# The Magnetic Hard Disk Drive

## Today's Technical Status And Future


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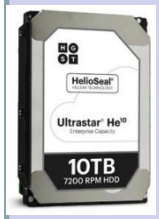
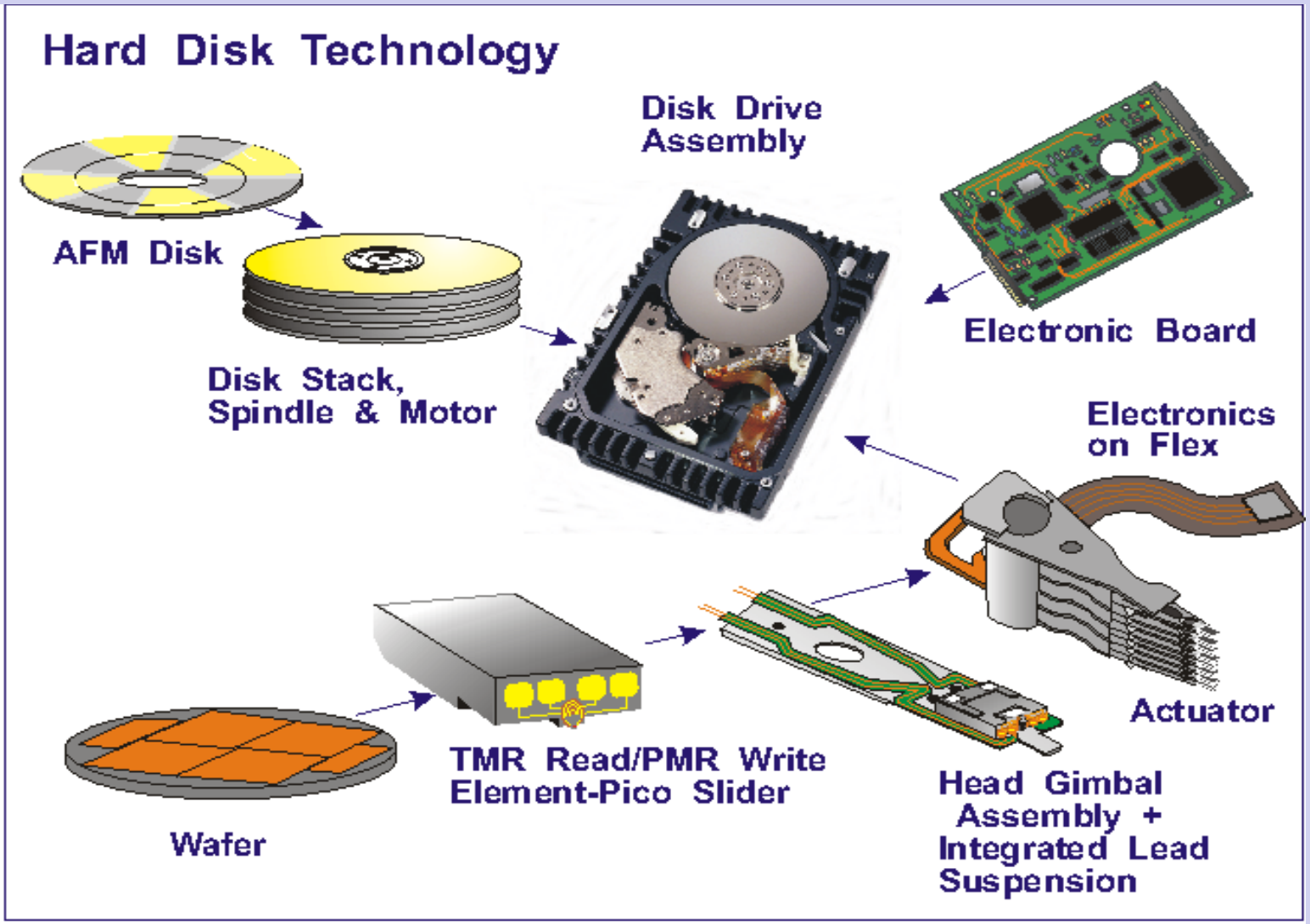
Santa Clara Hyatt
Santa Clara, CA




# 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


Hard Disk Technology
Disk Drive Assembly
AFM Disk
Disk Stack, Spindle & Motor
Electronic Board
Electronics on Flex
Actuator
TMR Read/PMR Write Element-Pico Slider
Wafer
Head Gimbal Assembly + Integrated Lead Suspension
HDD Components
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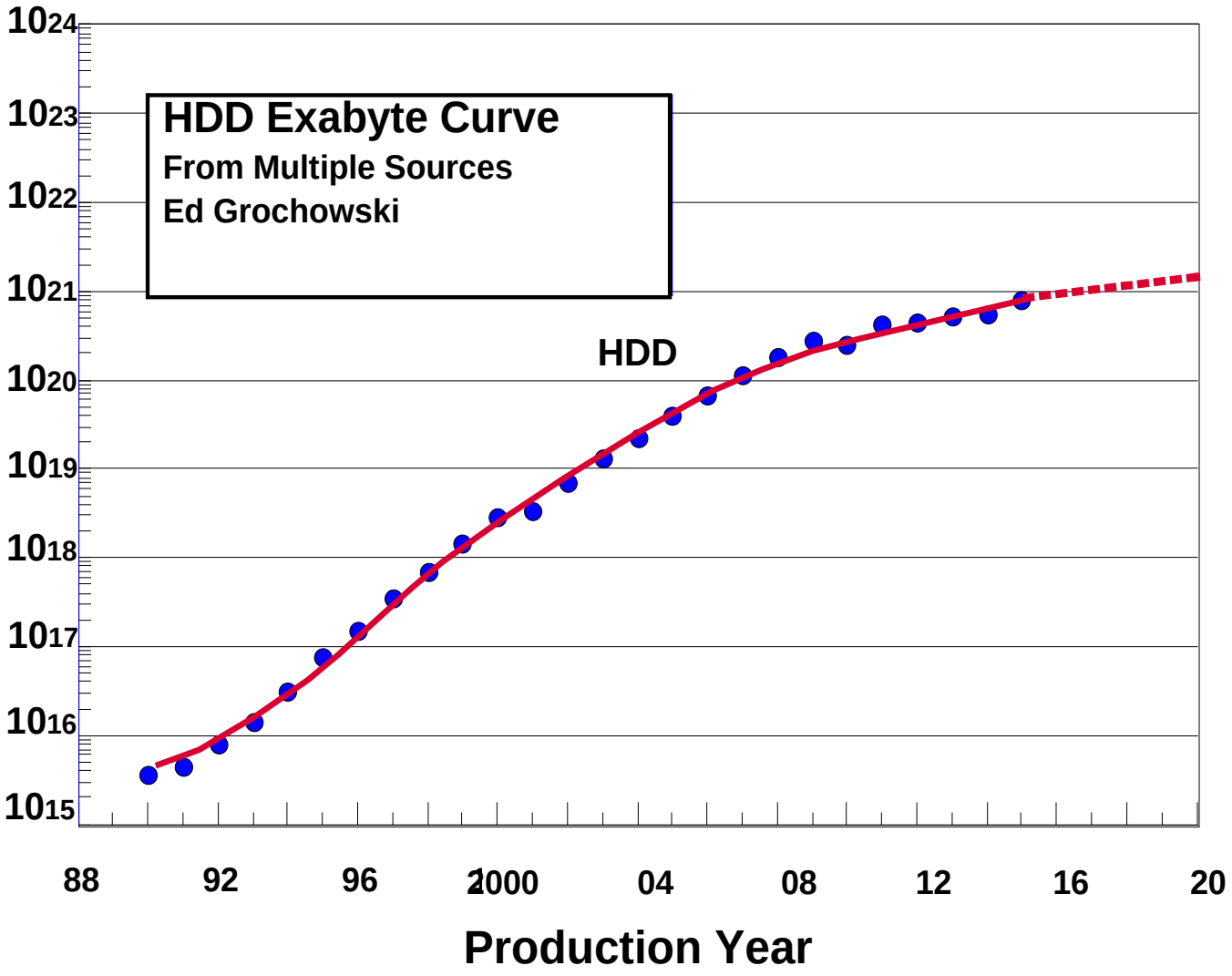
HGST
HelioSeal
Ultrastar He10
Enterprise Capacity
10TB
7200 RPM HDD


