Based on John Monroe, Gartner)

CGR = 73%
CGR = 70%

Bytes Shipped/Year

Production Year

HDD
NAND Flash

Petabytes
Exabytes
Zetabytes

10^24
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
10^15

Flash Memory Summit 2012
Santa Clara, CA
HDD and Flash Byte Ships

HDD (Ref. Coughlin/Grochowski 2012 Report)
NAND Flash (Ref. Based on John Monroe, Gartner)

Exabytes Shipped/Year

HDD
NAND Flash

Production Year

Ed Grochowski/Tom Coughlin
TB2012YZ.PRZ
HDD Capacity Roadmap

- 1 GB
- 8.1 GB
- 4 GB
- 1 GB
- 12 GB
- 20 GB
- 2.5 inch
- 1.8 inch
- 3.5 inch form factor
- 36 GB Server 15K RPM
- 300 GB 15K RPM
- 750 GB 10K RPM
- 2000 GB Desktop 7200 RPM
- 4TB Mobile 5400 RPM
- 300 GB
- 250 GB
- 12 GB
- 750 GB Server 10K RPM
- 2.5TB Server 10K RPM
- 12TB Desktop 7200 RPM
- 750 GB
- 4TB Mobile 5400 RPM
- 12TB Desktop 7200 RPM
- 1.8 inch
- 1.5TB
- 2.5 inch
- 12TB Desktop 7200 RPM
- 300 GB
- 4TB Mobile 5400 RPM
- 12TB Desktop 7200 RPM
- 1.5TB
Projected NAND Flash Memory Circuit Density Roadmap

- **Floating Gate**
  - 512 Mb 180 nm
  - 256 Mb 250 nm
  - 64 Mb 250 nm
  - 32 Mb 400 nm
  - 16 Mb 600 nm

- **MLC**
  - 2 Gb 90 nm
  - 1 Gb 130 nm
  - 128 Gb 12 nm
  - 80 Gb 24 nm
  - 64 Gb 24 nm
  - 16 Gb 45 nm

- **SLC**
  - 4 Gb 90 nm
  - 8 Gb 65 nm

- **Charge Trap**
  - 128 Gbit NAND 19nm
  - San Disk/Toshiba
  - 2012

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Three HDD “Innovations”

Shingled Write

Magnetic “Islands”
BAR = 2-4

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Shingled Write Dynamics

Disk Rotation Direction
Track Width

Track N-4
Track N-3
Track N-2
Track N-1
Track N

Substrate

Heat Activated Magnetic Recording Head (HAMR)

Source: Seagate Technology Corp.
U.S. Patent 7609480 Shuk et al.
Lithography Roadmap
Based on Multiple Sources

193 nm Lithography
Water Immersion

193 nm Lithography
Immersion
Double Pattern

193 nm Lithography
EUV, Self Assm.
Triple Pattern

Linewidth (nm)

Production Year

ITRS Roadmap2012.prz

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Flash Memory Summit 2012
Santa Clara, CA
FG Flash Electrical Scaling Challenges

Based on multiple sources

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Flash Chip Capacity (GBytes)

Year

Lithography nm

No. Electrons per Vt Shift

Standard Cell
finFET

Flash Memory Summit 2012
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NAND Flash Memory Endurance Properties

Program/Erase Cycles

Production Year

Lithography nm

SLC
MLC
TLC

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Flash Memory Summit 2012
Santa Clara, CA
The Promise of finFET Flash

- 2X Gate Peripheral Region
- Potential for Increase in Electron Storage
- 3D Structure = Process Complexity
- Follows Microprocessor Technology

3-Sided Channel Region

Gate

Fin

Insulator Substrate

Based on INTEL 2012
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The Future Promise of EUV

- Experimental Tool Stage
- >$100 M Tool Cost
- Reflective Mask Wearout
- Alternative For 14 nm?

Ref. Coughlin/Grochowski 2012 Report
HDD Critical Dimensions

Critical Dimension, nmeters

Areal Density Gigabits/in²

BPM Region

Trackwidth

Bit Length

Production Year

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Double Patterning

• Current 193nm Optics Allows The Ability To Produce 20nm Lines On 80nm Pitches

• NAND Requirements Are To Print Equal Lines And Spaces, IE. 20nm Linewidths With A Space Of 20nm And A Pitch Of 40nm

• Double Patterning Enables The Formation of 20nm Lines On 40nm Pitches Using Two Masks, Each Having 20 nm Lines On 80 nm Spaces

• Future Technology Could Allow Triple Patterning
Double Patterning

1) Coat resist on sample

2) Align mask 1 (1X spaces on 4X pitch)

3) Expose mask 1 (1X spaces on 4X pitch)

4) Develop resist

5) Etch hard mask

6) Strip resist

7) Apply resist

8) Align mask 2 (1X spaces on 4X pitch, shifted by 2X)

9) Align mask 2 (1X spaces on 4X pitch, shifted by 2X)

10) Develop resist

11) Etch hardmask

12) Remove resist (1X pattern on 2X pitch)

13) Etch device layer (1X pattern on 2X pitch)

