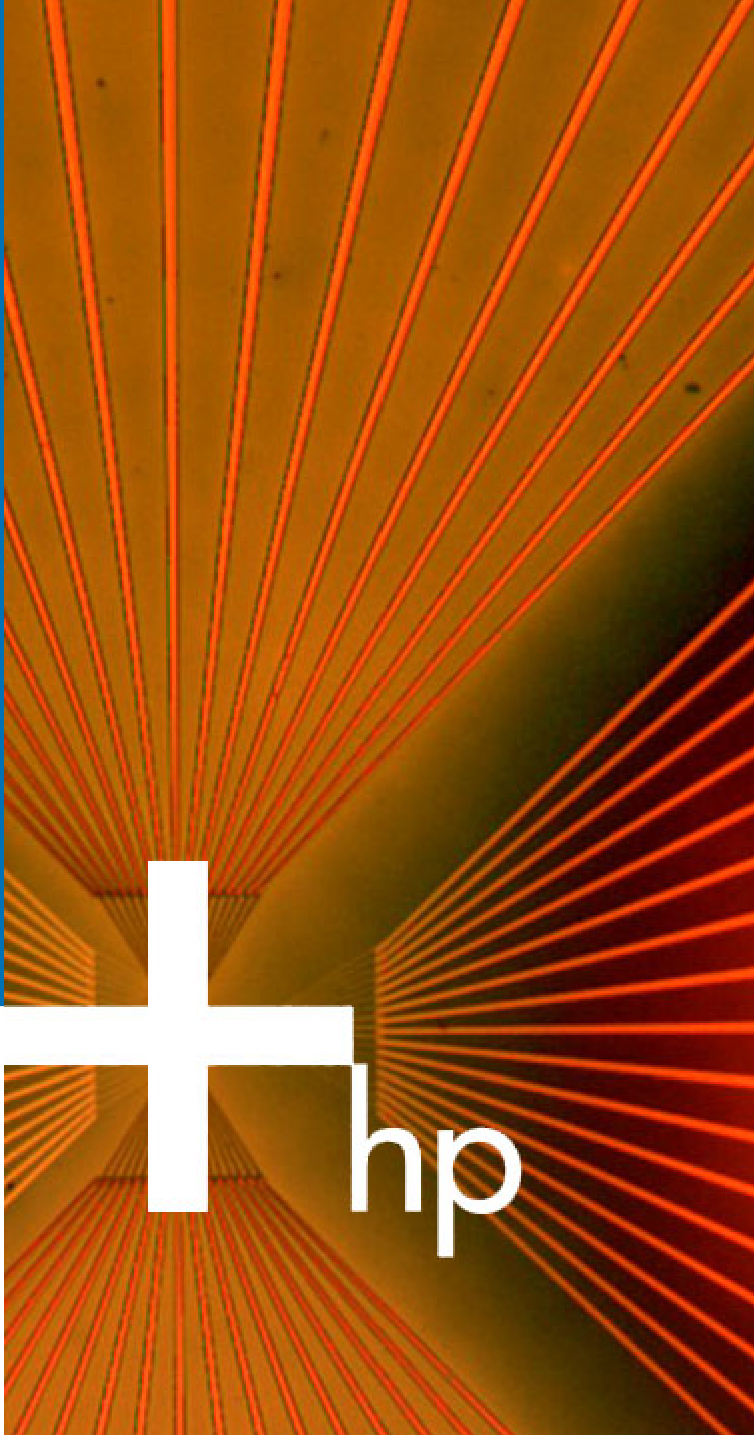
Nanotechnology in Electronics: Present and Future



Steve Naberhuis
HP laboratories

Nanotechnology (NT)

"Nanotechnology" touches upon a broad array of disciplines, including chemistry, biology, physics, computational science, and engineering. Like information technology, nanotechnology has the potential to impact virtually every industry, from aerospace and energy to healthcare and agriculture. Based on the ability to see, measure, and manipulate matter at the scale of atoms and molecules, nanotechnology was born in the mid-1980s with the advent of the AFM. Today many industries such as semiconductors and chemicals already are creating products with enhanced performance based on components and materials with nanosized features.

May 2005 Report on US National Nanotechnology Initiative

Nanotechnology encompasses the science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1 to 100 nanometers. However, nanotechnology is not merely working with matter at the nanoscale, but also research and development of *materials*, *devices*, and *systems* that have novel properties and functions due to their nanoscale dimensions or components.

Nanotechnology and Electronics

- Vision
- Evolution over time
  - Examples
  - Convergence in portable electronics
- Revolutions
  - Semiconductors
  - Disk drives
- Other evolving electronics technologies
  - Displays
  - Sensors
- What needs to evolve
- Conclusions

Nanotechnology and Electronics

Make Electronics

Faster

Cheaper

Smaller

Nanotechnology and Electronics

Evolutions

Nanotechnology: Evolutions

1979

Cassette
Tape technology
Discrete electronics
~ 30 songs
$50

2005

Cassette / Radio
Tape technology
Integrated electronics
~ 30 songs
$50

2005

MP3 Player
Hard Disk technology
Integrated electronics
~ 10,000 songs
$300

Nanotechnology: Evolutions

1976

35 mm film
141 x 92 x 48 mm
620 g + lens
Lens dependent
Lens dependent

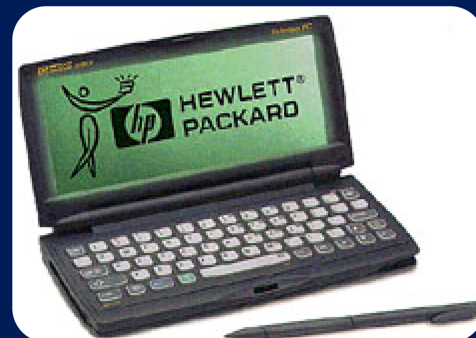
1996

35 mm film
90 x 60 x 27 mm
190 g
2x zoom
f/ 4.5 - 6.2

2005

7.1 megapixel digital
86 x 57 x 26 mm
170 g
3x zoom
f/ 2.8 – 4.5
Secure Digital

Nanotechnology: Evolutions



1991	1996	2004
MS-DOS	Windows CE	Windows Mobile
$599	$699	$420
IR	IR	WLAN + Bluetooth
qwerty	qwerty & touch screen	touch screen + DK
442 g	442 g	190 g
monochrome LCD	monochrome LCD	color LCD
2 Mbytes	4 + 4 CF Mbytes	64 + 1000 SD Mbytes
2 AA batteries	2 AA batteries	1800 mAh Li ion battery
		4-band GSM / GPRS phone
		VGA Camera

Nanotechnology: Evolutions

2000

GPS
mapping
monchrome LCD
20 MByte
$450

2005

GPS
positioning
monochrome LCD
limited
$160

2005

PDA + GPS (Bluetooth)
mapping +++
color LCD
1 GByte (SD)
$420 + $199

Nanotechnology: Evolutions

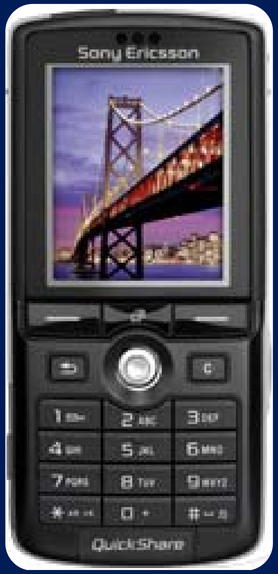
2000

CD / DVD
External monitor
Limited memory
Plug-in game controller(s)
$300

2005

WLAN / USB / MS Duo / Mini-Disk
LCD – 480 x 272 pixel – 24 bit color
32 MB internal + > 1 GByte (MS Duo)
Integrated controller
$250

Nanotechnology: Convergence



Sony Ericsson
K750i

Screen
- **176x220 pixel**
- **256 k color LCD**

Sound
- **polyphonic, 40 voices**

Memory
- **34 MB (> 1 GB MS Duo)**

Networks
- **3-band GSM, GPRS**
- **Bluetooth**

Size
- **100 x 46 x 20.5 mm**

Nanotechnology: Convergence

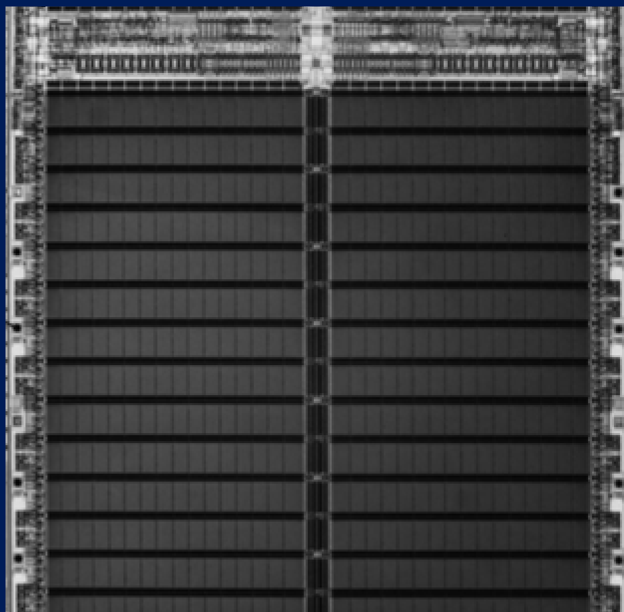
+ MP3 Player
+ Camera
  - 2 Megapixel
  - Auto-focus
  - LED Photo Light
  - Video recorder
+ FM radio
+ Games
+ EMS & MMS
+ E-mail
+ Calendar
+ Contacts
+ Tasks
+ Light
+ Clocks

