

# **NAND at Center Stage**

**Flash Memory Summit**

**Santa Clara, August 8, 2007**

**Eli Harari**  
Chairman and CEO

**SanDisk**

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# Forward-Looking Statement

During our meeting today we will be making forward-looking statements. Any statement that refers to expectations, projections or other characterizations of future events or circumstances is a forward-looking statement, including those relating to revenue, pricing, market share, market growth, product sales, industry trends, expenses, gross margin, production capacity and technology transitions and future products. Actual results may differ materially from those expressed in these forward-looking statements including due to the factors detailed under the caption "Risk Factors" and elsewhere in the documents we file from time-to-time with the SEC. We undertake no obligation to update these forward-looking statements, which speak only as of the date hereof.

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# Topics

- A Bit of Flash Storage History
- NAND Technology & Challenges
- NAND Manufacturing
- NAND Industry Players
- Technology Contenders
- Future Outlook

# Beating Moore's Law

**1991**  
2.5 inch  
20MB  
4Mb chip  
35KB/sec  
\$50/MB

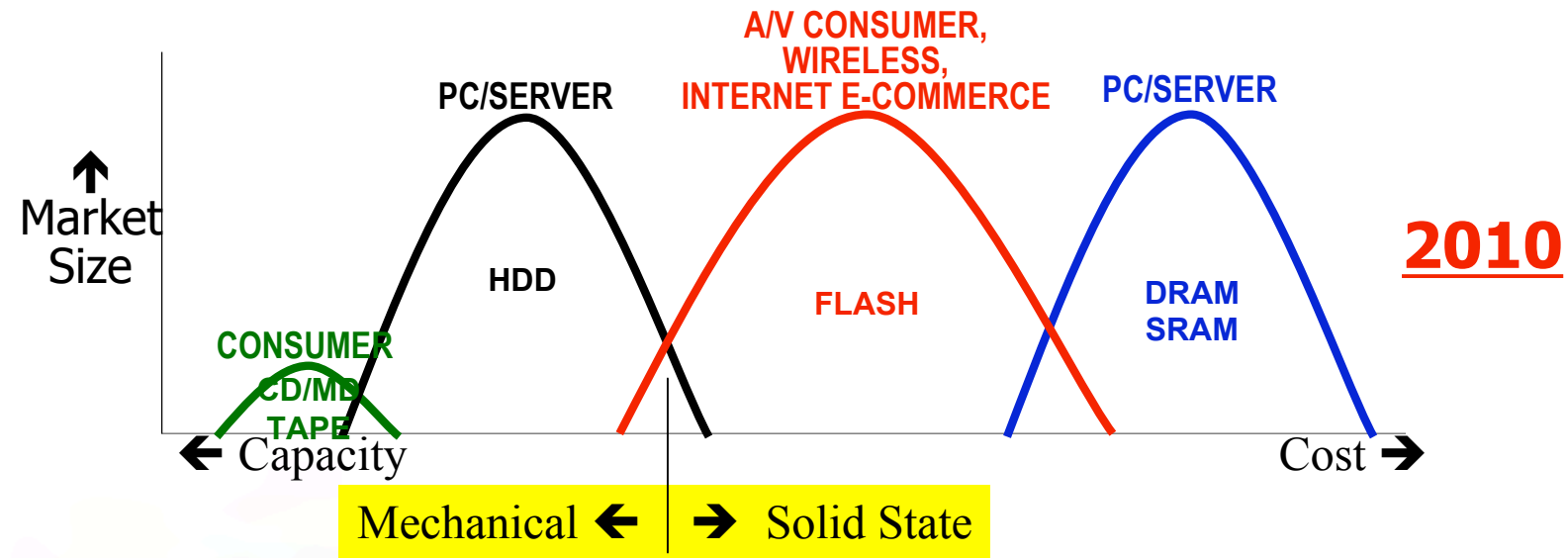
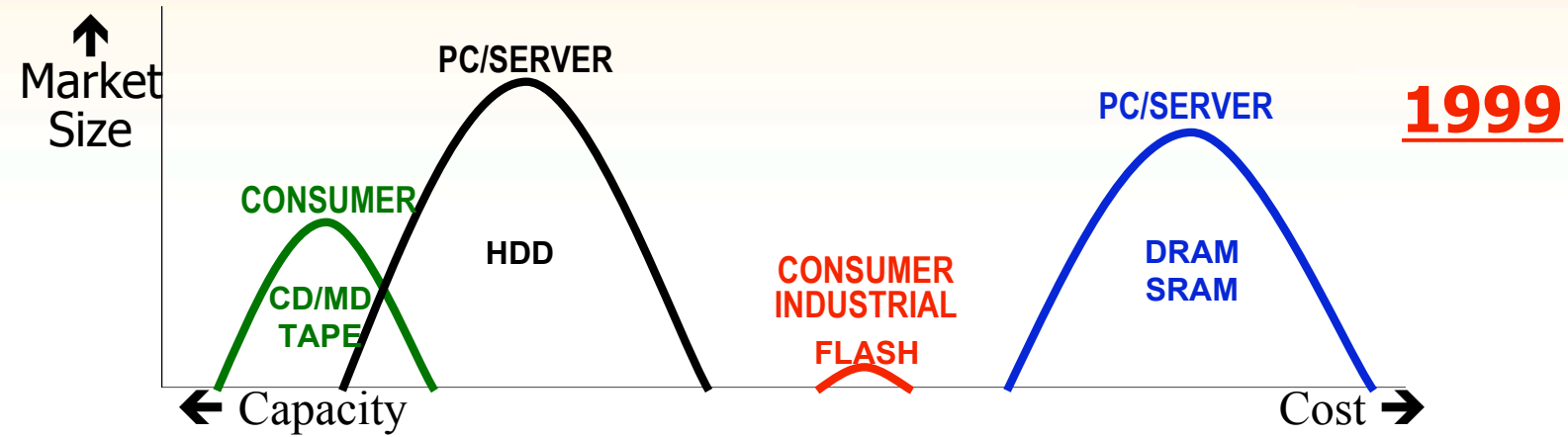


