Future Technology Challenges For NAND Flash And HDD Products

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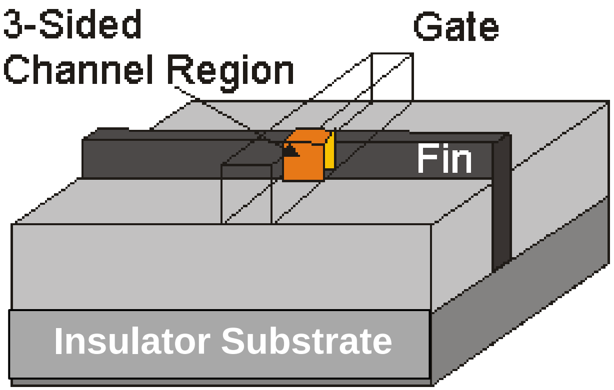
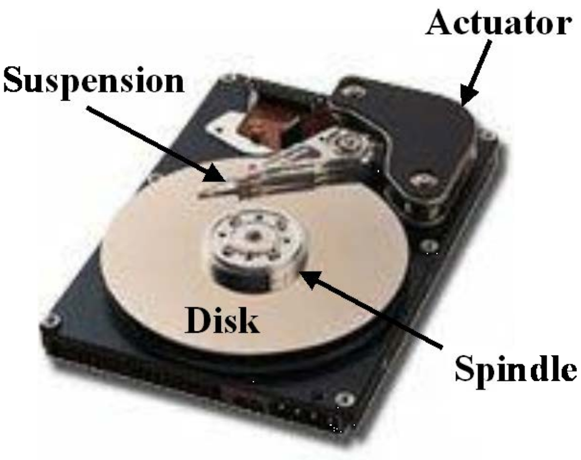
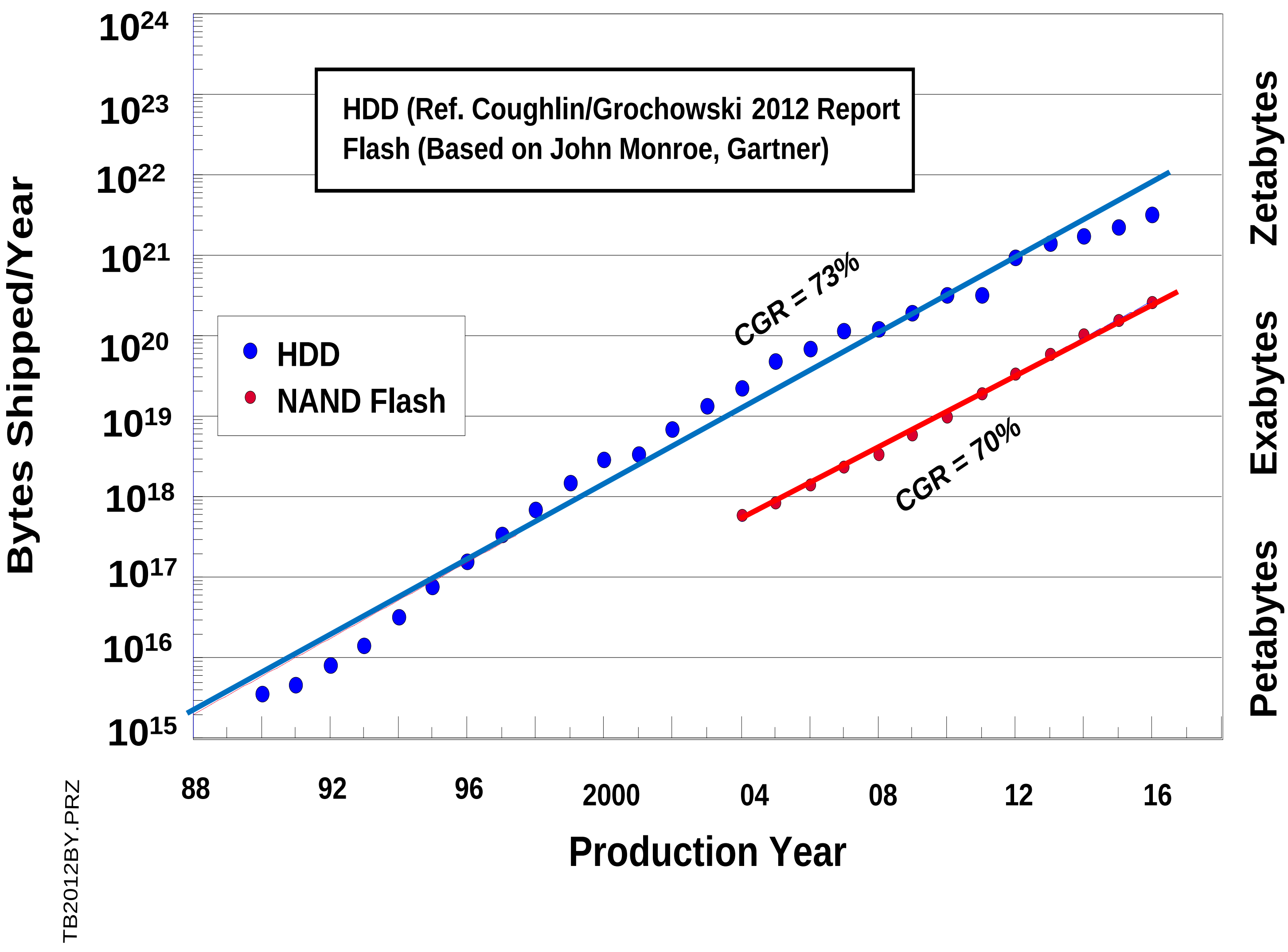