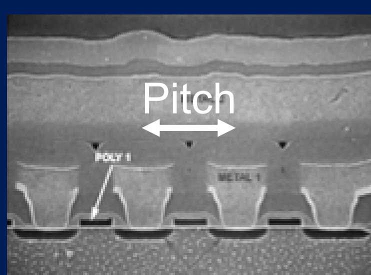
Nanotechnology: Convergence

Nanotechnology and Electronics

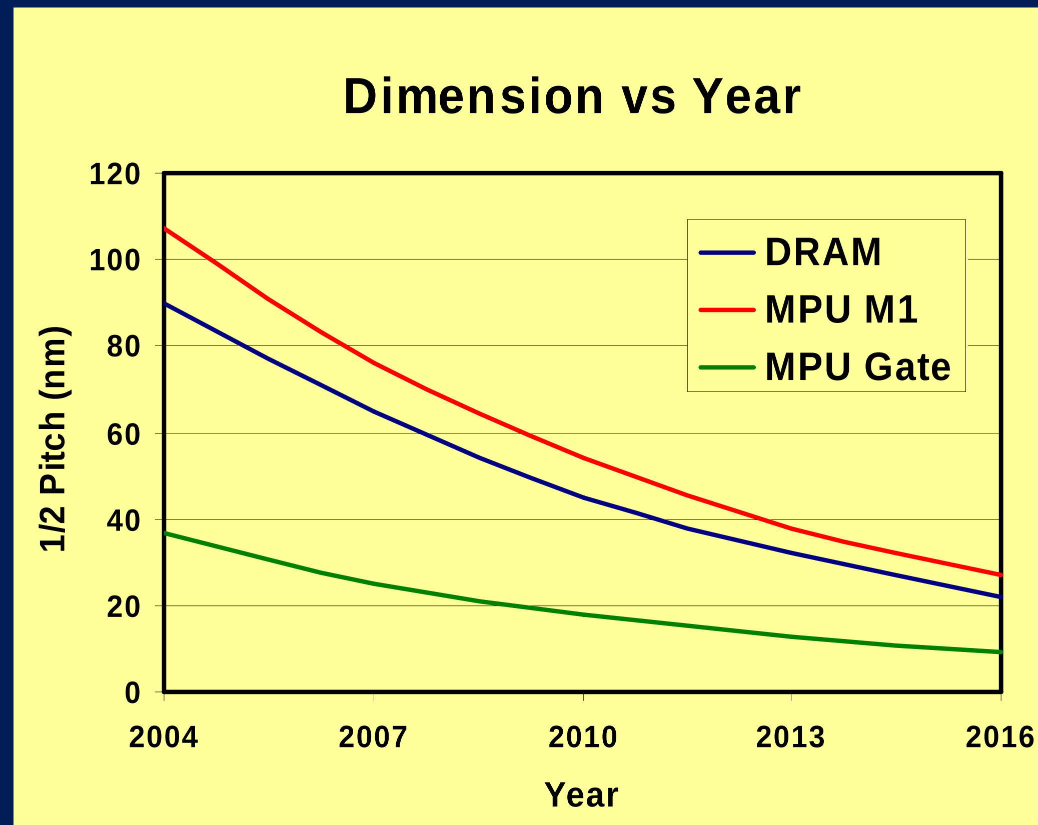
Revolutions

NT: Semiconductors





Samsung DRAM KM44C4000J-7
ICE Shared Construction Analysis



NT: Memory Limits

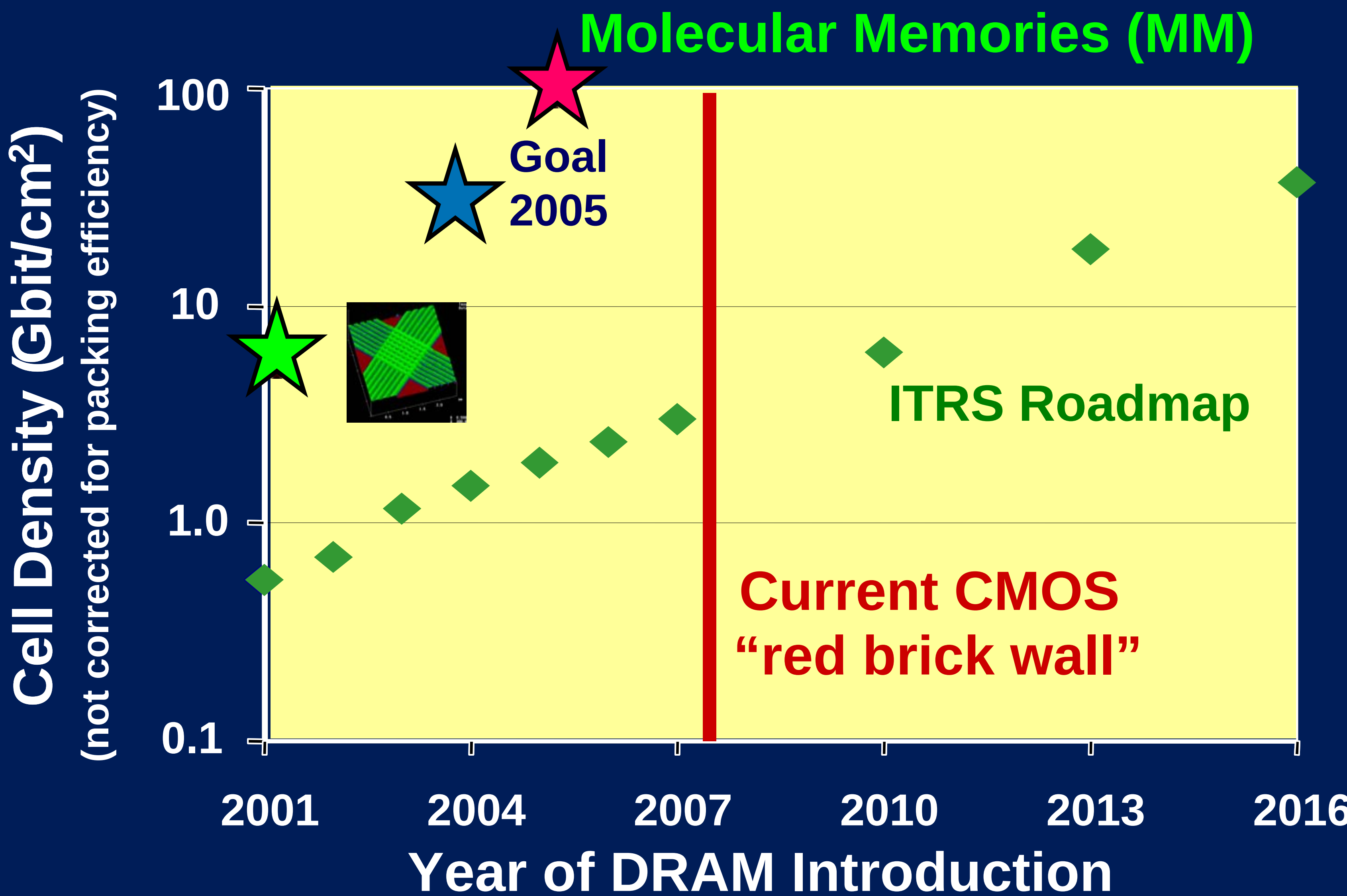
The ITRS - red lights ahead for memory!

International Technology Roadmap for Semiconductors 2000 Update

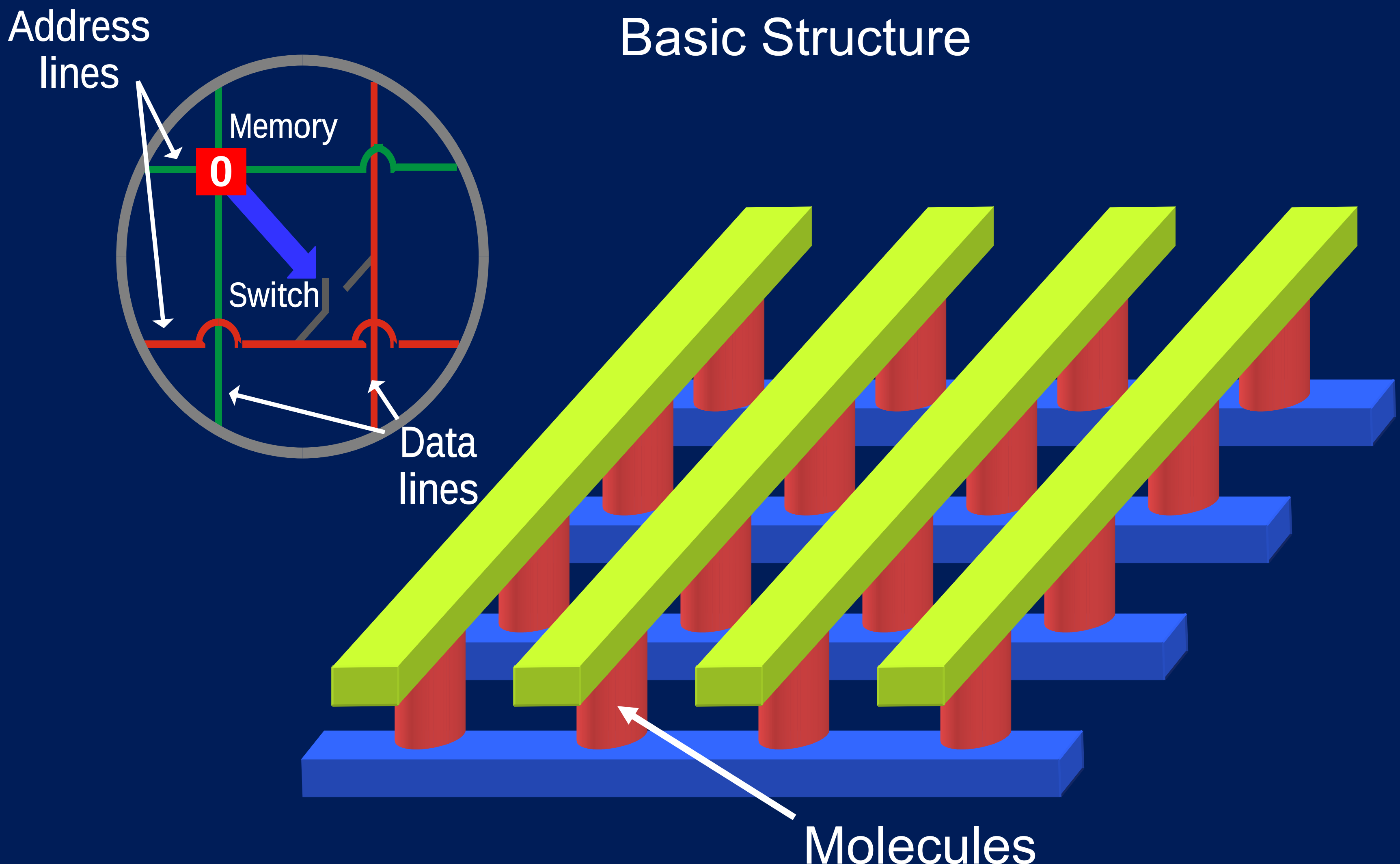
Year	2002	2003	2004	2005	2008	2011	2014
Half-pitch (nm)	130	120	110/90	100	70/60	50/40	35/30
Min Vdd (V)	1.2	1.2	0.9	0.9	0.6	0.5	0.3
DRAM cell (um2)	0.1	0.08	0.07	0.044	0.018	0.008	0.003
DRAM ret. (msec)	250	250	250	500	500	500	500
NVM ret. (yrs)	10	10	10	10	10	10	0.1
Endur. (cycles)	100k	100k	100k	100k	100k	1M	1M
Cost/bit (uc)	17	11	8	5.3	1.9	0.6	0.2

The “red brick wall”

