YEARS OF DESTINY:
HDD CAPITAL SPENDING
AND TECHNOLOGY
DEVELOPMENTS FROM
2012-2016

Tom Coughlin
Ed Grochowski
Coughlin Associates

HDD Exabyte Curve
From Multiple Sources
Ed Grochowski/Tom Coughlin

CGR = 75%

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AVERAGE $/GB FOR HDDS AND FLASH

Average Retail Prices of Storage

- DRAM
- Desktop
- Enterprise
- Flash
- Mobile
- 1"

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Ed Grochowski 2011
HDD AREAL DENSITY GROWTH AND PROJECTIONS.

HDD Areal Density Perspective

- HDD Products
- HDD Products w/PMR

1st MR Head
25% CGR

1st GMR Head
60% CGR

1st AFC Media
40% CGR

Perpendicular Recording

TMR Head

SMR

BPM

HAMR Head

4K Region

>300 Million X Increase

25% CGR

100% CGR

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AREAL DENSITY GROWTH OF HDDS AND FLASH MEMORY

HDD/Flash Areal Density Perspective

- HDD Products
- Flash Products

1st AFC Media
- 60% CGR

1st GMR Head
- 100% CGR

1st MR Head

Perpendicular Recording

TMR Head
- 40% CGR

4K Sector Region

8 GB 20nm

64 GB (3 MLC ?)

32 GB (2 MLC)

16 GB (2 MLC)

16 MB

64 MB

256 MB

512 MB

1 GB

2 GB

4 GB

8 GB

16 MB (2 MLC)

32 GB (3 MLC)

64 GB (3 MLC)

103

102

101

10

10-1

10-2

10-3

10-4

Production Year

Areal Density GigaBits/in2

90 95 2000 2005 2010 2015

1E+1

1E+2

1E+3

1E+4

1E+5

1E+6 1E+7

60% CGR

100% CGR

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16 MB (2 MLC)

32 GB (3 MLC)

64 GB (3 MLC)
BANDED HDD UNIT VOLUME ESTIMATES.

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ESTIMATES OF DRIVE, HEADS AND DISKS TO 2016.
PROJECTIONS FOR HDD CAPACITIES AT VARIOUS FORM FACTORS
INDUSTRY HDD MTBF SPECIFICATIONS.
HDD TECHNOLOGY INTRODUCTION WITH UNIT VOLUME GROWTH.
BLOCK OVERWRITING PROCESS IN SMR

Shingled Rewrite Dynamics

1. Objective: To rewrite sector on track M-1
2. Write duplicate band N
3. Erase initial band M
4. Rewrite prior tracks M-4, M-3, M-2
   Write new sector on track M-1
   Rewrite prior track M
   Erase temporary band N

Disk Rotation

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AREAL DENSITY AND DISK COERCIVITY EVOLUTION.

Disk Coercivity, KOe

Areal Density, Gbits/in²

Write Head Limits

Perpendicular Recording

AFC Media

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LITHOGRAPHY ROADMAP SHOWING HDD HEAD AND BPM/BPM TRENDS VS. ITRS SEMICONDUCTOR REQUIREMENTS.
SELF-ALIGNING DOUBLE PATTERN LITHOGRAPHY

First Pattern Photoresist On Hardmask layer

Deposition

Spacer Formation By Etching

First Pattern Removal

Etching With Spacer Mask

Final Pattern Trim Mask Required

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EXPERIMENTAL EUV EXPOSURE TOOL

Source O. Wood GLOBALFOUNDRIES

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MAGNETIC RECORDING TRILEMMA.

Writeability (2.4 Tesla)  SNR Log_{10} N  Thermal Stability $K_u V/kT$
HEAT ASSISTED MAGNETIC RECORDING

Source: Seagate Technology Corp.

Coercivity

Heating

Cooling

Head Field

$T_{\text{operating}}$

$T_{\text{write}}$

Media Temperature

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EVOLUTION OF PERPENDICULAR MAGNETIC RECORDING MEDIA.