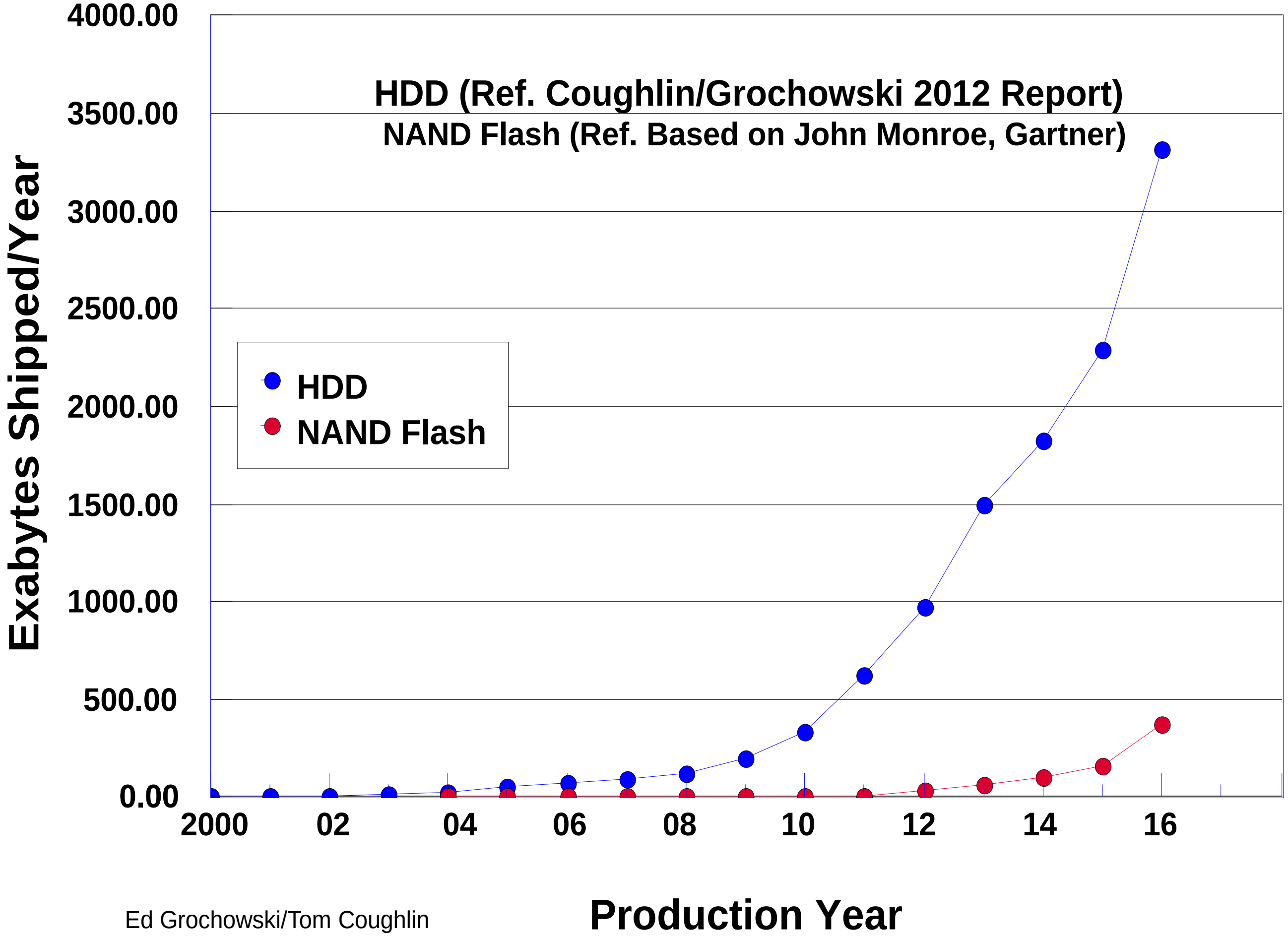
Introduction and Topics

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 and Flash Byte Ships



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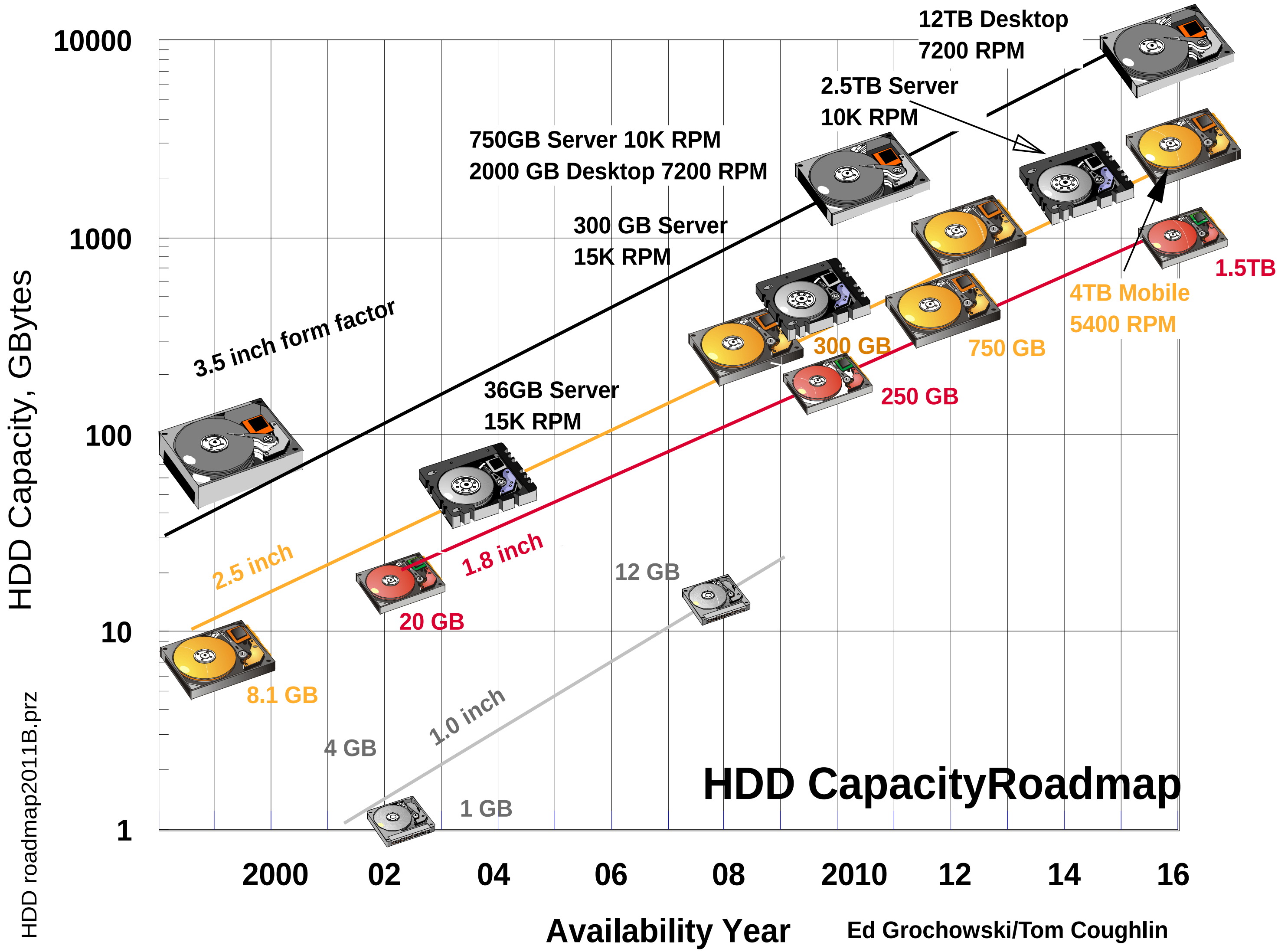
TB2012YZ.PRZ



