DISKCON®
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Tuesday Conference
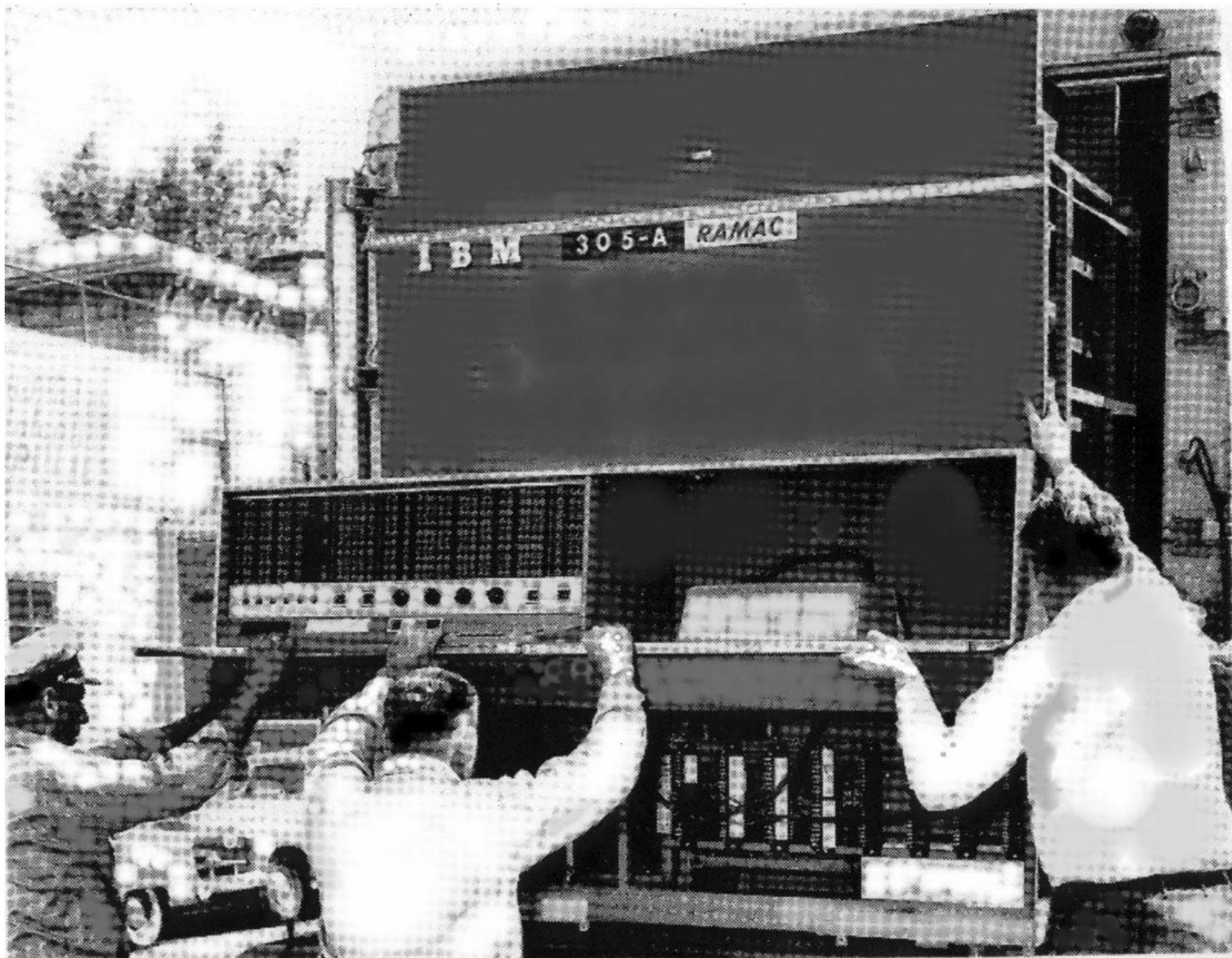
Session 3

Roadmaps:

The Past and Future of Storage

DISK DRIVES:
A hard life,
but never boring

James N. Porter

DISK/TREND

YESTERDAY'S DISK DRIVES

RAMAC Officially Announced

RAMAC Is First Major Achievement Of Mushrooming IBM San Jose Plant

Conceived and developed in the IBM San Jose Research and Development Laboratories, the huge electronic data processing machine equipped with the "juke box" memory file, known as RAMAC for Random Access Memory Accounting, was announced by press, radio and television September 14.

Hailed by President Thomas J. Watson, Jr., as "providing one of the most significant advancements toward business control and operation by electronics thus far," RAMAC is the result of four years of intensive research and development by upwards of 200 San Jose IBM engineers and technicians. In addition, scores of Product Planning, Test, Customer Engineering, CE School, Manufacturing and Sales personnel have collaborated to make the RAMAC electronic "brain" a reality.

RAMAC has spearheaded a tremendous growth for the IBM plant here in San Jose with several thousand persons expected to be employed at the new plant by 1960. Up-
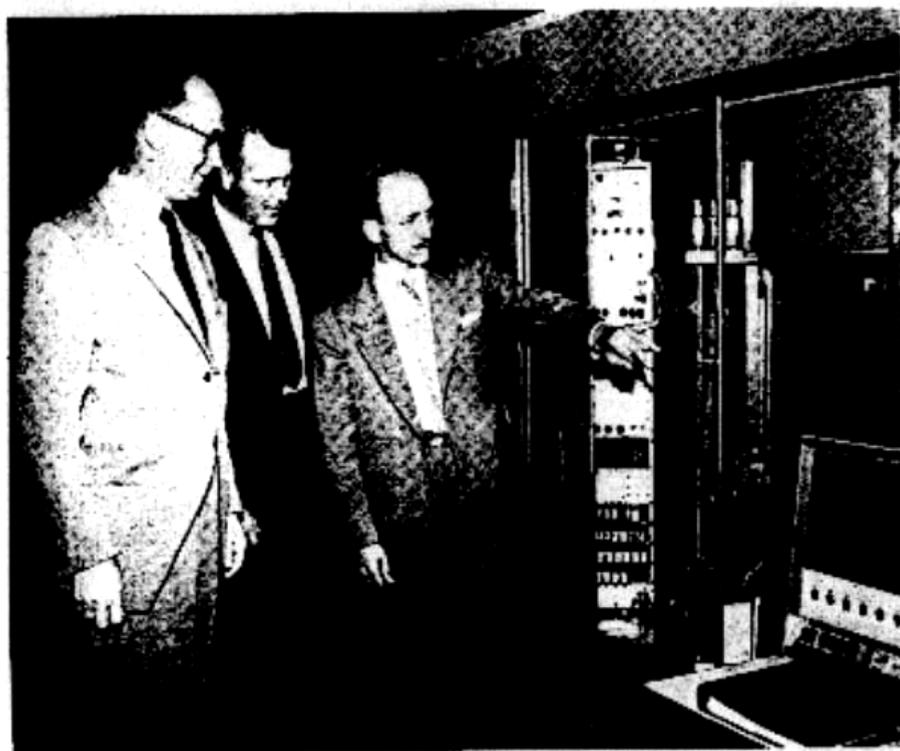
IBM's SAN JOSE BRAIN CHILD.— Watching the operation of the random "juke box" memory device of the San Jose-born RAMAC are Reynold B. Johnson, left, manager of the Research Laboratory, who with his associates originated the idea of the disk file; L. D. Stevens, manager of Development Engineering, and J. D. Fernbach, Engineering Laboratory manager, who were responsible for the development and engineering of the much-publicized

The 1950's

1956: IBM 350 RAMAC -- 5 MB

- First disk drive
- 50 24-inch disks
- Hydrostatic air bearing heads
- Demonstrated market and producibility

The 1960's

1961: Bryant Computer 4240 -- 90 MB
- First disk drive with zoned recording
- 24 39-inch disks

1962: IBM 1301 "Adv. Disk File" -- 28 MB
- First drive with hydrodynamic air bearing heads
- 25 or 50 24-inch disks

1963: IBM 1311 "Low Cost File"--2.68 MB
- First drive with removable disk pack
- First production 14-inch disk drive

The 1960's

1965: IBM 2310 "Ramkit" -- 1.024 MB
- First single disk cartridge drive
- First voice coil actuator

1966: IBM 2314 Storage Facility--29.17 MB
- Eight drives with single controller
- Removable disk pack (11 disks)
- First drive with ferrite core heads

1967: Memorex 630 -- 7.25 MB
- First IBM plug compatible disk drive

The 1970's

1971: IBM 3330-1 "Merlin" -- 100 MB
- First track-following servo system

1971: IBM 23FD "Minnow" -- 81 KB
- First production flexible disk drive
- 8-inch disks, read only

1973: IBM 3340 "Winchester" -- 35/70 MB
- First disk drive with low mass heads, lubricated disks, sealed assembly
- Removable 3348 Data Module

The 1970's

1974: IBM 3330-11 "Iceberg" -- 200 MB
- IBM's last disk pack drive

1975: IBM 62GV "Gulliver" -- 5/9 MB
- First drive with rotary actuator

1976: Shugart Associates SA400 -- 218 KB
- First 5.25-inch flexible disk drive

The 1970's

1976: IBM 3350 "Madrid" -- 317.5 MB
- Reintroduction of fixed disk media

1979: IBM 3370 "New File Project"--571 MB
- First moving head drive with thin film heads, 2-7 encoding.

1979: IBM 3310 "Piccolo" -- 64.5 MB
- First 8-inch rigid disk drive

The 1980's

1980: Shugart Technology ST506 -- 5 MB
- First 5.25-inch rigid disk drive

1981: Sony OA-D30V -- 437.5 KB
- First 3.5-inch flexible disk drive

1983: Rodime RO 352 -- 10 MB
- First 3.5-inch rigid disk drive

The 1980's

1983: Maxtor XT-1140 -- 126 MB
- First 5.25-inch drive with in-hub motor

1986: Conner Peripherals CP340 -- 40 MB
- First 3.5-inch disk drive with voice coil actuator

1988: PrairieTek 220 -- 20 MB
- First 2.5-inch rigid disk drive

The 1990's

1991: IBM 0663 "Corsair" -- 1,004 MB
- First rigid disk drive with magnetoresistive heads

1991: Integral Peripherals 1820

"Mustang" -- 21.4 MB
- First 1.8-inch disk drive

1993: Seagate Technology ST12550

"Barracuda" -- 2,139 MB
- First 7,200 RPM disk drive

The 1990's

1997: IBM DTTA-351680 "Titan" -- 16.8 GB
- First drive with giant magnetoresistive heads

1997: Seagate Technology ST19101

"Cheetah 9" -- 9.1GB
- First 10,000 RPM disk drive

1998: Seagate Technology ST118202

"Cheetah 18" -- 18.2 GB
- First 10,000 RPM drive with 3-inch disks

The 1990's

1998: Hitachi DK3E1T-91 -- 9.2 GB
- First 12,000 RPM drive, using 2.5-inch disks

1999: IBM "Microdrive" -- 340 MB
- First 1-inch disk drive
- Compact Flash format, Type II

The 2000 millennium

**2000: Seagate Technology ST318451
"Cheetah X15" -- 18.4 GB**
- First 15,000 RPM drive, using 2.5-inch disks

2005: Toshiba drive, 3.3 x 24 x 32 mm
- First drives with .85 inch disk

TODAY'S
DISK DRIVES

DISK DRIVE MANUFACTURERS WORLDWIDE TOTAL

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
RIGID	76	75	65	68	63	59	57	47	40	30	24	26	22	16	16
FLEXIBLE	52	63	57	56	52	49	36	26	21	19	19	19	17	16	13
OPTICAL	16	21	28	34	36	36	38	36	43	57	60	56	53	52	44

RIGID DISK DRIVE SHIPMENTS SUMMARY BY DRIVE CAPACITY

Worldwide Unit shipments (000)	1998 Shipments	Forecast	
		1999	2000
Disk cartridge drives	1,290	970	1,120
FIXED DISK DRIVES			
<2 Gigabytes	2,014	376	250
2 - 3 Gigabytes	27,730	8,813	2,645
3 - 5 Gigabytes	70,968	48,772	13,140
5 - 10 Gigabytes	36,109	67,034	52,695
10 - 20 Gigabytes	6,689	39,468	77,205
20 - 40 Gigabytes	58	2,733	42,830
40 - 80 Gigabytes	110	189	3,705
>80 Gigabytes	0	0	230
TOTAL SHIPMENTS	144,967	168,354	193,820
Annual increase	11.1%	16.1%	15.1%

RIGID DISK DRIVES
CAPACITY AND PRICING HISTORY

Year	Worldwide drive sales ($ million)	÷	Total capacity shipped (Terabytes)	=	Overall average price per Megabyte	per Gigabyte
1988	20,424		1,770		$11.54	$11,540
1989	22,660		2,436		9.30	9,300
1990	25,578		3,727		6.86	6,860
1991	24,632		4,711		5.23	5,230
1992	24,550		8,180		3.00	3,000
1993	21,730		14,856		1.46	1,460
1994	23,231		32,933		.705	705
1995	26,633		80,677		.330	330
1996	28,819		160,623		.179	179
1997	31,736		338,061		.094	94
1998	30,077		694,340		.043	43
1999	32,400		1,393,435		.023	23

TOMORROW'S DISK DRIVES

The rapid rate of change in the disk drive industry will continue.

What are the *causes* for those changes? What will be the *effect* on the industry?

CAUSE:

- **Most of the human race still does not have a personal computer.**

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EFFECT:

- **Personal computer shipments will continue to increase, and they will all use disk drives.**

CAUSE:

- **Demand by computer users to communicate with others, and to have access to a wide range of network applications, will continue to grow.**

CAUSE:

EFFECT:

- Demand by computer users to communicate with others, and to have access to a wide range of network applications, will continue to grow.

- The market for network storage will continue to grow, keeping the server drive market very healthy.

CAUSE:

- **Demand for computer data storage will continue to grow rapidly, but at a lower rate than annual increases in areal density.**

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- **Demand for computer data storage will continue to grow rapidly, but at a lower rate than annual increases in areal density.**

EFFECT:

- **Expansion of the market for disk drive recording heads and disks will continue to be limited.**

CAUSE:

- **Patterns of mobile computing usage will evolve rapidly in this decade, with less weight, more capabilities, and lower prices.**

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- **Patterns of mobile computing usage will evolve rapidly in this decade, with less weight, more capabilities, and lower prices.**

EFFECT:

- **Fast growing markets for handheld devices, more applications, improved ease of use -- with sharp increases in the market for miniaturized disk drives.**

CAUSE:

- **New disk drive applications in consumer electronics will evolve into major markets.**

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- **New disk drive applications in consumer electronics will evolve into major markets.**

EFFECT:

- **Growth in consumer electronics markets will provide a major supplement to disk drive traditional markets and require production of disk drives with special specifications.**

CAUSE:

- **Annual increases in areal density for disk drives using conventional magnetic recording will be limited by the middle of the decade.**

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- **Annual increases in areal density for disk drives using conventional magnetic recording will be limited by the middle of the decade.**

EFFECT:

- **Disk drives using new recording technologies will become commercially important by the middle of the decade.**

CAUSE:

- Disk drive markets will continue to grow, and products will adapt to new markets, with higher capacities, evolving interfaces, smaller physical size, and, of course, lower prices.

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- **Disk drive markets will continue to grow, and products will adapt to new markets, with higher capacities, evolving interfaces, smaller physical size, and, of course, lower prices.**

EFFECT:

- **<u>Well-managed</u> disk drive manufacturers will survive.**

The factors which shape the disk drive industry...

- The **PRODUCTS**
- The **MARKETS**
- The **COMPETITION**

…will continue to evolve at an exceptionally fast pace.