14) Strip hard mask
3D Packing Technology

3D NAND Flash Design (Toshiba)

+’s: Real Estate Savings, Reduction Transfer Energy, Bandwidth

Hybrid Memory Cube (IBM/Micron)

-’s: Process Complexity, Costs/Yield

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Volumetric Density

- **Local (Media) Volumetric Density:** The volumetric density of the memory media alone (using the maximum areal density) within a final memory component, i.e. tape on a reel, disks in an HDD stack, NAND flash in a package.
- **Device Volumetric Density:** The volumetric density of the memory component, i.e. a tape cartridge, an HDD drive, a SSD drive

<table>
<thead>
<tr>
<th></th>
<th>HDD</th>
<th>SSD</th>
<th>TAPE (LTO)</th>
<th>TAPE³ (Enterprise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Areal Density</td>
<td>750 Gbit/in²</td>
<td>550 Gbit/in²</td>
<td>1.2 Gbit/in²</td>
<td>3.2 Gbit/in²</td>
</tr>
<tr>
<td>Local Volumetric Density</td>
<td>2.4 TB/in³</td>
<td>6.9 TB/in³</td>
<td>1.6 TB/in³</td>
<td>4.2 TB/in³</td>
</tr>
<tr>
<td>HDD/SSD/Cartridge Volume</td>
<td>23.8 in³</td>
<td>4.1 in³</td>
<td>14.1 in³</td>
<td>14.1 in³</td>
</tr>
<tr>
<td>HDD/SSD/Cartridge Capacity</td>
<td>3 TB</td>
<td>0.5 TB</td>
<td>1.5 TB</td>
<td>3.0 TB</td>
</tr>
<tr>
<td>Device Volumetric Density</td>
<td>126 GB/in³</td>
<td>122 GB/in³</td>
<td>106 GB/in³</td>
<td>212 GB/in³</td>
</tr>
</tbody>
</table>

HDD: 1 mm thick disks (two surfaces) separated by 1 mm gaps in a disk stack

SSD: 1 mm thick package with 4 thinned (75 um) NAND chips

TAPE: 5.2 um thick tape media wound on a cartridge spool
<table>
<thead>
<tr>
<th>HDD</th>
<th>Shingled Write</th>
<th>Increase Track Density 50%</th>
<th>Significant Disk Architectural Changes, Ideally Suited For Streaming Data Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAMR</td>
<td>Increase Bit Density</td>
<td>New Media Alloy Based on FePt Addition Of Laser To Head Disk Lube Depletion</td>
<td></td>
</tr>
<tr>
<td>BPM</td>
<td>Increased Areal Density, Data Stability</td>
<td>Disk Media Personalization, Massive Mfg. Operation, Capital Intensive, Lithographic Requirements (?)</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>Increased Unit Capacity</td>
<td>Cost Increased, Power</td>
<td></td>
</tr>
<tr>
<td>Flash</td>
<td>MLC</td>
<td>Increase Data Capacity Up To 3X</td>
<td>Significant Endurance Degradation New Controller Requirements</td>
</tr>
<tr>
<td>Lithography</td>
<td>&lt;20nm Required For Lower Costs</td>
<td>EUV Costs Data Leakage, Endurance</td>
<td></td>
</tr>
<tr>
<td>3D finFET</td>
<td>Increase Data Capacity</td>
<td>Increased Process Complexity, Costs, New Device Structure</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>Increased Unit Capacity</td>
<td>Increased Costs, Power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HDD</td>
<td>Flash (SLC)</td>
<td>Flash (MLC)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Cell Structure</td>
<td>None</td>
<td>1T/0C</td>
<td>1T/0C</td>
</tr>
<tr>
<td>Cell size ($F^2$)</td>
<td>0.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Read time (ns)</td>
<td>2000</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Write / Erase time (ns)</td>
<td>1000</td>
<td>1 ms / 0.1 ms</td>
<td>1 ms / 0.1 ms</td>
</tr>
<tr>
<td>Endurance</td>
<td>$10^{16}$</td>
<td>$10^5$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Write power</td>
<td>Low</td>
<td>Very high</td>
<td>Very high</td>
</tr>
<tr>
<td>Max. Areal Density Gbits/in²</td>
<td>750-1000</td>
<td>150</td>
<td>550</td>
</tr>
<tr>
<td>Voltage required</td>
<td>3-5V</td>
<td>12 V</td>
<td>12 V</td>
</tr>
</tbody>
</table>

**Existing products**

**Prototype**
CONCLUSION

1. Storage Market Demands Expected To Continue For Both HDD And Flash Products.

2. Flash Will Continue To Dominate Mobil/Handheld Market

3. Technology Improvements Are Slowing Based On Implementation Costs, Implementation Difficulties

4. Expect HDD Changes To Occur >2012 For Increased Data Density; HAMR, SMR, BPM

5. Flash Will Adopt 3D Technologies

6. No Alternative NV Technologies Have Demonstrated Leadership To Date; MRAM Progress Appears Attractive

7. Legacy Storage (As Tape) Will Continue To Grow