HDD Exabyte Curve
From Multiple Sources
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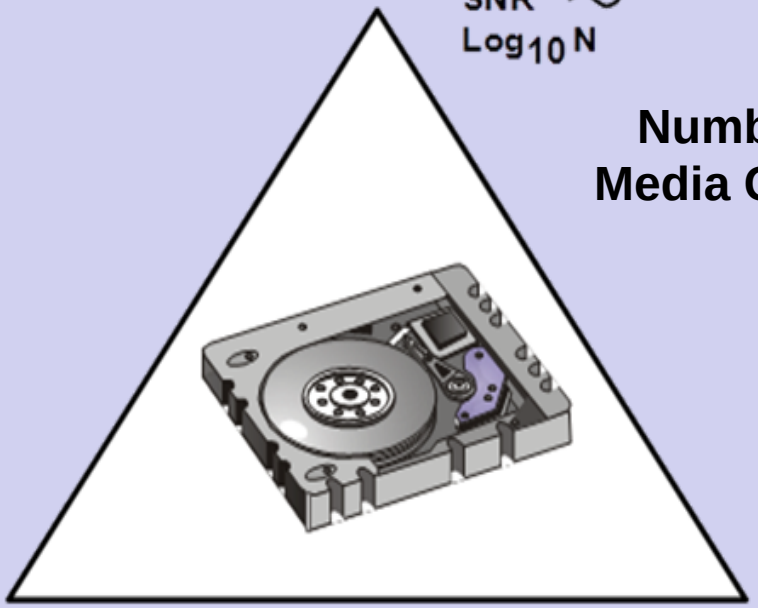
HDD
Bytes Shipped/Year
10^24
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
10^15
Zetabytes
Exabytes
Petabytes
88
92
96
2000
04
08
12
16
20
Production Year

