The Future of Data Storage

DISKCON 2007

Chris Bajorek
September 20, 2007

Agenda

- ACKNOWLEDGMENTS
- INTRODUCTION
- THE DOMINANT MEMORY HIERACHIES
- THE COST OF MEMORY TECHNOLOGIES
- THE FUTURE OF FLASH AND HARD DRIVES
- THE POTENTIAL OF EMERGING TECHNOLOGIES
- SUMMARY AND CONCLUSIONS

ACKNOWLEDGMENTS

- Trend Focus
- Hutchinson Technology
- SanDisk
- Intematix

INTRODUCTION

- DRAM, Flash and HDD dominate memory market
- Approaching $ 75 B/year world-wide
- Extraordinary progress by Flash
- Can NAND Flash replace HDD?
- Can an emerging technology replace NAND Flash or HDD?

THE DOMINANT MEMORY HIERACHIES

TABLE 1: DOMINANT MEMORY HIERARCHIES

	Enterprise Server	Desktop PC	Notebook PC	Set Top Box, DVR	Cell Phone, MP3, Digital Camera
SRAM	X	X	X	X	X
DRAM	X	X	X	X	X
FLASH					X
HDD	X	X	X	X	
OPTICAL	X	X	X		
TAPE	X				

- Extremely hard to penetrate
- Adequate non volatility even with volatile layers like DRAM and SRAM
- Only much lower (10 x or lower) cost per bit, with reasonable performance, has a chance
- But no current emerging technology option has 10 x cost leverage

THE COST OF MEMORY TECHNOLOGIES

TABLE 2: COST OF INCUMBENT MEMORIES

TECHNOLOGY	CELL SIZE (FxF) 2007	CELL SIZE (FxF) 2012	RELATIVE COST/bit 2007	RELATIVE COST/bit 2012
SRAM (6 T)	120	120	2,400	2,100
FRAM NVM (1T-1C)	30	20	600	350
eDRAM	n.a.	20	n.a.	350
MRAM NVM (1T-1MTJ)	20	15	400	263
DRAM (1T-1C)	6	6	120	105
PCRAM NVM (1T-1R)	6	6	120	105
NOR Flash NVM (MLC)	5	5	90	88
NAND Flash NVM (MLC)	2	2	**40**	**35**
3D-OTP NVM (1D-1R, 4 FxF/4)	1	1/2	20	12
HDD NVM (desktop PC)	1/2	1/2	**1**	**1**
DVD NVM	1	1	1/5	1/5
TAPE NVM	n.a.	n.a.	1/10	1/10

F = minimum feature
T = transistor
C = capacitor

MTJ = magnetic tunnel junction
R = resistor
NVM = non volatile

OTP = one time programmable
MLC = two b/cell
D = diode

MEMORY TECHNOLOGIES (continued)

- Comparisons during 2H'07, but cell sizes and ratios not expected to change much through 2012.

- In 2007 a 2 GB memory chip plus a 1 controller chip Flash card is projected to cost less than $15.00, less than $7.50/GB. The absolute cost is expected to remain unchanged but the cost/GB is expected to drop below $2.50/GB in 2012

- In 2007 a 250 GB 3 ½-in., one PMR disk HDD is projected to cost less than $50.00, less than $0.20/GB. The absolute cost is expected to remain unchanged but the cost/GB is expected to drop below $0.07/GB in 2012

MEMORY TECHNOLOGIES (continued)

TABLE 3: 2H'07 PMR-based HARD DRIVE CHARACTERISTICS

DRIVE SIZE (in.)	1.0	1.8	2.5	3.5
RELATIVE DISK SURFACE AREA	1/12	1/4	1/2	1
CAPACITY/DISK (GB)	20	60	125	250
DRIVE COST ($)	50	50	50	50
COST/GB ($)	2.5	0.8	0.4	0.2

- Ratio of NAND Flash to HDD cost/b dependent on disk size/surface area
- From only **3/1** for the smallest**,** to **9/1**, to **19/1**, to **37/1** for the largest above
- At ratio greater than 10/1 and for large capacity, HDD is the preferred choice
- But at ratio of only 3/1, other factors, like size, power and robustness can swing choice to Flash. This contest is over for drives 1.0-in. and smaller
- Bottom line:
  - NAND Flash will continue to be best for lowest entry cost/non mission critical applications, i.e. almost everything hand held
  - HDD will continue to be best for high capacity/mission critical applications
  - SSD with lower cost will see modest market for ultra rugged and compact applications starting in 2H'07