10000
1000
100
10
1
HDD Capacity, GBytes
HDD roadmap2011B.prz
2000
02
04
06
08
2010
12
14
16
Availability Year
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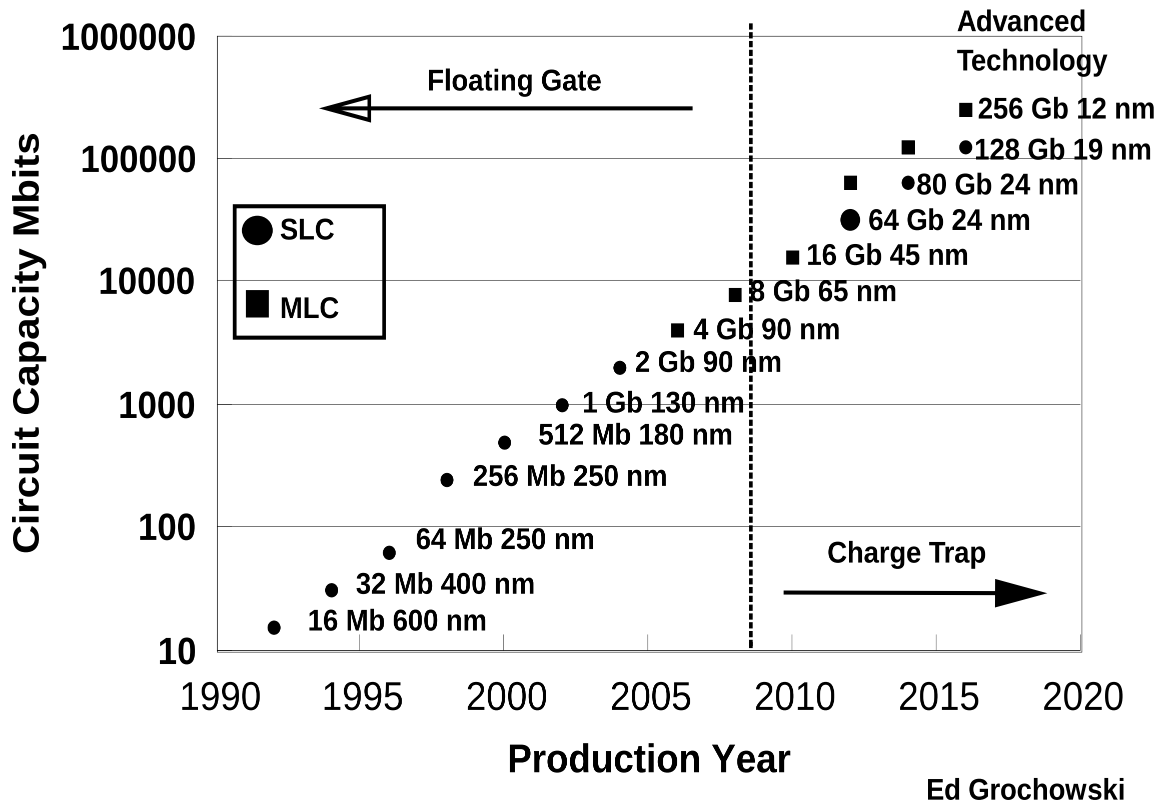
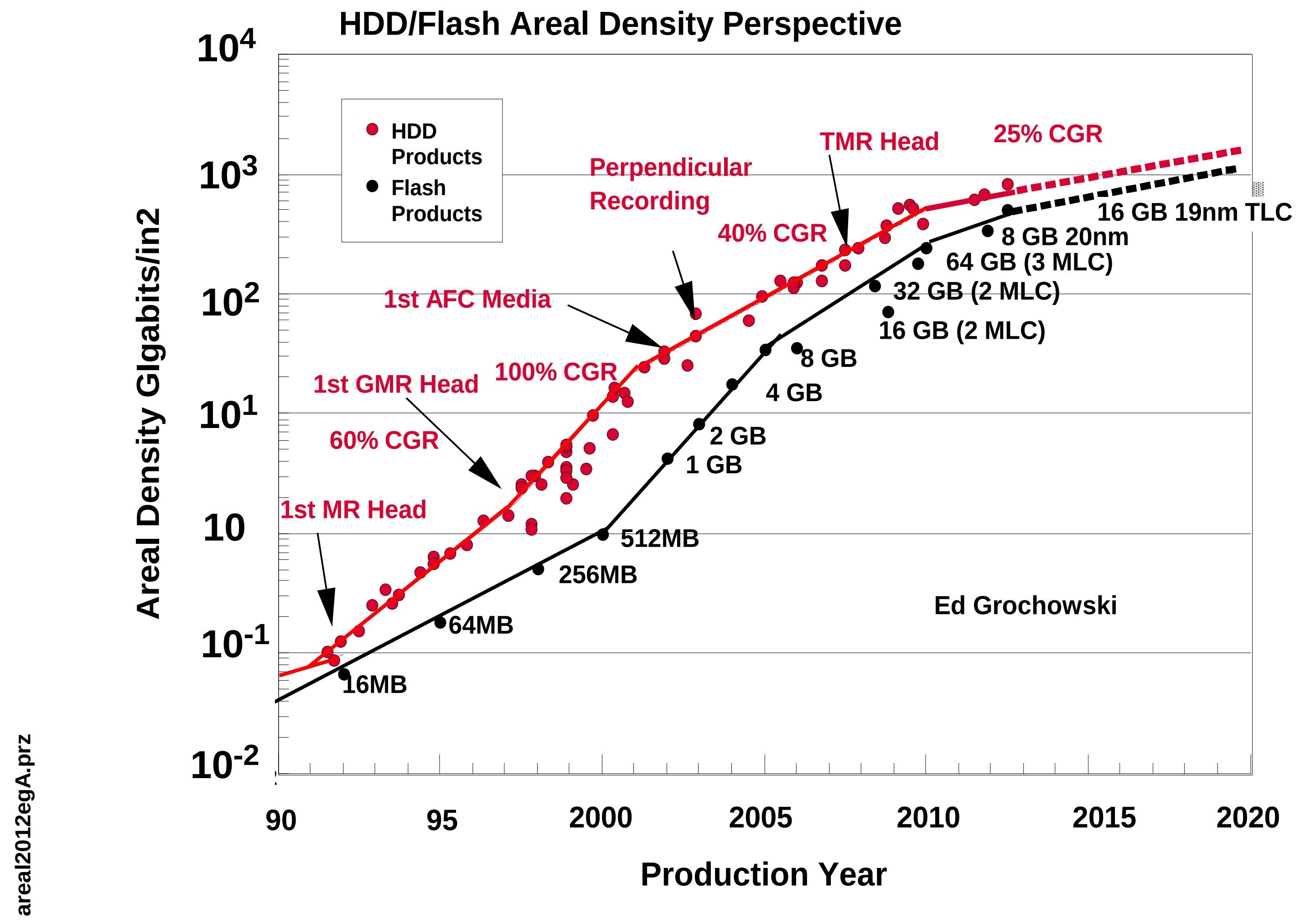
HDD CapacityRoadmap
12TB Desktop
7200 RPM
2.5TB Server
10K RPM
750GB Server 10K RPM
2000 GB Desktop 7200 RPM
300 GB Server
15K RPM
3.5 inch form factor
36GB Server
15K RPM
300 GB
750 GB
4TB Mobile
5400 RPM
1.5TB
250 GB
2.5 inch
1.8 inch
20 GB
12 GB
8.1 GB
4 GB
1.0 inch
1 GB

128 Gbit NAND 19nm
San Disk/Toshiba
2012

NAND Roadmap 2012X.prz

Projected NAND Flash Memory Circuit Density Roadmap




HDD/Flash Areal Density Perspective
Areal Density GIgabits/in2
Production Year
HDD Products
Flash Products
1st MR Head
60% CGR
1st GMR Head
100% CGR
1st AFC Media
Perpendicular Recording
40% CGR
TMR Head
25% CGR
16MB
64MB
256MB
512MB
1 GB
2 GB
4 GB
8 GB
16 GB (2 MLC)
32 GB (2 MLC)
64 GB (3 MLC)
8 GB 20nm
16 GB 19nm TLC
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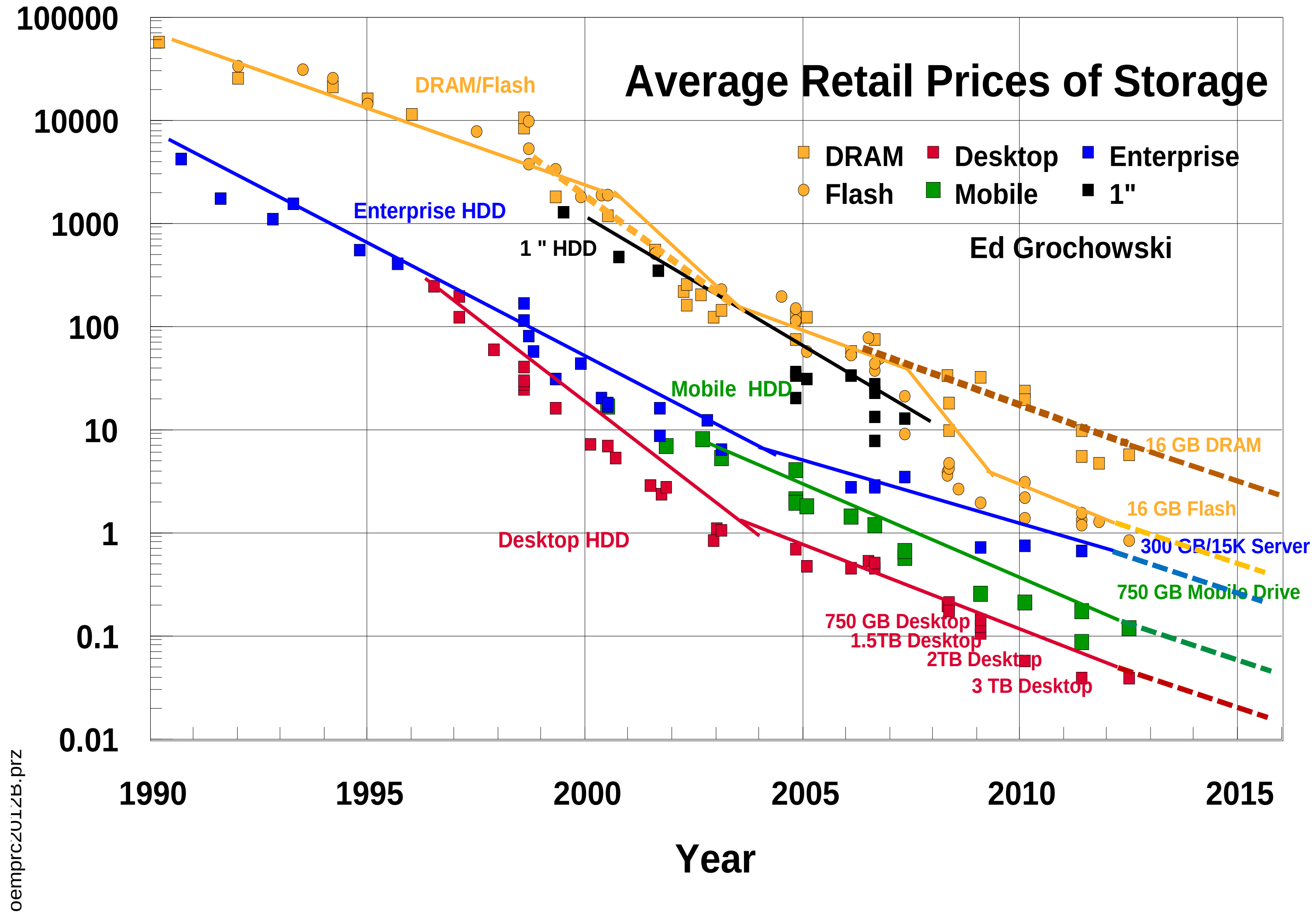
areal2012egA.prz