TB2020B.PRZ


# MAGNETIC TECHNOLOGY TRILEMMA




**Number of Disk Media Grains, Grain Diam.**

**Write Head Field Limit**

**Magnetic Coercive Field, Volume of Media Grain**

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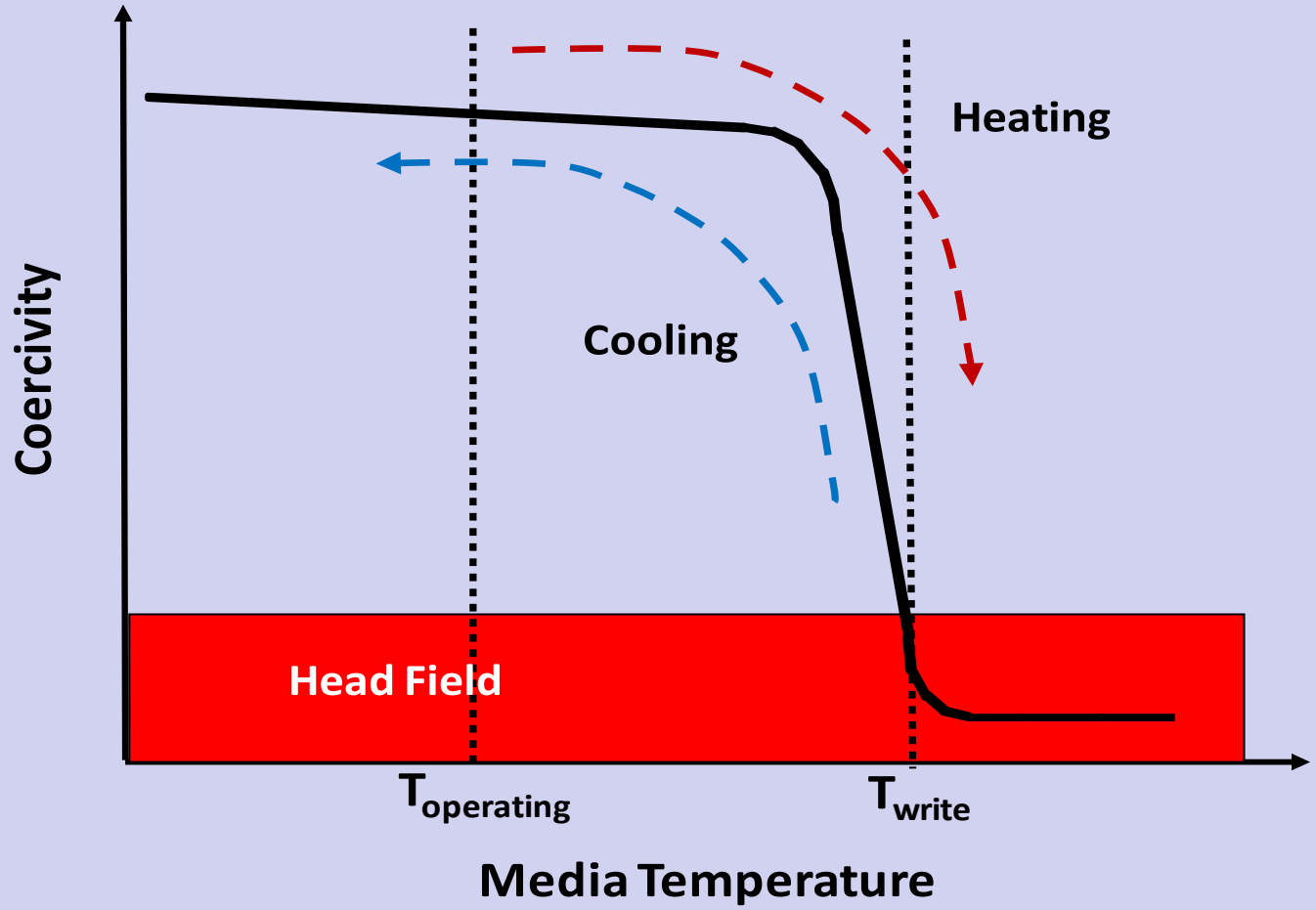
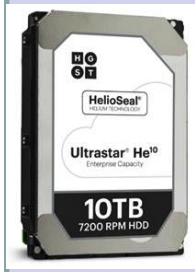
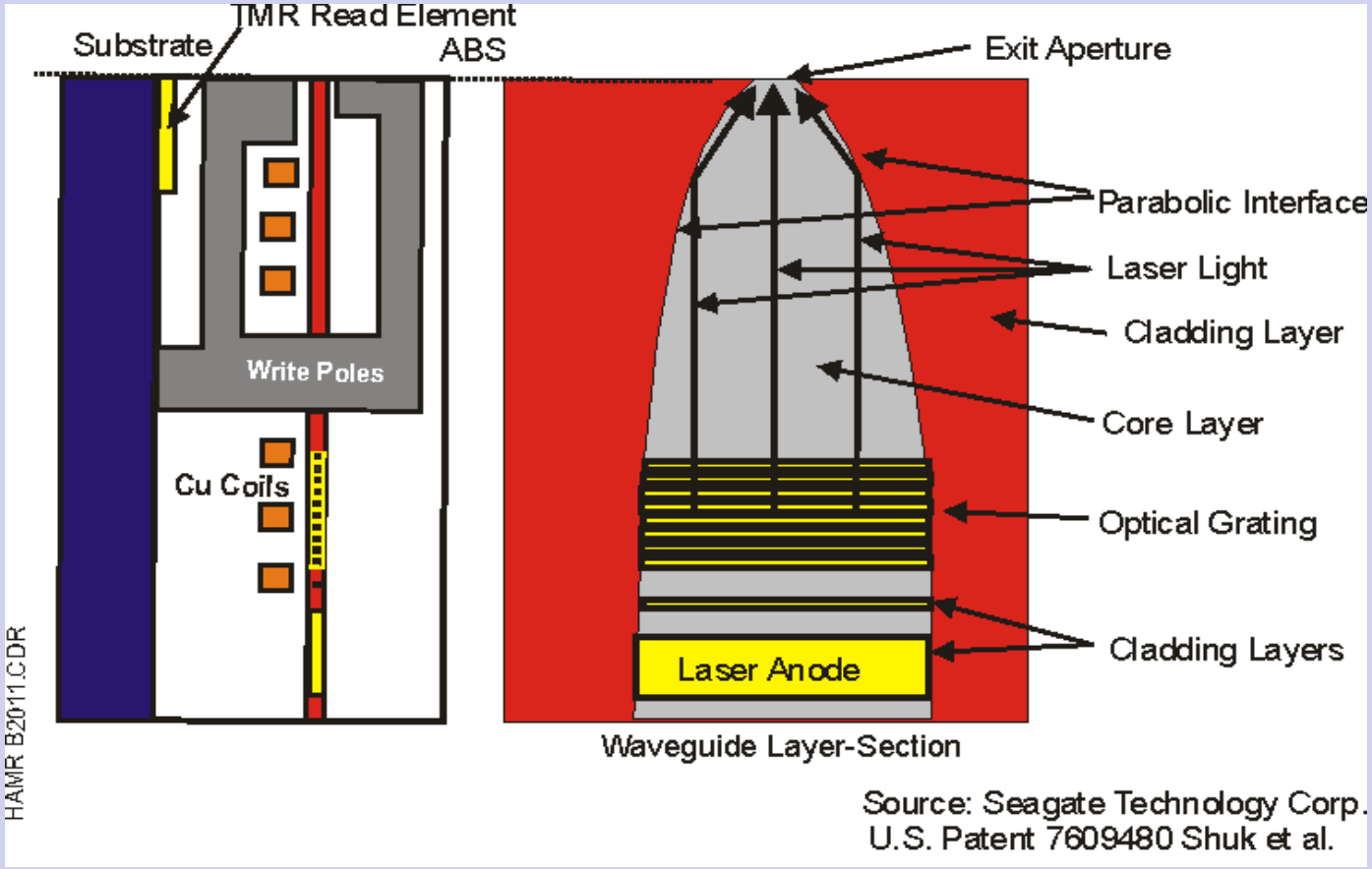
# Heat Activated Magnetic Recording (HAMR)

Source: Seagate Technology Corp.