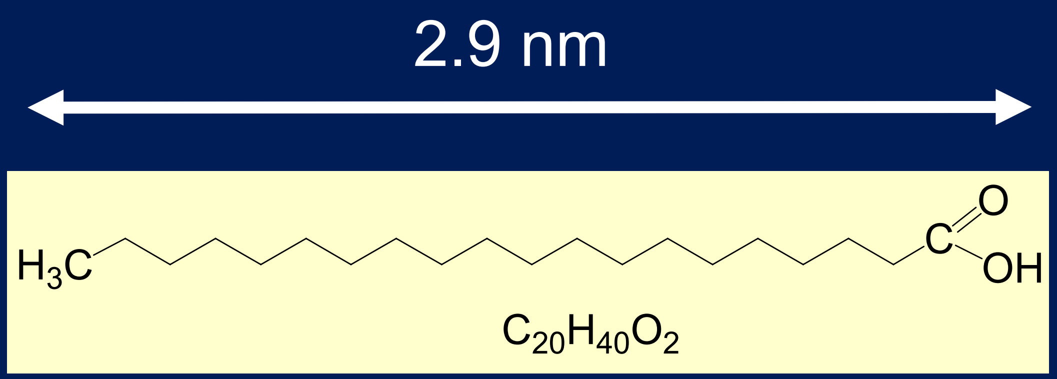
Nanotechnology: Revolutions



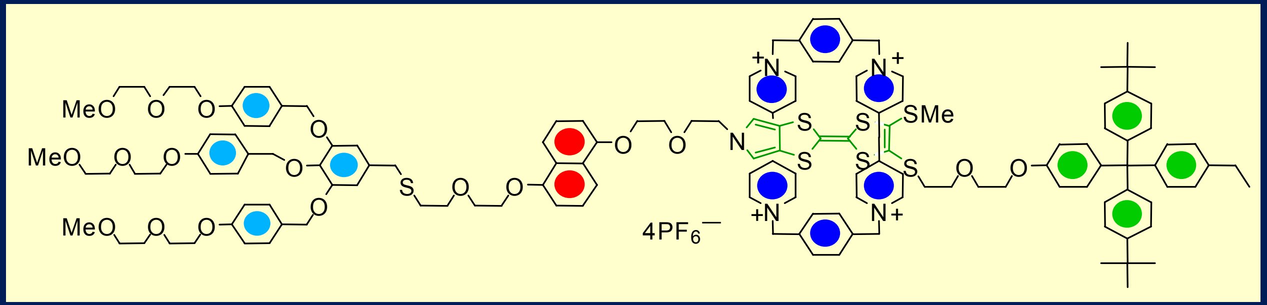
NT: Molecular Memories



NT: Molecular Memories

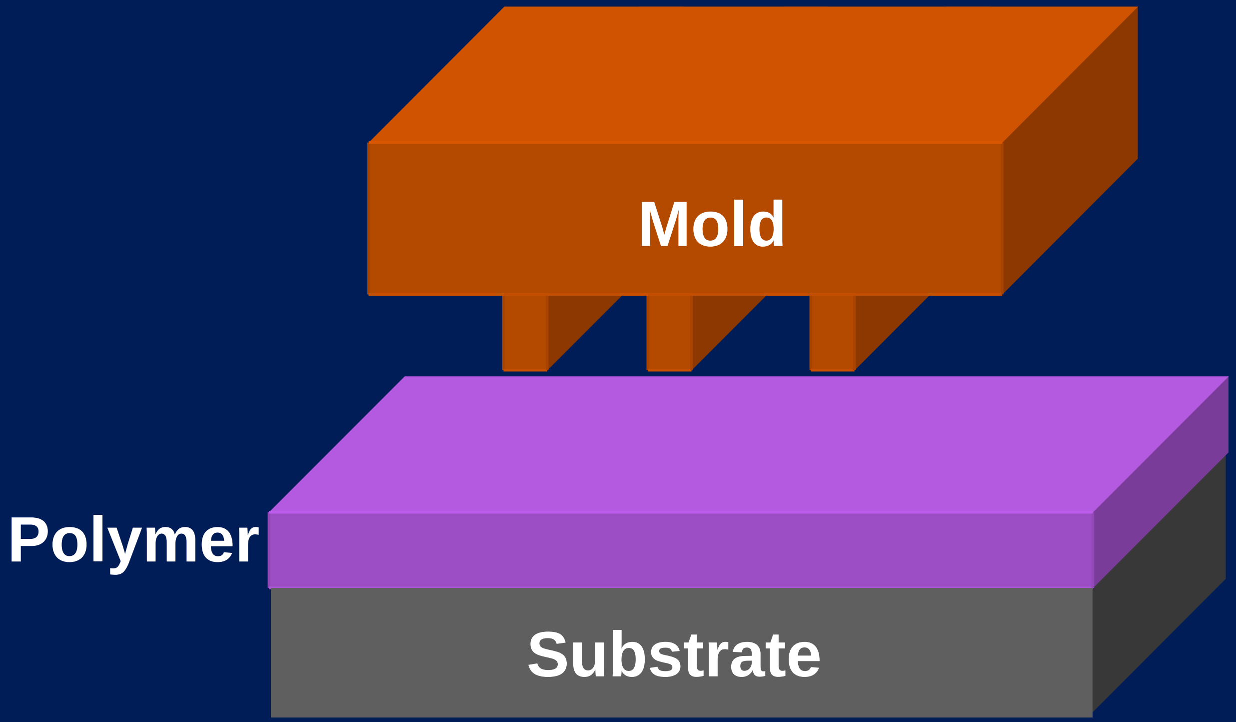


Eicosanoic Acid

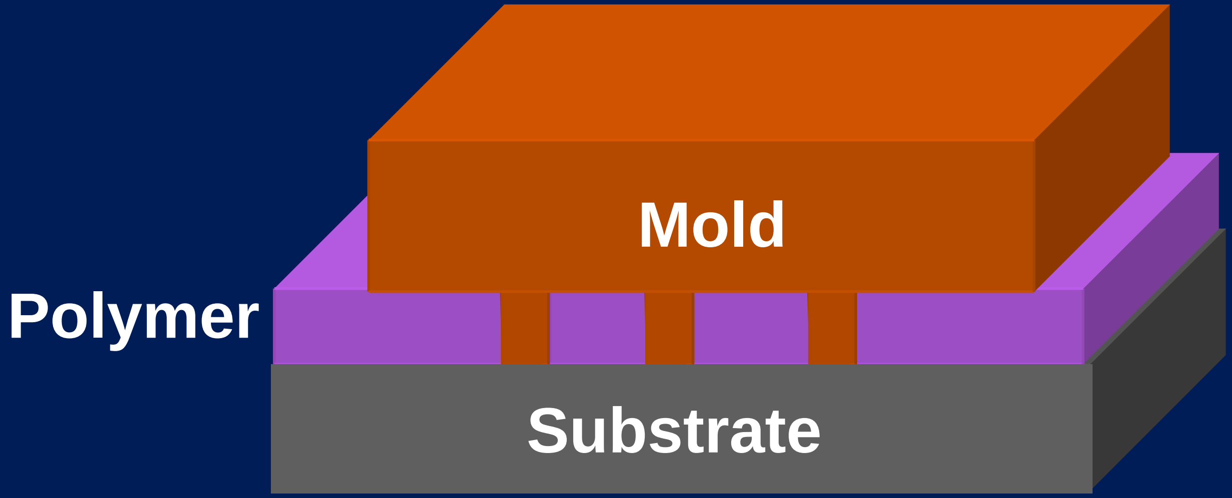


[2] Rotaxane

NT: Imprint Lithography for MM



NT: Imprint Lithography for MM



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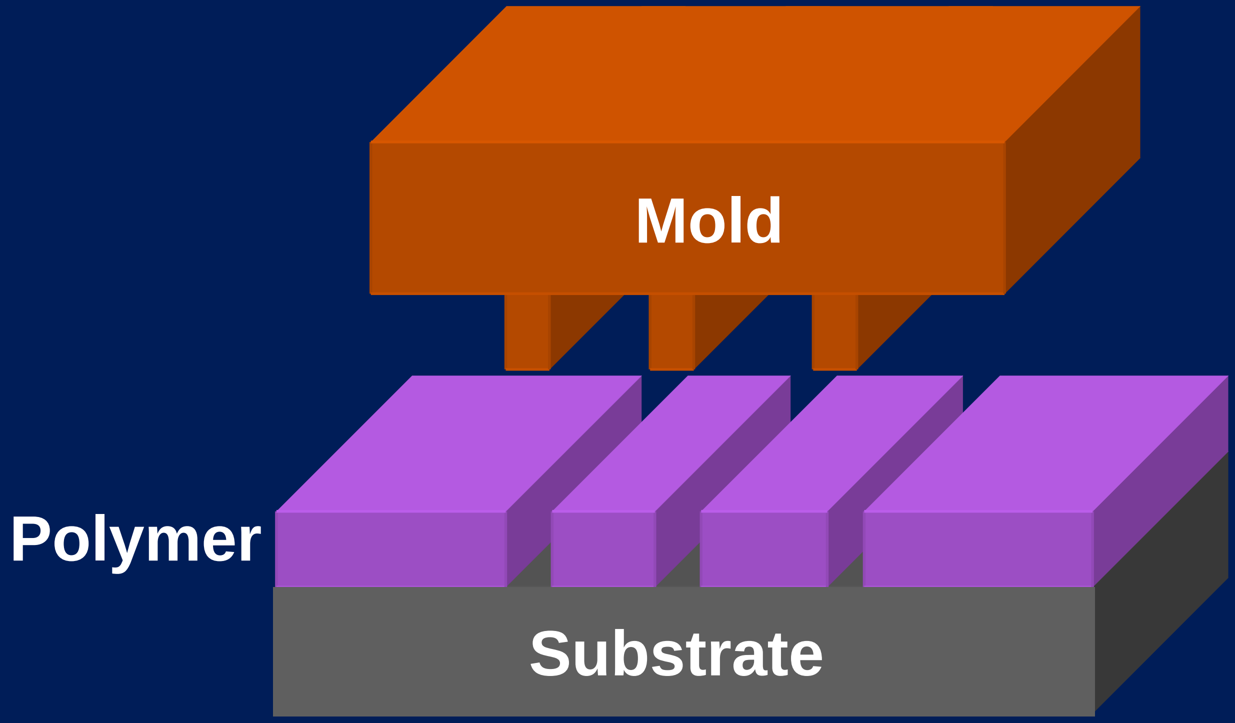
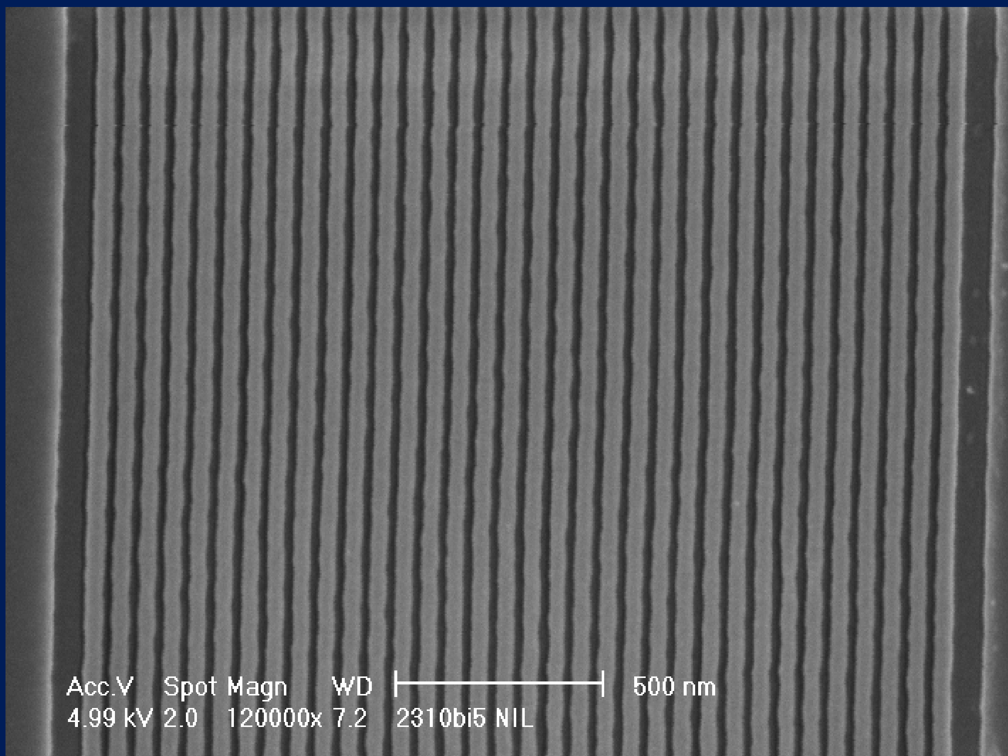
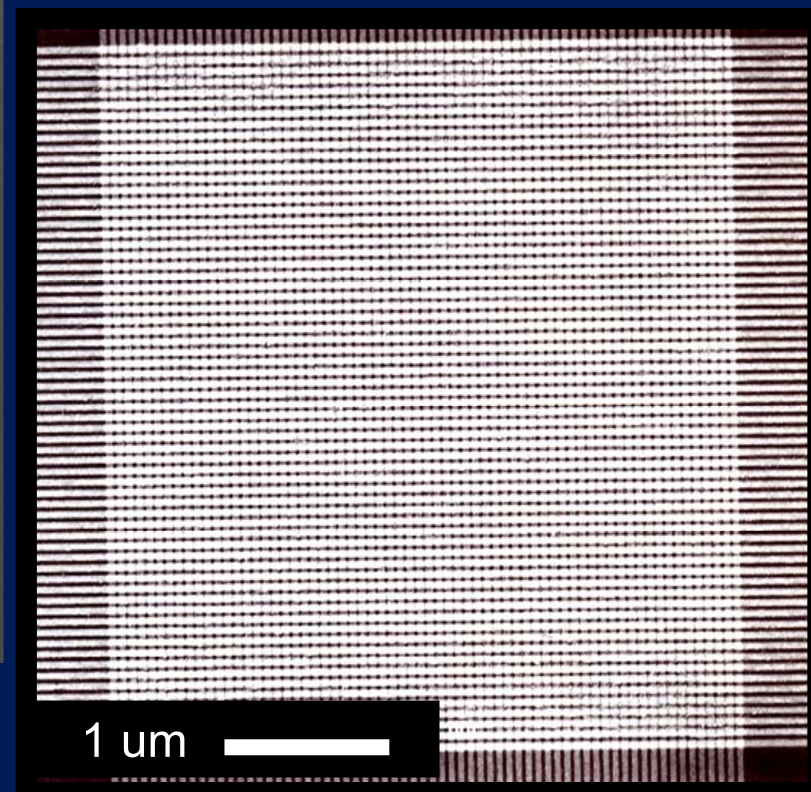