Average Retail Prices of Storage
DRAM
Flash
Desktop
Mobile
Enterprise
1"
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DRAM/Flash
Enterprise HDD
1 " HDD
Mobile HDD
Desktop HDD
16 GB DRAM
16 GB Flash
300 GB/15K Server
750 GB Mobile Drive
750 GB Desktop
1.5TB Desktop
2TB Desktop
3 TB Desktop
100000
10000
1000
100
10
1
0.1
0.01
1990
1995
2000
2005
2010
2015
Year
oemprc2012B.prz

Three HDD "Innovations"

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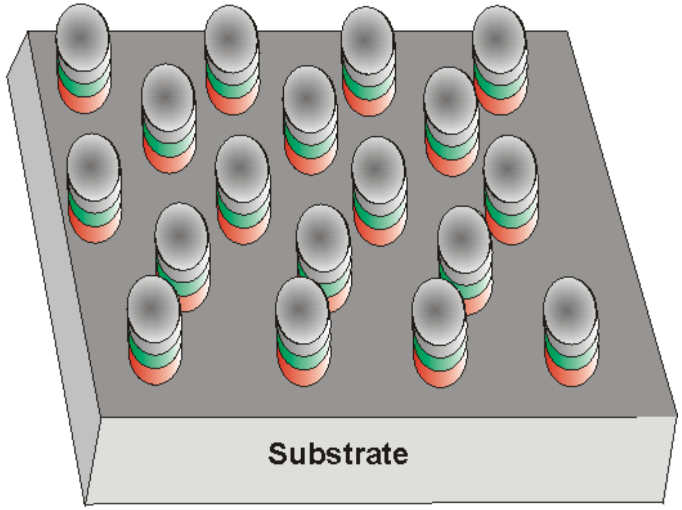
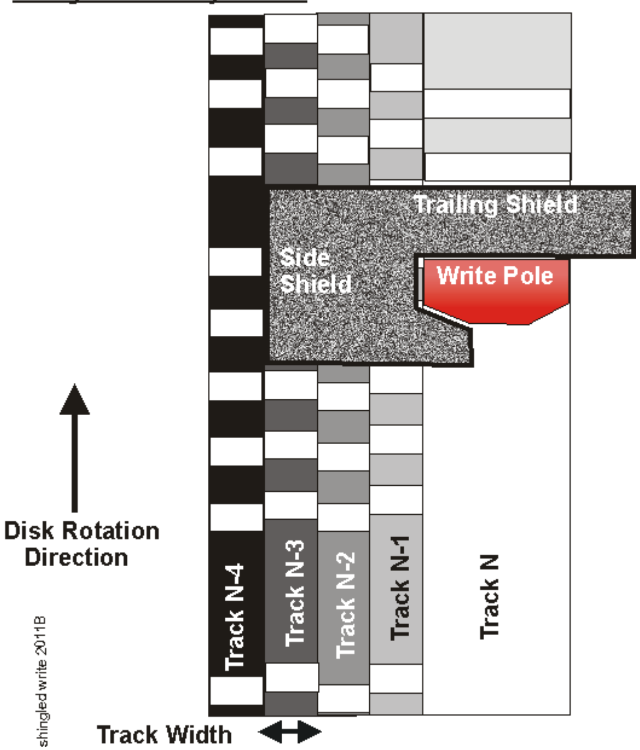
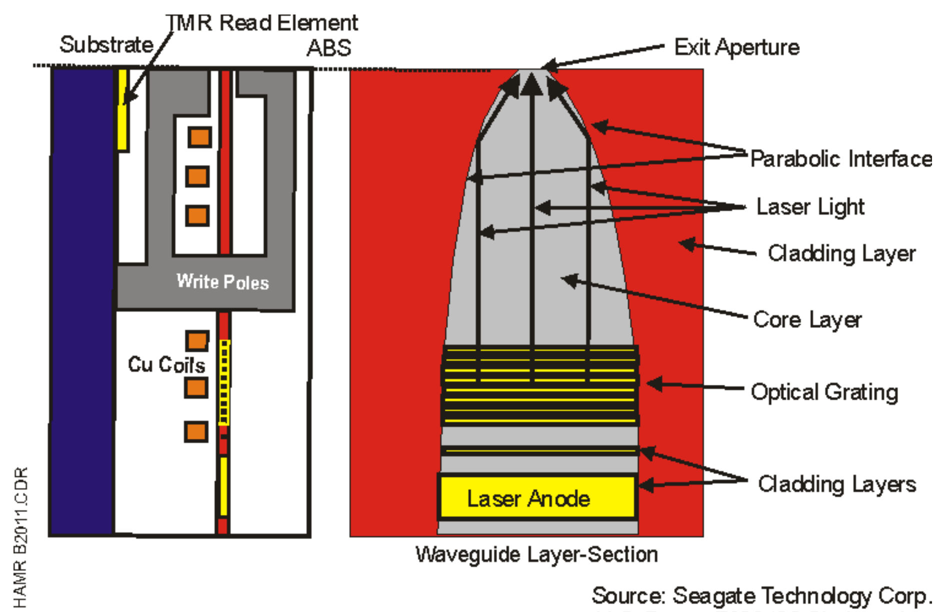
Magnetic "Islands"
BAR =2-4