- Early PMR Media
  - Lubricant + Carbon Overcoat
  - Hard Magnetic Layer
  - Ru Exchange Layer
  - Magnetic Underlayer
  - Soft Underlayer
  - Seed

- 8-Layer ECC Media
  - Lubricant + Carbon Overcoat
  - Hard Magnetic Layer
  - Ru Exchange Layer
  - Magnetic Underlayer

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ADVANCED ECC MAGNETIC MEDIA STRUCTURES

Advanced ECC Media
Single Exchange Break Layer

Low Ku
High Ku

Two Spin Model

Double Exchange Break Layer

Low Ku
High Ku
Graded Anisotropy

Three Spin Model
Based on Bertero, WD

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BLOCK COPOLYMER SELF ASSEMBLY.

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STRUCTURE OF TMR AND GMR CPP SENSORS.
HDD COMPONENT TESTING/METROLOGY ROADMAP VS. AREAL DENSITY.

Area Density Gigabits/in²

Production Year

Edward Grochowski

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HEAT ASSISTED MAGNETIC RECORDING WITH LASER SOURCE IN THE HEAD

Source: Seagate Technology Corp
U.S. Patent 7609480 Shuk et al.

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HEAT MICROWAVE ASSISTED MAGNETIC RECORDING (MAMR) PROCESS

Layer with perpendicular Anisotropy
Field generation layer (FGL)
Metal Interlayer
Perpendicularly magnetized reference layer

Electrode
Easy axis
Oscillating stack

Writing Pole
Trailing Shield

Disk Media
Soft Underlayer

Ref: Prof Jimmy Zhu, CMU

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DEVELOPMENT OF BIT ASPECT RATIO WITH TIME.

Projected Future Trend

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TRACK DENSITY, LINEAR DENSITY AND AREAL DENSITY TRENDS.
HDD SPACING AND AREAL DENSITY RELATIONSHIP.

![Graph showing the relationship between Physical Spacing (nm) and Areal Density (Gbts/in²). The graph includes data points for Lab Demos, 2.5/1.8 inch mobile HDD, 3.5 inch Server HDD, and 3.5 inch Desktop HDD. Key points include Contact Recording, Thermal Flying Height Control, and Includes Take-off Height.](image-url)
## HDD COMPANY REVENUE AND INDUSTRY CAPITAL EQUIPMENT SPENDING ESTIMATES (2007 TO 2016).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total HDD Est. Revenue</th>
<th>Total HDD Industry Capital Est. Equipment Spending</th>
<th>% Capital Equipment Spending/Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>$32.6 B</td>
<td>$2.28 B</td>
<td>7.0%</td>
</tr>
<tr>
<td>2008</td>
<td>$32.9 B</td>
<td>$2.37 B</td>
<td>7.2%</td>
</tr>
<tr>
<td>2009</td>
<td>$30.2 B</td>
<td>$1.35 B</td>
<td>4.5%</td>
</tr>
<tr>
<td>2010</td>
<td>$34.8 B</td>
<td>$3.01 B</td>
<td>8.6%</td>
</tr>
<tr>
<td>2011</td>
<td>$41.5 B</td>
<td>$3.64 B</td>
<td>8.8%</td>
</tr>
<tr>
<td>2012</td>
<td>$48.5 B</td>
<td>$4.23 B</td>
<td>8.7%</td>
</tr>
<tr>
<td>2013</td>
<td>$54.2 B</td>
<td>$4.83 B</td>
<td>8.9%</td>
</tr>
<tr>
<td>2014</td>
<td>$60.5 B</td>
<td>$5.66 B</td>
<td>9.4%</td>
</tr>
<tr>
<td>2015</td>
<td>$67.6 B</td>
<td>$6.77 B</td>
<td>10.0%</td>
</tr>
<tr>
<td>Total (2007-2015)</td>
<td>$402.7 B</td>
<td>$34.14 B</td>
<td>8.1% (avg)</td>
</tr>
</tbody>
</table>

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