NT: Imprint Lithography for MM

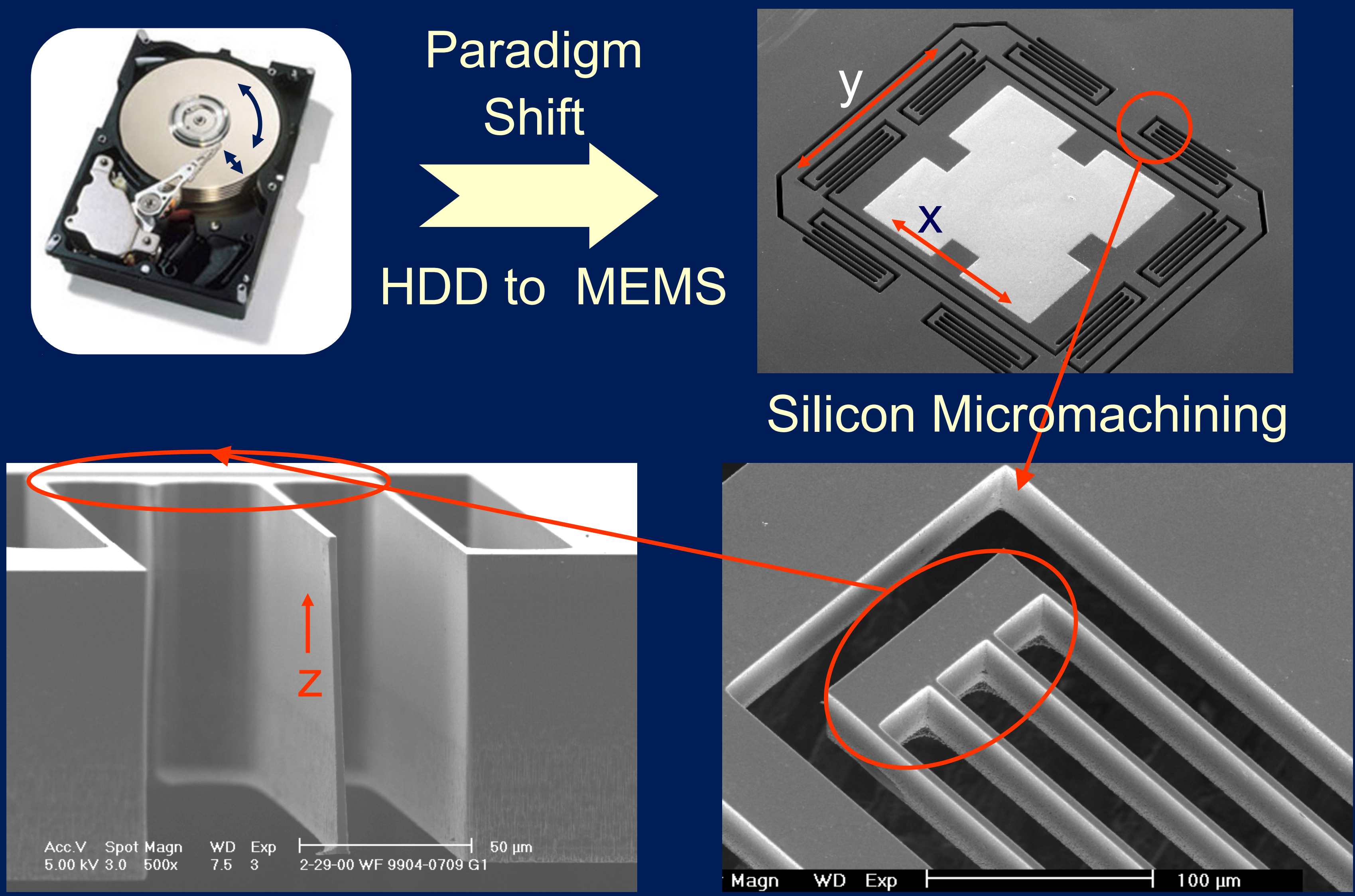


60 nm line pitch

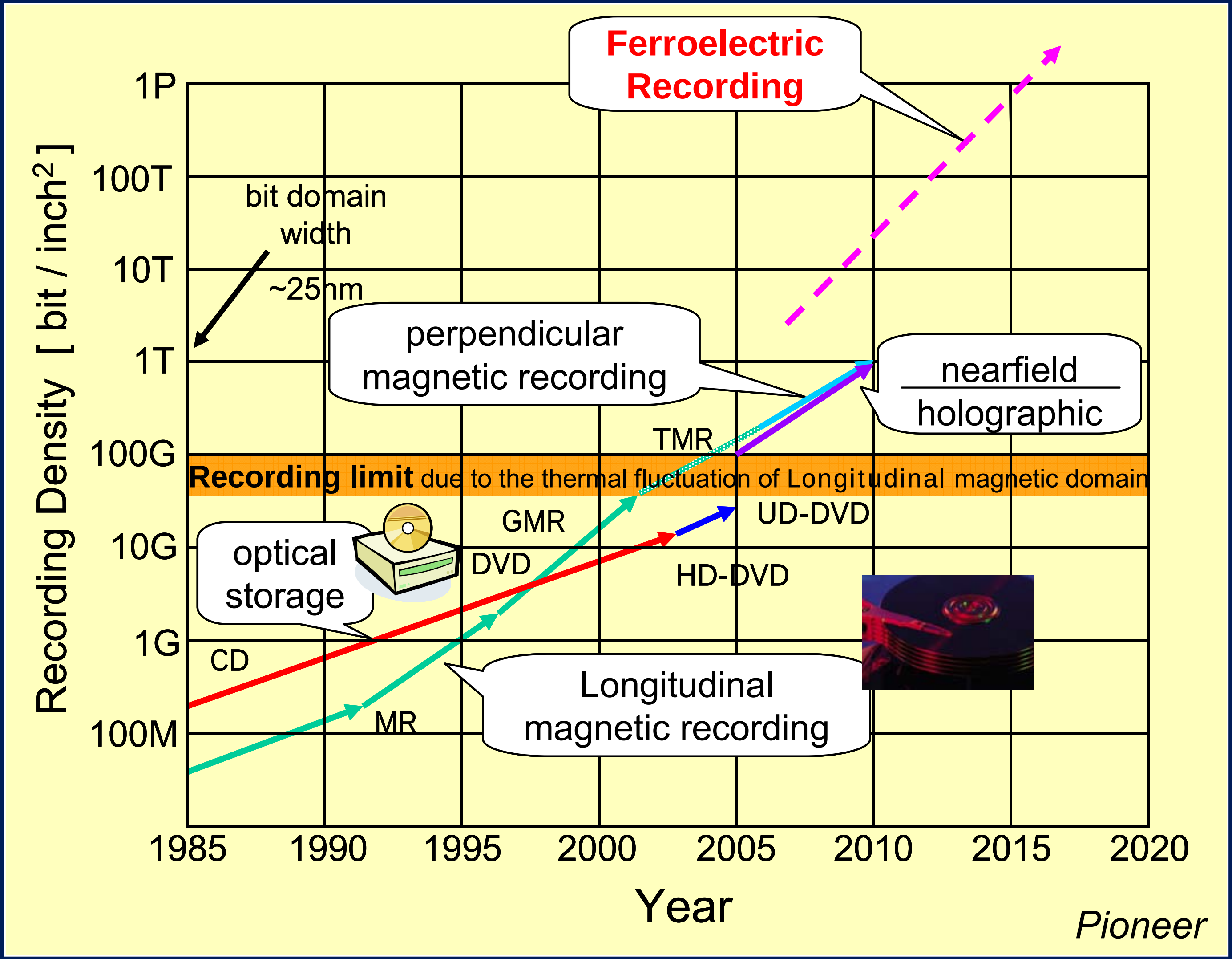
4 kB Crossbar Switch



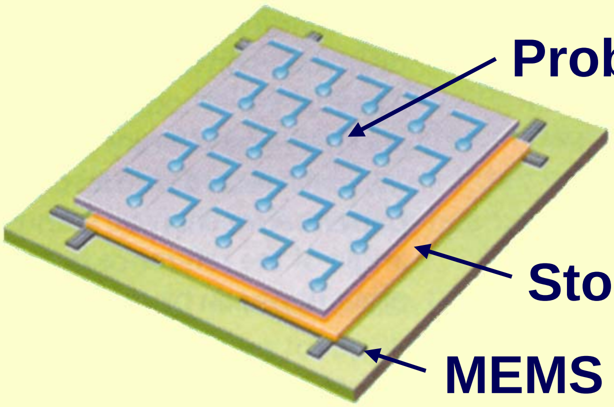
Nanotechnology: Revolutions



NT: Storage Limits

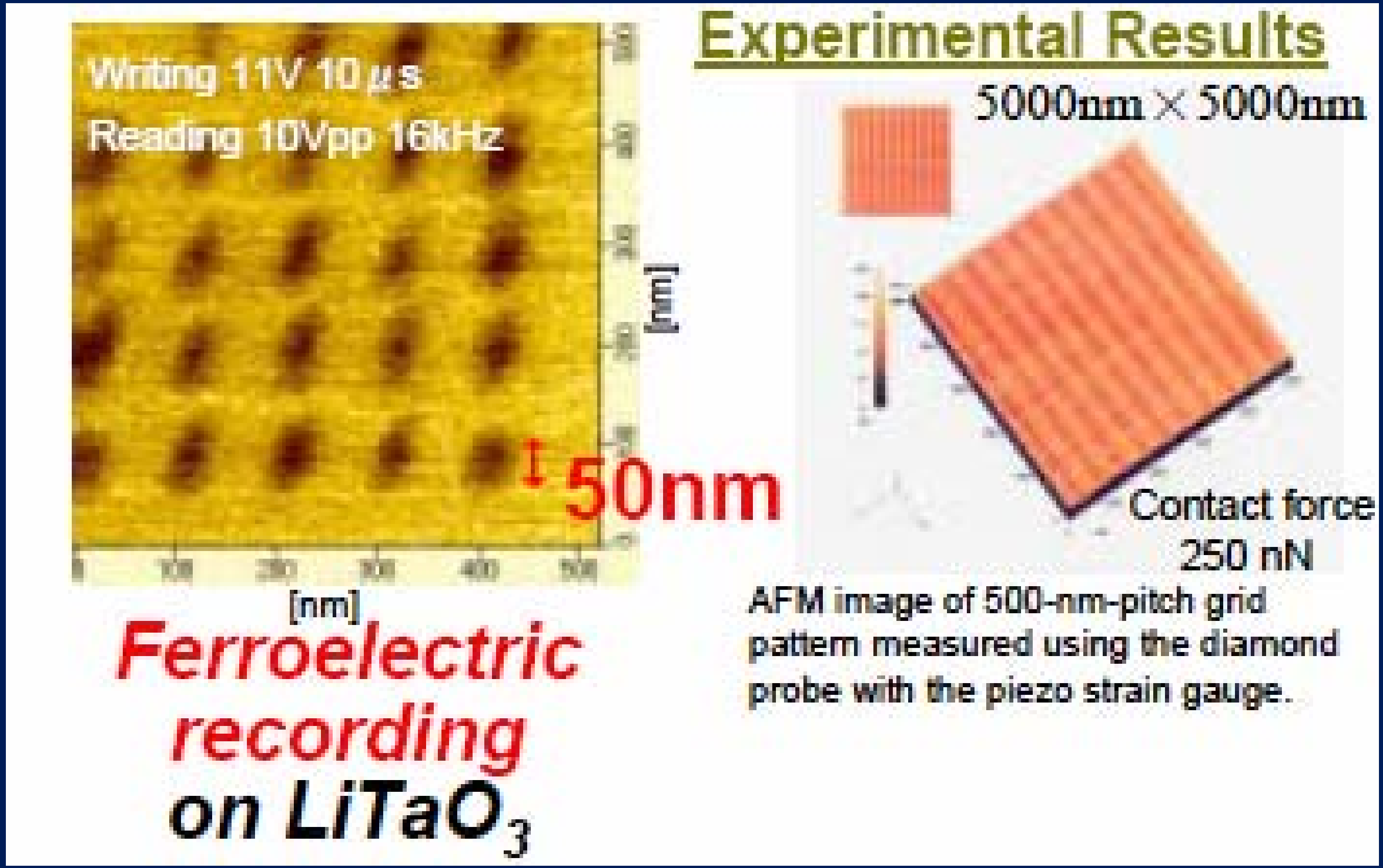


NT: Probe-Based Storage



- Storage medium
  - Rewritable
  - WORM
- Probe array
  - Individually addressable probes