Shingled Write

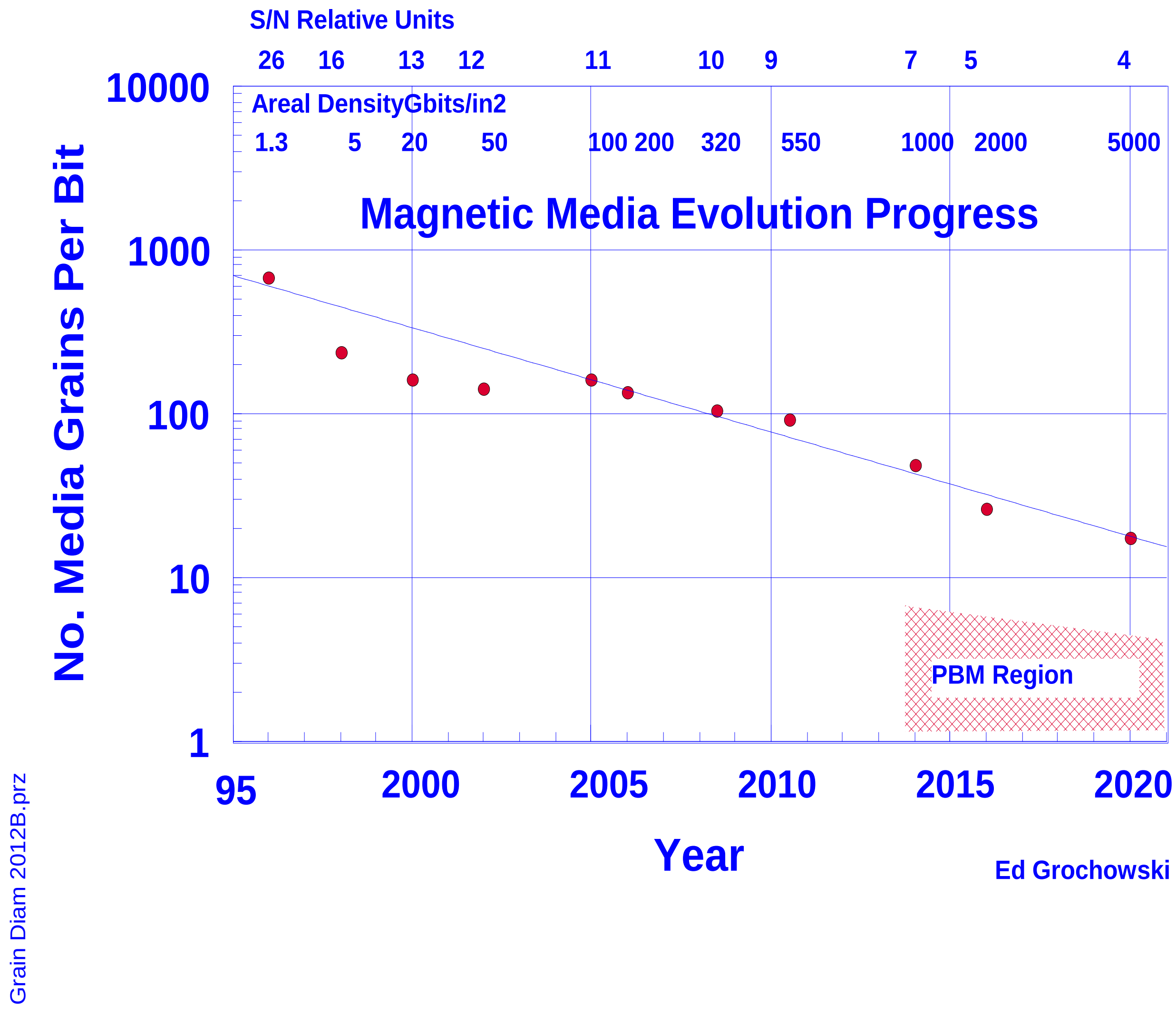
Shingled Write Dynamics





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

Heat Activated Magnetic Recording Head (HAMR)


S/N Relative Units
26 16 13 12 11 10 9 7 5 4
Areal DensityGbits/in2
1.3 5 20 50 100 200 320 550 1000 2000 5000
Magnetic Media Evolution Progress
No. Media Grains Per Bit
10000
1000
100
10
1
95 2000 2005 2010 2015 2020
Year
PBM Region
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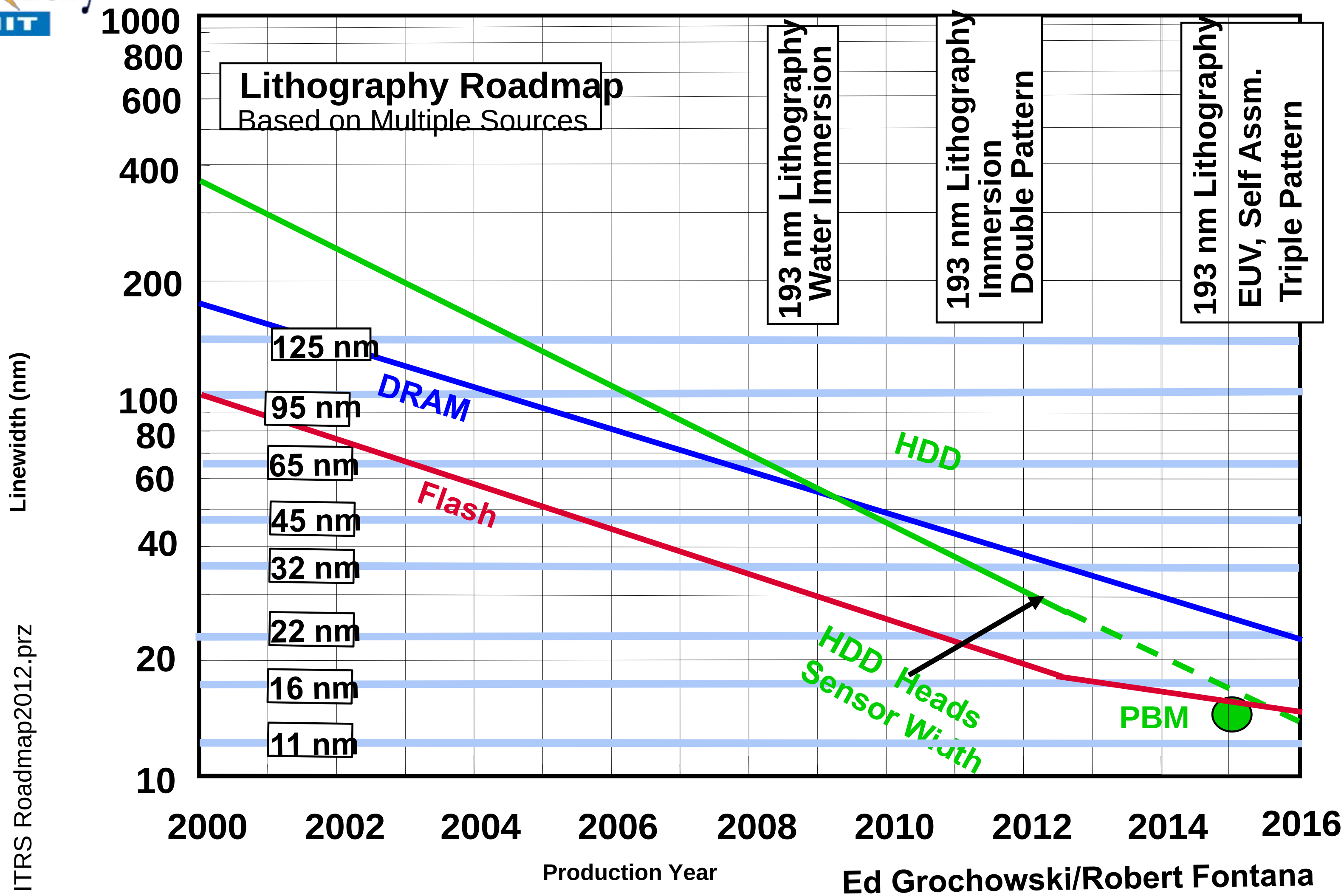
Grain Diam 2012B.prz



