The Perennial Hard Disk Drive
Storage Industry “Workhorse”

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"I HAVE COME TO PRAISE MAGNETIC HARD DISK DRIVES

NOT TO CRITIQUE FLASH MEMORY"

Based on: Shakespeare’s Julius Caesar, Act III, Scene II

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WORLD OF STORAGE
1000 EXABYTES/YEAR

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HDD

Ugh!
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WORLD OF STORAGE
1000 EXABYTES/YEAR

SSD

HDD
Nature Is Wonderful

- The Moon Regulates The Earth’s Rotation Rate
- It Evens Out The Earth’s Spin (Minimizes Wobble?)
- It Determines The Earth’s Internal Properties (Tides)
- So That SDD Regulates HDD Speed And Performance
- SSD Adds HDD Capacity
- SSD Supports HDD Reliability
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Annual HDD/SSD Storage Capacity Ships

- HDD
- SSD


HDD SSD

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10-20 X
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Annual HDD Unit Ships

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Hard Disk Technology "Boilerplate"

- AFM Disk
- Disk Stack, Spindle & Motor
- Disk Drive Assembly
- Electronic Board
- Electronics on Flex
- Actuator
- Wafer
- TMR Read/PMR Write Element-Pico Slider
- Head Gimbal Assembly + Integrated Lead Suspension

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HDD Areal Density Perspective

- HDD Products
- HDD Products w/PMR

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1/13/2015

- 1st MR Head
- 25% CGR
- 1st GMR Head
- 60% CGR
- 1st AFC Media
- 100% CGR
- Perpendicular Recording
- ~550 Million X Increase
- 40% CGR
- ~13% CGR

Production Year

Areal Density Gigabits/in2

- 10^4
- 10^3
- 10^2
- 10^1
- 10
- 10^-1
- 10^-2
- 10^-3
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[Graph showing HDD/Flash areal density perspective with key points marked for 1st AFC Media, 1st GMR Head, 1st MR Head, Perpendicular Recording, TMR Head, and areal density labels such as 16Mb, 64Mb, 512Mb, 256Gb, 64Gb, 32Gb, and 16Gb.]

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Average Retail Prices of Storage

- **DRAM**
- **Flash**
- **Desktop**
- **Mobile**
- **Enterprise**
- **1'' HDD**

**Price/GByte, Dollars**

- **16 GB DRAM**
- **64 GB Flash**
- **500 GB/15K Server**
- **3 TB Mobile Drive**
- **6 TB Desktop**

**Year**

- **1990**
- **1995**
- **2000**
- **2005**
- **2010**
- **2015**
- **2020**
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TRENDS IN RECORDED BIT LENGTH.

The Shrinking Bit Cell

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(1990) 0.09 Gbit/in² 20:1
(1992) 0.2 Gbits/in² 19:1
(1994) 0.5 Gbits/in² 18:1
(1996) 1.3 Gbits/in² 17:1
(1998) 5 Gbits/in² 14:1
(2000) 20 Gbits/in² 12:1
(2005) 100 Gbits/in² 8:1
(2008/9) 320 Gbits/in² 5.5:1
(2015) 1 Tbit/in² 5.0:1
(2016/17) 2 Tbit/in² 4.4:1

(2002) 50 Gbits/in² 10:1
(2006/7) 200 Gbits/in² 6:1
(2010/11) 550 Gbits/in² 5.5:1
(2015) 1 Tbit/in² 5.0:1
(2016/17) 2 Tbit/in² 4.4:1

Bit length, λ m

Trackwidth, λ m

0.60 0.41 0.27 0.17 0.094 0.052 0.036 0.028 0.023 0.019 0.015 0.011 0.008
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HDD Capacity Roadmap

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HDD Capacity, TBytes

Availability Year

2000 02 04 06 08 10 12 14 16 18 20 2020

HDD Capacity Roadmap

2000 GB Desktop 7200 RPM

750 GB Server 10K RPM

2000 GB Desktop 7200 RPM

300 GB Server 15K RPM

750 GB 1 TB

8TB Desktop 7200 RPM

2.5TB Server 10K RPM

4 TB

10TB Mobile 5400 RPM

36GB Server 15K RPM

1 TB

8TB Desktop 7200 RPM

20TB Desktop 7200 RPM

10TB Mobile 5400 RPM

8.1 GB

2.5 inch

3.5 inch form factor

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Cloud Storage System ca. 2020