- MEMS (MicroElectroMechanical Systems) motor
  - x-y actuation (preferable to rotation)
  - z stabilization (servo may be needed)
- Control circuitry
- Packaging

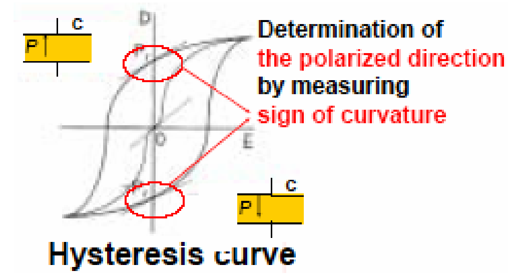
NT: Probe-Based Storage

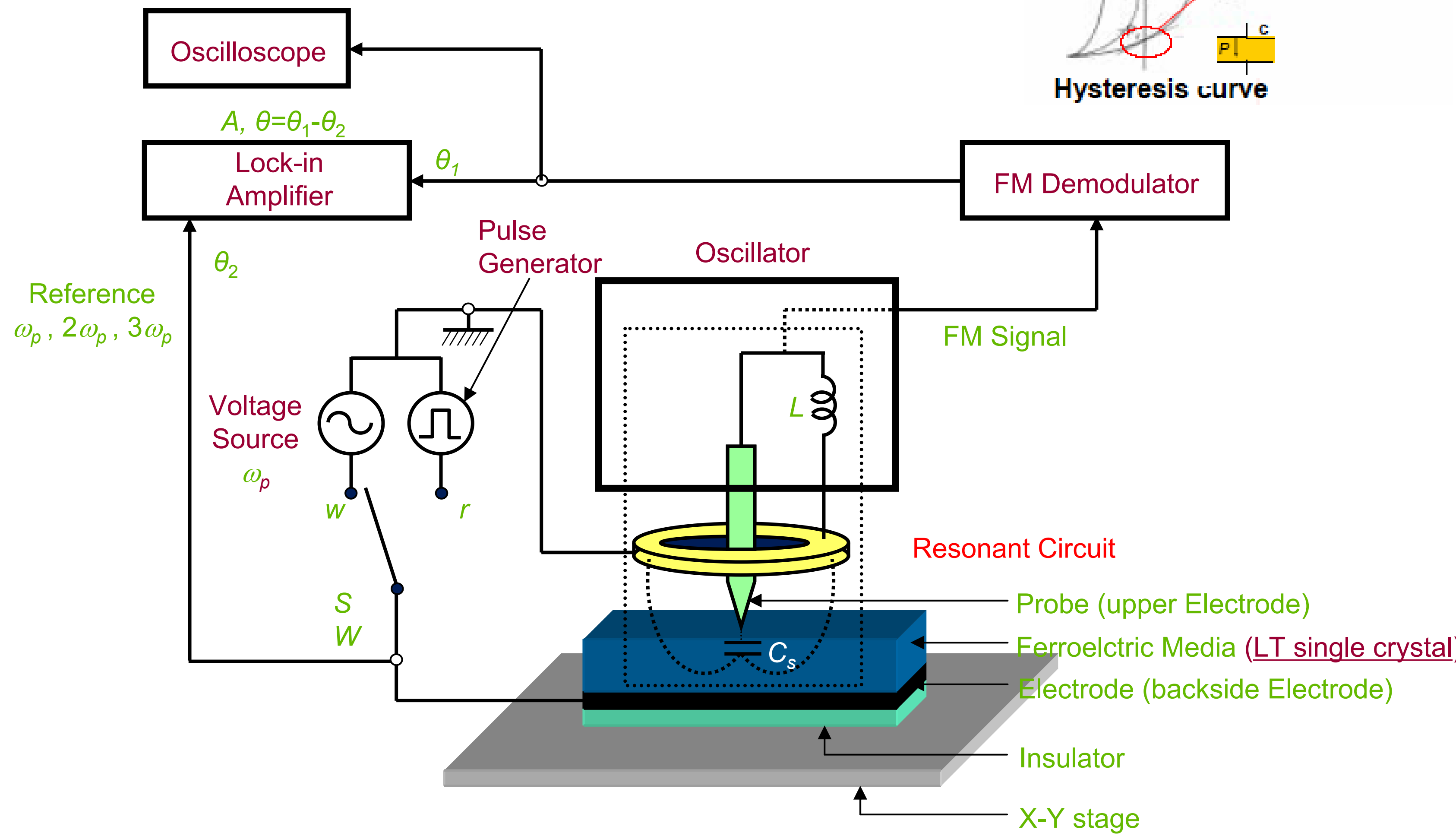


Pioneer and Tohoku University

NT: Probe-Based Storage

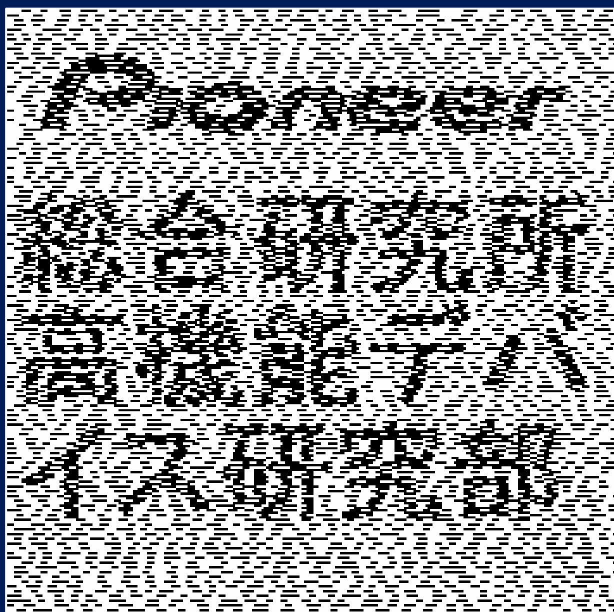
Basic Method of SNDM
(Scanning Nonlinear Dielectric Microscopy)