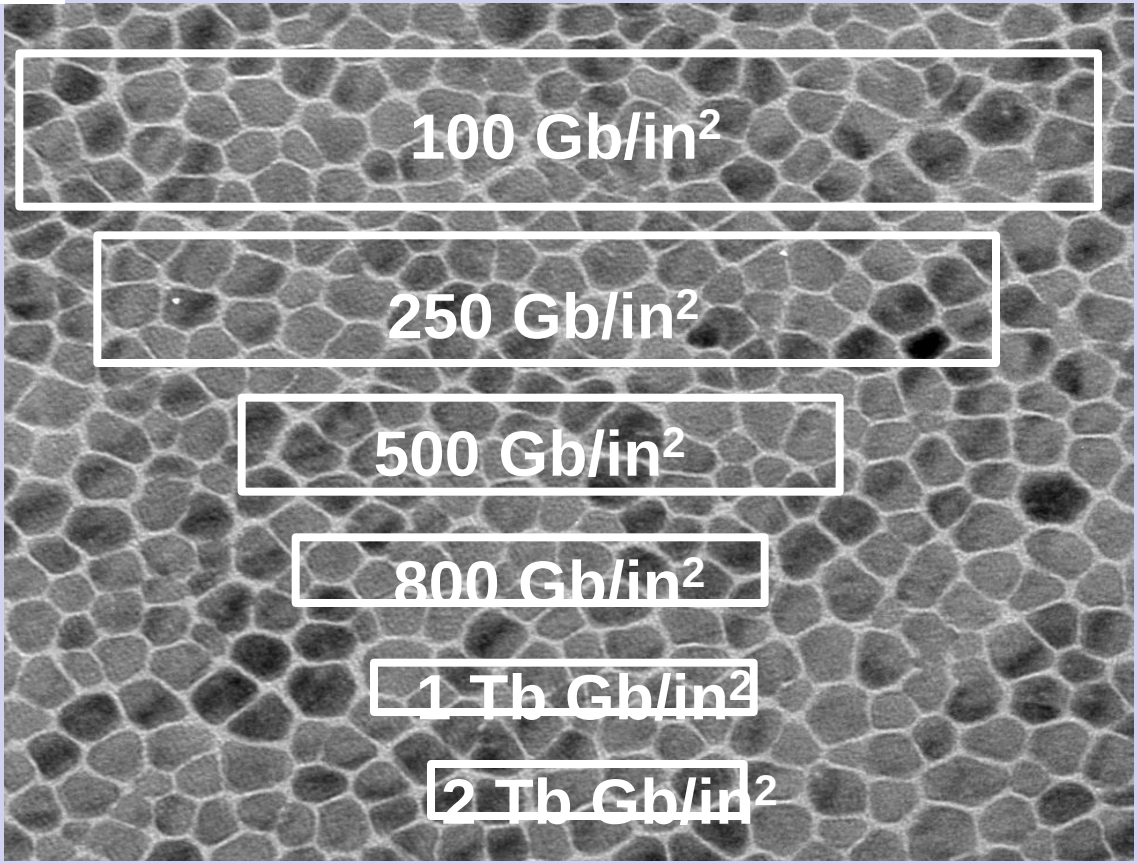

# HAMR HEAD w/LASER ELEMENT




# 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




~90Grains

~40Grains

~20Grains

~11Grains

~8Grains

~4-8Grains

Based on G. Bertero (WD) SCVM


Production Year

1997 1998 1999 2000 2001 2003 2013 2016 2020

Grain Diameter Perspective

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LMR PMR

LMR,PMR

HMR (Proj)

grain diameter nm

1E+2 10² 1E+1 10 1E+0 1

1 10 100 1000 10000

Areal Density, Gbits/sq.in.

Based on Weller &McDaniel, Bertero, Victora, Wang


Production Year

1991 1996 2000 2005 2016 2020

## Mag Spacing Perspective

Spacing nm

$10^3$ $10^2$ 10 1

HAMR Region?

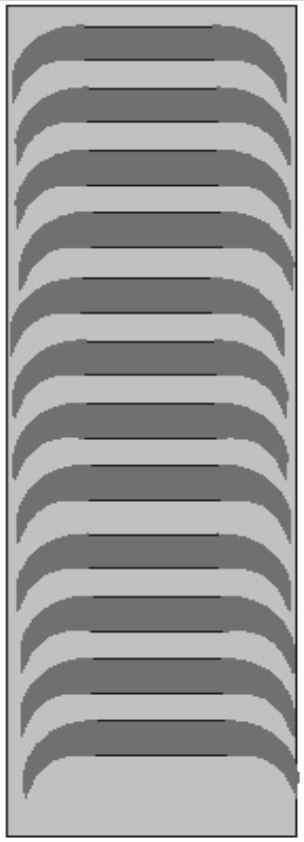
Based on Marchon & Olson, Victora & Wang and Other Sources

0.1 1 10 100 1000 10000

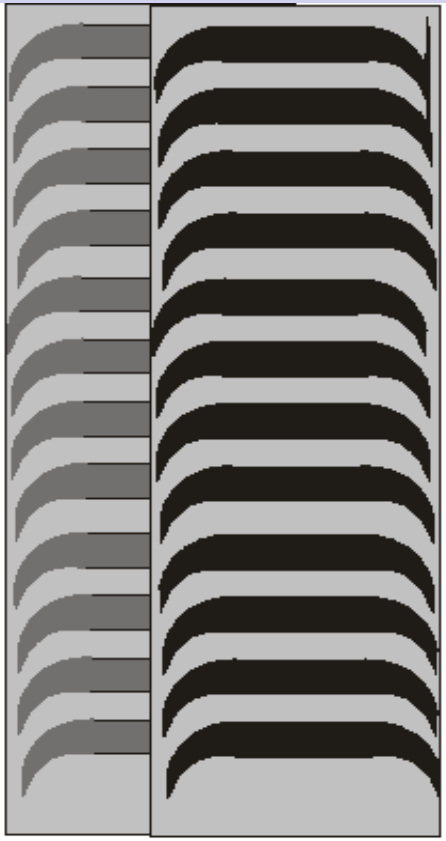
Areal Density, Gbits/in.sq.