NEMI Storage Roadmaps

Thomas M. Coughlin

Coughlin Associates

www.tomcoughlin.com

Tom Coughlin
Coughlin Associates

Tom Coughlin, President, Coughlin Associates has been working for over 25 years in the data storage industry at companies such as Ampex, Polaroid, Seagate, Maxtor, Micropolis, Syquest, and 3M. He has over 50 publications and six patents to his credit. Tom is active with IDEMA, the IEEE Magnetics Society, IEEE CE Group, and other professional organizations. He is the founder and organizer of the Annual Storage Visions Conference and co-organizer of the annual Network Storage Conference. Coughlin Associates provides market and technology analysis as well as data storage technical consulting services. For more information go to www.tomcoughlin.com.
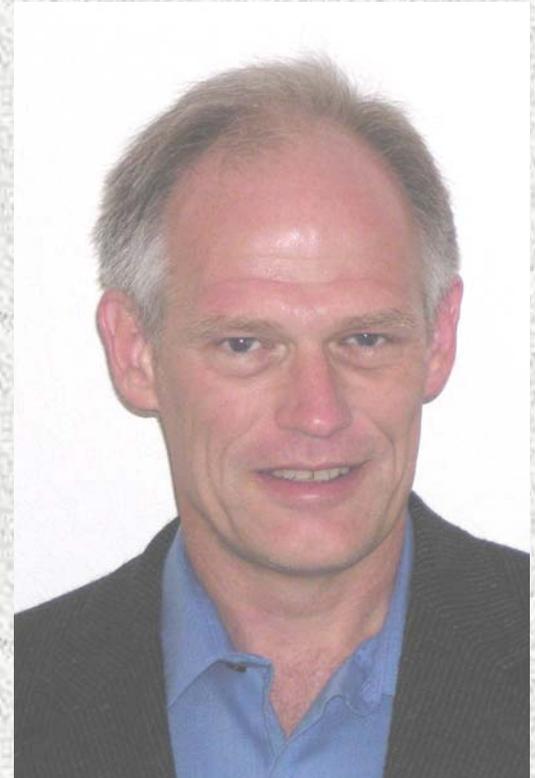
Outline

- iNEMI Roadmap and Participants
- Hard Disk Drive Roadmap
- Magnetic Tape Roadmap
- Optical Storage Roadmap
- Flash Memory Roadmap
- Other Storage Technologies and NVRAM Roadmap
- Conclusions

Abstract

In 2004 a group of distinguished storage technologists representing hard disk drive, optical storage, magnetic tape, semiconductor flash memory, as well as MRAM and other advanced solid state storage technologies met over several months to create a Mass Storage Roadmap out to 2015. This was done as part of the bi-yearly iNEMI (International Electronics Manufacturing Initiative) roadmap effort that covered all aspects of electronics technology. This presentation will present the main results of the iNEMI Mass Storage roadmap.

NEMI Mass Storage Roadmap Contributors

Chair—T. M. Coughlin, Coughlin Associates
Co-Chair— R. F. Hoyt, formerly Hitachi Global Storage Technology

S. Adamson, Asymtek
J. M. Daughton, Nonvolatile Electronics (NVE)
S. Naberhuis, Hewlett-Packard
P. Frank, Information Storage Industry Consortium (INSIC)
R. B. Goldfarb, National Institute of Standards and Technology (NIST)
J. Handy, Semico
G. Hughes, University of California at San Diego (UCSD)
M. Johnson, Naval Research Laboratory
F. Moore, Horison Information Strategies
R. Rottmayer, Seagate Technology
S. Wang, Stanford University
R. G. Zech, Advanced Enterprises (ADVENT) Group

The Storage Hierarchy

	Positioning Parameters		
	Price/GB	Capacity Limit	Access Time/ Performance
Central	$100K–300K	256 GB	±200 GB/sec
Expanded	< $75K	nx32 GB	20–40 ns
Solid-State Disk	$5K–10K	50 GB	< 0.1 ms
Performance Disk	$40–70	GB–TB	4–10 ms
High Capacity Disk/ATA Disk	$30–40	GB–100 TB	10–25 ms
Nearline Disk, MAID	$2–20	TB–PB	< 250 ms
Virtual Tape	$2–10	TB–PB	5–10 sec
Nearline Tape	$.20–$4*	TB–PB	5–10 sec
Far-line Shelved Data/Archival Storage	< $.001*	TB–PB	min, hr, day
Analog Data Micrographics Non-Digital Images Video Paper	+$20	PB–EB	min, hr, day

* Based on recording technology

Source: Horison Information Strategies

HORISON Information Strategies

www.horison.com Storage. New Game. New Rules

Disk Drive Technology Roadmap

HDD Quarter by Quarter Public Technology Demonstrations and Product Announcements compared to Toshiba MLC Flash Memory Areal Densities (Coughlin Associates)
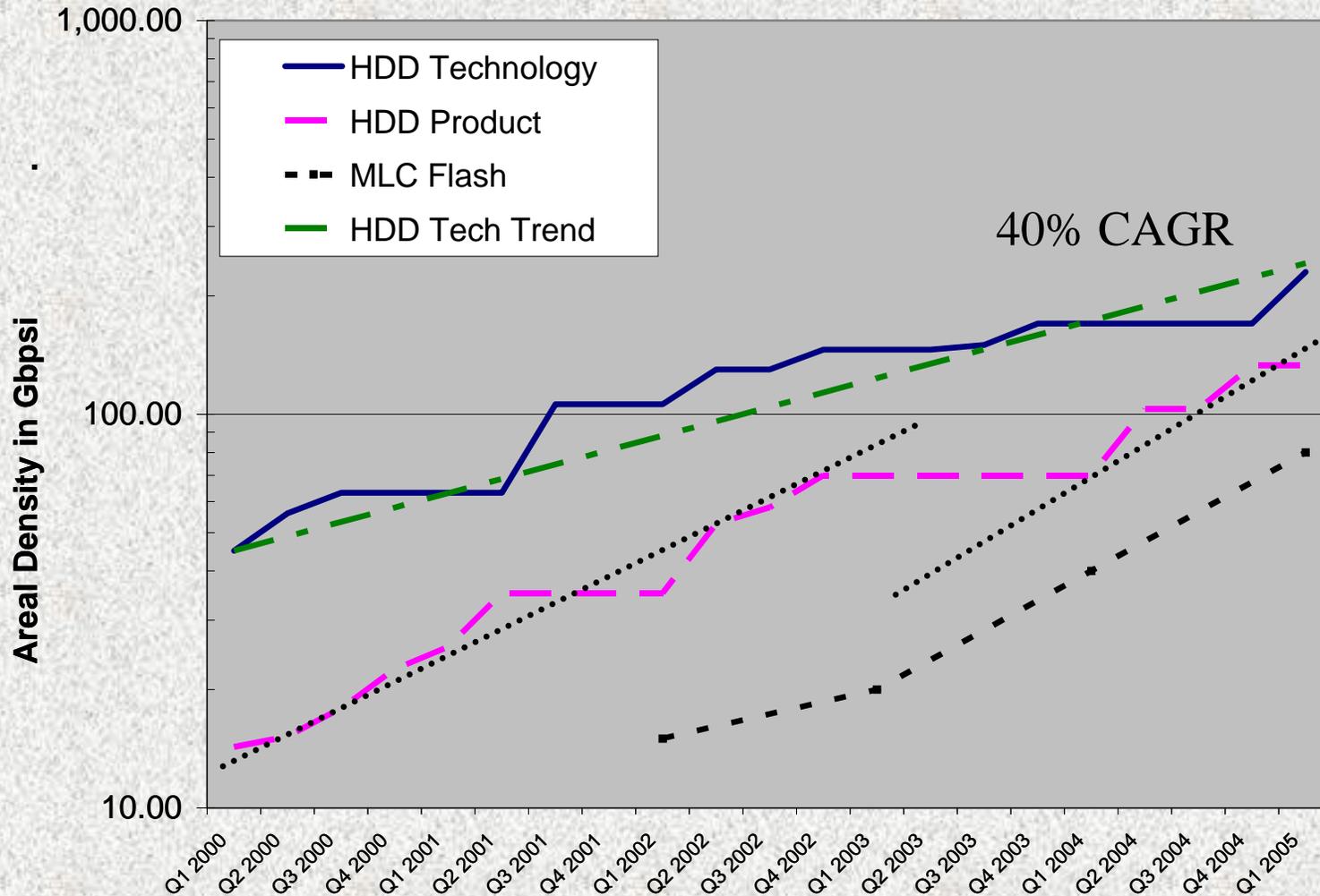
Projected Areal Densities and Recording Technologies in Production Hard Disk Drives
(Source: Coughlin Associates)
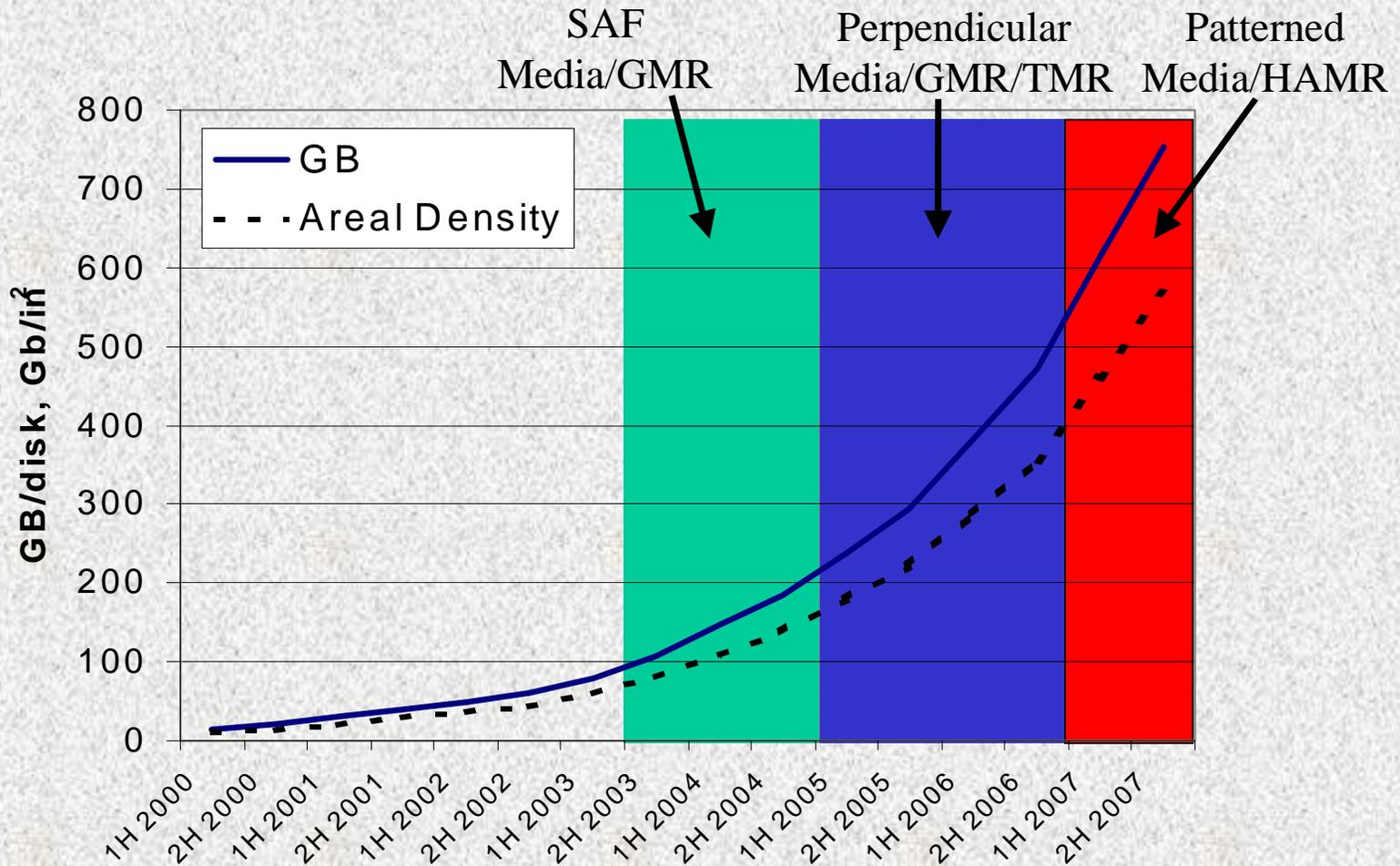
Projected Capacity vs. Form Factor
(Coughlin Associates)
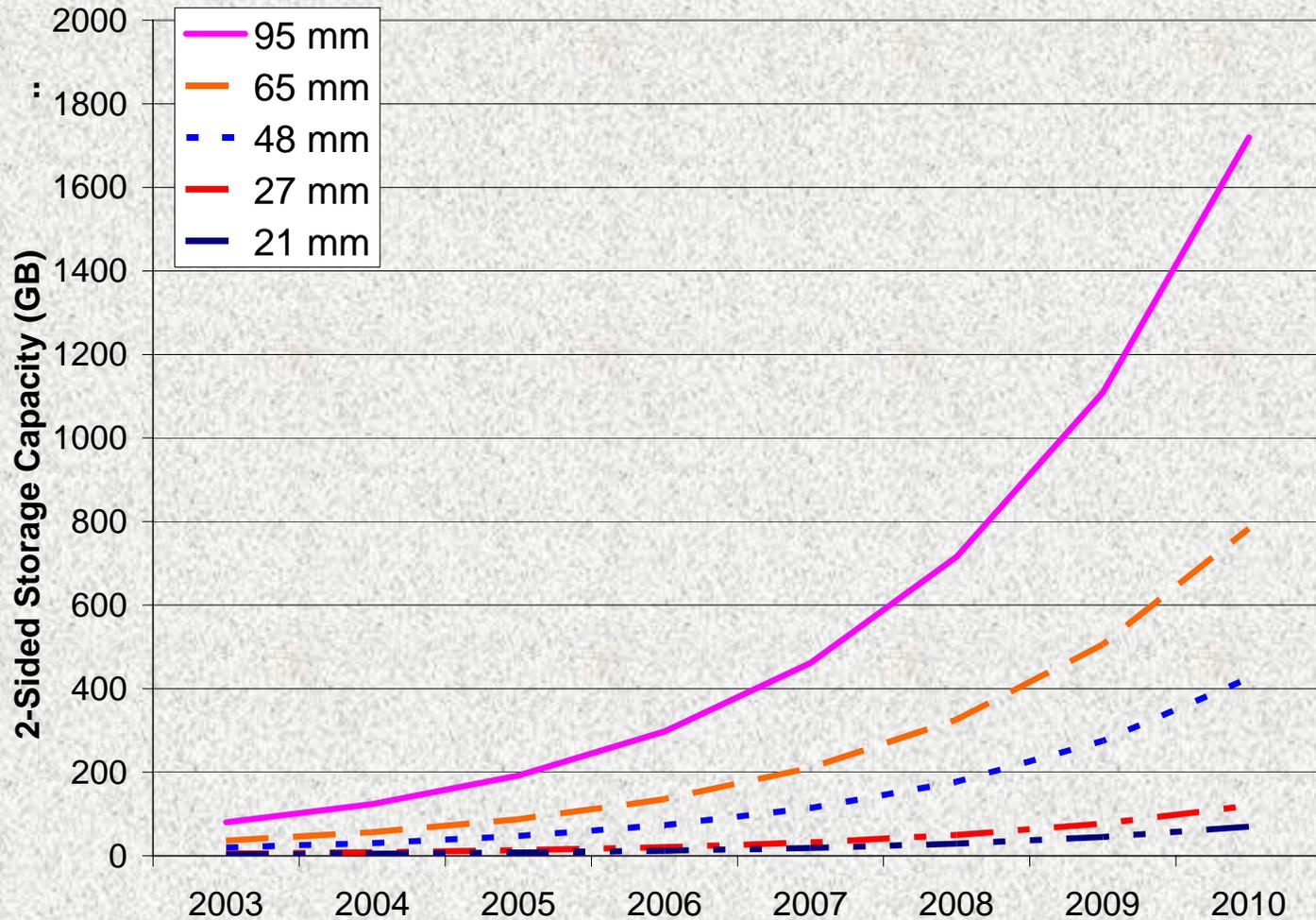
Magnetic Mass Data Storage Technology Roadmap — HDD