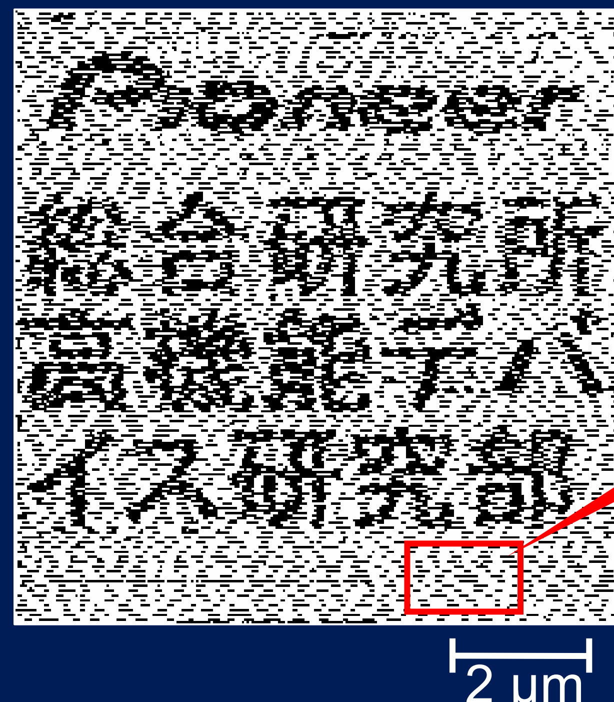
NT: Probe-Based Storage

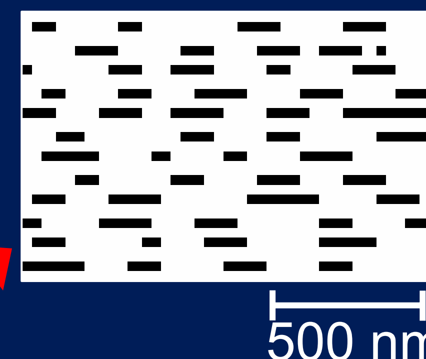
Recorded original data



Scan direction

Play-back signal

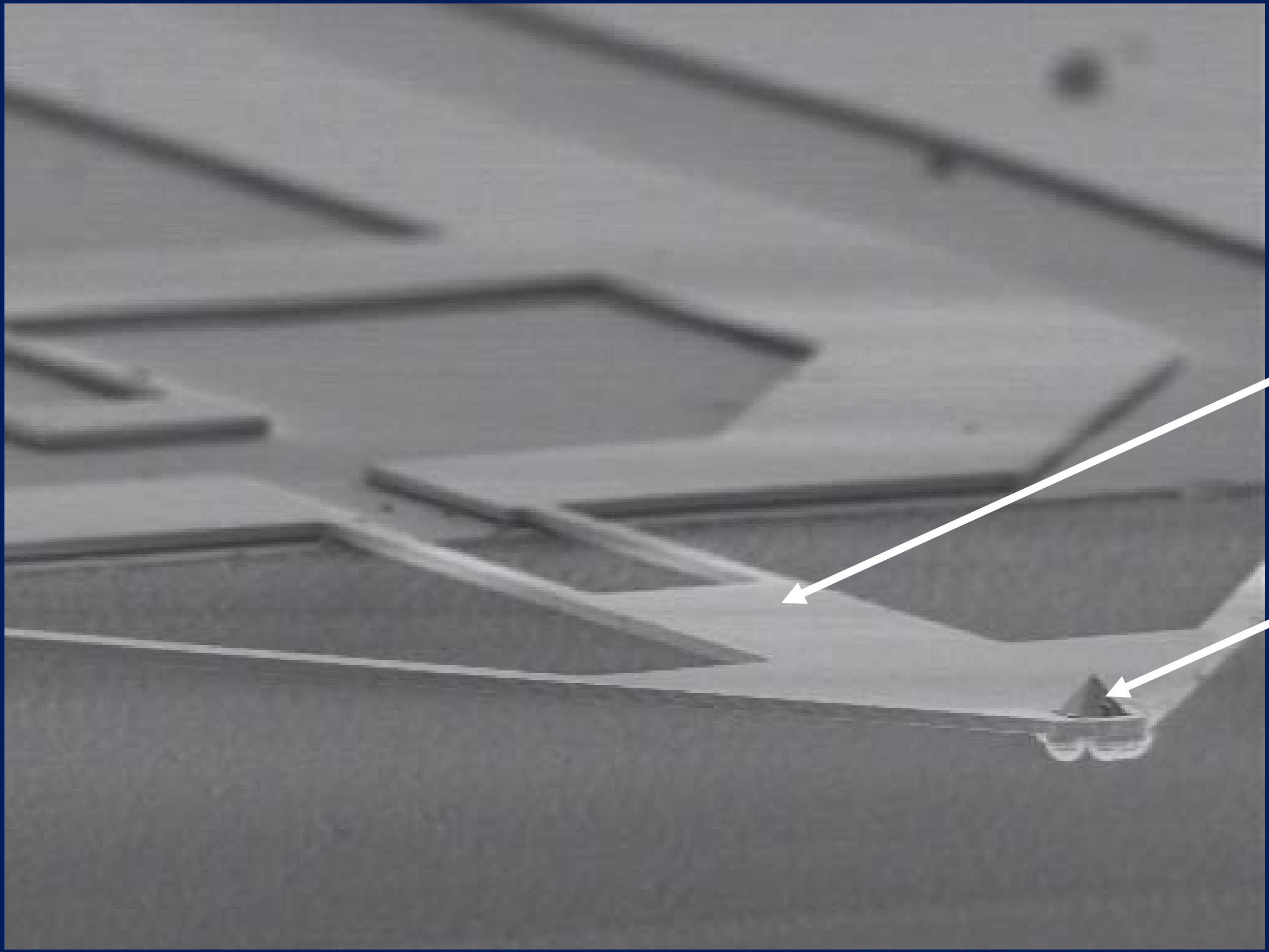




Error rate: 5.05%

Pioneer and Tohoku University

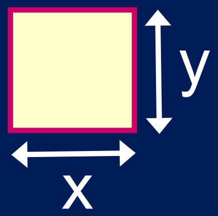
NT: Probe-Based Storage: Probe



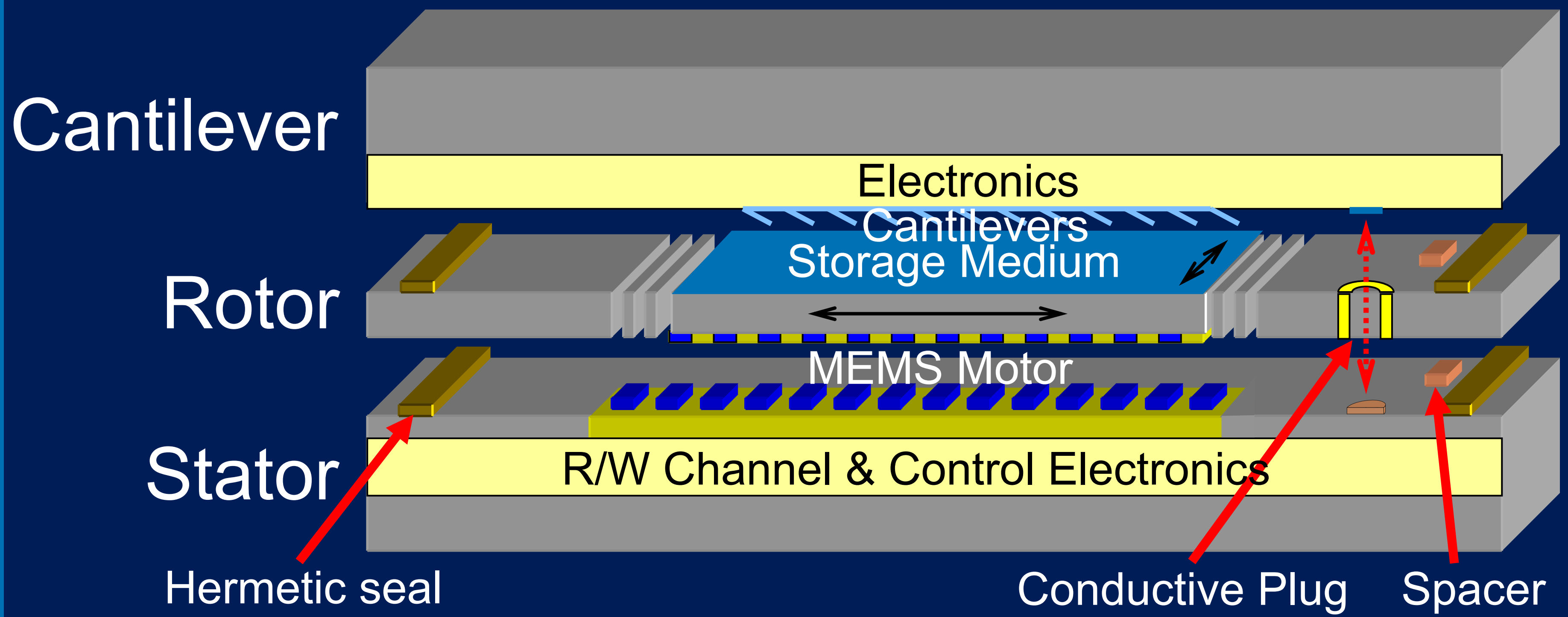
Pioneer and Tohoku University

NT: Probe-Based Storage - MEMS

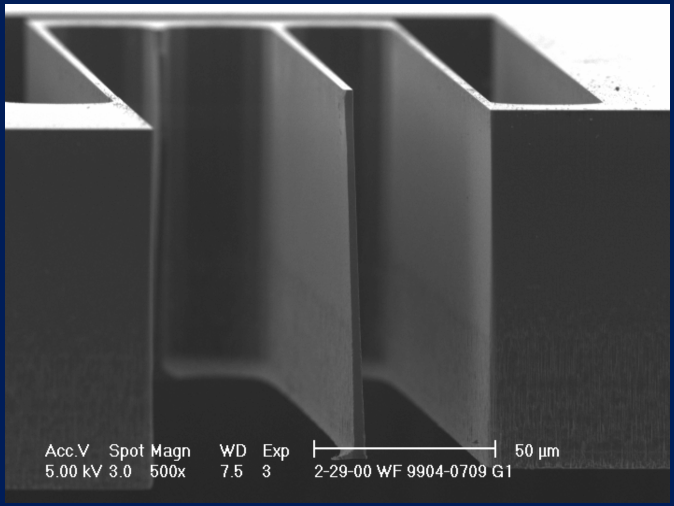
- Low Data Access Time
  - Force to access data (acceleration)
  - Short settling time
  - High accuracy of positioning (< 1nm)
- High Data Transfer Rate
  - Speed of motion
  - High range of travel
- High Capacity
  - x-y or rotational motion
  - High areal efficiency
- Low Cost
  - Simple to make
  - Easy to servo in x, y, and z (precision)
- Low Power
  - Electrostatic actuation
- High Shock Tolerance
  - High z-stiffness