magspac2016A.prz

# The Technology Of Shingled Writing



Shingled Write Dynamics



Erase Track Removes Significant Part Of Magnetized Energy In Data Bit

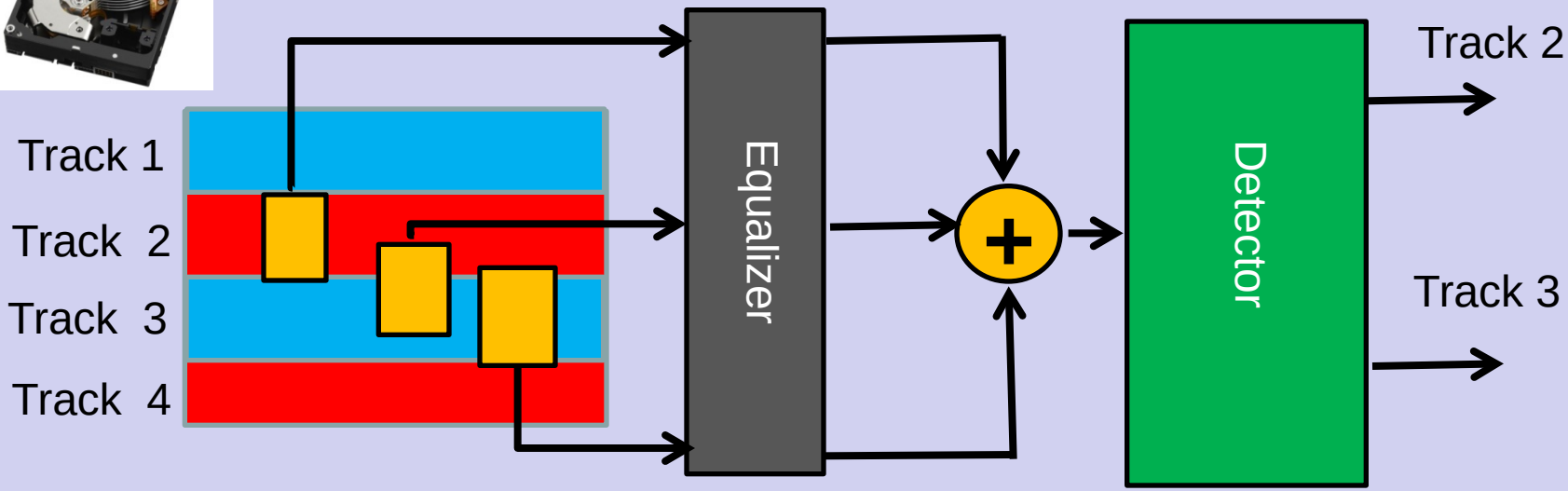
SMRErase2011.cdr

# The Perennial HDD-Storage Industry Workhorse

# 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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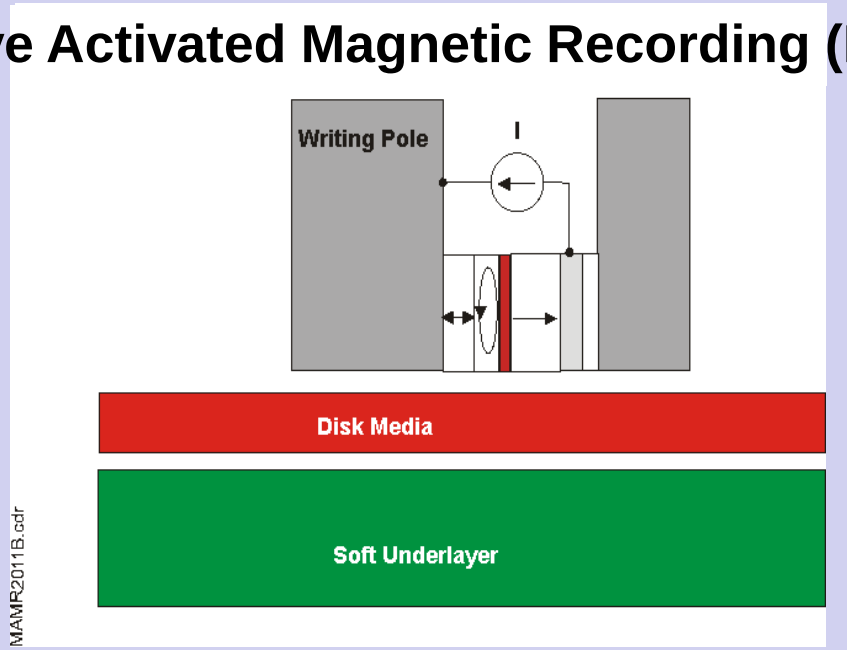
# Microwave Activated Magnetic Recording (MAMR)




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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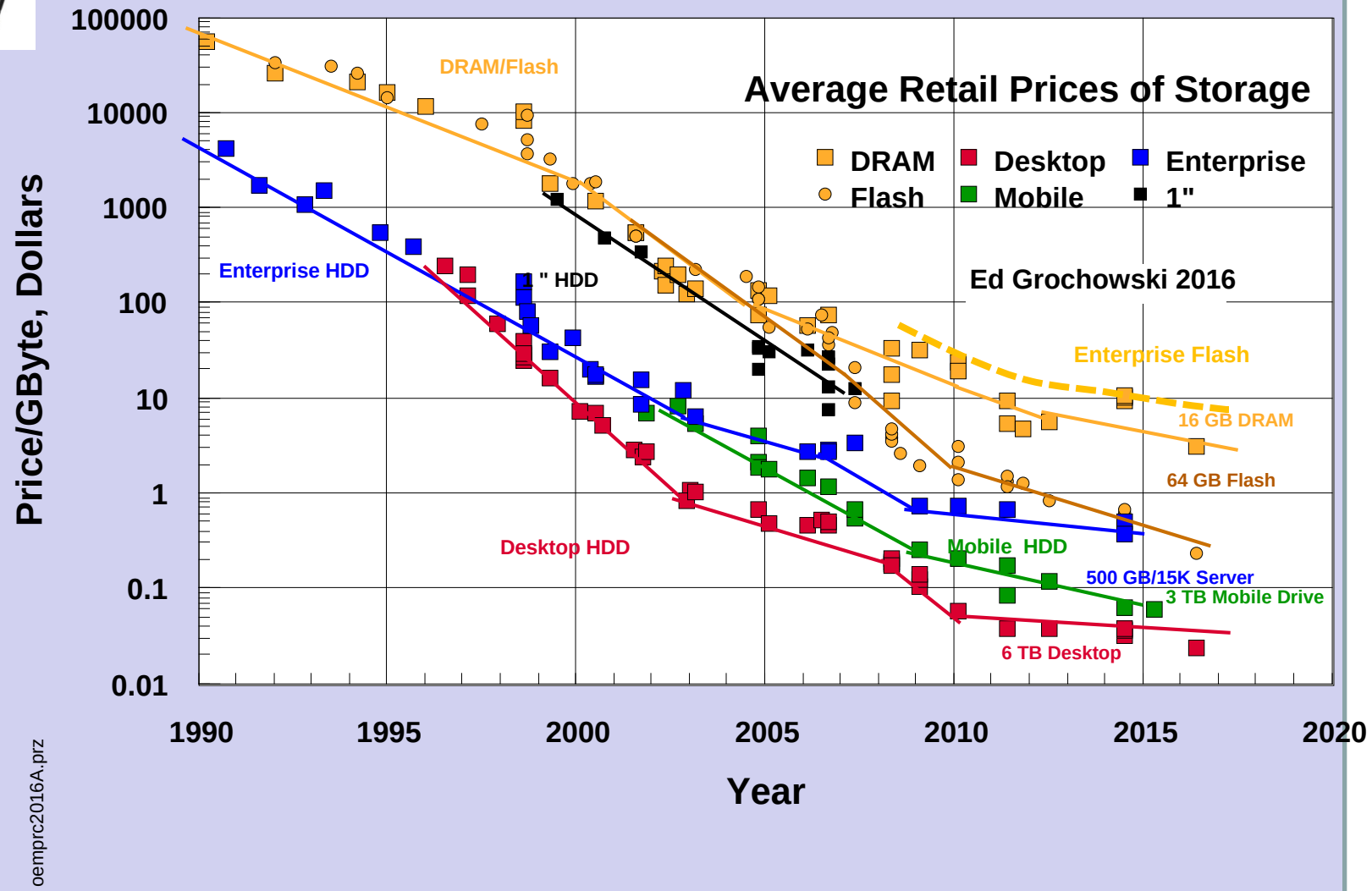
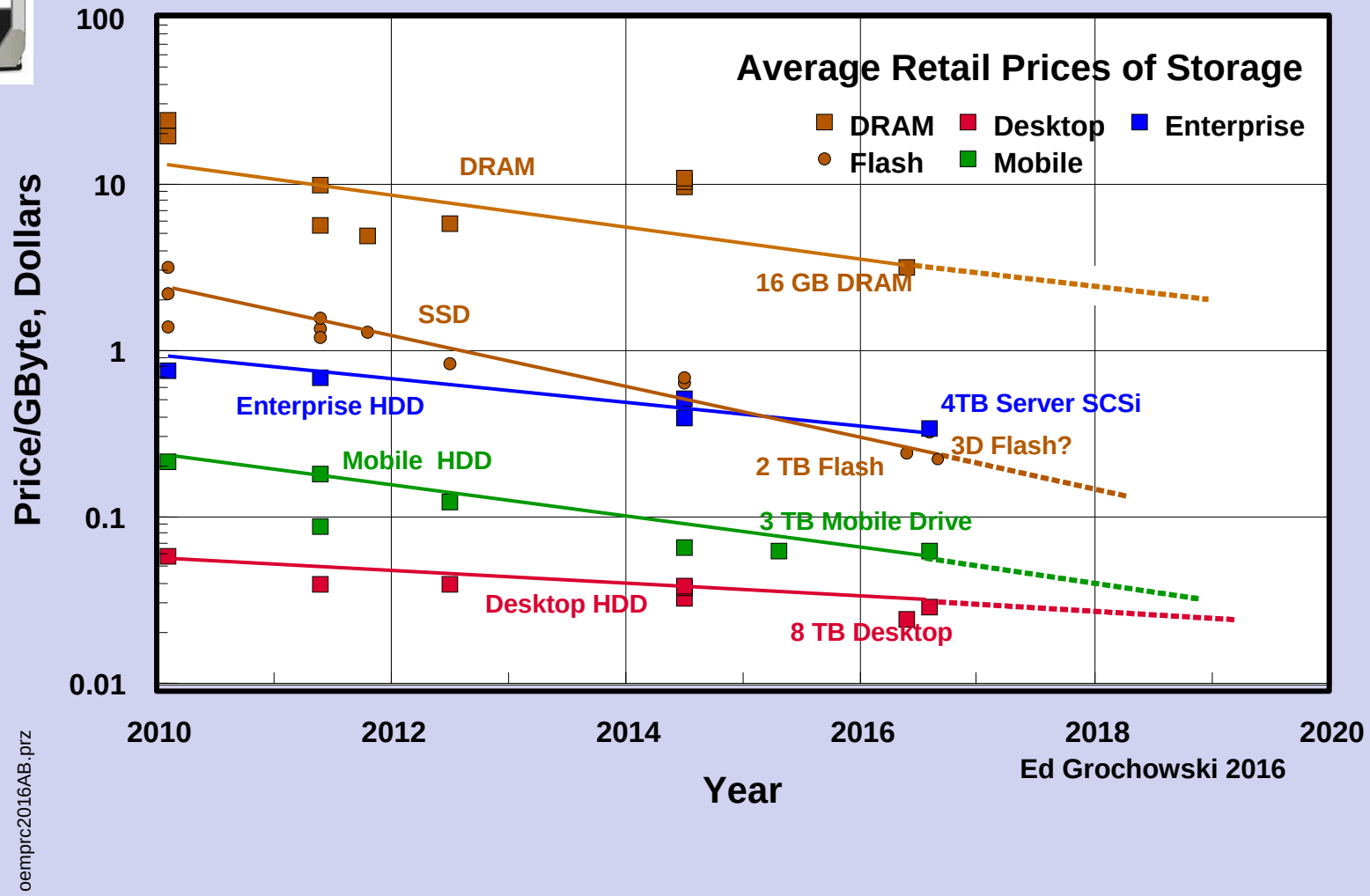