	Unit	2003	2005	2007	2009	2015
Industry Metrics						
Form Factor (dominant form factor is bold)	inches	**3.5**, 2.5, 1.8,1.0	**3.5**, 2.5, 1.8, ≤1.0	3.5, **2.5**, 1.8, ≤1.0	3.5, **2.5**, 1.8, ≤1.0	**2.5**, 1.8, ≤1.0
Capacity	GB	2-320	2-1200	4-1400	10-1600	20-4600
Market Size	units (M)	226	280	310	350	500
Cost/MB (avg.)	$/MB	0.01	<0.003	<.002	<0.002	<0.001
Design/Performance						
Areal Density	Gb/in^2	70	>100	>200	>400	≥1000
Rotational Latency	ms	2-6	2-12	2-12	2-12	2-12
Seek Time*	ms	3-5	3-5	3-5	2-5	2-5
RPM		4.3-15k	4.3-20k	3.6-20k	3.6-20k+	3.6-20k+
Data rate	MB/sec	80-100	10-150	10-250	10-400	>400
Power	watts	2–12	2–12	2-10	1-10	0.5-8
Reliability	Spec.	MTTF/AFR	MTTF/AFR	New Spec	New Spec	New Spec
Key Component Requirements						
Read Head	type	GMR	GMR	GMR/ TMR	GMR/ TMR	GMR/ TMR
Slider	type & size (% of 5.52 mm^2)	20%	20%	20%	20%	10%
Clearance	nm	10	<10	<10	<10	<10
Disk	type	AlMag, Glass	AlMag, Glass	AlMag, Glass	AlMag, Glass	AlMag, Glass
Disk Static Coercivity	Oe	5000	7000	8000	9000	10000
Magnetic Recording Technology		Longitudinal	Longitudinal/Perpendicular	Perpendicular	Perpendicular, HAMR	Perpendicular, HAMR, Patterned Media
Electronics/Channel	type	Noise Predictive GPR	Noise Predictive GPR	Noise Predictive GPR	Iterative GPR (Turbo)	Soft ECC
Channel Bandwidth	MHz	480	500-1200	80-2000	80-3200	>3200
SNR	dB	20	<20	<20	<20	<20
Actuator	type	Conventional	Conventional	dual/micro	dual/micro	dual/micro
Spindle	type	Ball bearing/Fluid	Ball bearing/Fluid	Ball bearing/Fluid	Fluid	Fluid

*Seek time is one third full stroke seek time and does not include microactuator local track

Magnetic Tape Technology Roadmap

SAIT

S-DLT

LTO

Active tape format CAGRs are about 40%. Disk Drive CAGRs are expected to be ~60%

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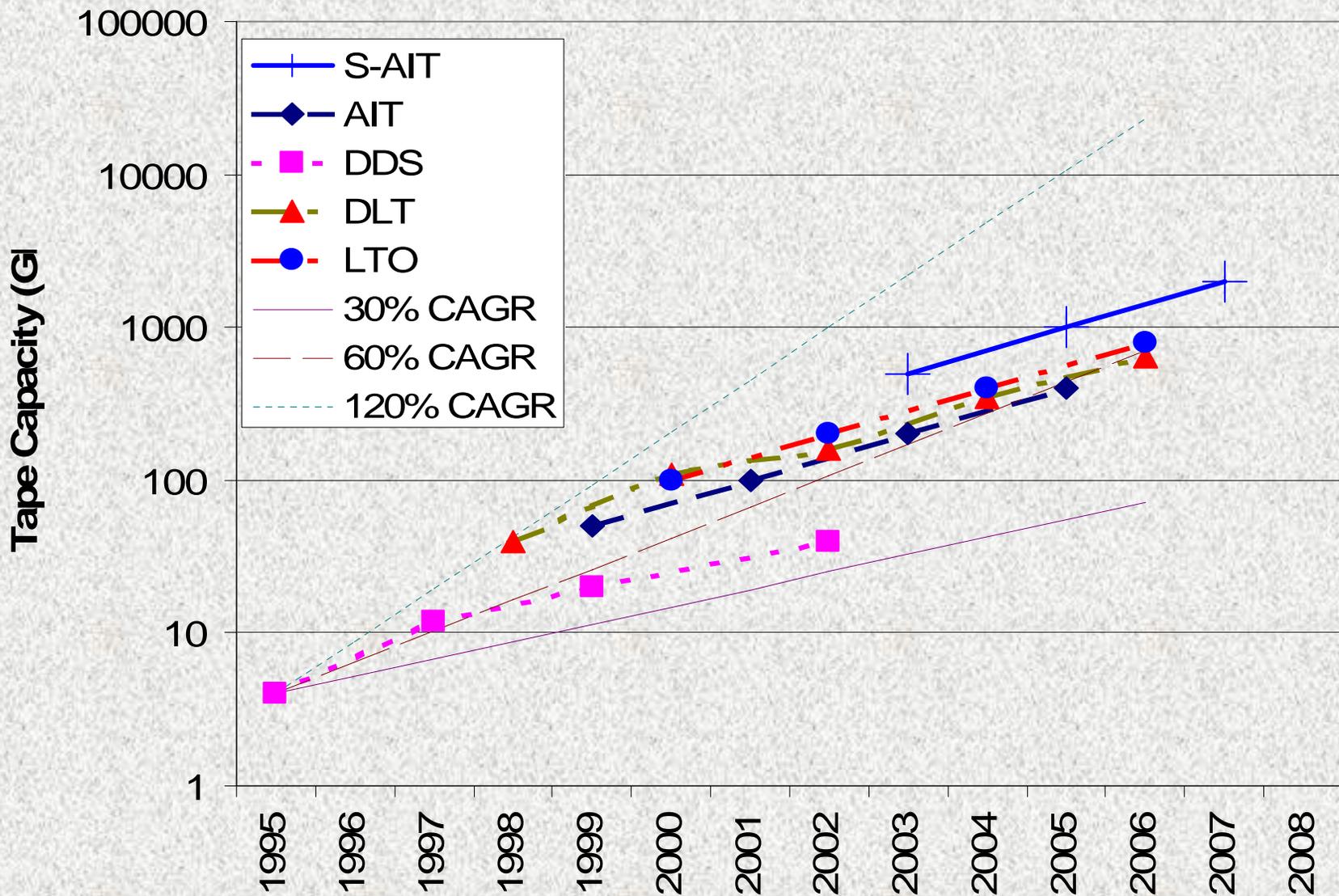
Magnetic Mass Data Storage Technology Roadmap — Tape

	Unit	2003	2005	2007	2009	2015
Form Factor	inch	5.25,3.5	5.25,3.5	5.25,3.5	5.25, 3.5	5.25,3.5
Longitudinal Tape						
Volumetric Density	GB/in^3	5.5	22	100-200	200-400	500-1000
Cartridge capacity (native)	GB/TB	200 GB	300-500 GB	1-2 TB	1,75-4 TB	4-10 TB
Areal Density	Gb/in^2	.12	.70	2-3	3.5-5.25	8-12
Data Rate	MB/s/drive	5-30	30-100	100-200	100-400	400-800
Tape Speed (for data)	meters/sec	2-8	4-11	4-25	5 -30	8-50
Head tracking precision required	+/- μm	1	.5	~.1	.1	<.1
Key Requirements						
Heads	type	MR	MR/GMR	GMR	GMR	GMR
Number of data channels	Number	4-16	4-24	4-32	4-40	4-64
Detection channel	type	EPRML	E^2 PRML	E^2 PRML	E^2 PRML, TURBO-CODE	E^2 PRML, TURBO-CODE
Magnetic film	type	dual layer metal particle	dual-layer metal particle metal film	multi-layer metal particle metal film	multi-layer metal particle metal film	multi-layer metal particle metal film
Tape/media thickness	μm (micron)	9	6	<=6	<6	<4
media substrate material	type	PEN	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	PEN Aramid*/ adv. polymer	Aramid*/ adv. polymer
Helical Tape						
Areal Density	Gb/in^2	.69	4-6	8-12	10-15	15-20
Data Rate	MB/s/drive	6-12	12-50	100-200	100-400	400-800
Cartridge Capacity (native) Note: the high range in last three columns is due to introduction of single-reel ½" cartridge.	GB/TB	50+ GB	200-400 GB	1-4 TB	2-8	8-14 TB
Head-Tape speed	meters/sec	17-34	22-36	35-42	35-46	40-54
Head tracking precision required	+/- μm	0.49	0.33	0.08	0.07	0.05
Key Requirements						
Tape thickness	μm	6	4	2.0	<2.0	<2.0
Media Substrate Material	Type/Pet*	PEN/PA*	PA *	PA or better	PA or better	PA or better

*polyethylene ethyl teraphalate/ polyethylene ethyl napthalate/polyamid (aramid)
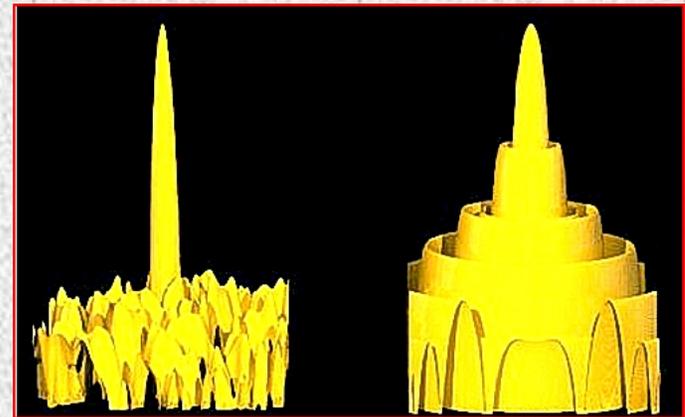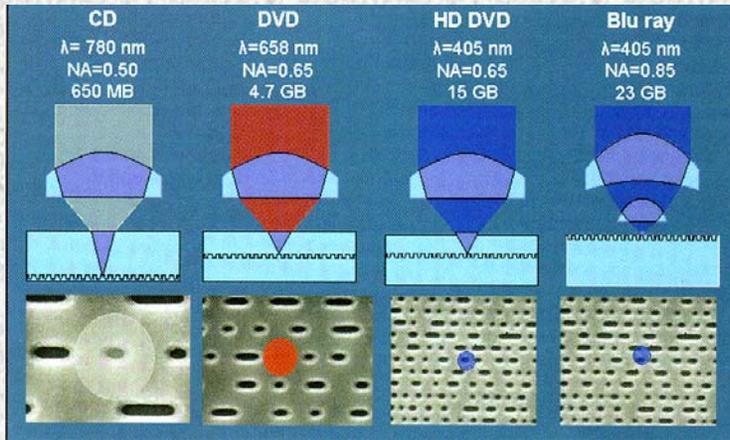
Optical Disk Technology Roadmap

Comparison of CD, DVD, and Blue Laser Optical Designs Spot Sizes and Spatial Structures (Source: UNAXIS USA, *Mediaware*, May/June 2004, p.16)
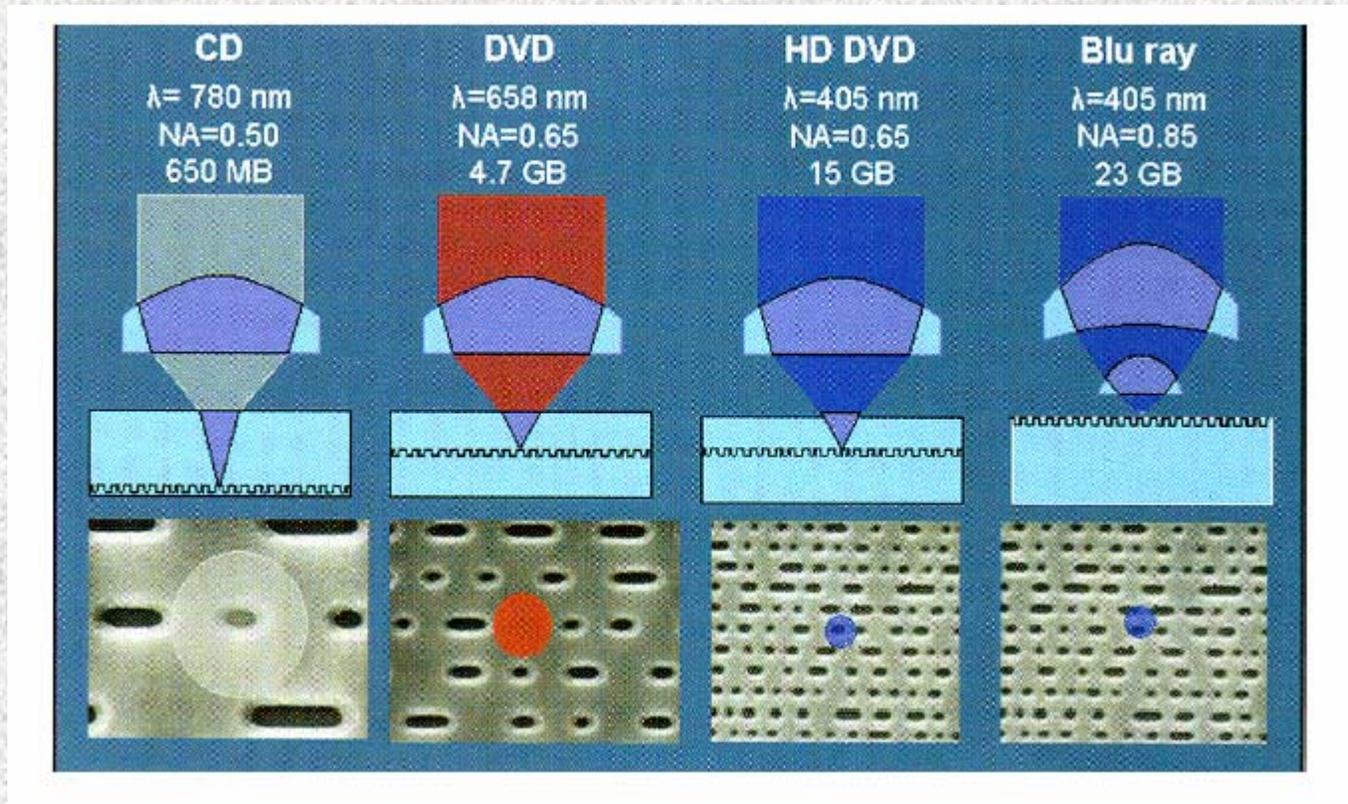
Optical Content Distribution Trends
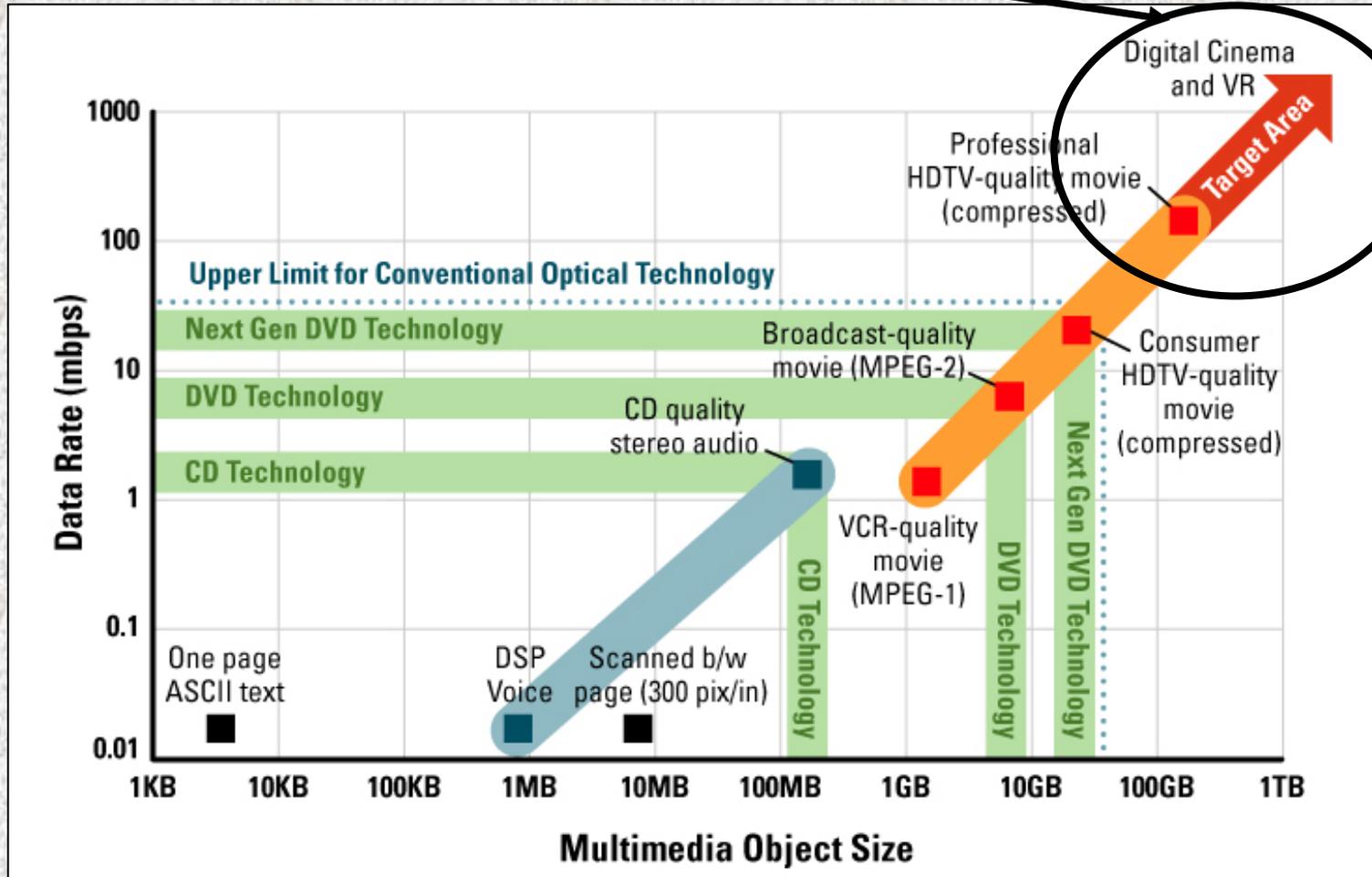
Percent Shipments of CD, DVD, and Blue Laser Hardware Units, Period 2003-2010

