The Magnetic Hard Disk Drive

Today’s Technical Status And Future

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Subjects To Be Addressed

• History
• Present HDD Market
• Future HDD Bytes Shipped
• Cloud Computing and HDD Design
• Today’s HDD Products and Future Trends
• HDD Performance Trend
• HDD Cost Analysis
• HDD Reliability/Endurance
• HDD Technology: Shingle Write, Helium Ambient, Form Factor/Disk Count
• Future Technology: HAMR, 2DMR, BPM
• Materials: Heads, Media
• Competitive Storage Technologies: Flash, NVM
• Summary and Conclusions
Heat Activated Magnetic Recording (HAMR)

Source: Seagate Technology Corp.
HAMR HEAD w/LASER ELEMENT

Source: Seagate Technology Corp.
U.S. Patent 7609480 Shuk et al.
Heat Activated Magnetic Recording (HAMR)

1. Major HDD Modification
2. Adds Laser Element to HDD Heads (+3X Mass To Slider)
3. Involves FePtX Magnetic Media (Lower Curie Temperature)
4. Grain Diameter Scaling Levels Out
5. Disk Lube, Overcoat Modifications
6. >>2 Tbits/sq.in AD Capability (2020?)
7. In Development prior to 2004
Magnetic Grains and Bit Size

- 100 Gb/in²: ~90 Grains
- 250 Gb/in²: ~40 Grains
- 500 Gb/in²: ~20 Grains
- 800 Gb/in²: ~11 Grains
- 1 Tb Gb/in²: ~8 Grains
- 2 Tb Gb/in²: ~4-8 Grains

Based on G. Bertero (WD) SCVM
Grain Diameter Perspective

Production Year

Based on Weller & McDaniel, Bertero, Victoria, Wang
Areal Density, Gbits/in.sq.


Mag Spacing Perspective

Based on Marchon & Olson, Victoria & Wang and Other Sources

Spacing nm

Areal Density, Gbits/in.sq.

HAMR Region?

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The Technology Of Shingled Writing

Shingled Write Dynamics

Erase Track Removes Significant Part Of Magnetized Energy In Data Bit
The Perennial HDD-Storage Industry Workhorse

Shingled Write Technology

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Computer Storage Consultant
Shingled Write

- Areal Density Enhancement: 15%
- Partial Erasure of Written Track By Next Adjacent Track
- Writing Easy, Rewriting Difficult In Inner Tracks
- Requires Block Erasure Prior To Rewriting
- Performance Penalty In Rewriting
- Optimal Implementation For Cold Storage- Infrequent Rewrites – Cloud Storage
- Optimal Implementation – Transparent To Host, Implemented Internally To HDD
- Customer Acceptance?
Two Dimension Magnetic Recording (TDMR)

1. Requires Multiple Reader Elements In Head
2. Reads Single Tracks With Multiple Elements
3. Detects Intertrack Interference (ITI), Media & Electronic, Noise
4. Allows For More Closely Spaced Tracks
5. Requires Complex Electronics
6. Ten Per Cent Areal Density Enhancement

Based on Yao, Broadcom

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Microwave Activated Magnetic Recording (MAMR)

1. Applying high frequency magnetic field reduces switching field
2. Requires HF element buried within write head
3. Switching field is below magnetic coercivity of disk media
4. Switching probability on media complex for single layer
5. Field drop off significant with spacing
6. Head design with microwave generator complex

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Average Retail Prices of Storage

- DRAM
- Desktop
- Enterprise
- Mobile
- 1"

Price/GB, Dollars

Year


64 GB Flash
500 GB/15K Server
3 TB Mobile Drive
6 TB Desktop
16 GB DRAM
64 GB Flash
Enterprise Flash
Enterprise HDD
"HDD
Desktop HDD
Mobile HDD

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oempic2016A.prz
Average Retail Prices of Storage

- **DRAM**
- **Desktop**
- **Enterprise**
- **Flash**
- **Mobile**

- **2 TB Flash**
- **Desktop HDD**
- **Mobile HDD**
- **DRAM**
- **16 GB DRAM**
- **4TB Server SCSi**
- **3D Flash?**
- **2 TB Flash**
- **3 TB Mobile Drive**
- **Desktop HDD**
- **8 TB Desktop**

