An Introduction to Emerging Memory Technologies

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Agenda

- Overview of Emerging Memory Alternatives
- Near Term Candidates
- Longer Term, Litho Defined Candidates
- Non Litho Defined Candidates
- Conclusions

→ Overview of Emerging Memory Alternatives

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Flash Technology Scaling History

1986 / 1.5µm

1988 / 1.0µm

1991 / 0.8µm

1993 / 0.6µm

1996 / 0.4µm

1998 / 0.25µm

2000 / 0.18µm

2002 / 0.13µm

2006 / 65nm

1/~1000

10X

10X

10X

Volume Production Year / Technology Generation

Source: Intel

- Flash Invented in mid 1980's
  - NOR flash evolved from EPROM
  - NAND started as poly-poly erase cell later evolving to present structure
- ~20 years & 10 Generations of High Volume Production
- 8+ years & 5 Generations of MLC: 2bit / cell

Emerging Memory Landscape

	Today	Tomorrow	Future
Evolutionary Enhancements	EEpROM HDD NOR NAND DRAM SRAM	Floating Trap Metal Gate Nano Dot Barrier Engineering	Multi Layer 3D 3D Gate
Emerging Alternatives		*FeRAM* *MRAM* *PCM*	*Multilayer 3D* *RRAM* *Bridging/Ionic* *Molecular* *Probe Storage* *e-Beam*

Focus of Today's Tutorial

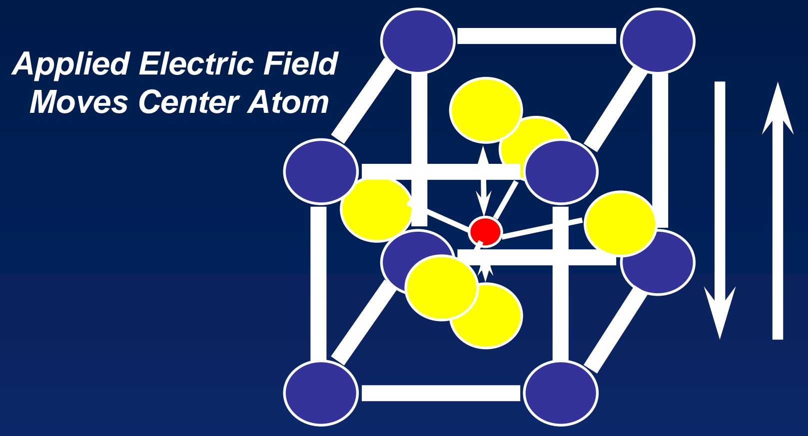
- Overview of Emerging Memory Alternatives
- → Near Term Candidates
- Longer Term, Litho Defined Candidates
- Non Litho Defined Candidates
- For Further Study

Near-term Candidates for Alternative NVM

PCM (Phase Change Memory)	MRAM	FeRAM
Data Storage Region Chalcogenide Phase Change Material Resistive Heater		
▪ Phenomenon: Resistance change in amorphous and polycrystalline phases. ▪Method: Phase change induced by injected current	▪ Phenomenon: Resistance change due to magnetic polarity ▪ Method: Polarity of one "plate" pinned while other is switched	▪ Phenomenon: Applied voltage changes dipole moment of center atom ▪Method: data read by sensing displacement current

Source: Intel

FeRAM



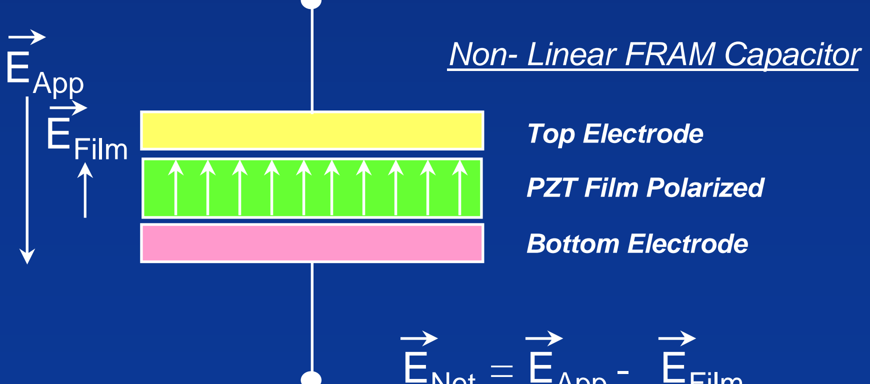
Key Attributes
- 1C + 1 Transistor
- Cell Area: $25F^2$ shipping
- Cell Area: $12\text{-}15F^2$ demonstrated

Advantages
- Fast R/W performance
- Low power operation
- Bit alterable (no erase)