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Product Name	Form Factor	Disc Type/ Diameter (mm)	Capacity (GB)	Write/Read Options	First Shipments	Market Segments
AOD/ HD DVD	5.25" HH	replicated & phase change/ 120mm	15/20	RO/RW	2005	1,2
AOD/ HD DVD (dual layer)	5.25" HH	replicated & phase change/ 120mm	30/32	RO/RW	2007	1,2
Blu-ray Disc (BD)	5.25" HH	replicated, dye layer & phase change/ 120mm	23/25/27	RO/WO/RW	2004-05	1,2
Blu-ray Disc (dual layer)	5.25" HH	replicated, dye layer & phase change/ 120mm	25/50	RO/WO/RW	2004-05	1,2
DataPlay Blue	SFFD	replicated & phase change/ 32mm	3	RO/WO	2006	1,2
Digital MultiDisc (DMD)	5.25" HH	replicated & phase change/ 120mm	15-60 (3-12 layers)	RO/WO	2005-07	1
EVD (dual layer)	5.25" HH	Replicated & dye layer/ 120mm	6 11	RO WO	2006-07	1
Hi-MD	2.5" HH	MO/ 64.8mm	1	RO/RW	2004	1,2
Holographic (InPhase)	5.25" (11" or 17" long)	photopolymer/ 130mm	200	WO	2005-06	3,4
Holographic (Optware)	19" RM	photopolymer/ 130mm	200	WO	2005-06	3,4
Prof. Disc for DATA -2	5.25" HH	phase change/ 120mm	50	WO/RW	2005-06	3
Prof. Disc for DATA -3	5.25" HH	phase change/ 120mm	100	WO/RW	2007-09	3
3.5" ISO MO	3.5" HH	MO/ 86mm	4.6-6.9	RW	2005-06	2,3
UDO-2 (dual layer)	5.25" HH	phase change/ 130mm	60	WO/RO	2005-06	3,4
UDO-3 (dual layer)	5.25" HH	phase change/ 130mm	120	WO/RO	2007-09	3,4
UV-ray Disc (dual layer)	5.25" HH	replicated & phase change/ 120mm	334	RO/WO/RW	2009	1,2

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Long-Term Roadmap, Optical Disk Storage Products — 2010-2015

Product Name	Form Factor	Disc Type/ Diameter (mm)	Capacity (GB)	Write/Read Options	First Shipments	Market Segments
AOD HD DVD (quad layer)	5.25" HH	replicated & phase change/ 120mm	60/80	RO/RW	2010-11	1,2
Blu-ray Disc (quad layer)	5.25" HH	replicated, dye layer & phase change/ 120mm	92/100/108	RO/WO/RW	2009-10	1,2
DataPlay Blue (dual/quad layer)	SFFD	replicated & phase change/ 32mm	6-12	RO/WO	2010	1,2
Digital MultiDisc Blue	5.25" HH	replicated & phase change/ 120mm	150-200 (10 layers)	RO/WO/RW	2010	1
EVD Blue (dual layer)	5.25" HH	replicated & dye layer/ 120mm	24 40	RO WO	2010-12	1
Hi-MD Blue	2.5" HH	MO/ 64.8mm	4-6	RO/RW	2010	1,2
Holographic (InPhase)	5.25" FH	photopolymer/ 130mm	1600	WO/RW	2012-15	3,4
Holographic (Optware)	5.25" FH	photopolymer/ 130mm	1000	WO/RW	2012-15	3,4
Prof. Disc for DATA-4 (quad layer)	5.25" HH	phase change/ 120mm	200	WO/RW	2010	3
3.5" ISO MO	3.5" HH	MO/ 86mm	13.8-18.4	RW	2011-12	2,3
UDO-4 (quad layer)	5.25" HH	phase change/ 130mm	240	WO/RO	2010-12	3,4
UV-ray Disc (quad layer)	5.25" HH	replicated & phase change/ 120mm	864	RO/WO/RW	2014-15	1,2

Flash Memory Technology Roadmap

NAND Flash Chip Roadmap

	2003	2005	2007	2010	2015
Design Rule (Minimum Feature Size f in nanometers)	145	116	94	65	36
Cell size (f)	5.5	5	4.5	4.3	4
Average bits/cell	1.14	1.46	1.82	3.00	4.00
Die Size in mm²	85	113	190	307	1007
Cost/GB ($/GB) @ $40/in^2 usable silicon	119.77	57.37	32.76	26.80	19.26
Average chip density (megabits)	360	957	2,932	14,848	211,813

Block Diagram of a Typical USB Flash Drive

Other Storage Technologies

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	2003	2005	2007	2009	2015
Metric					
Design Rule (Minimum Feature Size f in micrometers)	0.25	0.20	0.15	0.1	0.05
Cell size (f^2)	12	11	10	8	6
Areal density @ 50% Array Efficiency (Mb/in ^{2})	420	900	1400	3900	20,700
Cost / Mb ($/Mb) @ $40/in^2 usable silicon	0.1	.05	0.03	0.01	0.002
Performance					
Write / read time (ns)	20	15	10	8	6
Data rate (write or read limit) (MHz)	100	100	100	200	300
Energy to write 1 bit (picojoule)	300	250	200	200	150
Energy to read 1 bit (picojoule)	100	100	100	100	75
Key Attribute					
SNR (dB)	25	25	25	25	25
Faulty bits allowed (out of spec for any reason)	1 in 10^4	1 in 10^4	1 in 10^5	1 in 10^6	1 in 10^7
Chip yield (per wafer)	90%	92%	95%	95%	95%

Additional Storage Technologies to Watch

- ***Ferroelectric Random Access Memory (FRAM)***
- ***Ovonic Unified Memory (OUM)***
- ***Programmable Metallization Cell Memory (PMCm)***
- ***Probe Based Storage (PBS)***

Conclusions
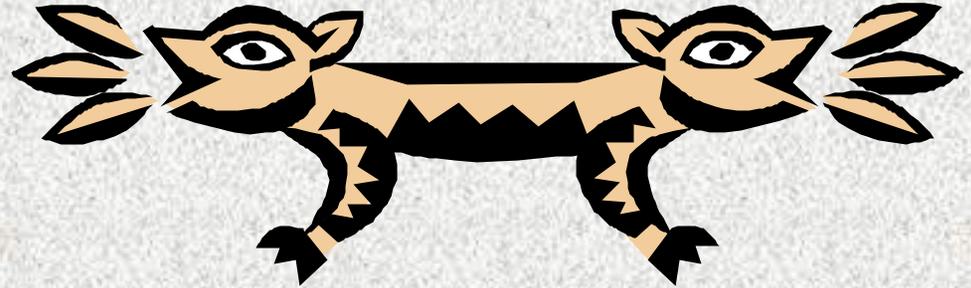
- Storage applications are increasing in capacity demand, driving all digital storage technologies

- HDDs are following a 50-60% annual areal density growth rate, fueling new applications in high capacity ATA-array storage as well as consumer electronic applications

- Flash memory and small form factor HDDs are pushing technology development to vie for mobile consumer electronics applications

- Optical storage capacity will increase going forward to meet the needs for content distribution as multimedia resolution increases

- New solid state and probe based storage technologies are being developed and are seeking applications in mobile and other electronic product applications

Sources

- **<u>2005 Entertainment Creation and Distribution Digital Storage Report</u>**, Coughlin Associates

- **2004 NEMI Mass Storage Roadmap Report,** various authors

For more information go to the tech papers section of www.tomcoughlin.com

The End

Thank
You!

Reserve Slides

First-Generation Blue Disk Optical Storage Products

	Toshiba/NEC	Matsushita	Sony	Plasmon
name	HD DVD	BD Recorder	Prof. Disc for DATA	UDO
market segments	1	1	2,3,4	2,3,4
1-layer capacity (GB)	15 (RO)/20 (RW)	25	23.3	15 (each disc side)
2-layer capacity (GB)	30 (RO)/32 (RW)	50	NA	NA
media types	RO/RW	RO (TBD) RW	WO/RW	WO/RW
rewritable media type	phase change	phase change (10,000 cycles)	phase change (10,000 cycles)	phase change (10,000 cycles)
data rate (MB/s)	8.5	8.5	9 write 11 read	2-4 write (with verification) 4-8
seek time (ms)	?	?	110 (CAV) 280 (CLV)	25
file format	micro-UDF	BD proprietary	BD proprietary	per ECMA 350
disc diameter (mm)	120	120	120	130
thickness (mm)	0.6 x 2	1.2	1.2	1.2 x 2
wavelength (nm)	405	405	405	405
NA	0.65	0.85	0.85	0.70
modulation code	ETM	(1,7)PP	(1,7)PP	(1,7)RLL
read channel	PRML	PRML	PRML	PRML
track pitch (nm)	40	320	320	370/400
track density (tpi)	63,500	79,375	79,375	68,649 (max)
min. mark length (nm)	204	149	160	314
recording density (bpi)	182,677	226,772	211,653	107,795
areal density (Gb/in^2)	11.6	18	16.8	7.4
first shipment	(2005)	July 2004	November 2003	October 2003
drive price (US$)	TBD	2,800	2,995 (int) 3,299 (ext)	3000
media price (US$)	TBD	35 (25 GB RW) 70 (50 GB RW)	45	60 (30 GB WO) 75 (30 GB RW)
ODL	No	No	Sony 19" rack mount	Plasmon G-Series
3rd party software	TBD	TBD	Yes	Yes

Optical Storage Component/Subsystem Attributes

Component/Subsystem	2005	2007	2009	2015	Comments
Laser Wavelength (nm)	405-780	405-780	375-650	256-405	Through 2009, convergence on 405nm is expected. Beyond about 2010, UV lasers and media must be planned, if not implemented.
Laser Power (mW)	3-30	3-30	3-30	3-30	Recording speed and recording layer sensitivity are the pacing factors. Historically , this has been the range in laser powers for each generation.
Objective Lens NA	0.45-0.85	0.60-0.85	0.60-1.5	0.60-2.5	Assumes the introduction of NFR to obtain NA >1.
Disc Types	replicated, WO, RW, holographic	replicated, WO, RW, holographic	replicated, WO, RW, holographic	replicated, WO, RW, holographic	Media types will probably stay the same. WO should survive the roadmap period.
Recording Layers	2	2-4	2-6	2-20	Each side of the disc. By 2009, areal densities will be so high that cartridge media will be required.
Data Encoding/Read Channel	RLL/PRML	RLL/PRML	RLL/PRML	TBD	Multi-level, multi-layer, NFR, and combinations will require significant coding and signal processing as 100 Gb/in^2 areal densities are approached.
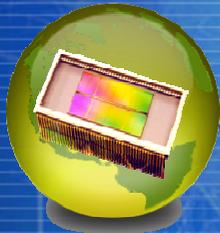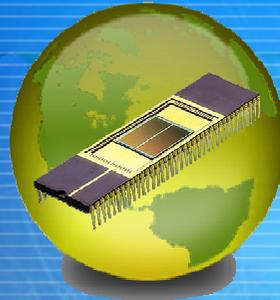
Memory Market Outlook

Don Barnetson
Associate Director, Flash Marketing
Samsung Semiconductor, Inc
d.barnetson@ssi.samsung.com

Memory Market Forecast

■ `04 Memory Market Showed Healthy Growth of 45% (Growth Peak)

- Memory Market Growth Rate Peak in `04 & Modest Downturn in `05

($B)

Memory Revenue — **Memory Market G/R**

Year	95	96	97	98	99	00	01	02	03	04	05	06
Revenue	54	36	29	23	32	49	25	27	33	47	47	45
G/R	65%	-33%	-19%	-22%	40%	52%	-49%	9%	20%	45%	0%	-4%
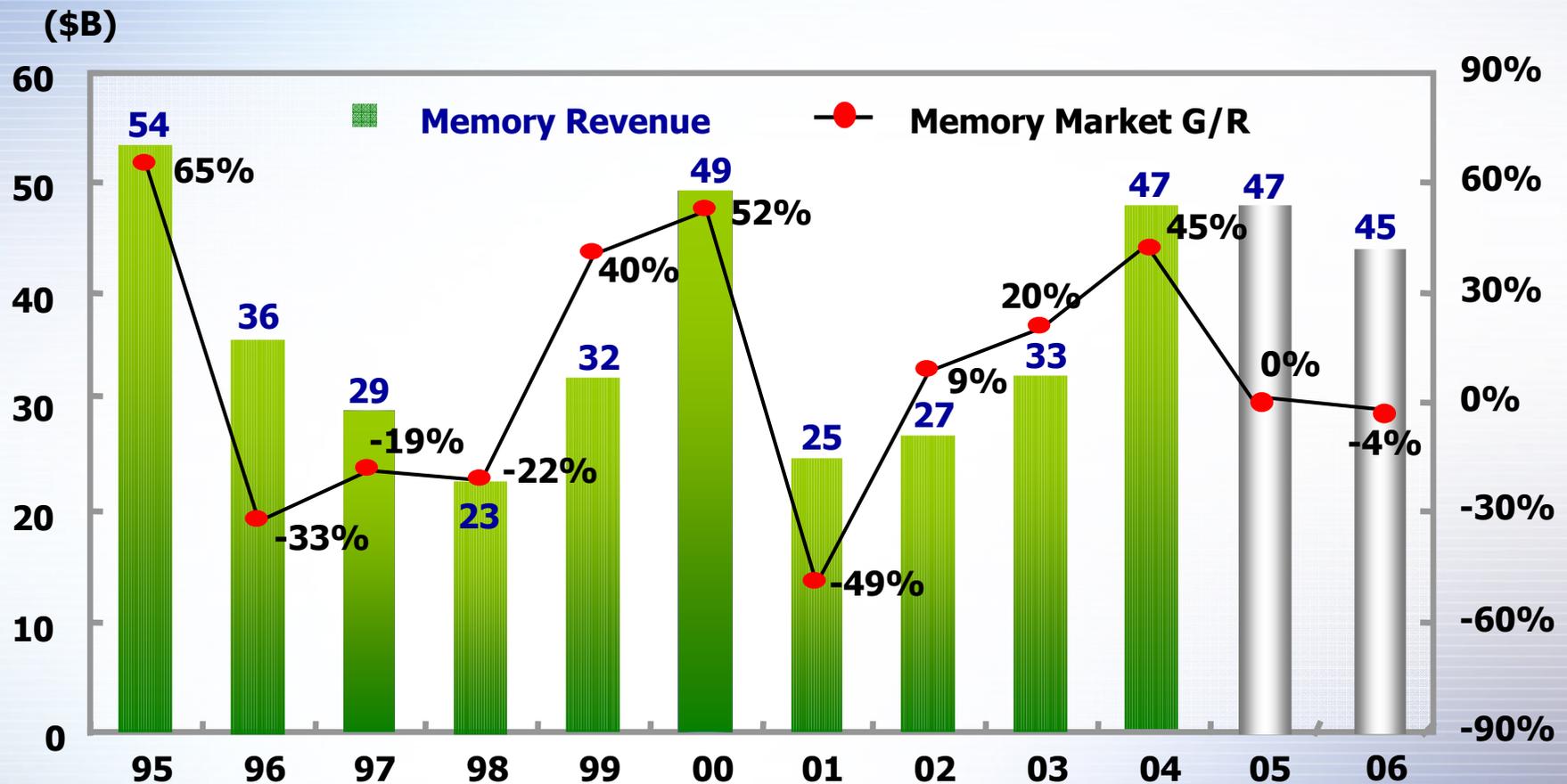
* Source : WSTS(05.5)