20 TB HDD
3.5 Inch
7200 RPM
6 ms Access

Per Drawer
8-20 TB HDD
w/Electronics + SSD

Per System
16-Drawers
128 HDA’s
=2560 EB
w/Cooling+
Electronics

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MAGNETIC TECHNOLOGY TRILEMMA

Inductive Write Head Limit

Writeability (2.4 Tesla)

SNR \sim \frac{\text{Log}_{10} N}{\text{K_u} V/kT}

Thermal Stability

Maximum Number Of Media Magnetic Grains

Maximum Magnetic Properties, Volume Of Magnetic Media Grain

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Magnetic Grains and Bit Size

Based on G. Bertero (WD) SCVM
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Based on G. Bertero SCVM
HDD TECHNOLOGY ENHANCEMENTS

1. Heat Assisted Magnetic Recording (HAMR)
2. Shingle Write Recording (SMR)
3. Two Dimensional Magnetic Recording
4. Bit Patterned Media
5. Mechanical HDD Enhancements

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Heat Activated Magnetic Recording (HAMR)

Source: Seagate Technology Corp.

Coercivity

Heat Activating

Cooling

Head Field

$T_{\text{operating}}$

$T_{\text{write}}$

Media Temperature

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HAMR HEAD w/LASER ELEMENT

Substrate, TMR Read Element, ABS, Exit Aperture, Parabolic Interface, Laser Light, Cladding Layer, Core Layer, Optical Grating, Cladding Layers, Waveguide Layer-Section

Source: Seagate Technology Corp. U.S. Patent 7609480 Shuk et al.
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The Technology Of Shingled Writing

Shingled Write Dynamics

Erase Track Removes Significant Part Of Magnetized Energy In Data Bit

+ Performance effect on rewriting

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NAND Flash Memory Circuit Density Roadmap

- **Floating Gate**
  - 2 Gb 130 nm
  - 1 Gb 180 nm
  - 512 Mb 250 nm
  - 256 Mb 280 nm
  - 64 Mb 280 nm
  - 32 Mb 450 nm
  - 16 Mb 600 nm

- **Charge Trap**
  - 64 Gb 24 nm
  - 80 Gb 24 nm
  - 64 Gb 24 nm
  - 16 Gb 45 nm
  - >256 Gb 19 nm
  - >256 Gb 14 nm

- **Advanced Technology**
  - 4 Gb 14 nm
  - 4 Gb 90 nm
  - 2 Gb 90 nm
  - 1 Gb 130 nm
  - 512 Mb 180 nm
  - 256 Mb 250 nm
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3D NAND Technology

Ref: Applied Materials/Samsung

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NEW NVM/STORAGE TECHNOLOGIES

1. STT RAM
2. RRAM
3. PRAM
4. FRAM
5. Carbon Nanotubes

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STT RAM: WHAT IS CLAIMED!

DRAM + SRAM + ROM + FLASH -----> STT RAM

(SPIN LOGIC TOO?)

“We are entering an era in which electronic devices function not by the quantity of electron flow but by their electron spin momentum. In a nano/pico scaling device environment this is of maximum importance.”

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“IS NVM/STORAGE 10 YEARS AWAY?”
(AND LOGIC TOO!)

STT RAM

RRAM

Figure 1

RRAM before form
Top Electrode TiN
HfO2
Bottom Electrode TiN

After +4V form
Top Electrode TiN
HfO2
Bottom Electrode TiN

After -2V Reset
Top Electrode TiN
HfO2
Bottom Electrode TiN

Figure 2

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STT RAM Computer Architectural Evolution

HOST → CONTROLLER A → FLASH
HOST → CONTROLLER B → HDD
HOST → CONTROLLER C → DRAM

HOST → CONTROLLER A → STT RAM
HOST → CONTROLLER B → HDD
HOST → CONTROLLER C → HIDDEN STORAGE?

Based on nvm(EXPRESS) FMS 2014

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Conclusion

1. Storage Mantra – Price, Capacity, Performance, Availability

2. New HDD Technologies Required Beyond 1+ Tb/in2

3. Flash Market: Mobile/Handheld, Laptop, Array

4. HDD Market: High Byte Capacity (Desktop, Laptop, Enterprise, Cloud)

5. Significant Mfg. Challenges For 3D Flash, HDD w/HAMR (About As Difficult!)

6. New Storage (Memory) Technologies On Horizon (STT RAM, RRAM) And Spin Logic Too!

7. Future Belongs To The Best

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HDD’s Get No Respect

The Next Time You Hear The Term
“Spinning Rust”
You Are Empowered To
Pull His (or Her) USB Plug!

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