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
1000
800
600
400
200
100
80
60
40
20
10
Linewidth (nm)
125 nm
95 nm
65 nm
45 nm
32 nm
22 nm
16 nm
11 nm
DRAM
Flash
HDD
HDD Heads
Sensor Width
PBM
2000
2002
2004
2006
2008
2010
2012
2014
2016
Production Year
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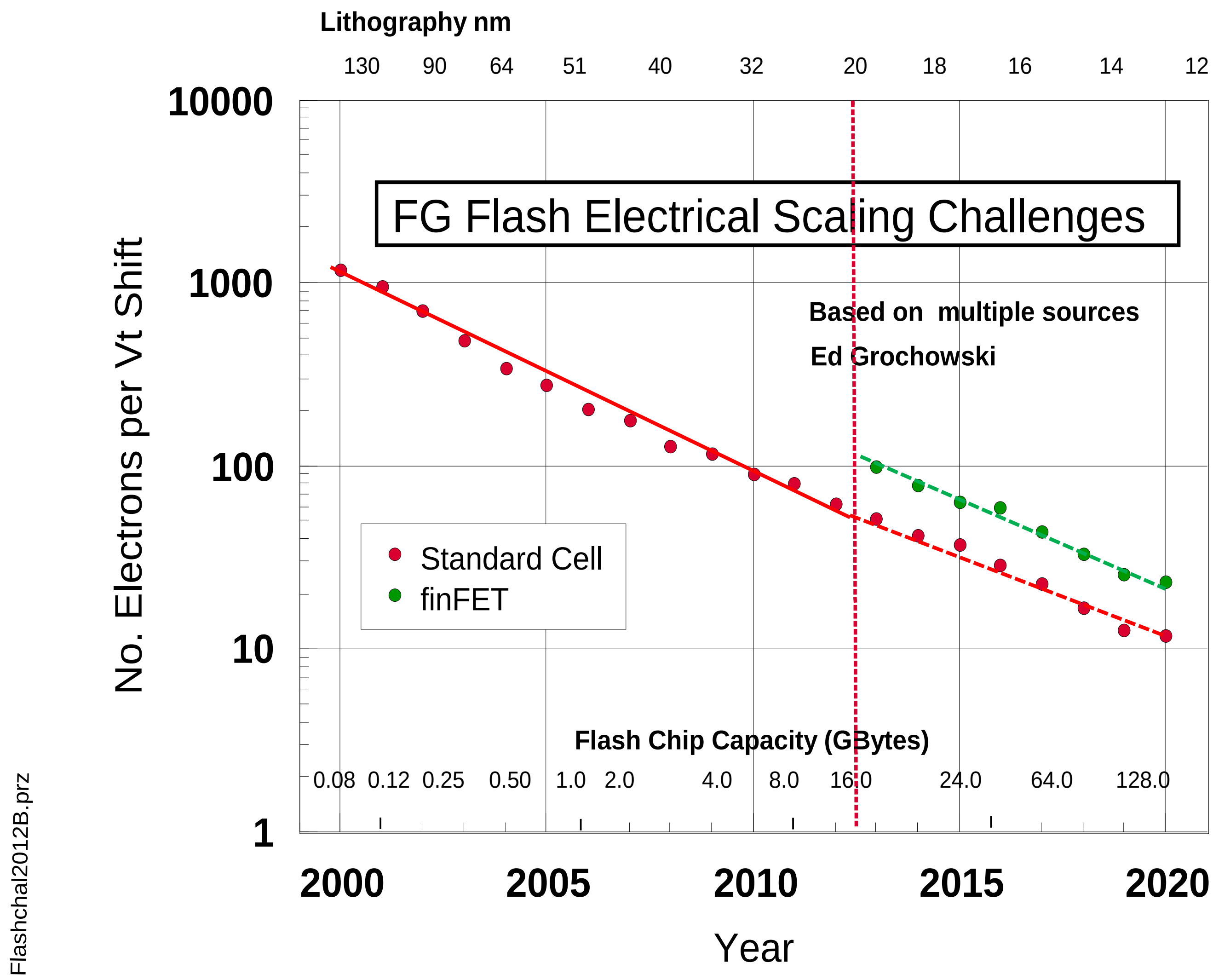
ITRS Roadmap2012.prz


Lithography nm
130 90 64 51 40 32 20 18 16 14 12
FG Flash Electrical Scaling Challenges
Based on multiple sources
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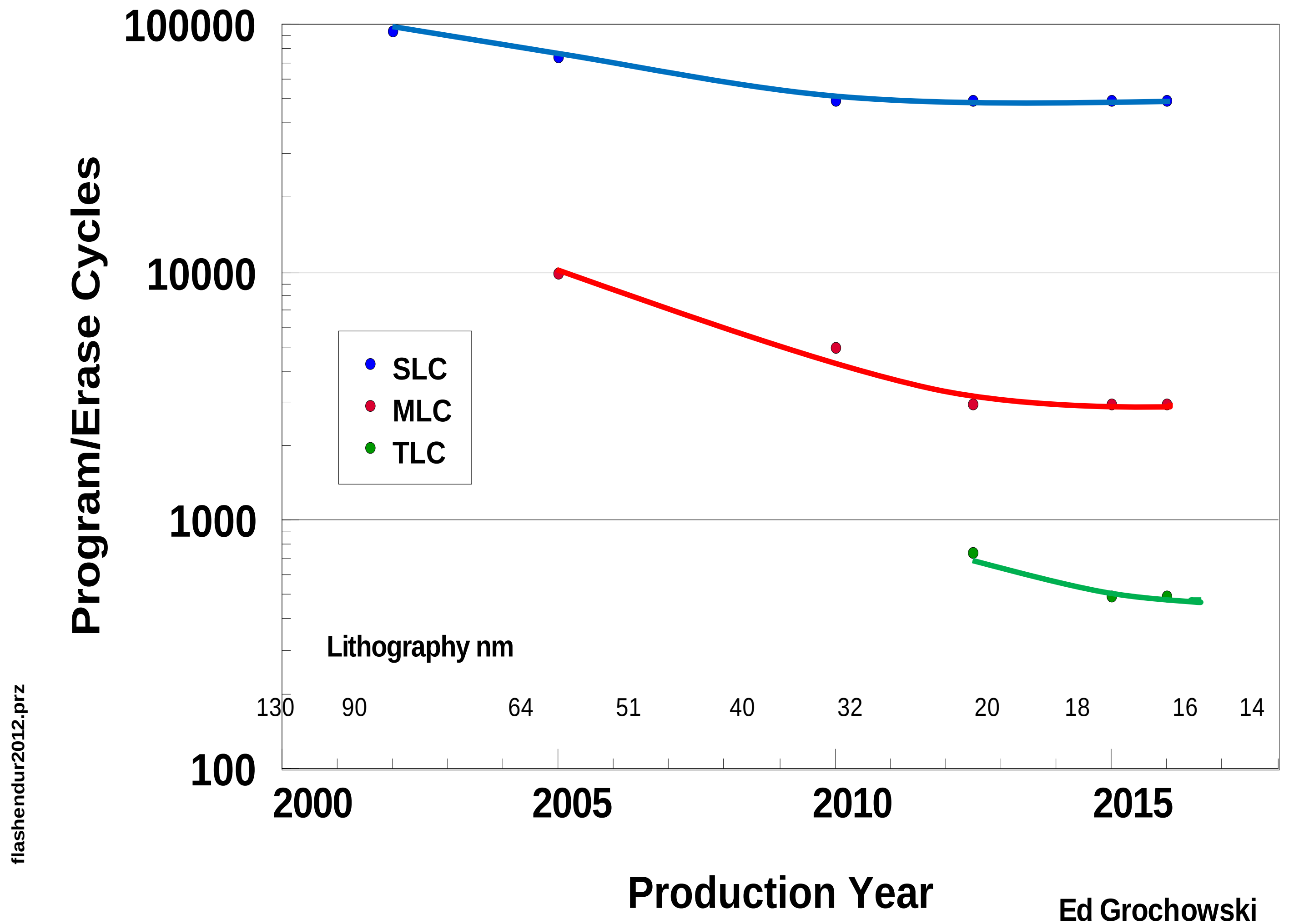
Standard Cell
finFET
Flash Chip Capacity (GBytes)
0.08 0.12 0.25 0.50 1.0 2.0 4.0 8.0 16.0 24.0 64.0 128.0
10000
1000
100
10
1
No. Electrons per Vt Shift
2000 2005 2010 2015 2020
Year
Flashchal2012B.prz