Semiconductor Makers' CAPEX Trend

❑ **Expect $5.8B In 2005 SEC CAPEX Exceeding Intel's ($5.6B)**

- **Hynix : $1.6B (2004) → $2.1B (2005)**
- **Infineon : $1.5B (2004) → $1.6B (2005)**

($B)

| | Samsung | Intel | Micron | Infineon | Hynix |
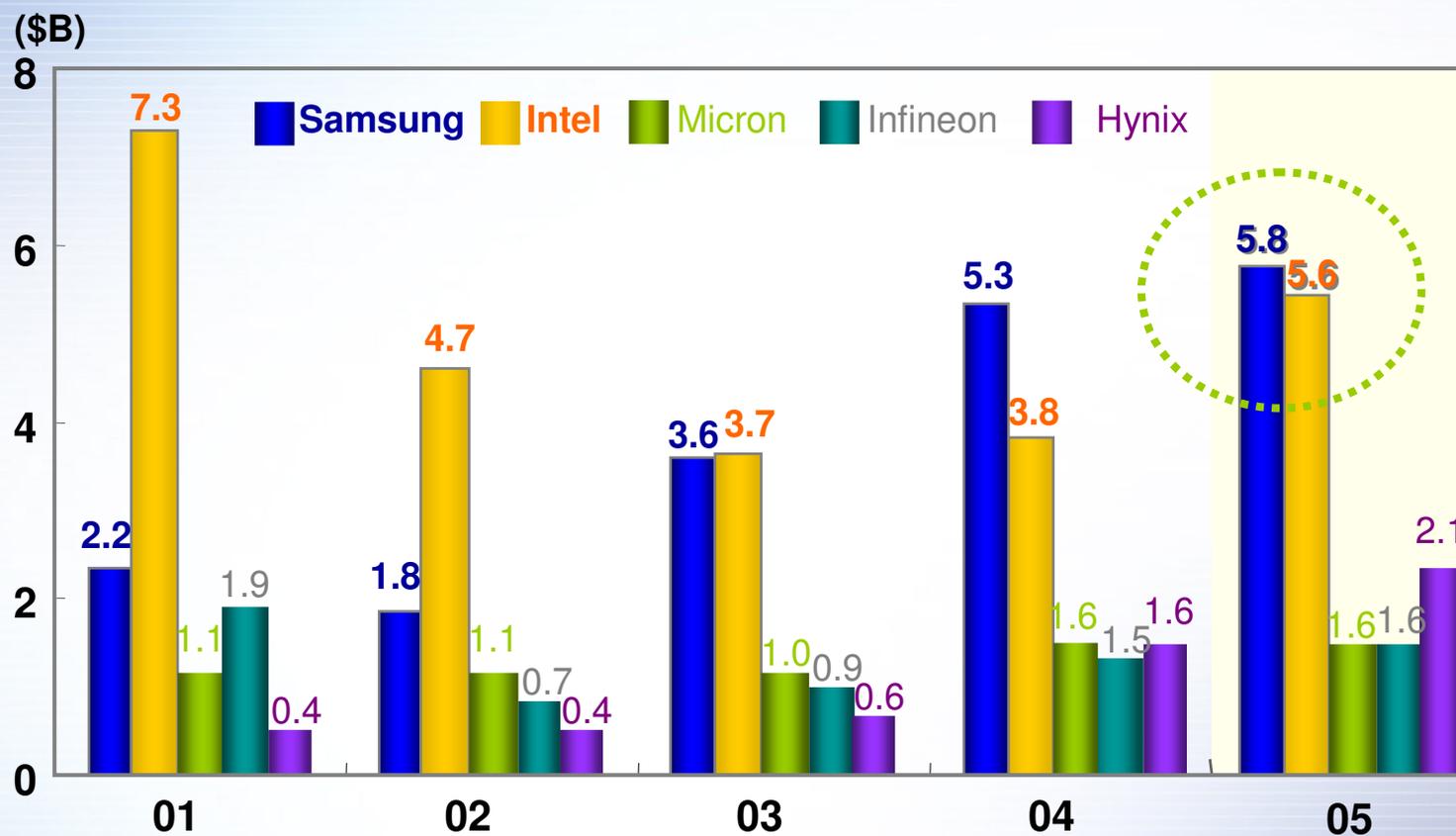
※ **Source : Company Reports, LB (Apr 2005), CSFB (Apr 2005), SEC Marketing**

Samsung Leads the Memory Industry
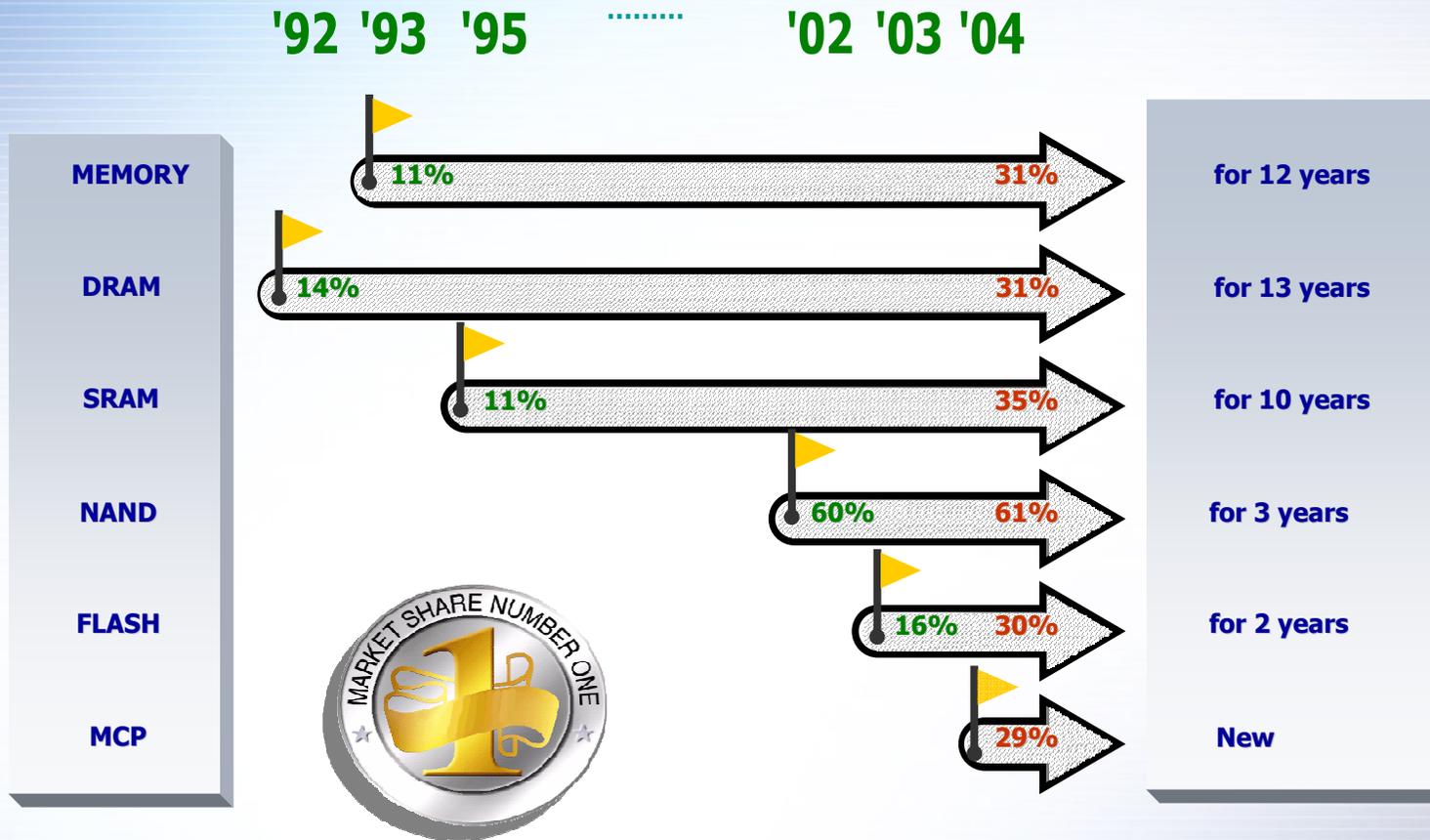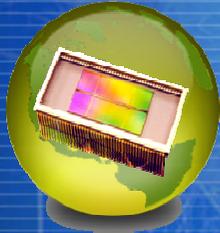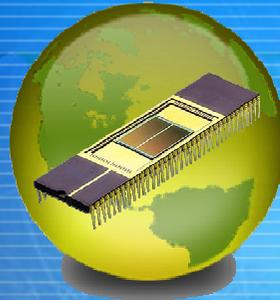
DRAM Outlook

9/20/2005

Don Barnetson

SSI, Marketing

Increasing DRAM Mix Complexity

Industry-wide DRAM Output by Technology and Density

- 512Mb DDR2 is the next mainstream DRAM...
- "Legacy / Specialty" to remain relatively constant

Source: DeDios

Paradigm Shift in DRAM Demand

- Market becoming less EDP−Centric
- Each segment has different needs...

SEC DRAM Revenue
Distribution Comparison

1995:
- Communication 4%
- Other 0.5%
- Consumer 9%
- Server 40%
- PC 47%

2005:
- Communication 10%
- Other 0.4%
- Consumer 22%
- Server 22%
- PC 45%

Staying in the DRAM "Sweet Spot"

Flash Market Forecast

■ **NAND revenue surpassed NOR in 2005; NOR Market set for decline**

- **The accelerated growth in NAND flash is due to the strong demand for data storage from the consumer electronics and hand-held applications.**

[$ B]

Legend: ■ NAND   ▨ NOR

Chart years: '98 '99 '00 '01 '02 '03 '04 '05

[Source:SEC MKTG]

`05 NAND Supply Outlook

■ **W/W NAND Supply Will be about 1,700M Units In 2005**

   ▪ **SAMSUNG NAND M/S is over 60% all throughout 2005**

   ▪ **SAMSUNG Semiconductor expect $5.8B in `05 SEC CAPEX**

(1G Eq. M Units)
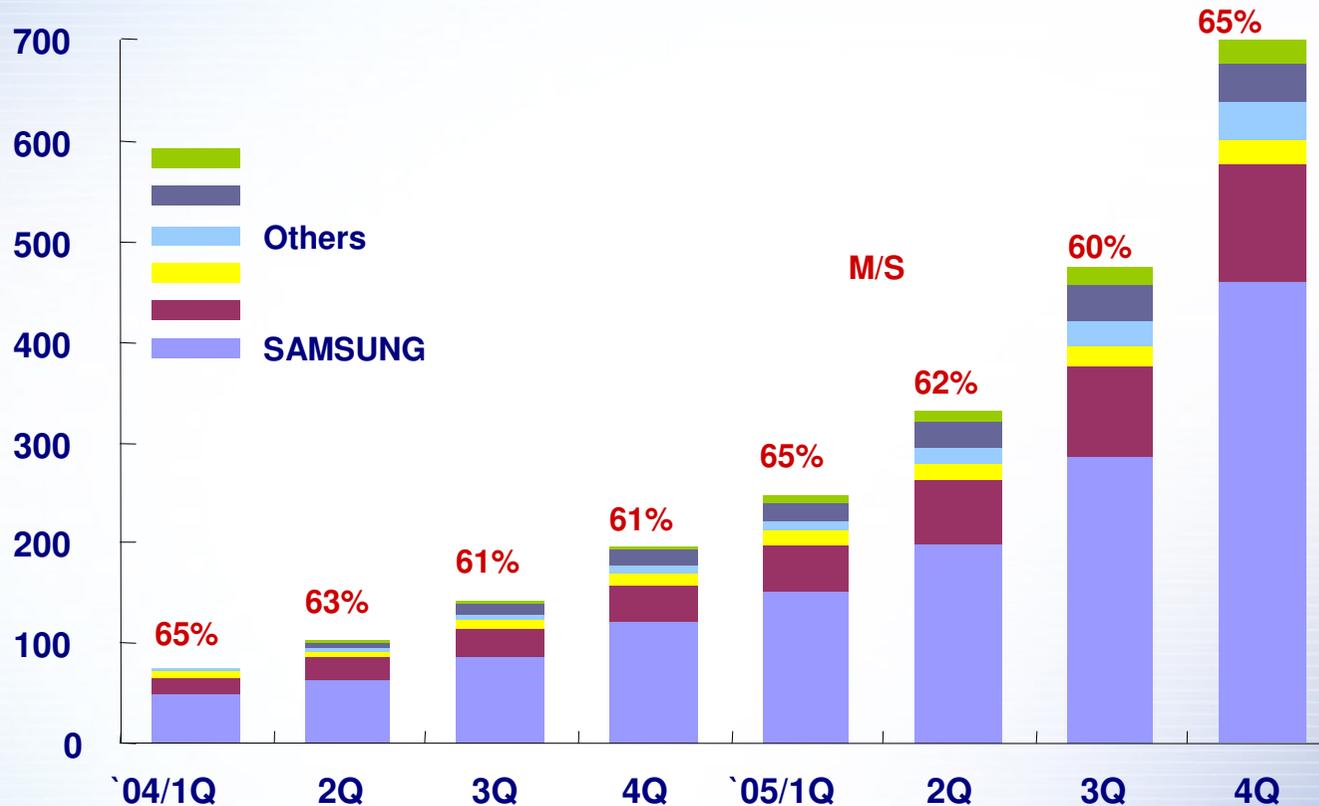
Long term technology migration

■ **Rapid migration to 90 nm /73nm enables Samsung to maintain a competitive edge.**