**2007**  
11x15x1mm  
8GB  
16Gb chip  
10MB/sec  
\$10/GB

12 generation (~4000X) in 16 years

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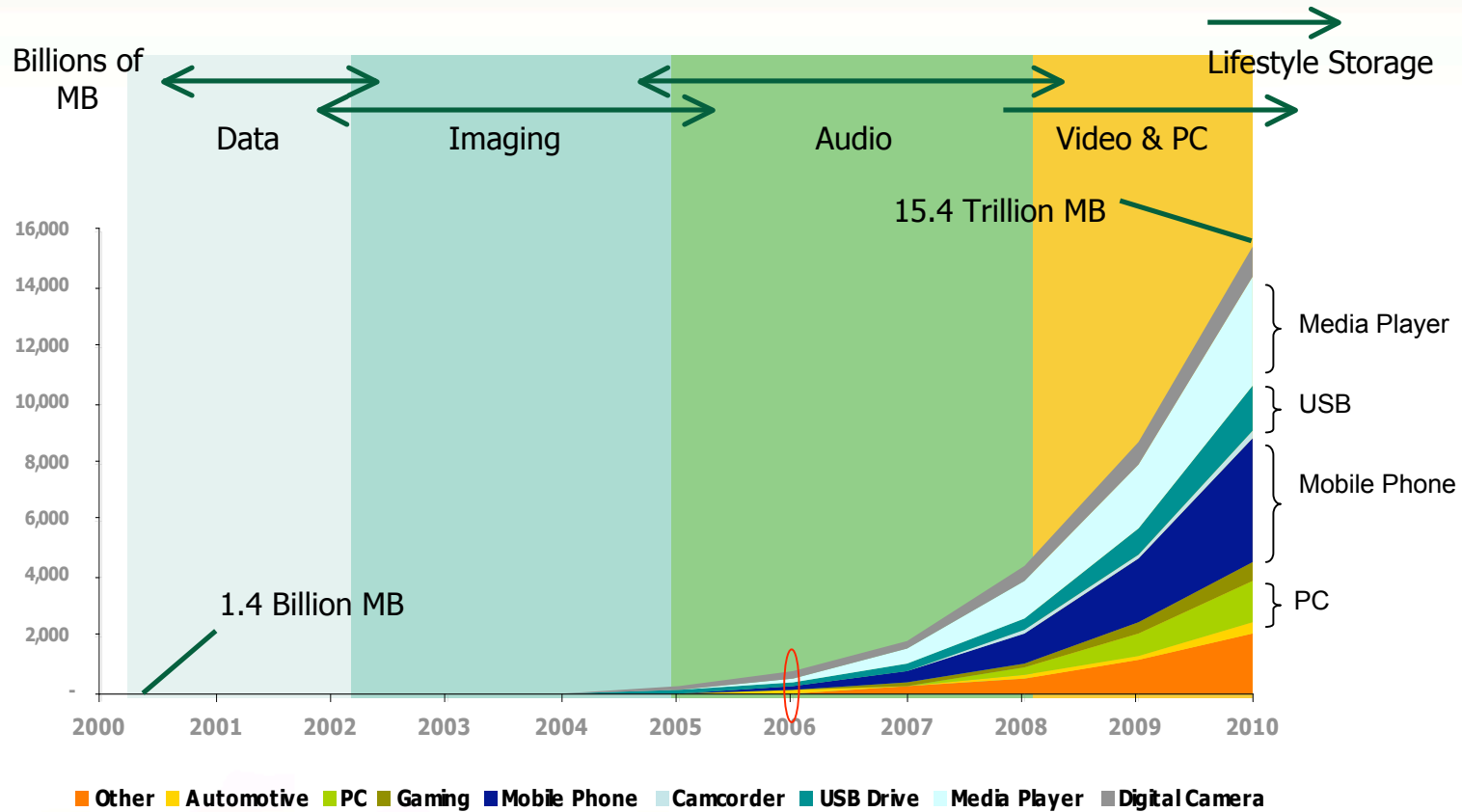
# Flash: Accelerating From A Slow Start