Average Retail Prices of Storage
DRAM
Flash
Desktop
Mobile
Enterprise
1"
Ed Grochowski 2016
DRAM/Flash
Enterprise HDD
1 " HDD
Desktop HDD
Mobile HDD
Enterprise Flash
16 GB DRAM
64 GB Flash
500 GB/15K Server
3 TB Mobile Drive
6 TB Desktop
Price/GByte, Dollars
100000
10000
1000
100
10
1
0.1
0.01
1990
1995
2000
2005
2010
2015
2020
Year
oemprc2016A.prz


HGST
HelioSeal
Ultrastar He10
10TB
7200 RPM HDD


Average Retail Prices of Storage
DRAM
Desktop
Enterprise
Flash
Mobile
Price/GByte, Dollars
100
10
1
0.1
0.01
2010
2012
2014
2016
2018
2020
Year
DRAM
16 GB DRAM
SSD
2 TB Flash
3D Flash?
Enterprise HDD
4TB Server SCSi
Mobile HDD
3 TB Mobile Drive
Desktop HDD
8 TB Desktop
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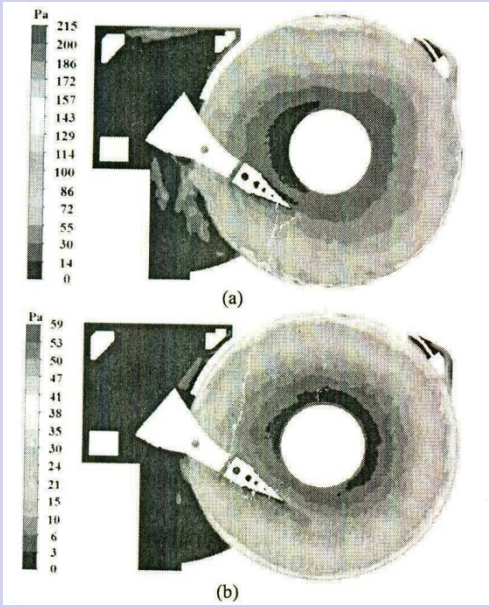
oemprc2016AB.prz


# 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 etal.
IEEETrans Mag. 52,4, 4/2016


Production Year

1991 1996 2000 2005 2015 2017

Spacing Perspective

Physical Spacing Includes Take Off Heights

Bit Length
Mag Spacing
Physical Spacing
Disk OC

Spacing nm

$10^3$

$10^2$

10

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

0.1 1 10 100 1000 10000

Areal Density, Gbits/in.sq.