NAND Flash Memory Endurance Properties



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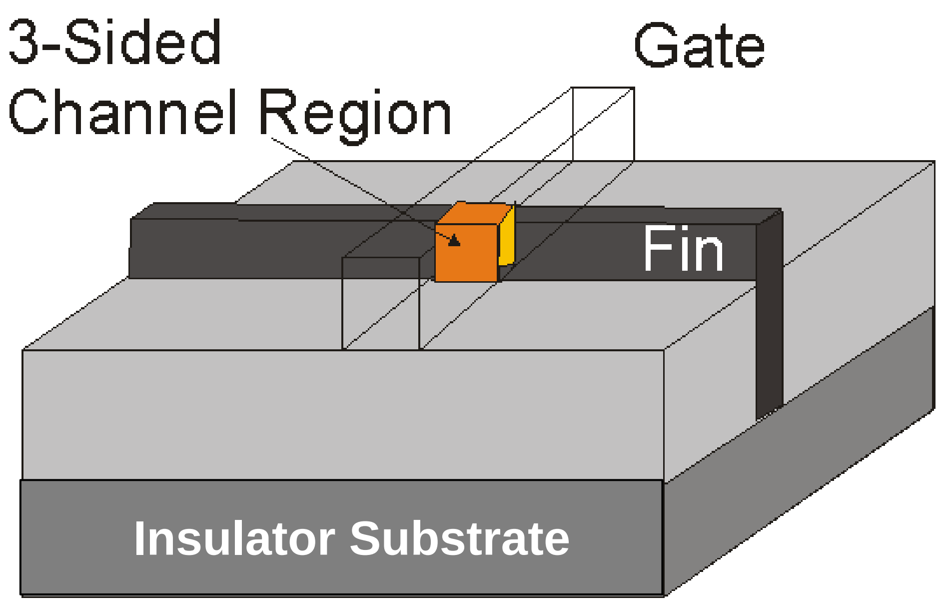
The Promise of finFET Flash



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

Based on INTEL 2012
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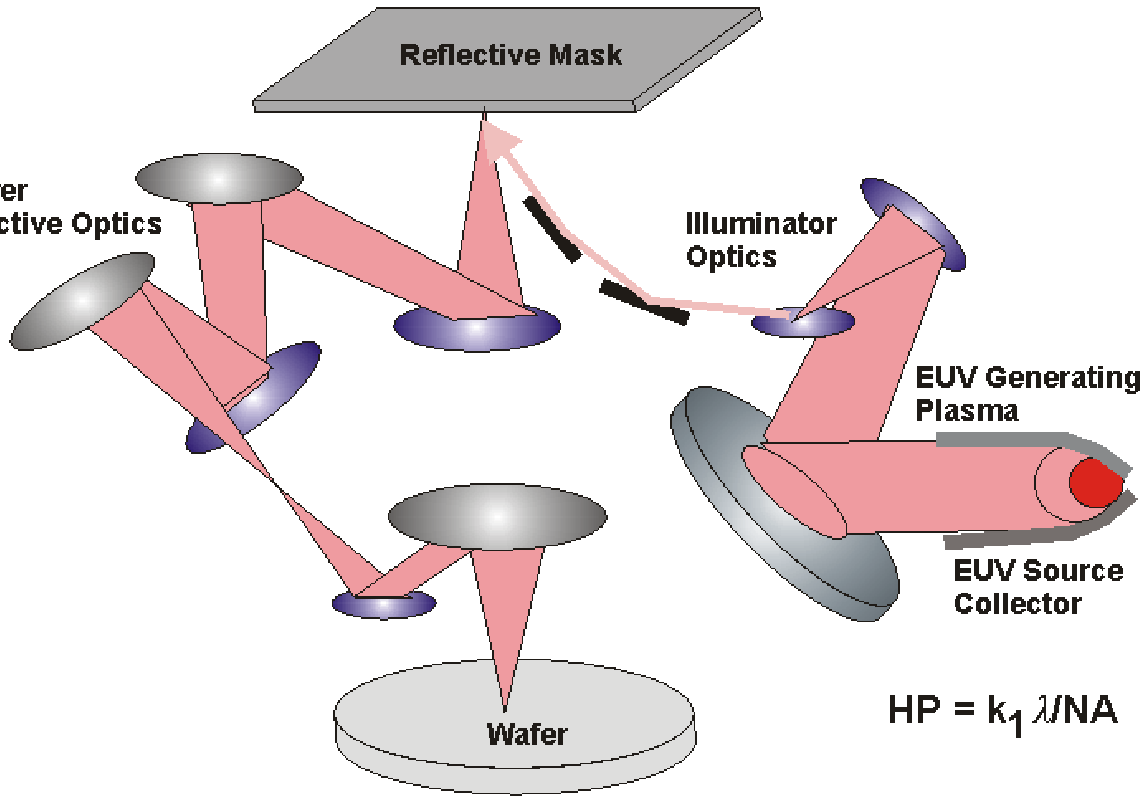
The Future Promise of EUV



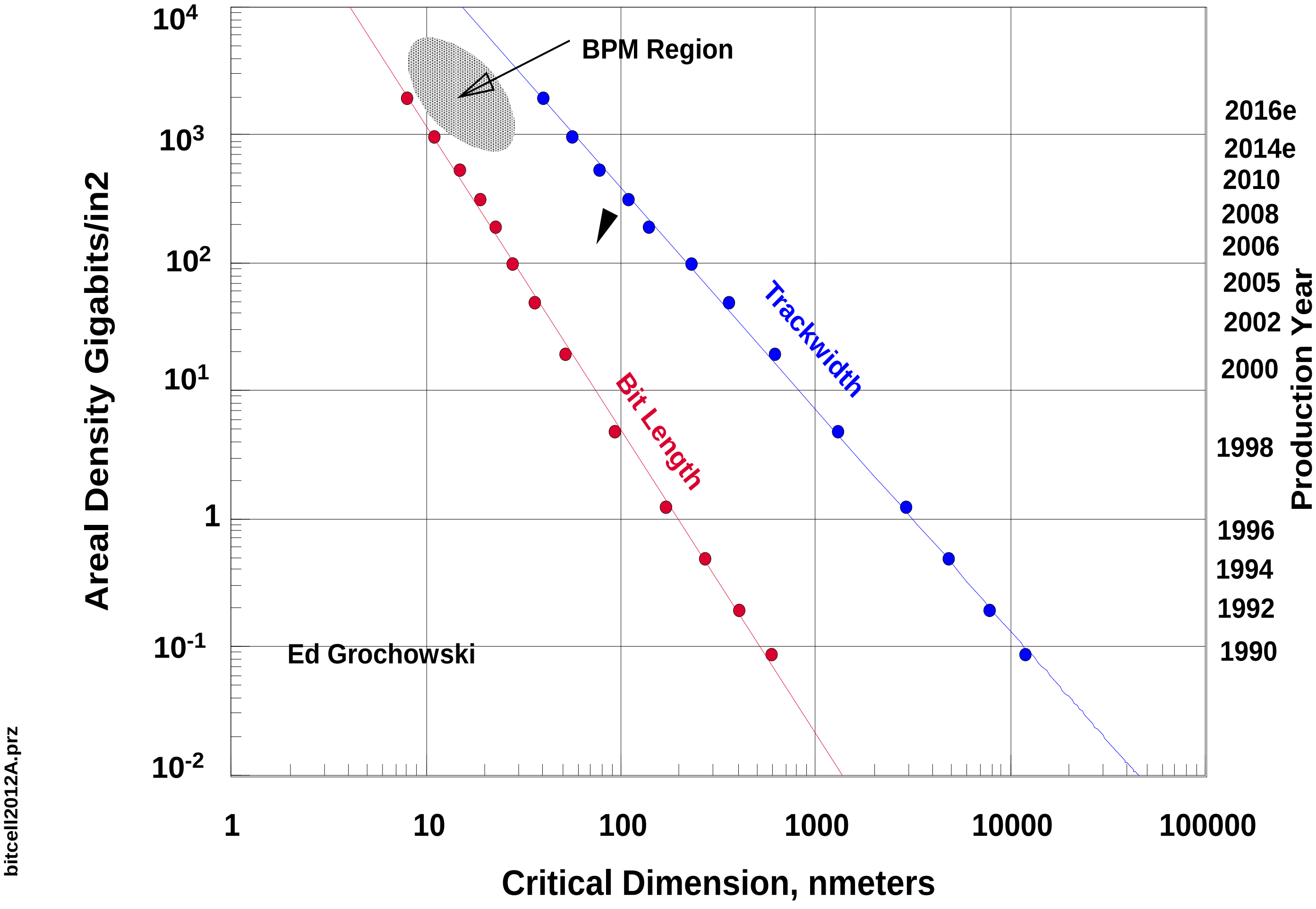
EUV Exposure Tool

$$HP = k_1 \lambda/NA$$

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

Ref. Coughlin/Grochowski 2012 Report

HDD Critical Dimensions



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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