■ **73nm is an intermediate technology to be converted into 63nm.**

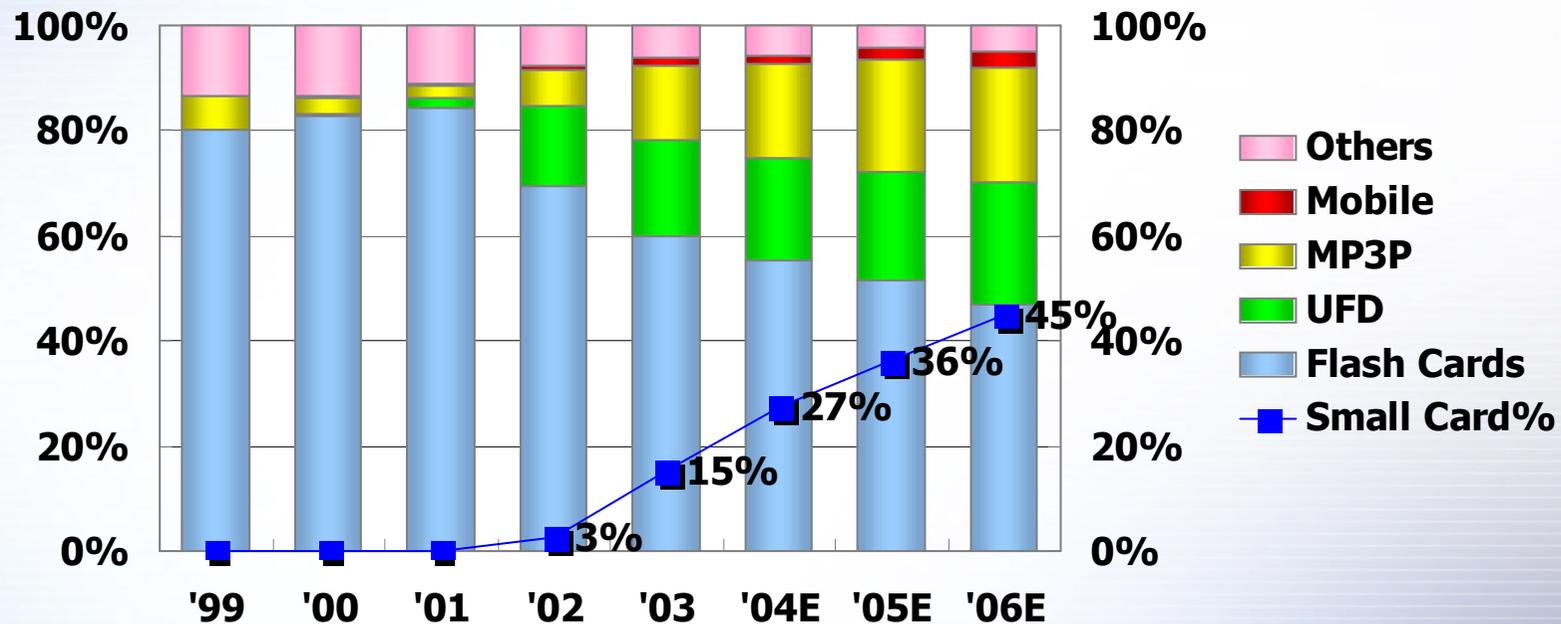■ **In 2005, 40% of NAND is produced using 300mm wafer.**
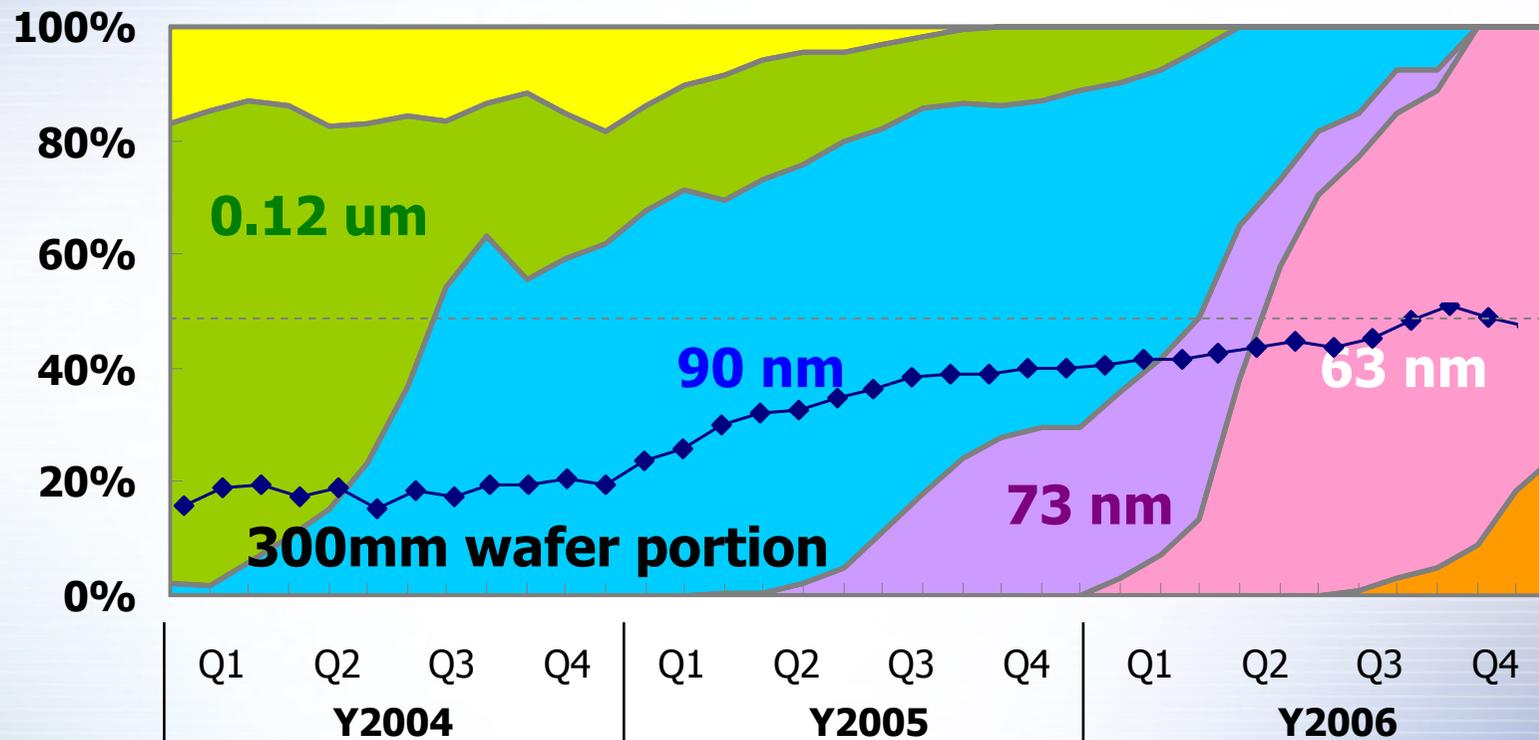
[Source:SEC MKTG]

NAND Major Market Drivers

■ **MP3P and UFD market are growing rapidly into the future.**

- Card market is driven by mobile devices as well as DSC.

- MP3 : MP3P market grows escaping chasm consuming significant MB/sys.
  '04 +330%, '05 +200%

- USB flash devices : Penetration to PCs. '04 +250%, '05 +180%

Legend: Others, Mobile, MP3P, UFD, Flash Cards, Small Card%

Small Card% values: '02 3%, '03 15%, '04E 27%, '05E 36%, '06E 45%

X-axis: '99 '00 '01 '02 '03 '04E '05E '06E

[Source:SEC MKTG]

NAND Flash Technology Segmentation

MLC NAND

**Low Cost
Highest Density**

Applications

MP3

Low-Mid DSC

Low Speed UFD

**Embedded Apps
where cost is only
consideration**

SLC NAND

**High Performance
Low Power
High Reliability**

Applications

Mid-High End DSC

High Speed UFD

Embedded Handset

Wireless Flash Cards

Industrial

OneNAND

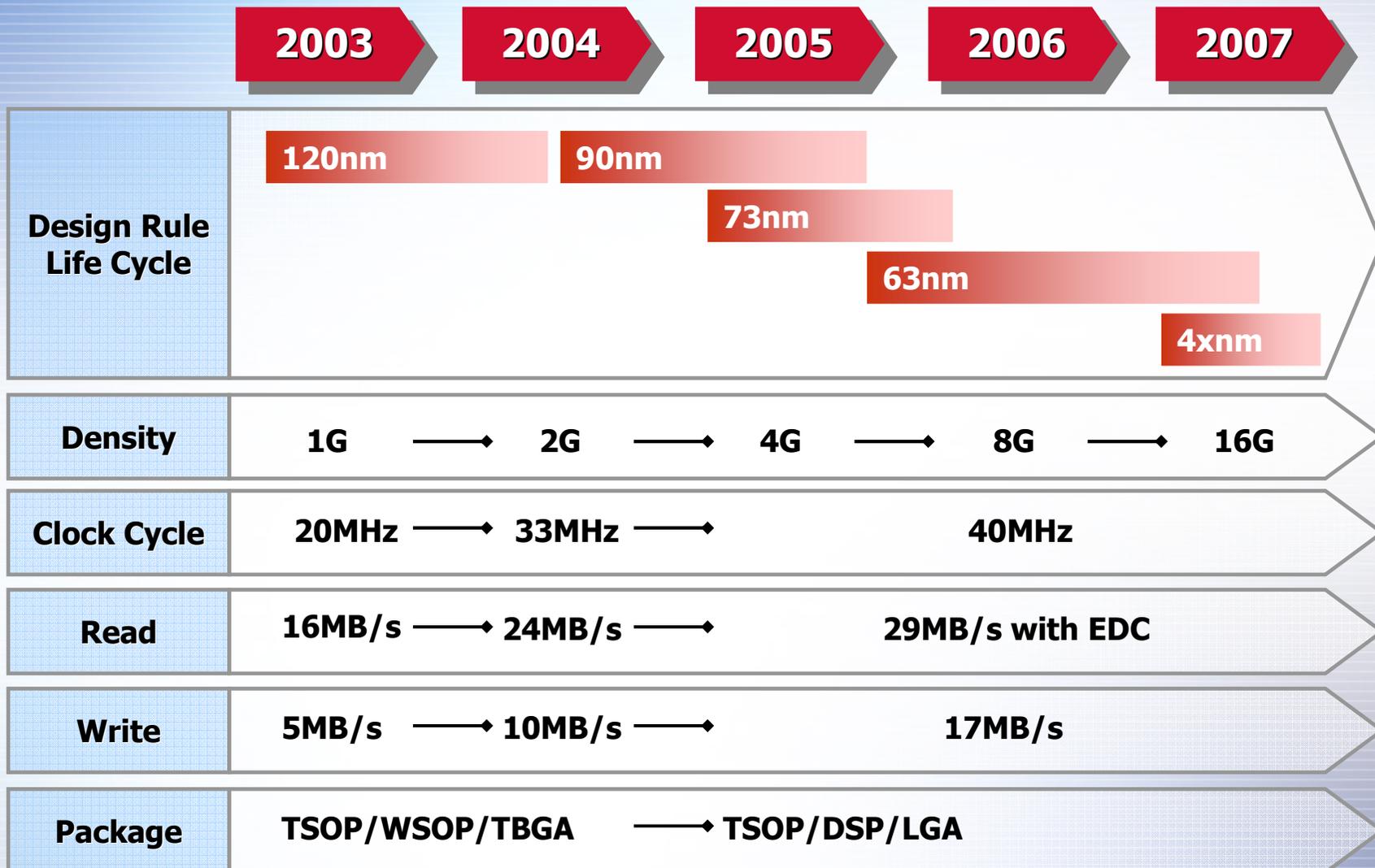**Worlds Fastest Flash
Low Power
High Reliability**

Applications

**Handset with
Converged code/data**

CE Embedded Storage
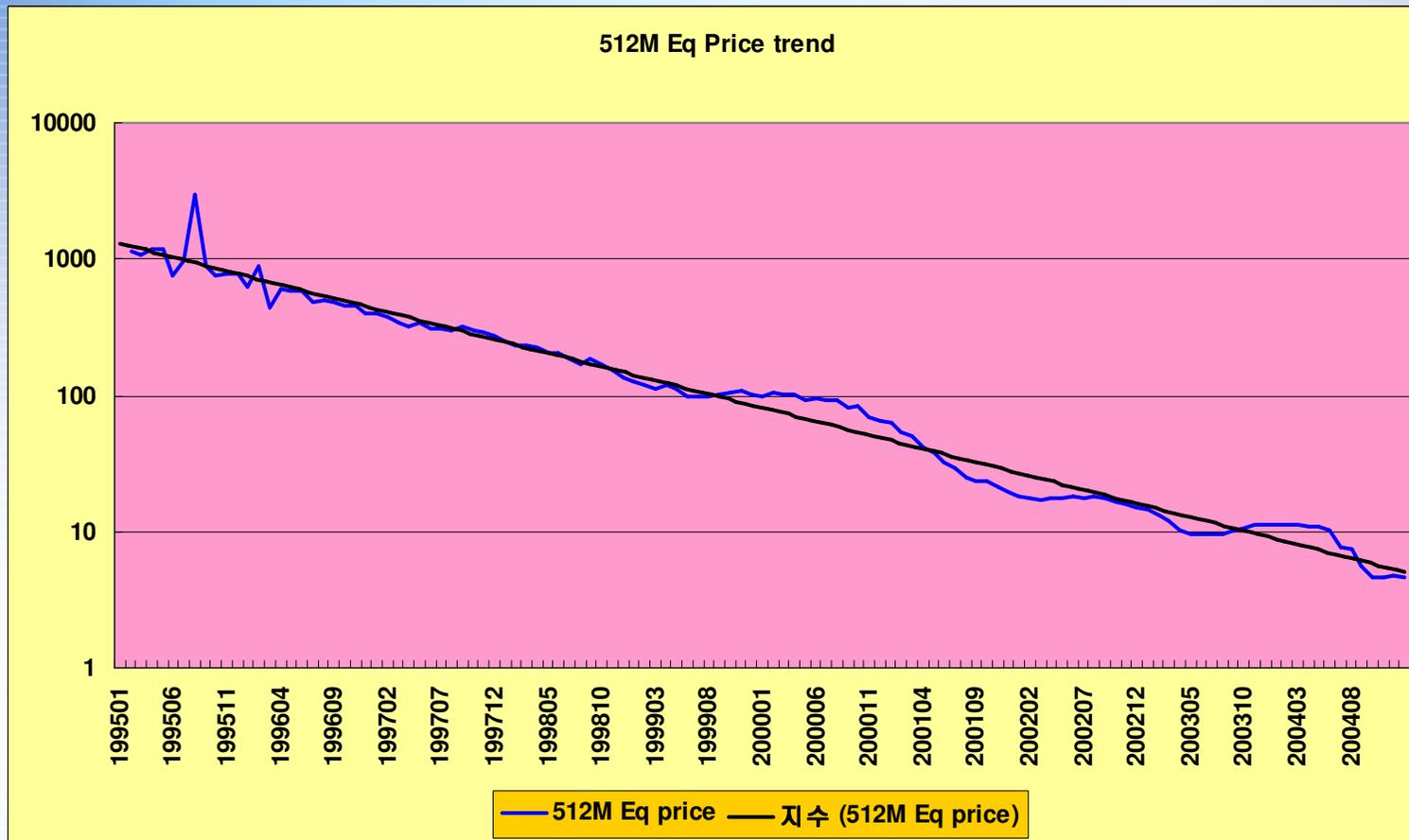
**High Performance
Embedded applications:
Hybrid Hard Drive**

Samsung NAND Process Technology

■ **73nm 4Gb NAND in Volume Production Now**

	2003	2004	2005	2006	2007
Design Rule Life Cycle	120nm	90nm	73nm	63nm	4xnm
Density	1G	2G	4G	8G	16G
Clock Cycle	20MHz	33MHz	40MHz		
Read	16MB/s	24MB/s	29MB/s with EDC		
Write	5MB/s	10MB/s	17MB/s		
Package	TSOP/WSOP/TBGA	TSOP/DSP/LGA			

Declining Cost Structure

512M Eq Price trend

- Flash bit cost has fallen an average of 4.5% per month over past 10 years

Low-Cost Storage Enables Digital Content

Analog Content	Digital	
	Removable or HDD	Solid State
Music		
Home Video		+
Movie & TV		or +
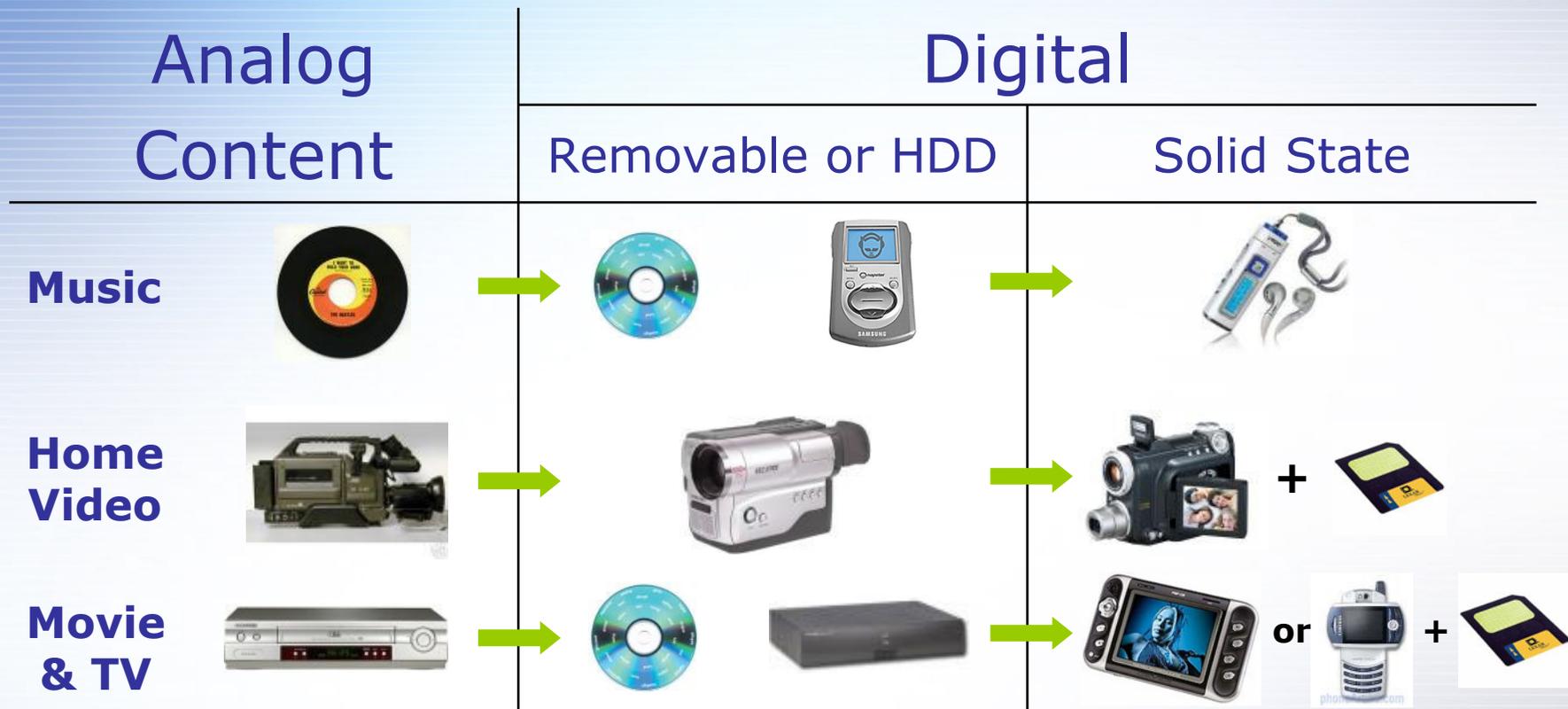
- Fixed content size vs. declining storage costs
  - Natural migration from analog – optical/magnetic - flash
- Storage Industry must work together to generate new demand