**Price/GB, Dollars**

**Year**

Helium Filled HDD Technology
(Employed By Seagate and WD)

1. Increases HDD Capacity (Allows Larger Areal Density)
2. Reduce Cost of Ownership
3. Relies on He Density 1/7 Air
4. Less Drag Force on Disk Media Stack (Reduces Motor Power)
5. Low He Density Reduces Dynamic Forces on Disks, Accessing Arms
6. Allows Closer Disk/Disk Spacing (More Disks Per HDD)
7. He Exhibits More Efficient Thermal Conduction, Cooler Running HDD
8. Less Acoustic Noise

(a) Air (b) Helium

Zhang et al.
IEEE Trans Mag. 52, 4, 4/2016
Spac2015A.prz

Based on Marchon & Olson (Hitachi GST) and Other Sources

Production Year


Spacing Perspective
Physical Spacing Includes Take Off Heights

- Bit Length
- Mag Spacing
- Physical Spacing
- Disk OC

Areal Density, Gbits/in.sq.

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NVM & Products Roadmap

HDD
- 3.5 inch
- 8-10 TB
- 12 TB
- 16 TB
- 20 TB

Flash
- 128 Mb
- 256 Mb
- 512 Mb
- 1 Gb
- 16 Gb

STT RAM
- 64 Mb
- 256 Mb
- 1 Gb
- 4 Gb
- 16 Gb

ReRAM
- 2 Mb
- 8 Mb
- 64 Mb
- 1 Gb
- 4 Gb

FeRAM
- 1 Kb
- 8 Kb
- 16 Kb
- 256 Kb
- 1 Gb

PCM
- 2 Mb
- 4 Mb
- 16 Mb
- 256 Mb

Availability Year
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020

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HDD/Flash Areal Density Perspective

Areal Density Gb/in²

Production Year

- HDD Products
- Flash Products

- TMR Head
- ~13% CGR
- Perpendicular Recording
- 40% CGR
- 256 Gb 19nm TLC
- 128 Gb 19nm TLC
- 64 Gb 20nm
- 64 Gb (3 MLC ?)
- 32 Gb (2 MLC)
- 16 Gb (2 MLC)

1st AFC Media
- 100% CGR

1st GMR Head
- 60% CGR

1st MR Head

512Mb
- 256Mb
- 64Mb
- 2 Gb
- 1 Gb
- 8 Gb
- 4 Gb
- 16 Gb
- 32 Gb (2 MLC)

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HDD/Flash Areal Density Perspective

Areal Density Gigabits/in²

- HDD Products
- Flash Products

- 13% CGR

- 64 Gb (2 MLC)
- 32 Gb (3 MLC ?)
- 64 Gb 20nm
- 128 Gb 19nm TLC
- 256 Gb 19nm TLC

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Bit Patterned Media

1. Involves Personalized Media For Islands And/Or Guides
2. Photolithography, Master + Stamping, or Directed Self Assembly
3. Chemical Processing Is Exotic
4. To date Defects In Pattern Significant
5. Improbable Mfg. (One Million Disks/Year X 2 Sided)
6. High Risk
## HDD Technology Introduction

<table>
<thead>
<tr>
<th>Implementation probability</th>
<th>Technology</th>
<th>2016</th>
<th>2020+</th>
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<tbody>
<tr>
<td>High</td>
<td>Helium Ambient</td>
<td>Implemented</td>
<td>Implemented</td>
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<td></td>
<td>Shingle Write</td>
<td>Implemented</td>
<td>Implemented</td>
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<tr>
<td></td>
<td>2DMR</td>
<td>Development</td>
<td>Implemented</td>
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<td>8 + Disk HDD</td>
<td>Development</td>
<td>2017-2018 Implemented</td>
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<td>Moderate</td>
<td>HAMR</td>
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<td>MAMR</td>
<td>Development</td>
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Summary and Conclusions

1. HDD Products Will Continue To Dominate Storage Market
2. HDD Is The Low Cost Technology
3. HDD Products Will Continue To Migrate To Cloud Storage
4. Today 80% Storage Bytes Are HDD
5. Significant Technology Challenges Exist To Enhance Areal Density
6. Conservatively, Expect 10-20% AD Increase To 2020