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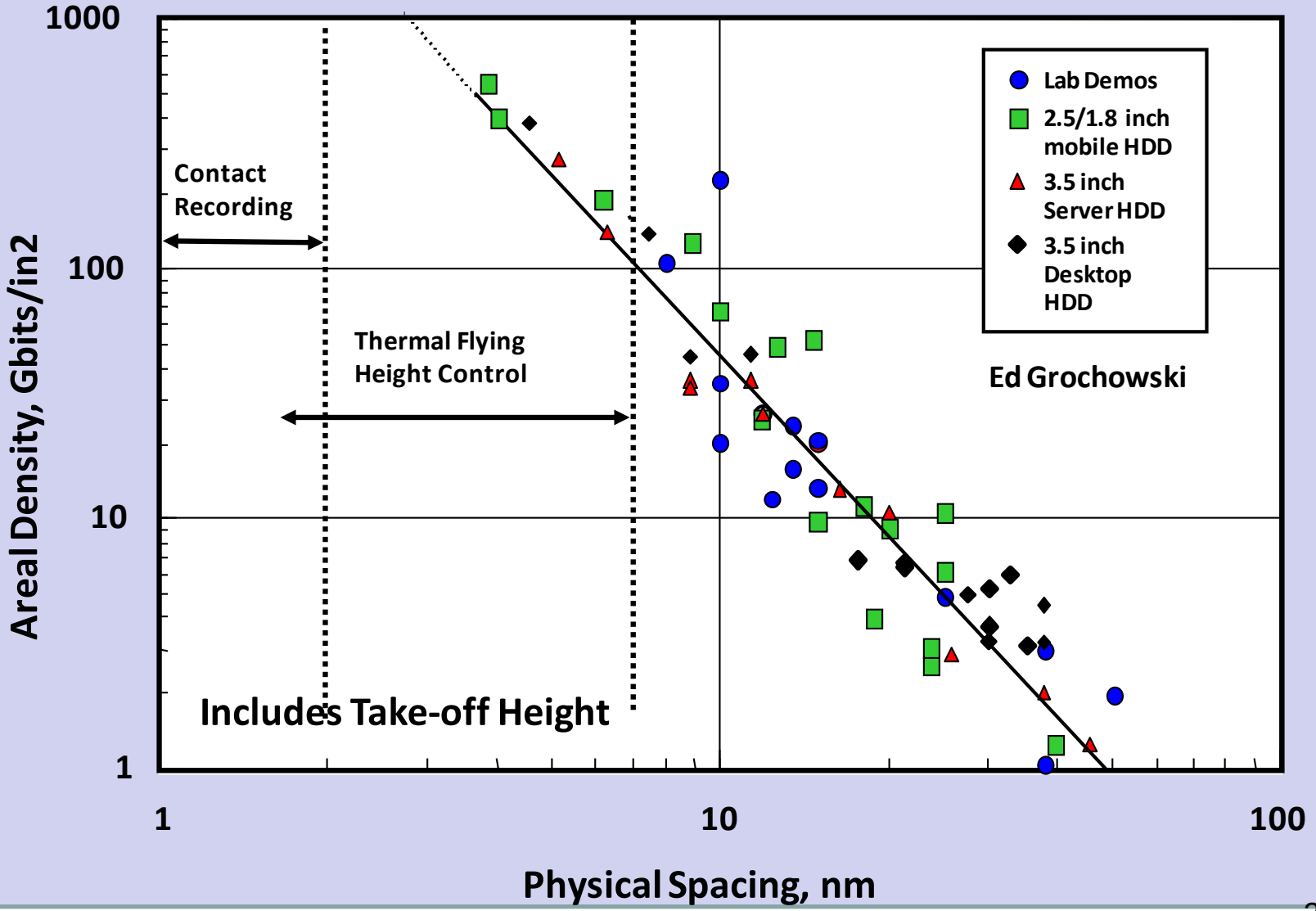
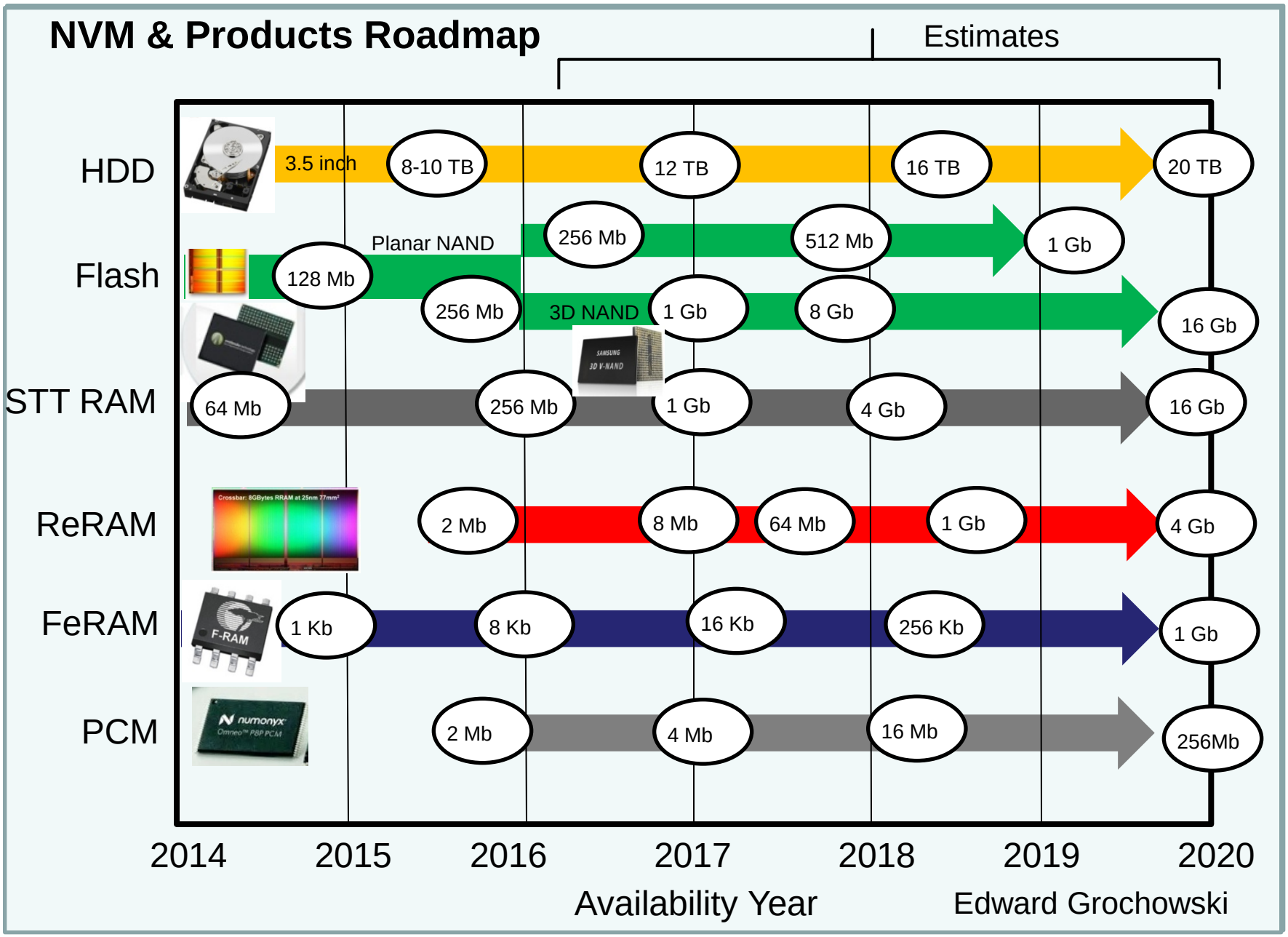
Spac2015A.prz

# Physical Spacing-Areal Density Perspective




spacing2008AB.ppt

# NVM & Products Roadmap




## HDD/Flash Areal Density Perspective

Areal Density Gigabits/in2

$10^4$
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-2}$

HDD Products
Flash Products

TMR Head
Perpendicular Recording
~13% CGR
40% CGR
1st AFC Media
100% CGR
1st GMR Head
60% CGR
1st MR Head