EH 8-25-99



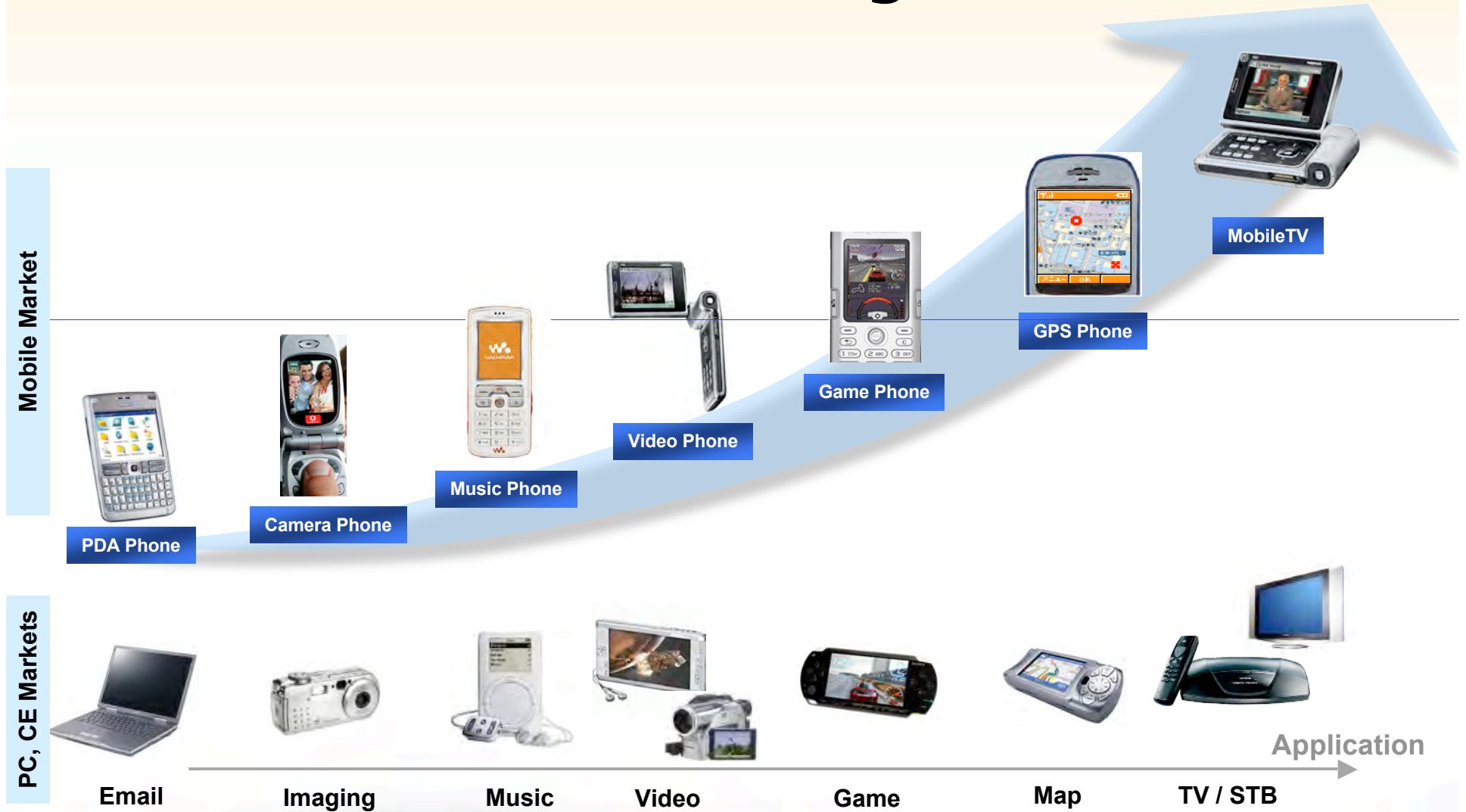
# Projected NAND Demand: ~20X from 2006→2010



Source: Gartner Dataquest, November 2006

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# Mobile/CE/PC Driving NAND Future



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# Industry Standards—Key to Mega-Markets