TABLE 4: NAND FLASH MEMORY TECHNOLOGY REQUIRMENTS

Year of Production	2007	2008	2009	2010	2011	2012	2013	2014	2015
F (nm)	57	51	45	40	36	32	28	25	23
Bit density (Gb/cm^2)	16	19	24	32	38	48	64	78	92
Wafer size (mm)	300	300	300	300	300	300	450	450	450
Tunnel oxide (nm)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Interpoly dielectric (nm)	11	11	11	11	11	11	9.5	9.5	9.5
Endurance	10^5	10^5	10^5	10^6	10^6	10^6	10^6	10^6	10^6
Bits per cell	2	2	2	4	4	4	4	4	4

TABLE 5: HDD TECHNOLOGY REQUIREMENTS

Year of Production	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Recording mode	LMR	PMR	PMR	PMR	PMR	PMR	PMR	PMR	PMR	PMR
Bit density (Gb/cm^2)		31	46	62	93	124		248		496
Continuous media	X	X	X	X	X					
Patterned media						X	X	X	X	X
Heat assistance						X	X	X	X	X

THE FUTURE OF FLASH AND HARD DRIVES (continued)

- Near term challenges will be solved for 3 x density improvement for both technologies in approximately the same timeframe: 2011
- Sustaining/improving Flash endurance will require increasingly powerful wear leveling, encoding and error correction methods
- CE applications expected to move from 2 b/cell, to 3, to 4 b/cell but at modest endurance levels. A 4 b/cell design is projected to cost 30% less/b than the 2 b/cell design
- SSD applications expected to remain at 1 b/cell to attain acceptable endurance

TABLE 6: PROGRAMMABLE RESISTANCE TECHNOLOGIES

TECHNOLOGY	PRINCIPLE
Advanced MRAM	Magnetic tunnel junction devices requiring lower switching power and enabling smaller than 20 FxF cell sizes
Solid electrolyte	Forming and breaking conductive filaments in a low conductivity matrix material with an electric field
Polymer	Materials with molecules susceptible to changing conductivity with an electric field
Advanced PCRAM	Phase change resistors with lower power switching thresholds
Complex metal oxides	Oxides, such as Nb_2O_5, TiO_2, WO_3 and NiO, that exhibit electrically induced resistance changes
Carbon nano tubes	Nano carbon tube-based switches susceptible to making and breaking inter tube contacts with electric fields

THE POTENTIAL OF EMERGING TECHNOLOGIES (continued)

- All options dependent on lithography
- Most options require a 1T-1R cell, 6 FxF minimum cell size, not competitive with NAND Flash or HDD
- Until now, only MRAM has shown acceptable endurance. But smallest cell size, even with inventions not yet made, is projected to be bigger than 13 FxF
- All other options have shown endurance of only 1-100 cycles
- Some dream of being lithography-independent, but not likely
  - Probe and Nano e-beam
  - Must show capability at greater than 500 Gb/cm^2 vs. current 100 Gb/cm^2
- Only reversible version of 3D-OTP NVM, or an equivalent 3D design, has a chance to be competitive with NAND Flash: 1/4 to 1 FxF cell size vs. 2 FxF

SUMMARY AND CONCLUSIONS

- NAND Flash and HDD technologies have strong momentum and long life potential
- At least 3 x density improvement potential by 2011, relative to 2H'07 benchmarks for both technologies
- NAND Flash and HDDs are expected to continue to coexist as the main forms of data storage for digital products through at least 2012
- NAND Flash will continue to offer the lowest total entry cost and be the preferred choice for highly mobile consumer applications where extreme endurance is not critical
- HDDs will continue to offer the lowest cost/bit for large capacity on line data storage and be the preferred choice for computation intensive, high endurance applications

SUMMARY AND CONCLUSIONS (continued)

- However, HDDs 1.0-in. and smaller, will not compete well with Flash. The 1.8-in. and 2.5-in. will have to use the latest PMR technology to sustain meaningful cost/b advantages over Flash
- Continued reductions in cost/b for Flash, below $11.00/GB, in combination with improvements in endurance are also likely to create a meaningful market for Solid State Drives, in very compact and ultra shock resistant note book computers. SSDs projected to achieve cost below $3.50/GB by 2012
- The coexistence of Flash and HDDs will only increase the competition for new applications by both classes of storage
- This competition will require continued attention to reducing the absolute manufacturing cost of both technologies, to much below $15.00/card and $50.00/drive
- Only a reversible version of the current 3D-OTP NVM memory, or an equivalent 3D design, has a small probability of penetrating this storage market in this timeframe