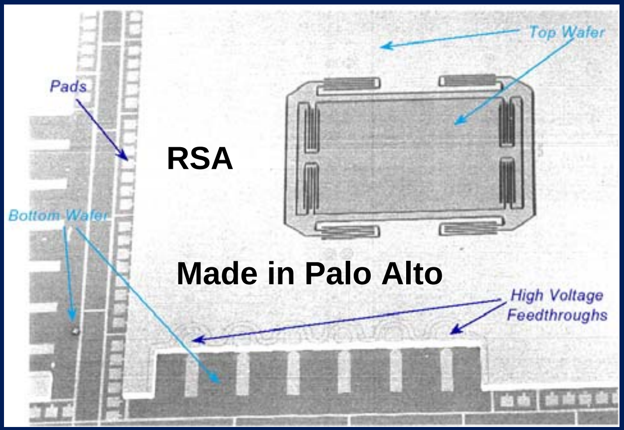


NT: Probe-Based Storage - MEMS

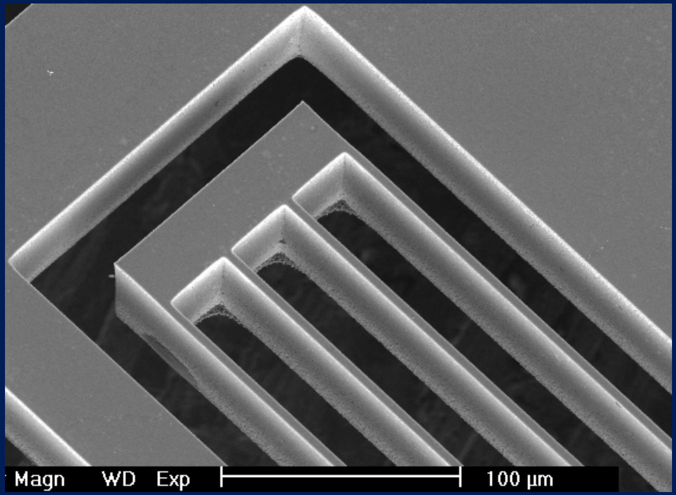


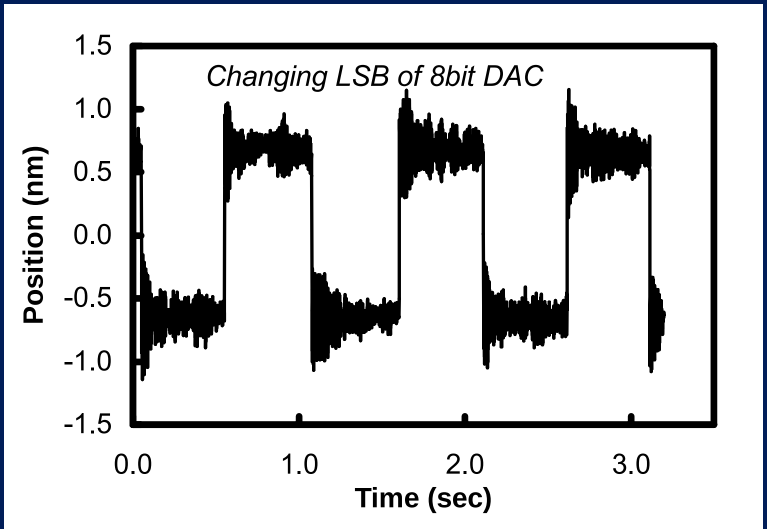
NT: Probe-Based Storage - MEMS





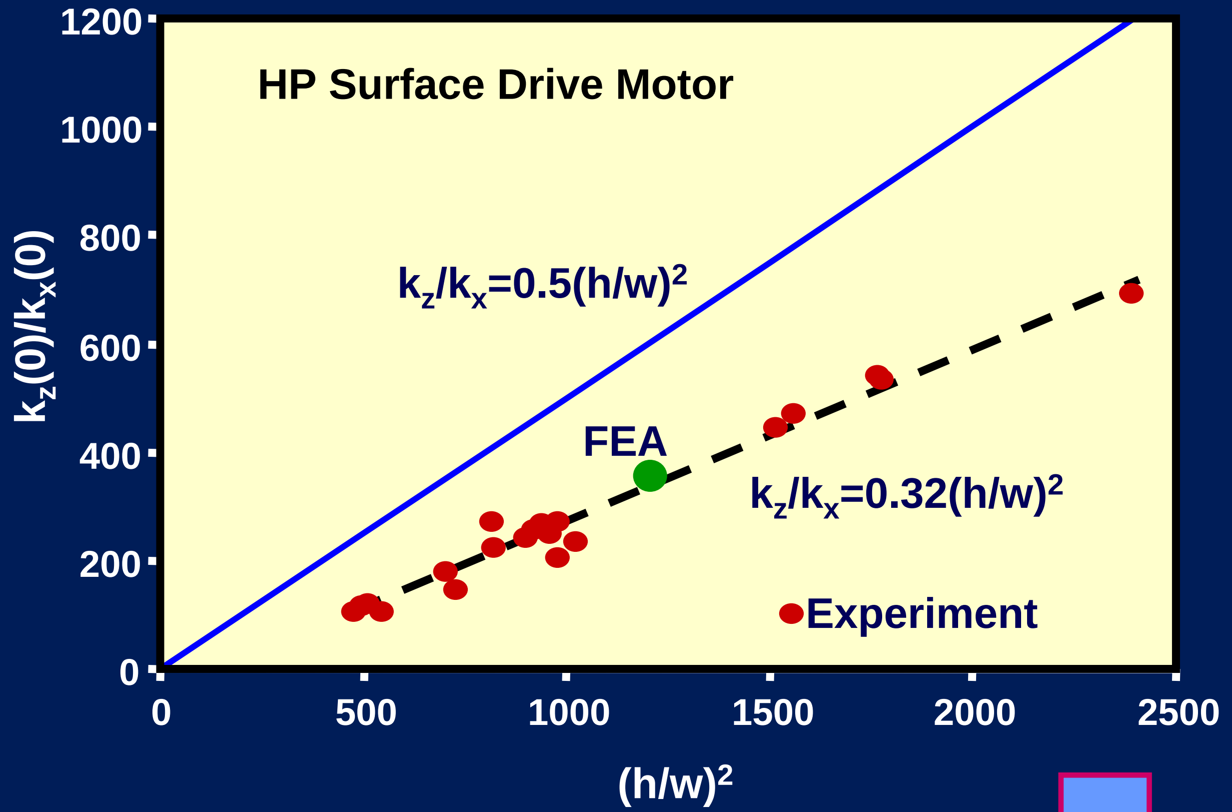
Flexure after release





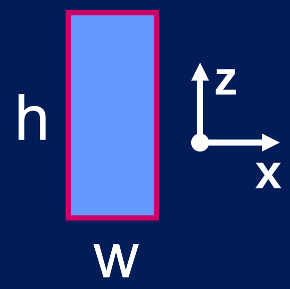
No feedback

NT: Probe-Based Storage - MEMS



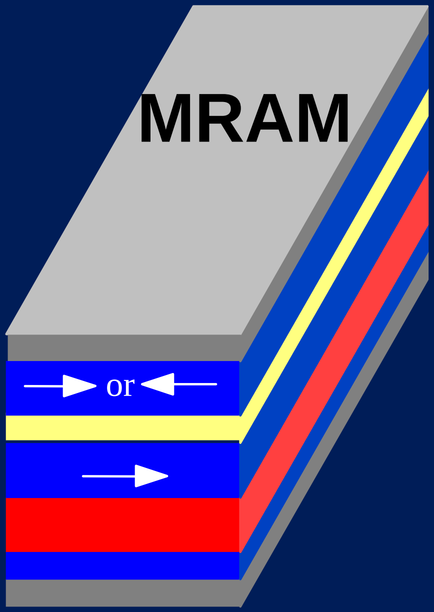
Assumption:

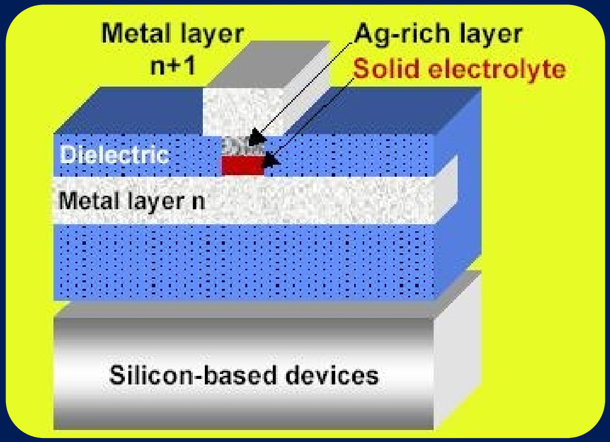
Rectangular beam of height h, width w and spring constants k_x and k_z

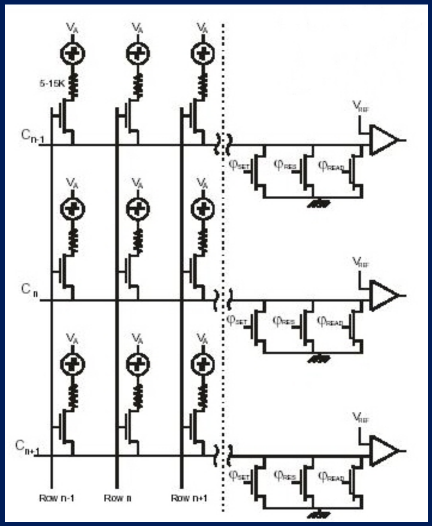


D. Horsley, *et al*, Solid-State Sensor and Actuator Workshop, Hilton Head, SC, 2000.

NT: Nonvolatile Memories







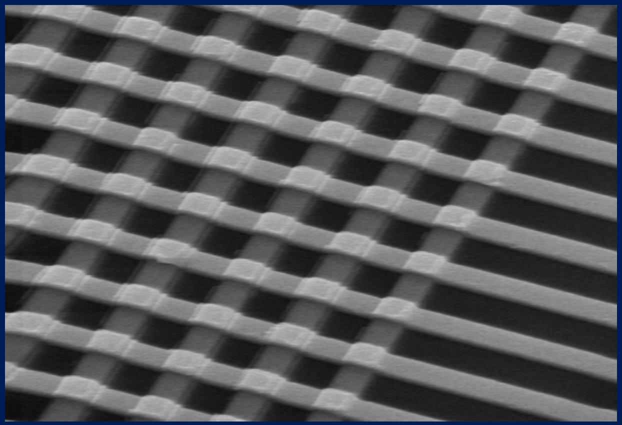
PMCm
Programmable Metallization Cell

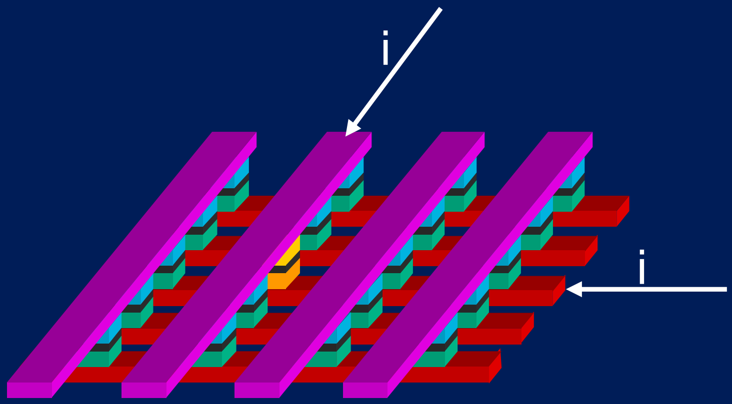
Ovonic
Phase Change Memory

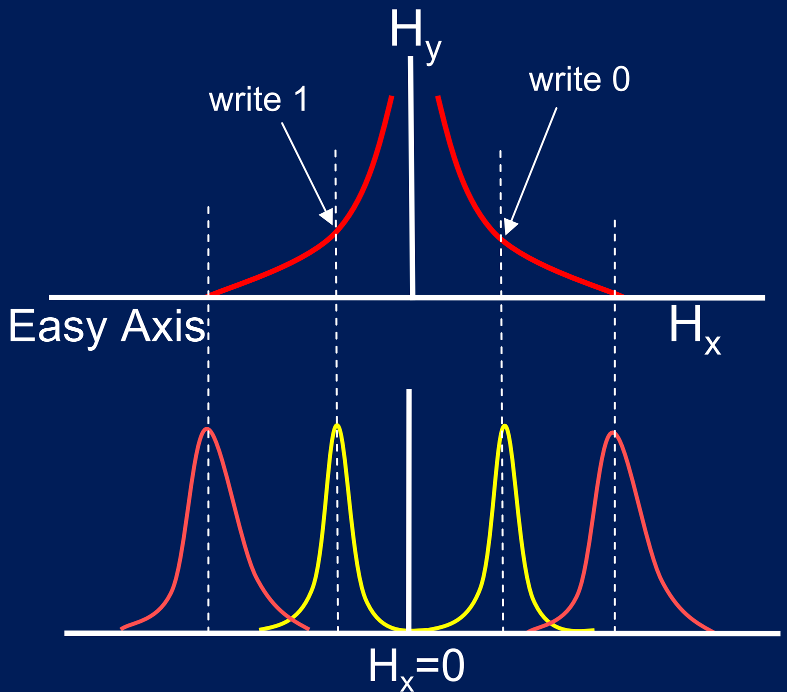
MRAM	PMCm	Ovonic
Scalability	Scalability	Scalability
Cyclability	Cyclability	Cyclability
Speed	Speed	Speed
Power	Power	Power
Cost	Cost	Cost

NT: MRAM

- Coercivity (H_c) magnitude
  - Low enough to switch with available current
    - power, data rate, Si overhead tradeoffs
  - High enough to be thermally stable
    - superparamagnetic limit
- Coercivity distribution
  - Unselected bits must not switch

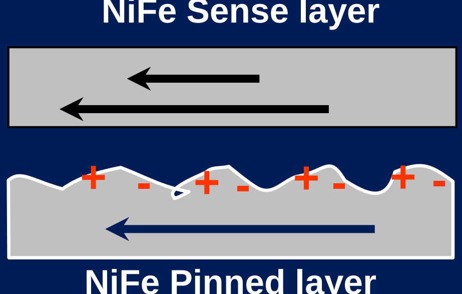


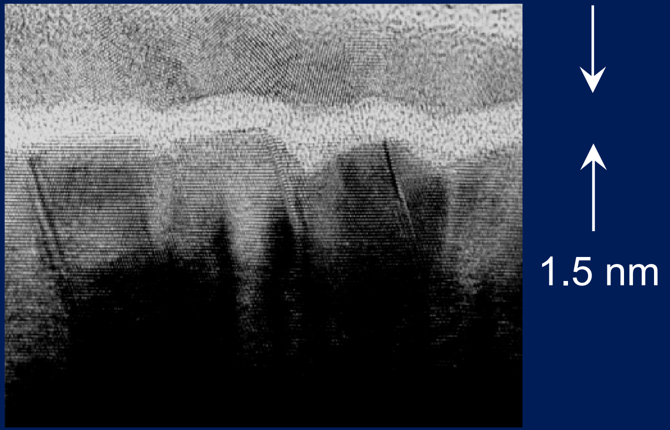




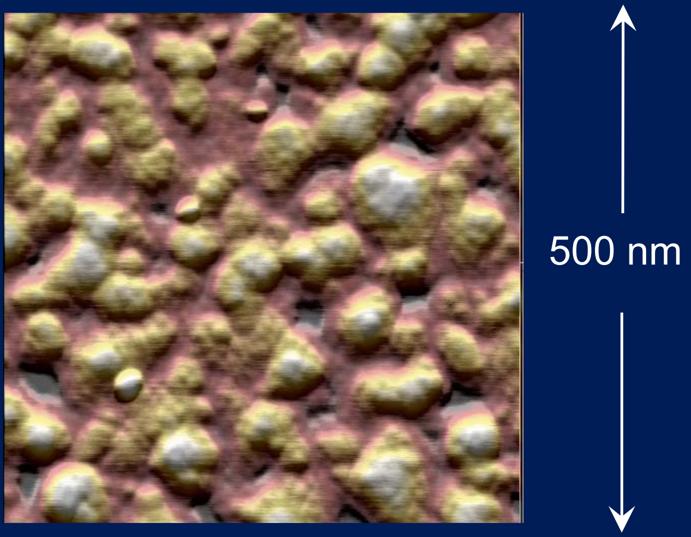
NT: MRAM

- Interfaces often rough
  - columnar growth leads to “domed” grains
  - ~10 nm scale
- Roughness creates FM coupling between magnetic layers
  - adversely affects switching control