**Panasonic  
TOSHIBA**

Introduced by SanDisk,  
Toshiba and Panasonic  
in **1999**

**SIEMENS**

Introduced by  
SanDisk and Siemens  
in **1997**

Introduced by SanDisk  
in **1994**

Pioneered by SanDisk  
Standardized by the  
PCMCIA Association

**SONY**

Introduced by  
SanDisk and Sony in  
**2000**

**Panasonic  
TOSHIBA**  
NTT  
**Do Co Mo**

Introduced by SanDisk  
in March **2003**  
Standardized in  
**Jan 2004**

**MOTOROLA**

Introduced by SanDisk in  
March of **2004**  
Standardized in  
**May 2005**

**M-Systems**  
Flash Disk Pioneers

Introduced by  
SanDisk and M-  
Systems in **2005**

Introduced by  
SanDisk in  
**Sep 2005**



Microsoft  
May 2007

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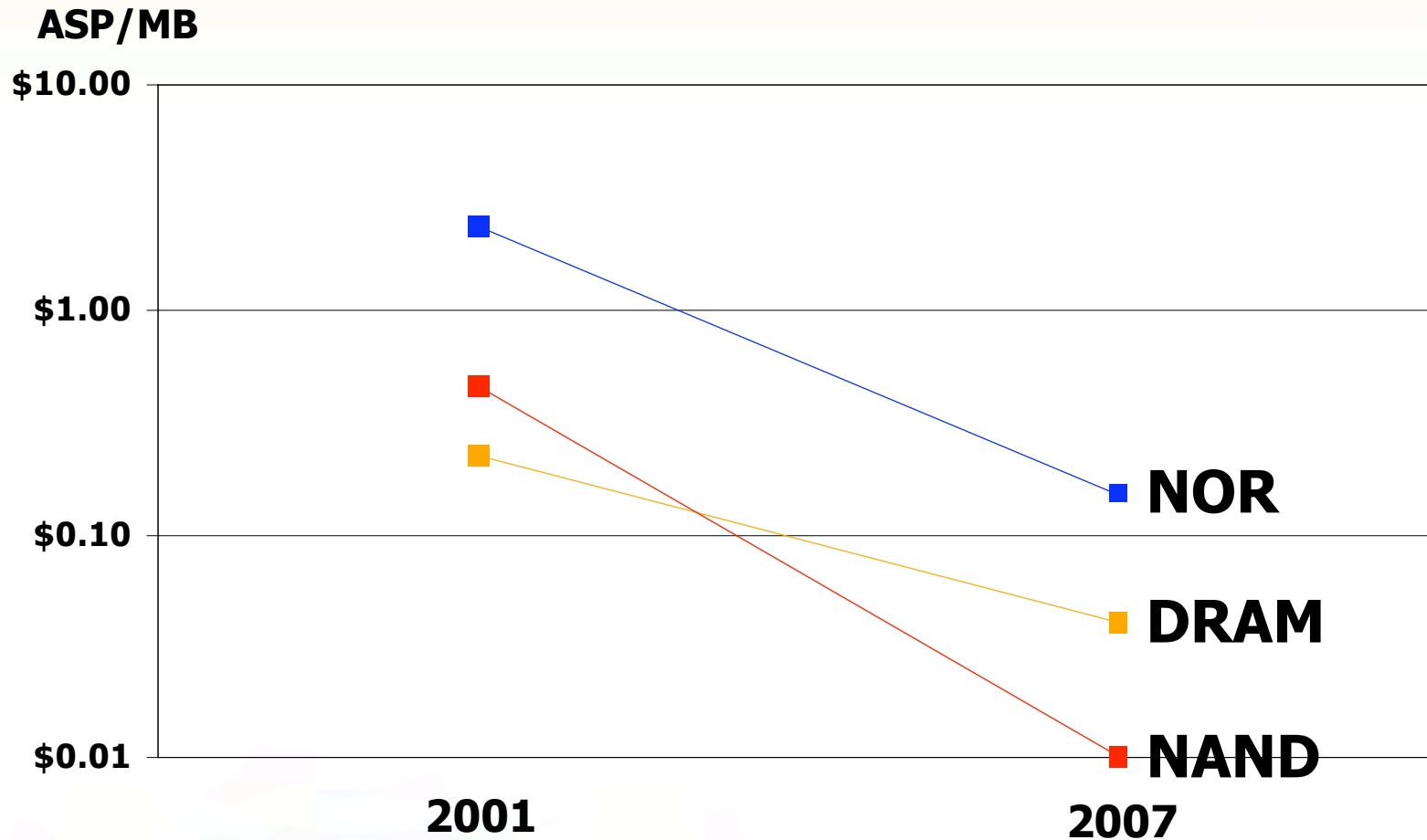
# Flash: A License to Disrupt

- Past 10 years:
  - 35mm film
  - Floppy, Zip, Klik
  - Tape
  - CD
  - 1.3" KittyHawk, 1" Microdrive, .85" Drive
  - NOR Flash
- Next 5-7 years:
  - 1.8" HDD
  - DRAM ?
  - DVD ?
  - 2.5" HDD ?