256 Gb 19nm TLC
128 Gb 19nm TLC
64 Gb 20nm
64 Gb (3 MLC ?)
32 Gb (2 MLC)
16 Gb (2 MLC)
8 Gb
4 Gb
2 Gb
1 Gb
512Mb
256Mb
64Mb
16Mb

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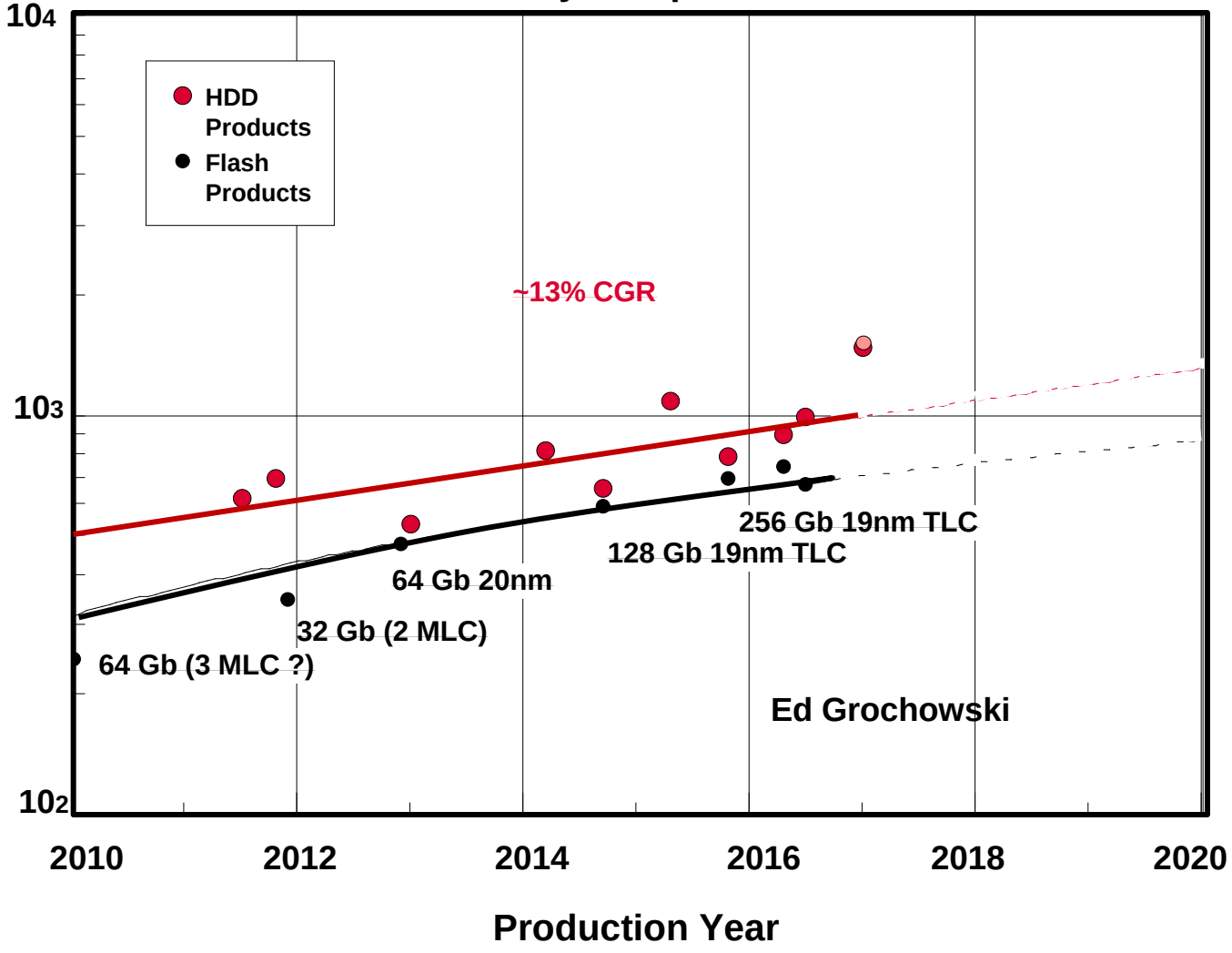
90 95 2000 2005 2010 2015 2020

Production Year

areal2020gR.prz

## HDD/Flash Areal Density Perspective

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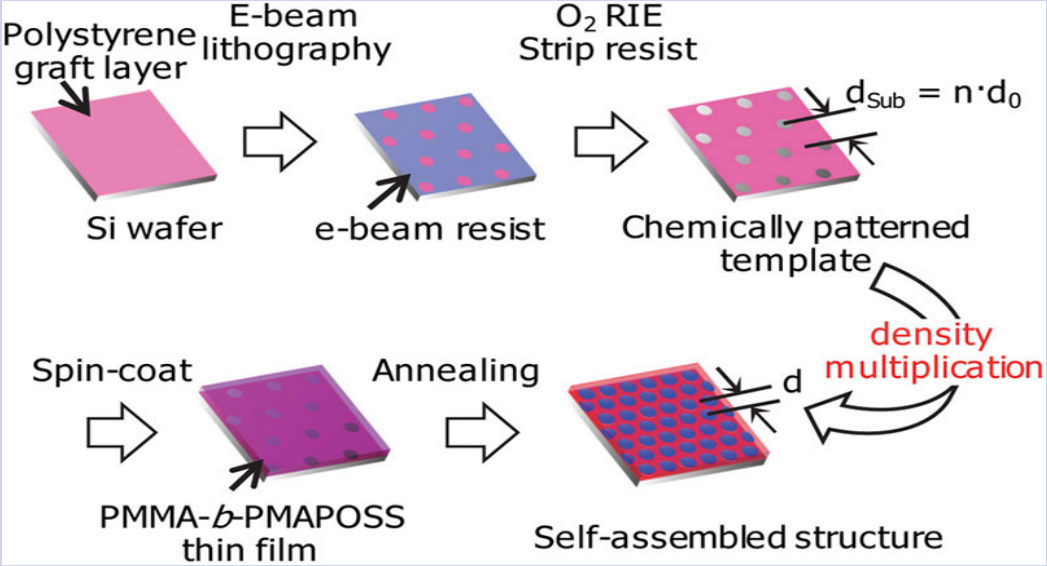
# Bit Patterned Media




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. **<u>Improbable</u> Mfg. (One Million Disks/Year X 2 Sided)**
6. **High Risk**


# HDD Technology Introduction

| Implementation probability | Technology | 2016 | 2020+ |
|---|---|---|---|
| High | Helium Ambient | Implemented | Implemented |
| | Shingle Write | Implemented | Implemented |
| | 2DMR | Development | Implemented 2017-2018 |
| | 8 + Disk HDD | Development | Implemented |
| Moderate | HAMR | Development | Implemented |
| Low | BPM/Thermal Dots | Development | Development |
| | MAMR | | |

## 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