Issues
- Scaling path <100 nm
- Destructive read
- Read & Write limited ($1e^6 \rightarrow 1e^{10}$)
- No path to flash/dram level costs

Perovskite Crystal Unit Cell
PZT (PbO,ZrO_2, TiO_2) Lead-Zirconate-Titanate

- Tetra/Pentavalent Atom
- Di/Monovalent Metal Atoms
- Oxygen Atoms



$\vec{E}_{App}$ $\vec{E}_{Film}$

$$\vec{E}_{Net} = \vec{E}_{App} - \vec{E}_{Film}$$

Source: Intel

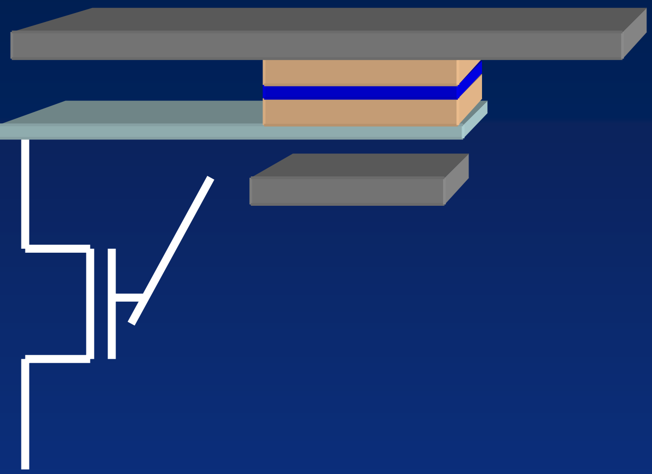
MRAM

Key Attributes
- 1MTJ + 1 Transistor
- Cell Area: $35F^2$ shipping (Toggle)
- Cell Area: $6F^2$ theoretical (STT)

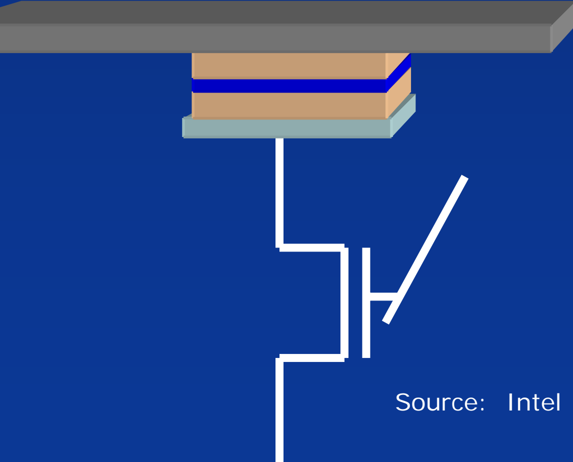
Advantages
- “Unlimited” R/W endurance
- Fast R/W latency (<35 ns)
- Bit alterable (no erase)

Issues
- Scaling path
- Write disturbs, power
- New materials, CMOS compatibility
- No path to flash/dram level costs

Basic MTJ Toggle MRAM
(1MTJ + 1T)



Spin Torque Transfer MRAM
(1MTJ + 1T)



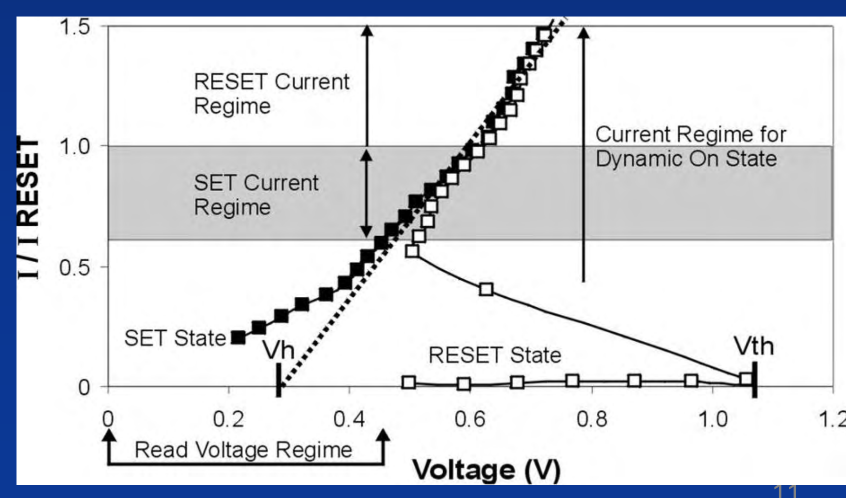
Source: Intel

Phase Change Memory (PCM)

Key Attributes
- 1R + 1 select
- Cell Area: 5.5-12F2 sampling
- Cell Area: <6F2 demonstrated