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# Next Flash 10X Cost Reductions → New Architectures



Source: Gartner

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# Market Pull

- Digital revolution creating new mega-markets
- Price-elastic demand from consumer markets
- 1 Billion new consumers

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# NAND Technology & Challenges

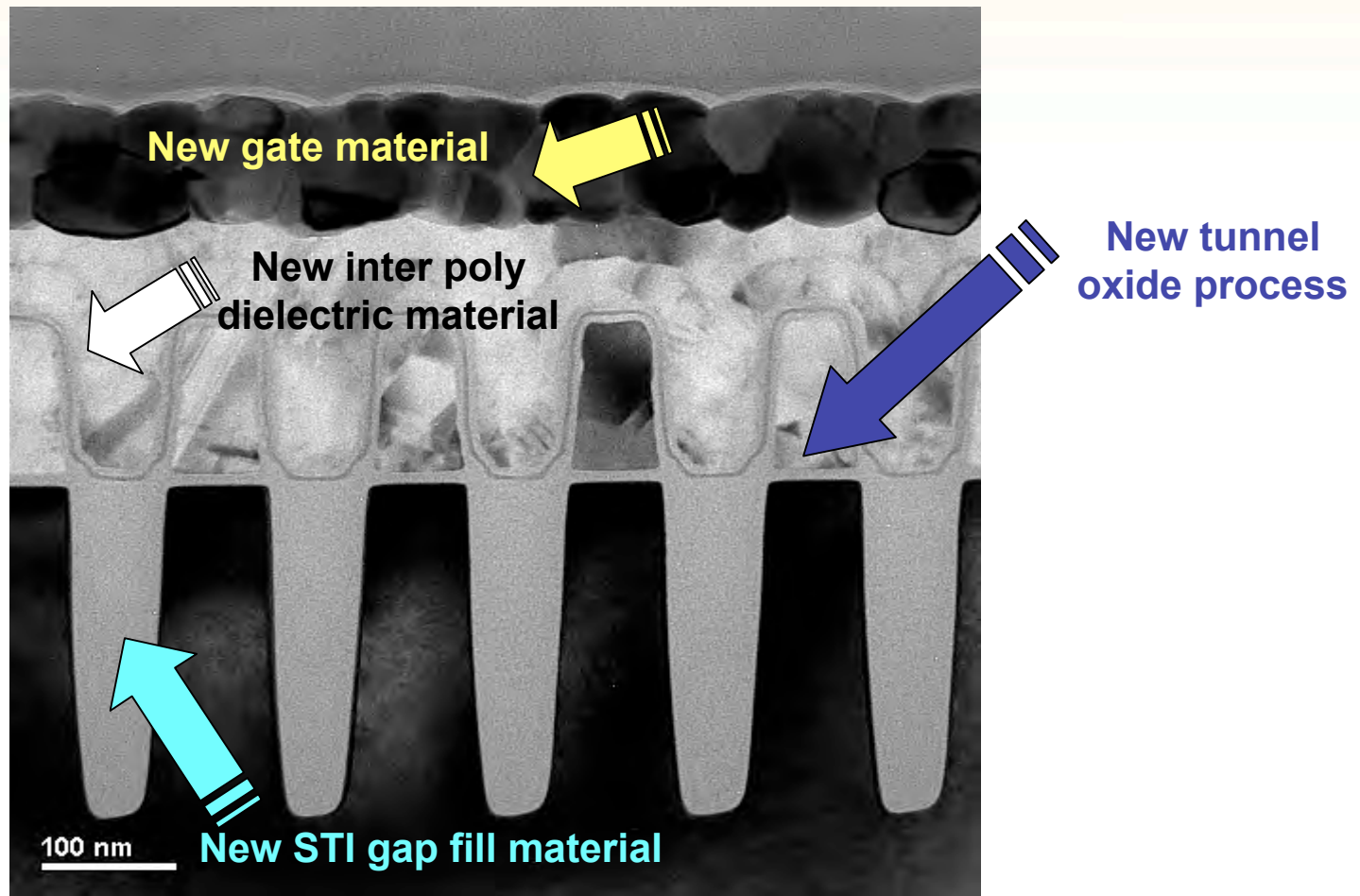
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# NAND: A Remarkable Technology

- NAND Flash has become process technology driver for the semiconductor industry
- NAND's unprecedented scaling rate outstripping lithography, other tools capabilities

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# Increasing Process Complexity