Conclusions

- Stage is set for growth of Memory Industry
  - DRAM market continues to recover
  - NAND Flash Rapid Revenue Growth

- Demand for storage is driven by content & usage models
  - Grow the eco-system for new usage models

- If content size is fixed, migration from magnetic media to flash is natural and inevitable
  - Embrace this and move forward

Legal Disclaimer

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Agenda

- **Mobile Platform trends**
- **Application challenges for mobile devices in the digital home and beyond.**
- **Understanding *Mobile* Users and Usages.**
- **Initiative developments around interface changes (CE-ATA)**
- **Future Outlook for mobile storage**

Mobile Compute Platforms Trends

Digital Office

**Thin and Light
Great Battery Life
Wireless Connectivity**

Digital Home

**Wide aspect ratio screens
Portable/Ultra mobile
Performance
Wireless Connectivity**

Source: Intel PCG Strategic Marketing

4
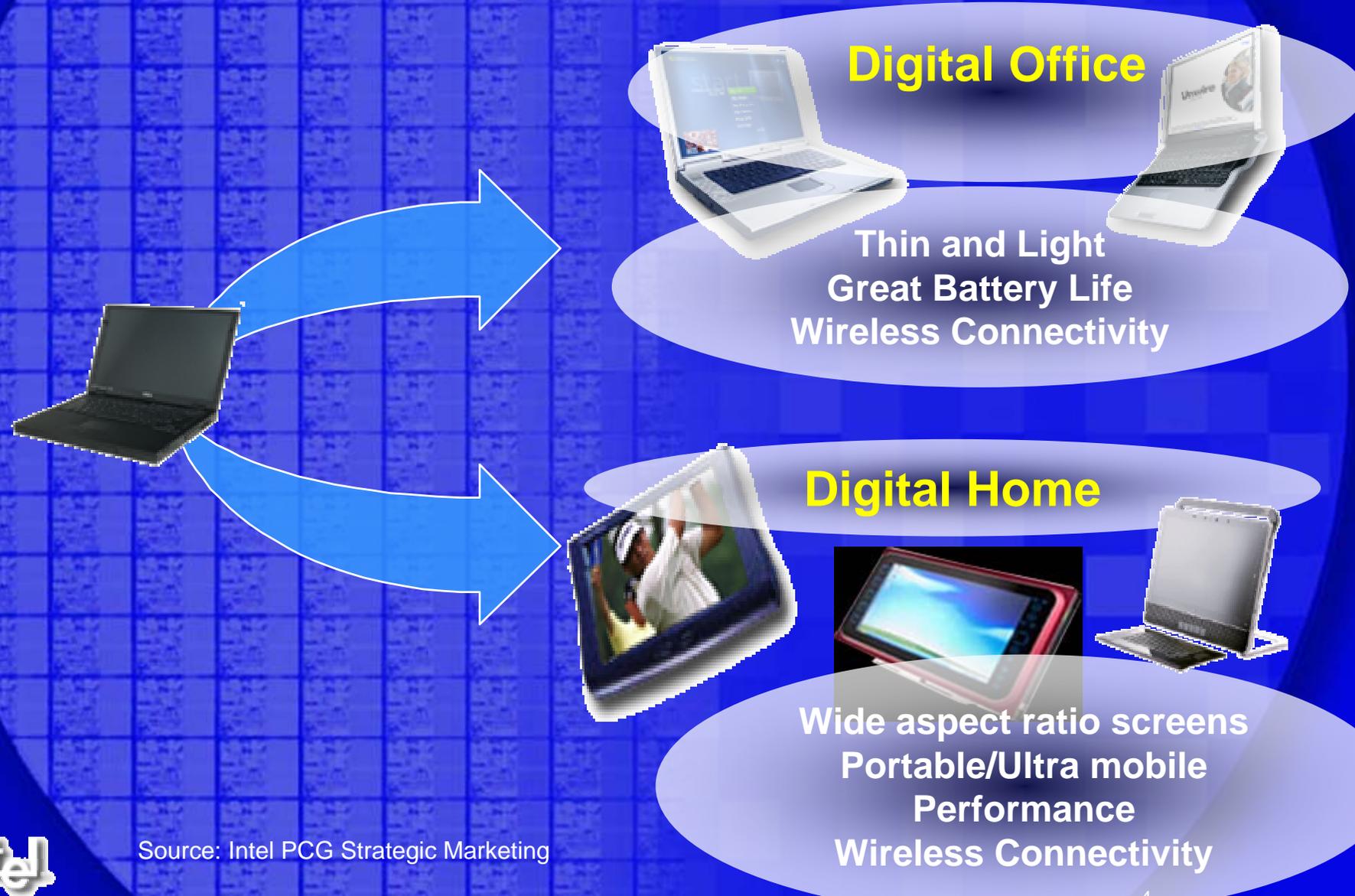
Consumer purpose built Platforms Trends

PVRs, Media Players, Camcorders, MP3

High Density HDD (10-120GB)

HDD's going to 1''

Low Density HDD (170MB-8GB)

PMPs, Cameras, MP3s, PDAs, Phones

0.85" too close to Flash Capacity

Trends affecting workplace and Home and Mobile Environments

Manageability and Security

Geographic Dispersion

Mobility

Information Paradox

Broadband Networked Devices

Digital Content PC Growth

Digital TV

Quick market look at Mobility, Manageability and Security.

Security breaches and manageability costs rising

Manageability and Security

140,000

70,000

0

'88   '91   '94   '97   '00   '03
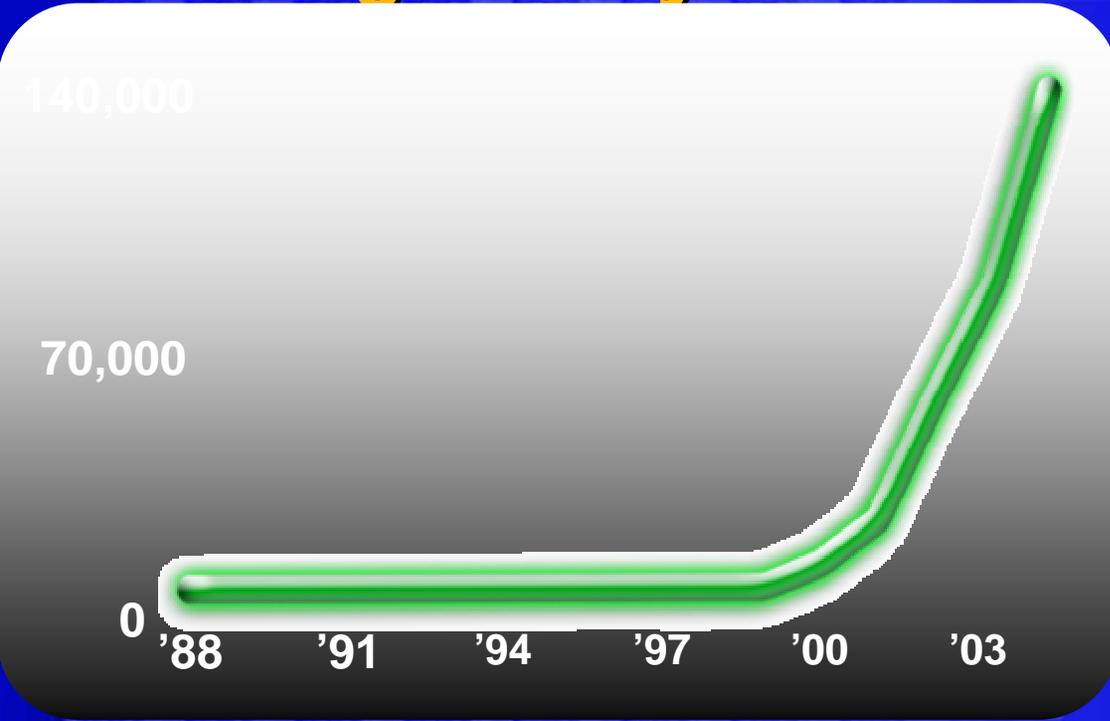
Incidents per year increasing

SW Support $50B

HW Support $80B

Headcount $240B

Asset Management $130B
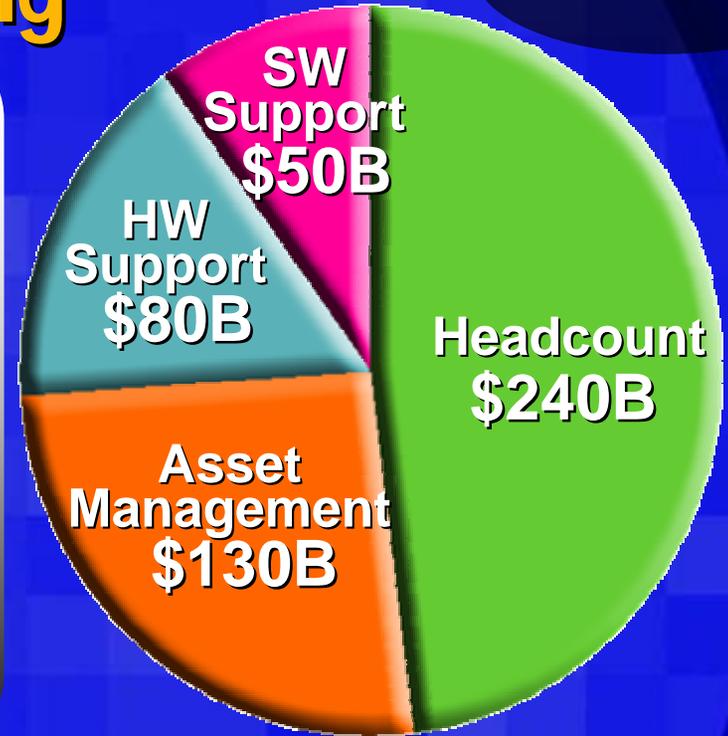
Manageability costs are high

PDA's, Laptops and other devices have personal and business data – A solution is to Encrypt

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People on the Move

Mobility

Worldwide Converged Mobile Phone Forecast

Converged devices are expanding their devices beyond their core telephony functionality (GPS, Pictures, Video, Compute and MP3)

Still Only 0.7% of total mobile phones in 2008 (790M units)

Shipment (M)

10

5

0

'03   '04   '05   '06   '07   '08
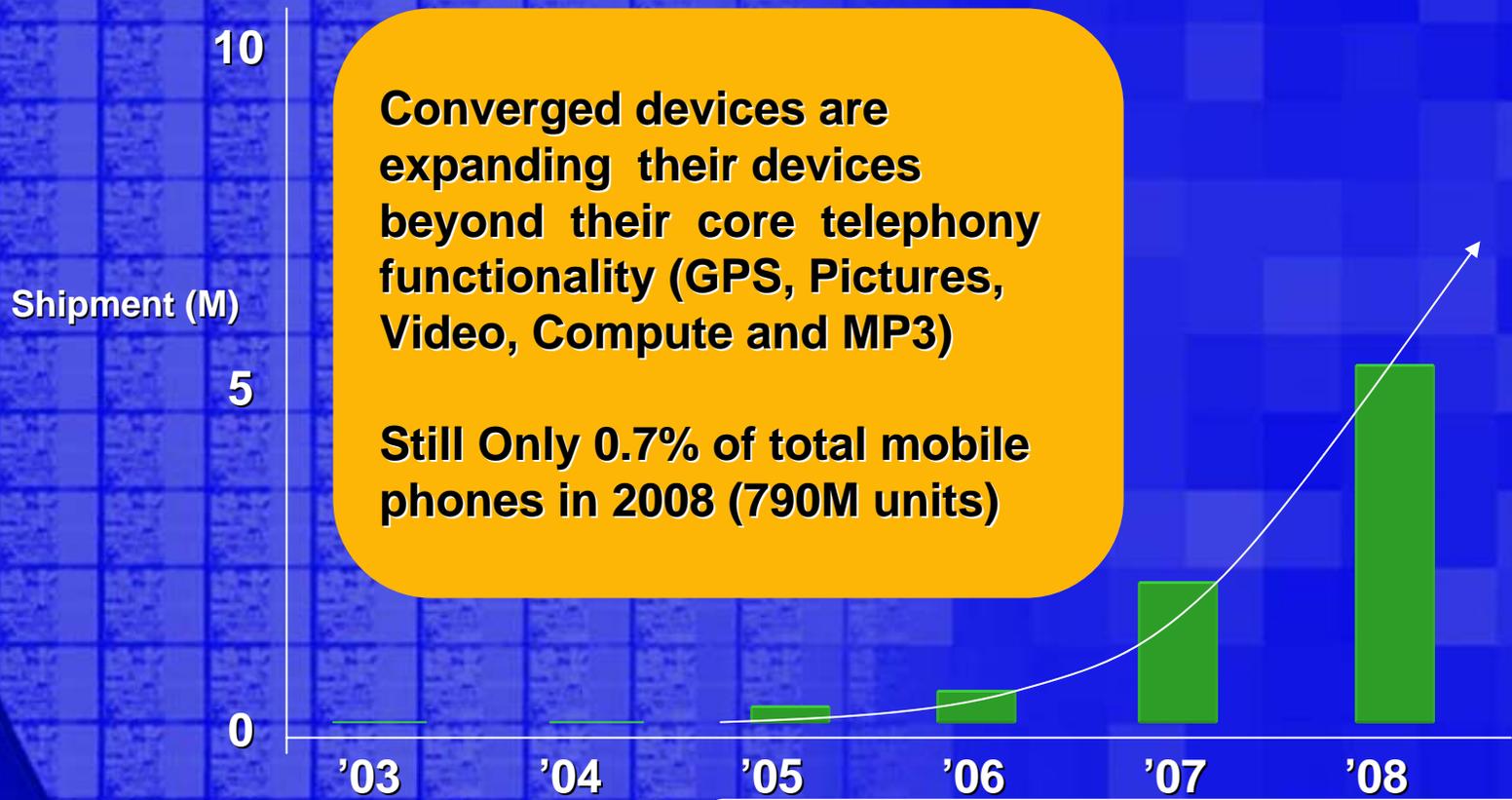
█ HDD based Converged Mobile Devices

Source: IDC 2004

Fast Adoption of Instant Messaging

Data Growth on Moore's Law
Petabytes Shipped

Mobility

New Users — 100M, 50M, 0
Total Users — 250M, 125M, 0

Enterprise
- New Users
- Total Users

'01   '04   '07

2800   1400   0

'03   '04   '05   '06
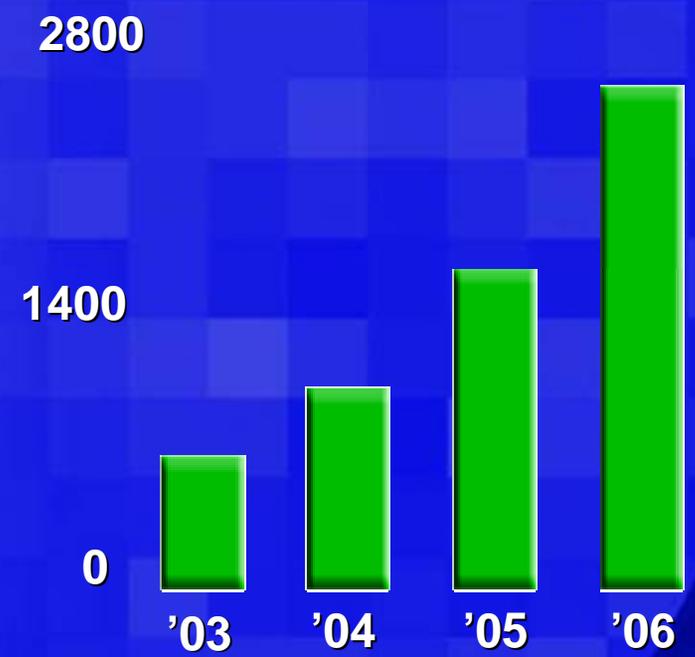
Instant Messaging has created a "always connected" environment. Users feel attached to the devices.