Advantages
- Clear scaling path to <20 nm
- Ease of CMOS integration
- Fast, "unlimited" read
- Bit alterable (no erase)

Issues
- Write endurance limited: 1e6 to 1e12
- Write latency vs. DRAM



Source: Intel

Emerging Alternative Memory Attribute Comparison

Key Metrics	PCM	MRAM	FeRAM
Cell Size	~SBC NOR/NAND ($5.5\text{-}12F^2 \rightarrow <5F^2$)	Larger ($35\ F^2 \rightarrow 6\text{-}16F^2$)	Largest ($32F^2 \rightarrow 12\text{-}15F^2$)
CMOS Integration	Good	Fair to Poor	Fair
Scaling	Excellent	Fair: current, materials	Poor: materials, 3D
Read Latency	Fast, ~NOR	Fastest, ~ xRAM	Fast, ~NOR
Write Speed/Power	~Flash → Higher	Fastest latency, high power	Fast – RAM like
Bit Alterable?	Yes	Yes	Yes
Read Endurance	Unlimited	Unlimited	Limited
Write Endurance	High	Unlimited	Higher
Logic Integration	Easiest	Harder	Easier
Application Reach	Flash + Most RAM + Embedded Memory	Embedded/Cache Memory	Embedded Memory

Source: Intel

- Overview of Emerging Memory Alternatives
- Near Term Candidates
- → Longer Term, Litho Defined Candidates
- Non Litho Defined Candidates
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Future Research Trend: Extending in Multiple Layers

Source: Intel

R&D Example (circa 2003):
Read/Write Eight Layer Memory using Ferroelectric Polymer

- Litho defined memories seeking to extend scaling in vertical dimension
  - Industry work on everything from NAND to polymer
- Ideal Effective Cell Area:

  $Z = 4F^2 / y$

  Where y = # of layers
- Challenge is manufacturing cost of multiple layers

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Other NVM Candidates in the Longer Term Research & Discovery Phase (Part 1 of 2)

Material	Structure	Description	Effect
RRAM		Resistance change in CMO (usually crosspoint and multilayer)	Resistance change based on an applied field
Ferroelectric Polymer	Word line Word line Polymer Layer Bit line Bit line Bit line Polymer Layer Word line	Cross-point, multi-layer capacitive storage in Polymer	Change in capacitance based on an applied field
Resistive Polymer		Cross-point, multi-layer resistive storage in Polymer	Change in resistance based on an applied field

Source: Intel

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Other NVM Candidates in the Longer Term Research & Discovery Phase (Part 2 of 2)

Material	Structure	Description	Effect
Programmable Metallization		Silver Dissolved in Chalcogenide	Field Driven "Electroplating"
Carbon Nanotube	Carbon Nanotube	Cross Point Array of Nanotubes Switches	Electrostatic Attraction + Van der Waals Adhesion
		CNT as Circuit Element	CNTs as replacement structure
Molecular	Image Courtesy of the University of Sydney	Molecules in CrossPoint Array	Voltage Driven Change in electronic states in Redox

Source: Intel

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➔ Non Litho Defined Candidates