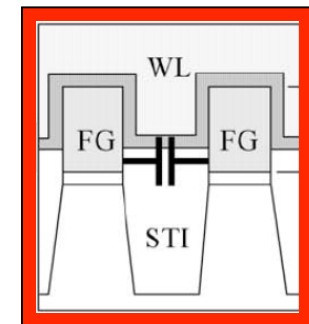
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# Technology Push

- NAND rapid scaling benefits from:
  - Simple array architecture,  $4F^2$ , self aligned
  - Si Floating gate >30 years industry experience
  - Carry-over between successive generations
  - Tunnel write/erase current → massive parallelism
  - Multi-level cell (x2 now, x3, x4 in next few years)
- However, NAND as we now know it may approach practical limits in  $\sim 4$  generations ( $\sim 20\text{nm}$ ) at  $\sim 256\text{Gbit}$

# NAND Challenges

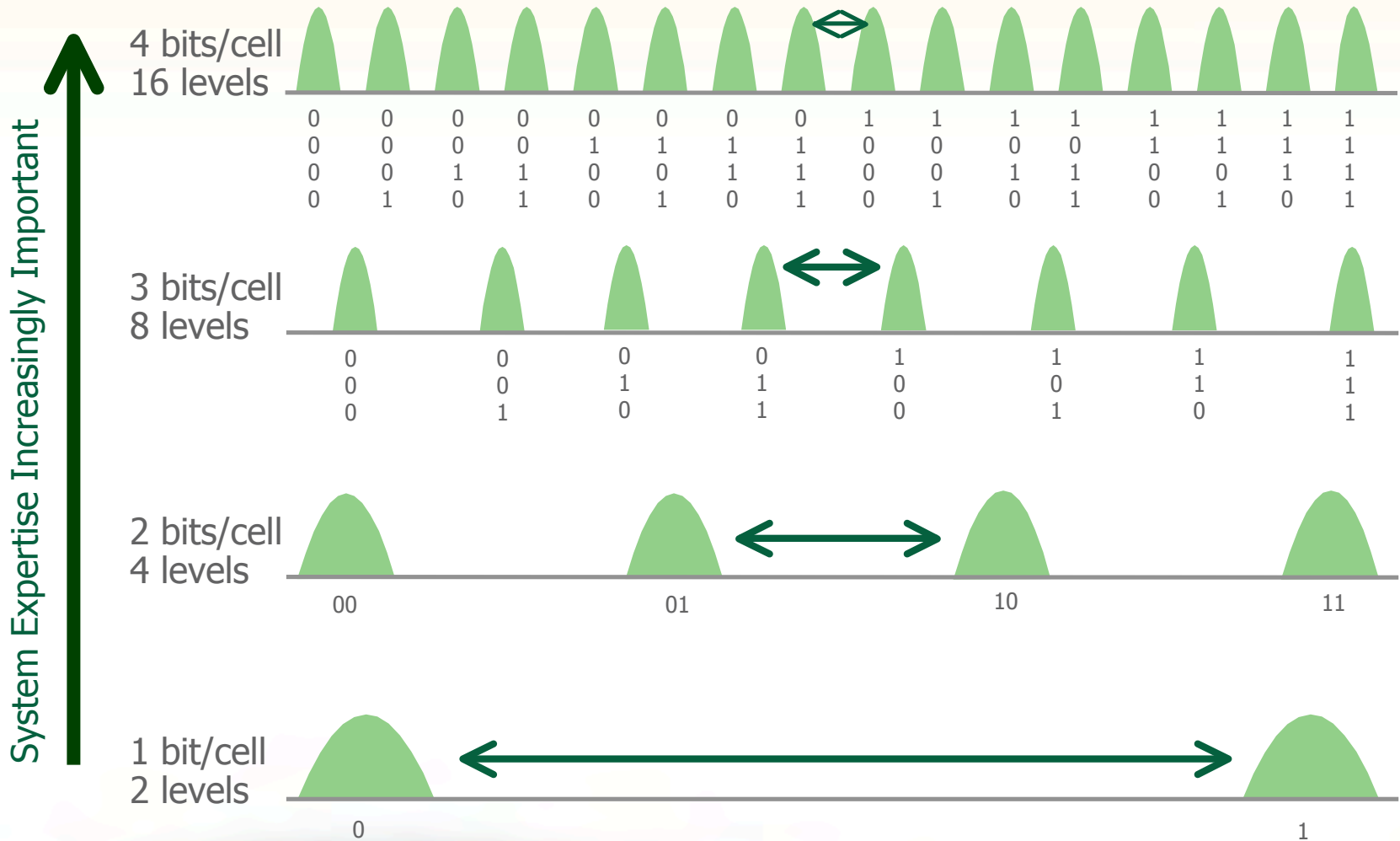
- Technology:
  - Lithography, Mask tools, Resists
  - New materials
  - Tight process tolerances, LER
  - High aspect ratios, STI fill, Contacts
- Device (cell):
  - Parasitic capacitive coupling
  - $V_{pg} > 20V$  on chip
  - Reduced number of electrons on floating gate