9

NVM Industry Trends

NAND vs. DRAM Price per MB
January 2004 - April 2005
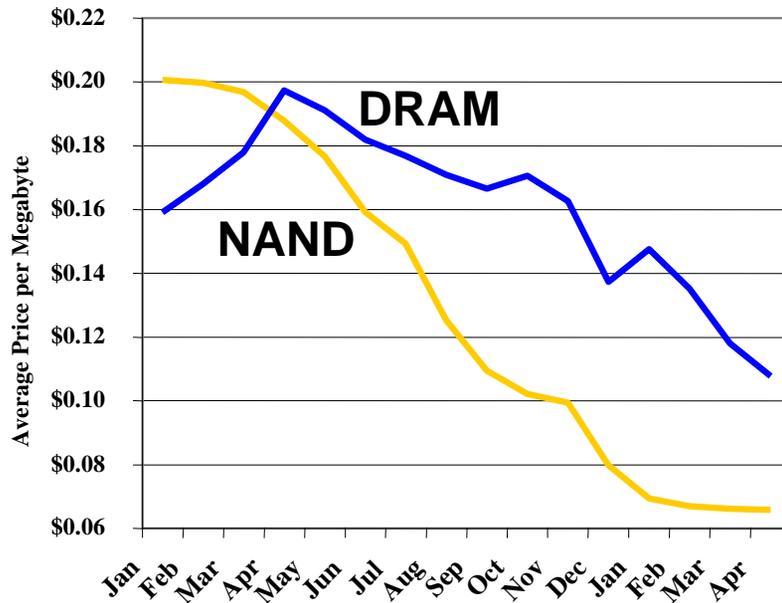
DRAM

NAND

$ per GByte
2005 - 2009

NOR

DRAM

NAND

HDD
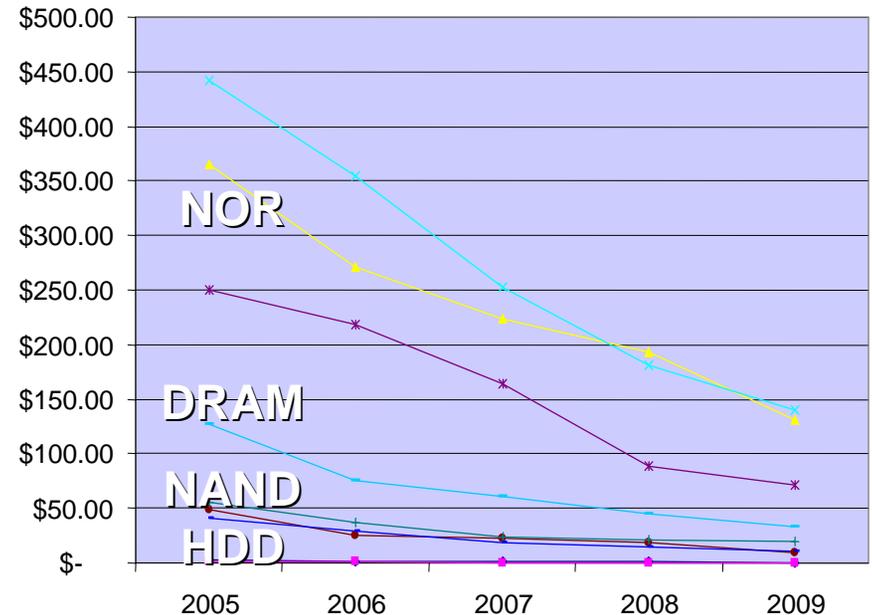
2004
NAND crosses over DRAM on cost

2005 – 2009
$/GB NOR > DRAM > NAND > HDD

- **NAND cost better than DRAM**
- **NAND cost NOT expected to cross HDD in next 5 years; but has power benefits**
- **HDD floor cost still around $30 - $40**

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10

How is Intel Understanding *Mobile* Users ?

Ethnography

Mobile Kits and Urban Practices

- **Young urban professionals**
- **What do they carry, how & why is it used?**

Urban Practices: What They Need

- **Privacy, security, efficiency**
- **But also, and in terms of:**
  - **Transaction tracking**
  - **Content collecting**
  - **Maintaining boundaries**

Surprising similarities - Calendar, wallet, keys, phone, reading/music. Wallet for exchangeables, credentials, residues

- **People have to juggle multiple devices, identities, contexts, credentials, receipts**
- **Provide control, flexibility and simplicity**

Ensembles

- **No simple platform likely to suffice**
- **Opportunity:**
  - **enable ensembles of cooperating platforms**

Aim to fit in!

Mobile in the Digital Home

Create and Enjoy "My Content" Anywhere

Rich Communication

High Definition Video & Audio

Wireless Mobile Digital TV

- "Outside- In"
- Synch-n-Go
- Soft DMA
- 3D gaming
- Battery Life

- Wideband Codecs
- Array Microphones
- Integrated Camera
- VoIP/Video Chat
- Bluetooth* headsets
- High Bandwidth Interfaces

- Next gen WLAN
- Next generation DVD
- VoW

- TV in the Home
- TV on the Go
- PVR

Mobile in the Digital Home

Create and Enjoy "My Content" Anywhere

Rich Communication

High Definition Video & Audio

Wireless Mobile Digital TV

- **"Outside- In"**
- **Wideband Codecs**
- **Next gen WLAN**
- **TV in the**

Interface requirements and applications are Key to any user experience.

- **3D gaming**
- **VoIP/Video Chat**
- **VoW**
- **PVR**
- **Battery Life**
- **Bluetooth* headsets**
- **High Bandwidth Interfaces**

Go

Consumer HDD Interface Options

Interface	Industry Supporter	Read BW	# pins	I/O Volt	Current Spec Ver.	Segment	HDD Products
CF/CF+/CF v2	**Compactflash .org**	**8MB/s CF+ 16MB/s v2.0**	**50**	**3.3/5**	**CF+ V2.0, Type II (ATA-mode)**	**Mobile and Ultra Portable**	**Yes**
S-ATA	**SATA Working Group**	**150MB/s**	**4**	**250mV Differential**	**SATA v2.5**	**PC and Laptop, Mobile**	**Yes**
S-ATA 3Gb		**300MB/s**	**4**			**PC and Laptop**	**Yes**
HS-MMC	**MMC**	**52MB/s**	**13**	**1.65-1.95 2.7-3.6v**	**4.0 HS-MMC**	**Mobile and Ultra Portable**	**Yes** **ATA over MMC just released 1.0**
SDIO	**Sdcard.org**	**10MB/s**	**9**	**3.1-3.5v**	**1.0**	**Mobile and Ultra Portable**	**No**
USB 2.0		**60MB/s**		**3.3v**	**2.0**	**Mobile and Ultra Portable**	**Yes**
CE-ATA	**CE-ATA working group**	**26MB/s (4bit) 52MB/s (8bit)**	**12/16**	**1.8/3.3v**	**1.0 4bit with 8bit future**	**Ultra Portable**	**Yes**

Consumer HDD Interface Options

Interface	Industry Supporter	Read BW	# pins	I/O Volt	Current Spec Ver.	Segment	HDD Products
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S-ATA	**SATA Working Group**	**150MB/s**	**4**	**250mV Differential**	**SATA v2.5**	**PC and Laptop, Mobile**	**Yes**
S-ATA 3Gb		**300MB/s**	**4**			**PC and**	**Yes**
USB 2.0		**60MB/s**		**3.3v**	**2.0**	**Mobile and Ultra Portable**	**Yes**
CE-ATA	**CE-ATA working group**	**26MB/s (4bit) 52MB/s (8bit)**	**12/16**	**1.8/3.3v**	**1.0 4bit with 8bit future**	**Ultra Portable**	**Yes**

CE-ATA was created to address the consumer Embedded HDD market where Cost, Power and Reliability are top priorities
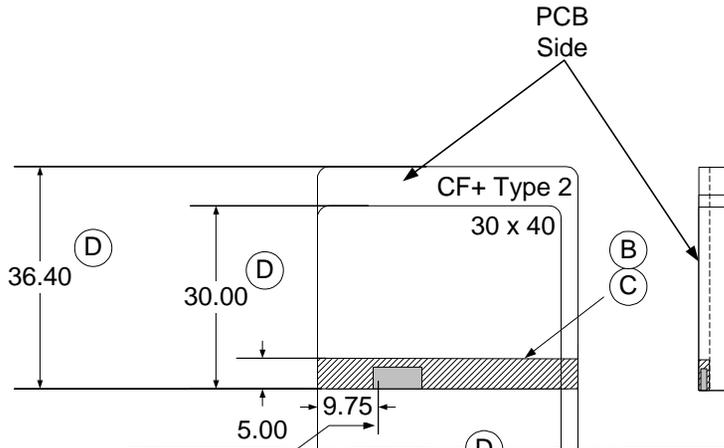
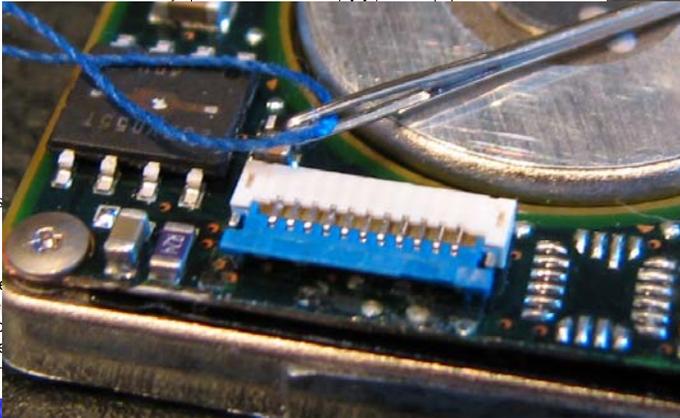Source: Intel PCG Strategic Marketing

CE-ATA Background/Refresher

- **The CE gadget segment is seeing explosive growth**
- **The current small form factor disk interface is CF+ (Compact Flash +** *Parallel ATA***)**
  - **50 pin connector with 5V signaling**
- **CE segment needs highly efficient integration**
  - **PATA already being displaced in desktop due to integration issues (high pincount, 5V tolerance, …)**
  - **SATA is not ideal for tiny handheld gadgets with modest requirements**
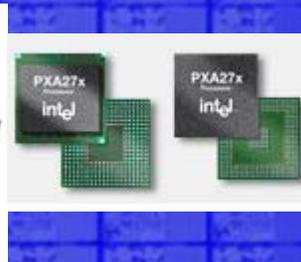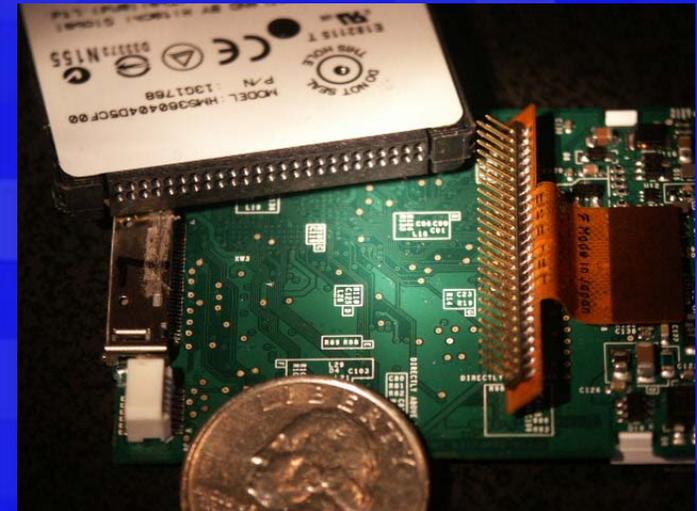
Connector Location Standardization

30mm X 40mm formfactor

ZIF connector
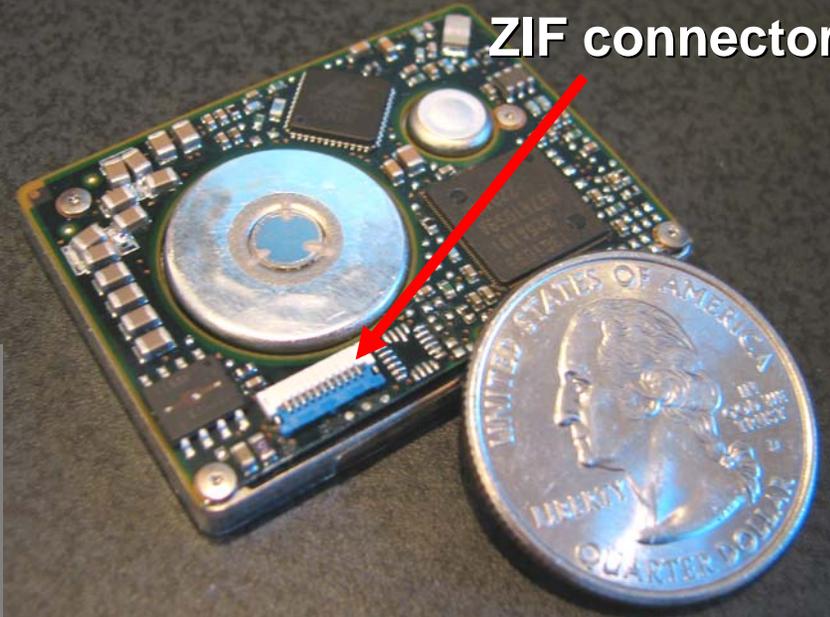
PCB Side

CF+ Type 2
30 x 40

D
D
B
C

36.40
30.00

9.75
5.00

Note:
Units: mm
Tolerance ± 0.2 unless otherwis
A - Centerline of pin 1
B - Drives less than 5 mm thick
C - Maximum out of form factor
  - Needed for system asse
  - Maximum connector de
D - Drive dimensions are only to
  - See the SFF Committee

Hitachi GST* prototype sample that supports CE-ATA

CE-ATA interconnect and connector well suited to handheld applications

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Future Outlook

- **It's the hot topic…**
  - **Mobile devices with HDDs will arrive -> growing range of solutions**
    - **'Making statements of innovation' vs. volume opportunity**
    - **Flash memory -> increasing capacity, decreasing price**
      - Will challenge HDD adoption until HDD can leverage favorable $/MB
  - **Subscriber education = critical**
  - **General convergence will continue**
    - **Winners = solutions with clear value proposition**
      - Consider Nokia (Symbian/Series 60), RIM
    - **Losers = solutions with unclear value proposition**
      - Consider expensive devices, attempting to offer 'everything'

Source: IDC 2004

Backup

To Learn More on Understanding Mobile Users and Usages: An Ethnographic Approach

- **Visit our website**

  People and Practices Research Lab

  http://www.intel.com/research/exploratory/papr

- **Ask us questions**

Scott Mainwaring	**scott.mainwaring@intel.com**
Ken Anderson	**ken.anderson@intel.com**

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