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Seek & Scan Probe Storage

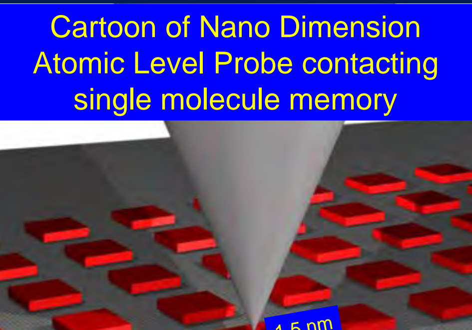


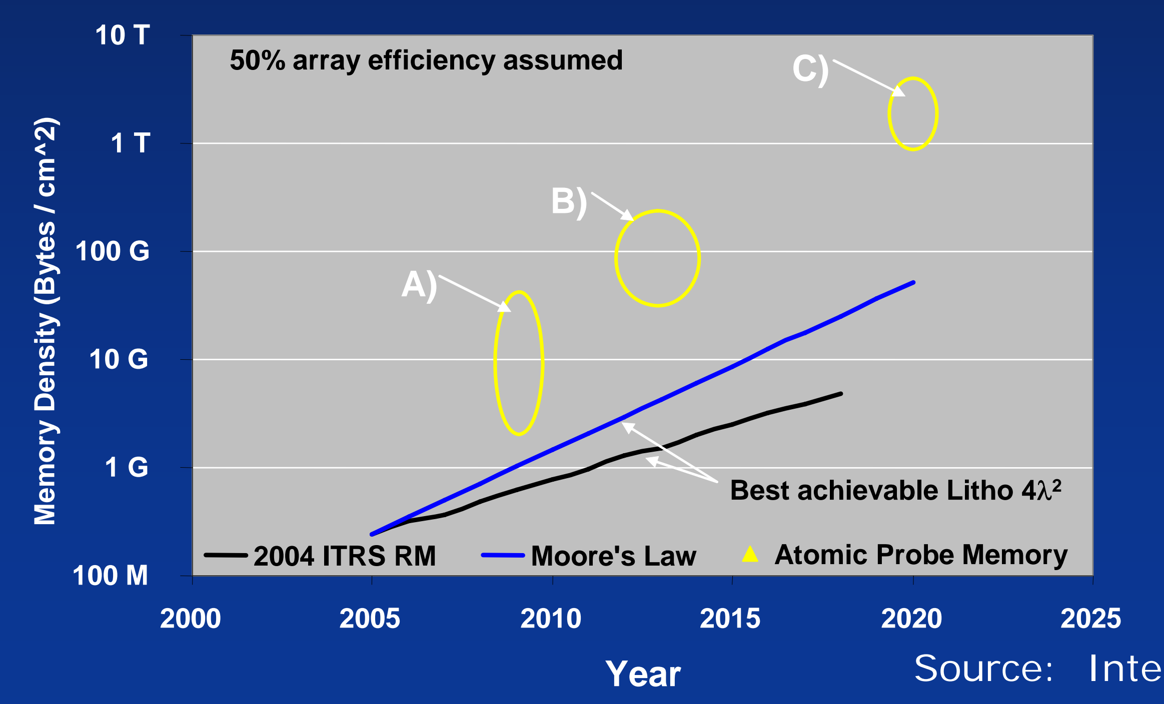
Image Courtesy of the University of Sydney

Seek & Scan Probe (SSP):

- MEMs device with nanopositioned probe tips
- Employs alternative storage media
- Molecular level storage is ultimate goal

Best achievable memory density projections over time:

A) IBM Millipede today
B) Improved storage media
C) Full molecular memory storage capability



Source: Intel

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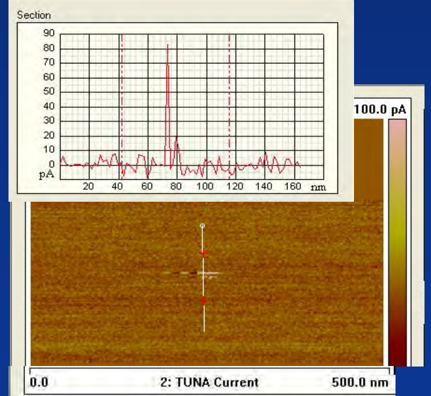
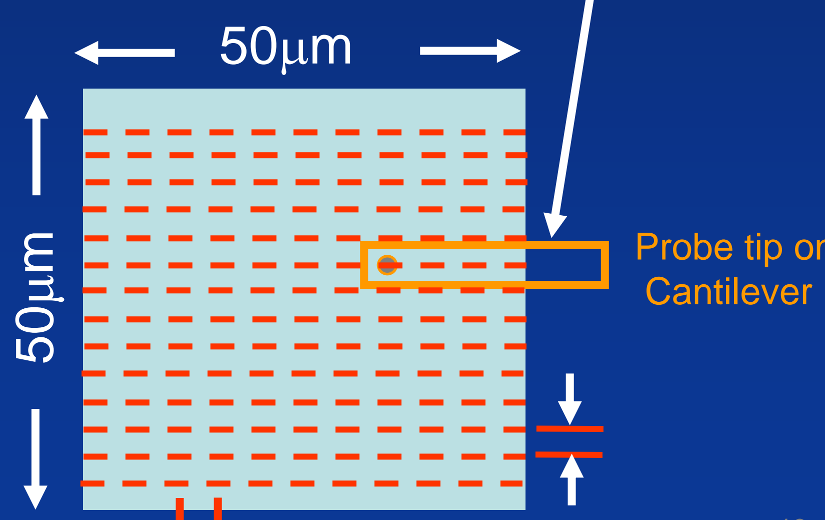
Scaling: Not by Lithography

- Bit size: Determined by Media & Tip interactions
- Track Pitch/Position: Determined by Nano-positioning
  - Motor resolution < 1nm resolution reported
- Tip Scaling: Determined by tip field focusing
  - Tip shape & media fields & current distribution



~10 nm bit on PCM media via AFM

Source: Intel



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➔Conclusions

Key Findings

- Flash memory technology working to address scaling challenges
- New memory technology is rare
  - Last to break beyond a niche was flash ~20 years ago
- Phase Change Memory is the most promising of near-term candidates
- Multi-level, 3D and MEMS devices hold most promise for the future

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