**Parasitic capacitance**



# Logical Scaling: Beyond 2b/c



# System Solution Becoming Critical

- Flash Memory Chip+ Controller
  - Defect management, wear-out leveling, cell-cell interference mitigation
  - Mass storage emulation, file/bad block management
  - Standard I/O (hide chip algorithmic changes)
  - Performance boosting
  - DSP, Powerful ECC to enable x4

# NAND Manufacturing

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# Dynamics Of NAND Fabs

- In past 2 years, 200mm DRAM → NAND capacity conversion to capture higher margins
- >50% of current industry-wide NAND capacity is 200mm, becoming obsolete in ~12 months
- Projected annual ASP/MB cost reductions of ~40% in next 5 years (best performers)
- ~60% annual ASP/MB price reductions of 2006/7 not sustainable going forward

# NAND Economies of Scale: \$5B+ per Fab

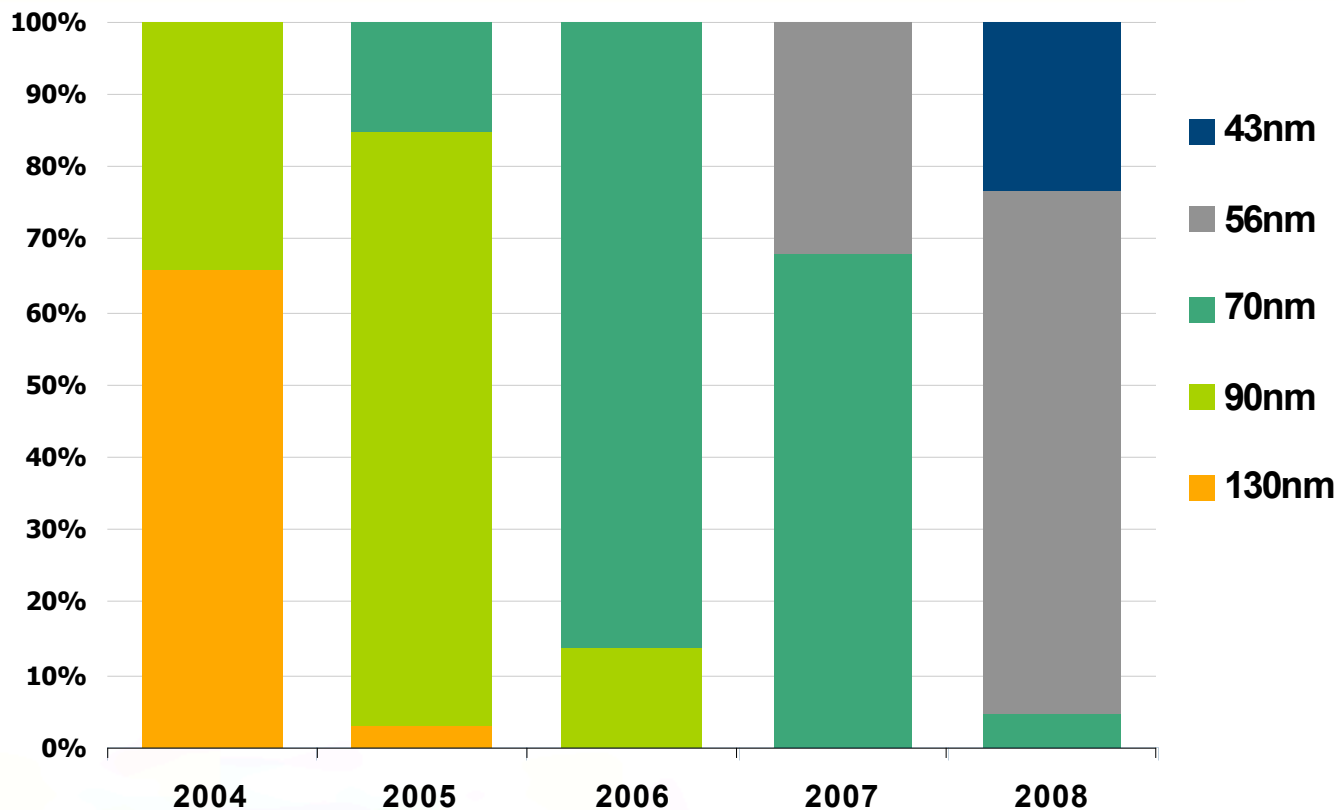


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# Short Technology Life Cycles

**5 generations in 5 years in production**

% of production



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Source: SanDisk

# Flash Competitors

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# Flash Competitors & Alliances