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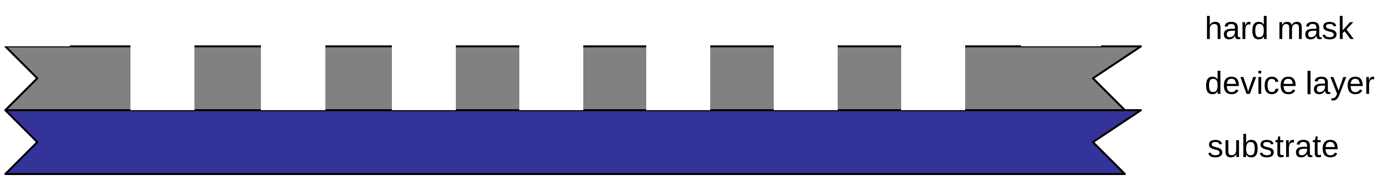
Double Patterning



14) Strip hard mask

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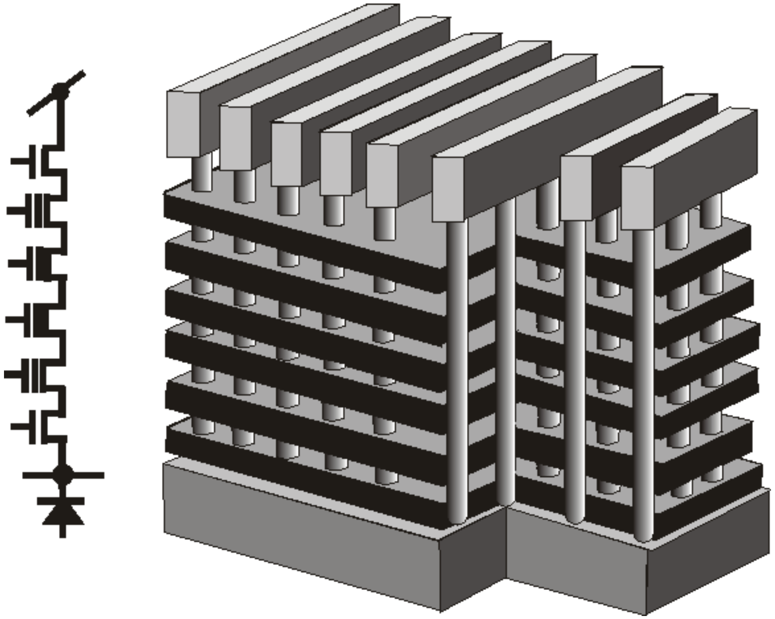
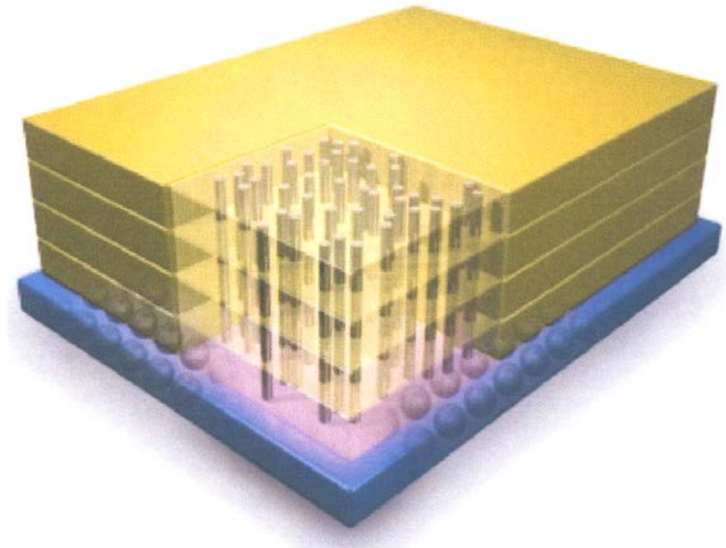
3D Packing Technology



3D NAND Flash Design (Toshiba)



Hybrid Memory Cube (IBM/Micron)

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

-'s: Process Complexity, Costs/Yield

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Volumetric Density

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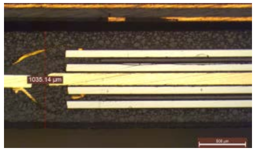
- Local (Media) Volumetric Density: The volumetric density of the memory media alone (using the maximum areal density) within a final memory component, i.e. tape on a reel, disks in an HDD stack, NAND flash in a package.
- Device Volumetric Density: The volumetric density of the memory component, i.e.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



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

	HDD	SSD	TAPE (LTO)	TAPE[3] (Enterprise)
Maximum Areal Density	750 Gbit/in^2	550 Gbit/in^2	1.2 Gbit/in^2	3.2 Gbit/in^2
Local Volumetric Density	2.4 TB/in^3	6.9 TB/in^3	1.6 TB/in^3	4.2 TB/in^3
HDD/SSD/Cartridge Volume	23.8 in^3	4.1 in^3	14.1 in^3	14.1 in^3
HDD/SSD/Cartridge Capacity	3 TB	0.5 TB	1.5 TB	3.0 TB
Device Volumetric Density	126 GB/in^3	122 GB/in^3	106 GB/in^3	212 GB/in^3

TECHNOLOGY CONCLUSIONS

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		+'s	-'s
HDD	Shingled Write	Increase Track Density 50%	Significant Disk ArchitecturalChanges, Ideally Suited For Streaming Data Sets
	HAMR	Increase Bit Density	New Media Alloy Based on FePt Addition Of Laser To Head Disk Lube Depletion
	BPM	Increased Areal Density, Data Stability	Disk Media Personalization, Massive Mfg. Operation, Capital Intensive, Lithographic Requirements (?)
	Packaging	Increased Unit Capacity	Cost Increased, Power
Flash	MLC	Increase Data Capacity Up To 3X	Significant Endurance Degradation New Controller Requirements
	Lithography	<20nm Required For Lower Costs	EUV Costs Data Leakage, Endurance
	3D finFET	Increase Data Capacity	Increased Process Complexity, Costs, New Device Structure
	Packaging	Increased Unit Capacity	Increased Costs, Power

NV Memory Technology Comparison

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	HDD	Flash (SLC)	Flash (MLC)	FeRAM	MRAM	PCM	ReRAM	STT-RAM	Race-Track	Mole-cular
Cell Structure	None	1T/0C	1T/0C	1T/1R	1T/1R	1T/1R	1T/1R	1T/1R	None	1T/1R
Cell size (F^2)	0.5	3.5	3.5	15	16=30	5-7	6-10	6–20	0.5e	10-5
Read time (ns)	2000	50	50	20–80	3–20	20–50	20–50	2–20	500	100e
Write / Erase time (ns)	1000	1 ms / 0.1 ms	1 ms / 0.1 ms	50/50	3-20	100	20–50	2–20	200	300e
Endurance	10^{16}	10^{5}	10^{3}	10^{12}	$>10^{15}$	10^{12}	10^{8}	$>10^{15}$	10^{16} e	10^{8} e
Write power	Low	Very high	Very high	Low	High	High	Low	Low	Low	Low
Max. Areal Density Gbits/in²	750-1000	150	550	0.1	10	200e	200e	300e	>1000e	400e
Voltage required	3-5V	12 V	12 V	2–3 V	3 V	1.5–3 V	1.5–3 V	<1.5 V	3-5V	3-5V
	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**

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