SAMSUNG

TOSHIBA

SanDisk®

hynix

intel®

RENESAS

Micron™

ST

Qimonda

SPANSION™

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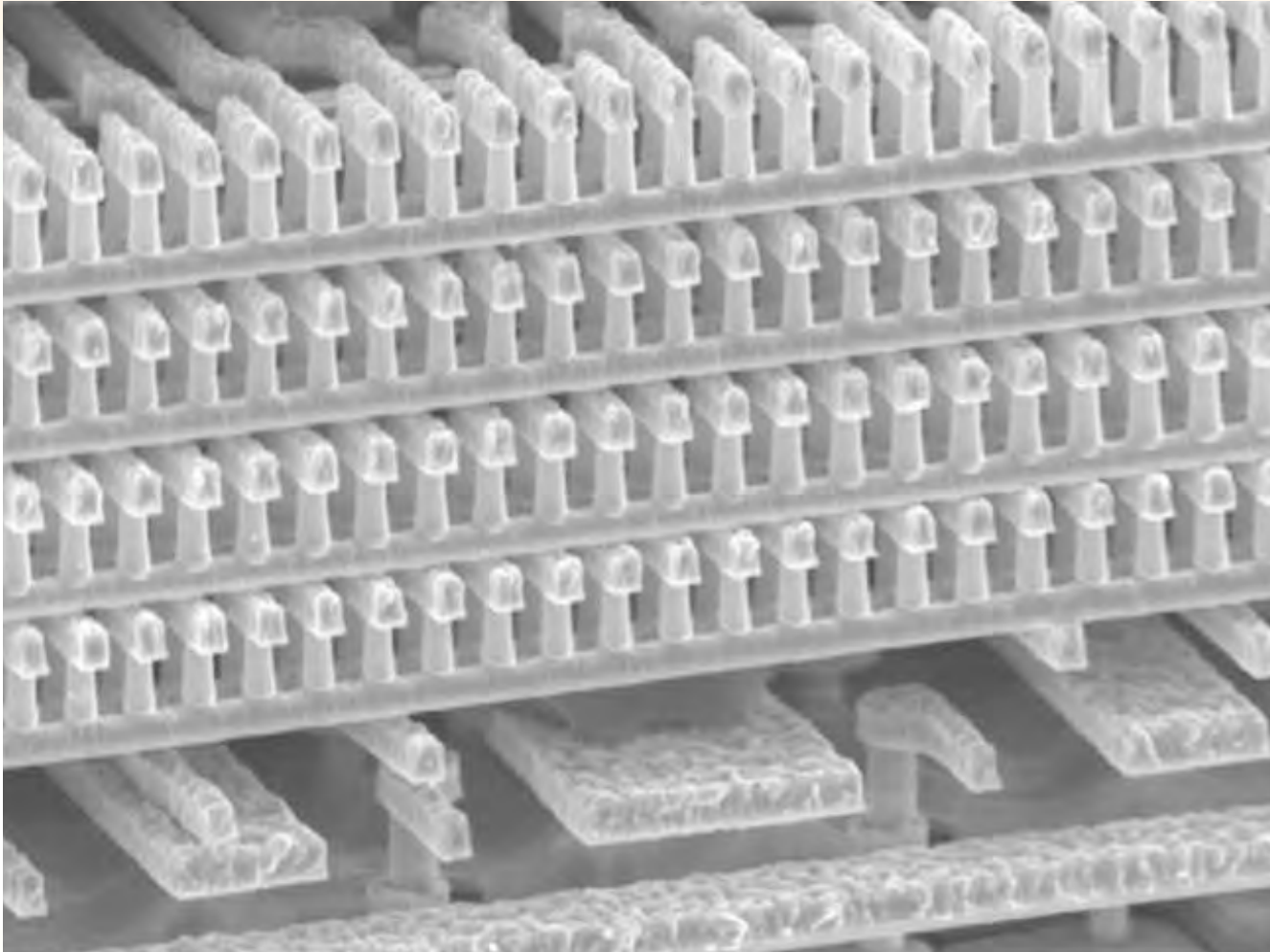
# Competing NVM Technologies

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# Contenders

- CTF: NAND SONOS/TANOS
- NROM/Mirror Bit/Quadbit
- PCM/Ovonic
- Magnetic RAM (MRAM), Ferroelectric RAM
- Probe/Milipede
- 3D: Diode , NAND

# 3D Memory-Disrupting NAND, HDD?



Required Breakthrough: Write/Erase Switching

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# Conclusions

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# Summary: NAND at Center Stage

- Young, fast-growing mega-markets for Flash storage
- Flash a disruptive/enabling force in CE, PC
- Huge manufacturing scale and IP required to compete
- Flash device scaling challenges will dictate system level solutions
- **Flash's 10X cumulative cost reductions in next 5-7 years will complete Flash's journey to Center Stage**

# The Future of Flash Memory is ... **NOW, and EVERYWHERE!**



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