HREM

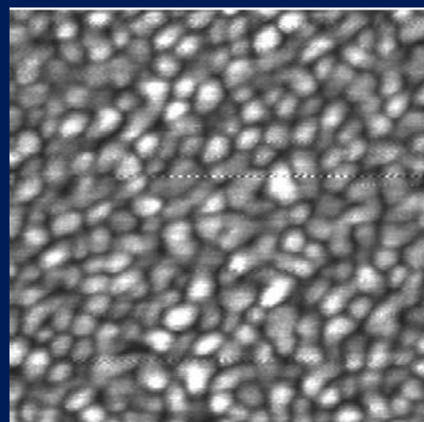


AFM

NT: MRAM

Ion smooth interface prior to deposition of barrier layer

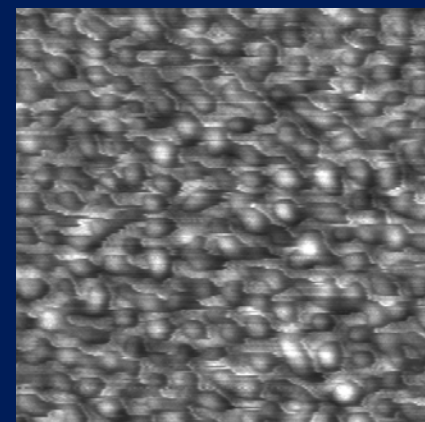
w/o Ion Etch Process



p-p height ~1.5 nm

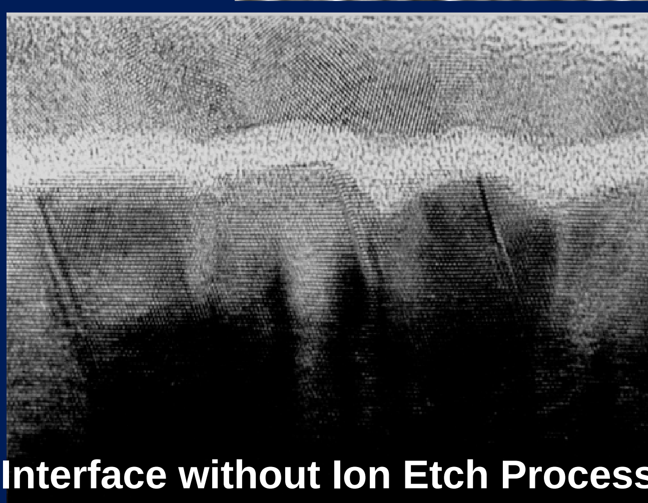
AFM

w/ Ion Etch Process

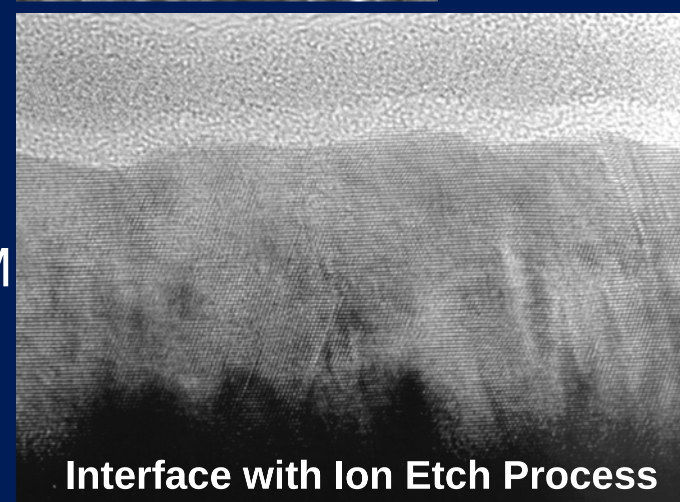


p-p height ~0.9 nm

HREM



Interface without Ion Etch Process



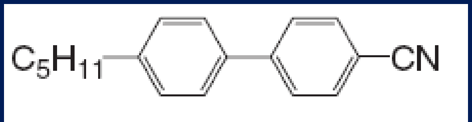
Interface with Ion Etch Process

Other Basic Technologies

NT: Displays – Liquid Crystal

LG Philips Displays

Liquid Crystal Displays
1st in monitors
1st in portables
Growing in TVs



typical cyanobiphenyl
liquid crystal material
~ 2 nm long

- Wants
  - Faster response
  - Higher contrast
  - Larger viewing angle

NT: Displays - OLEDs

RiT Display
China

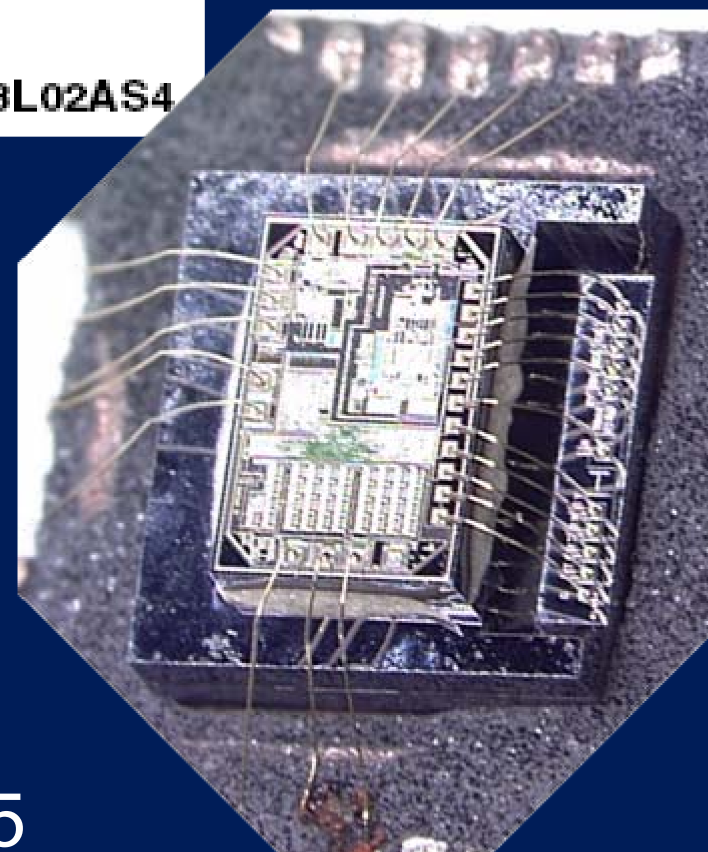
Target
- Displays for potable devices
- Cell Phones

Partner
- Dupont

Competitors
- Samsung, Kodak, others

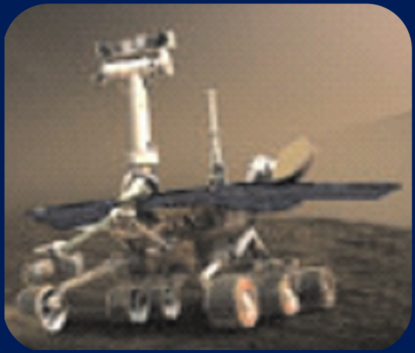
Status
- Full color – 2006
- Blue lifetime an issue
  - Improving
  - Nanoparticle stabilization

NT: Inertial Sensors



Sensitivity:	30 nG/√Hz
Bandwidth:	2.5 kHz
Δ Capacitance:	100 fF
Δ x:	~ 1 nm
Electronics:	Integrated
Size (mm):	10.5 x 7.5 x 2.5

NT: Inertial Sensors



NT: Inertial Sensors

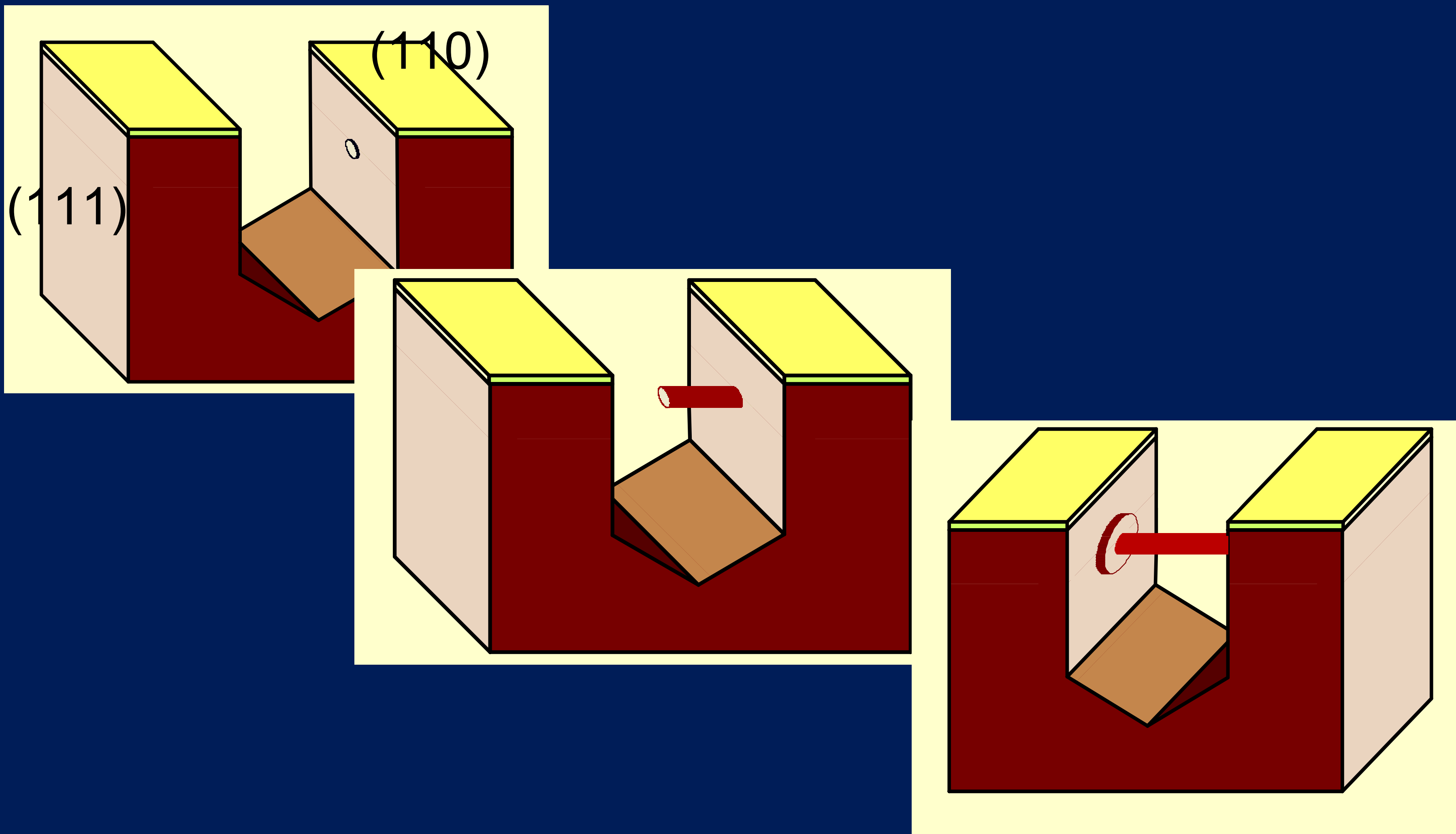
2005 $560,000,000

2008 $800,000,000

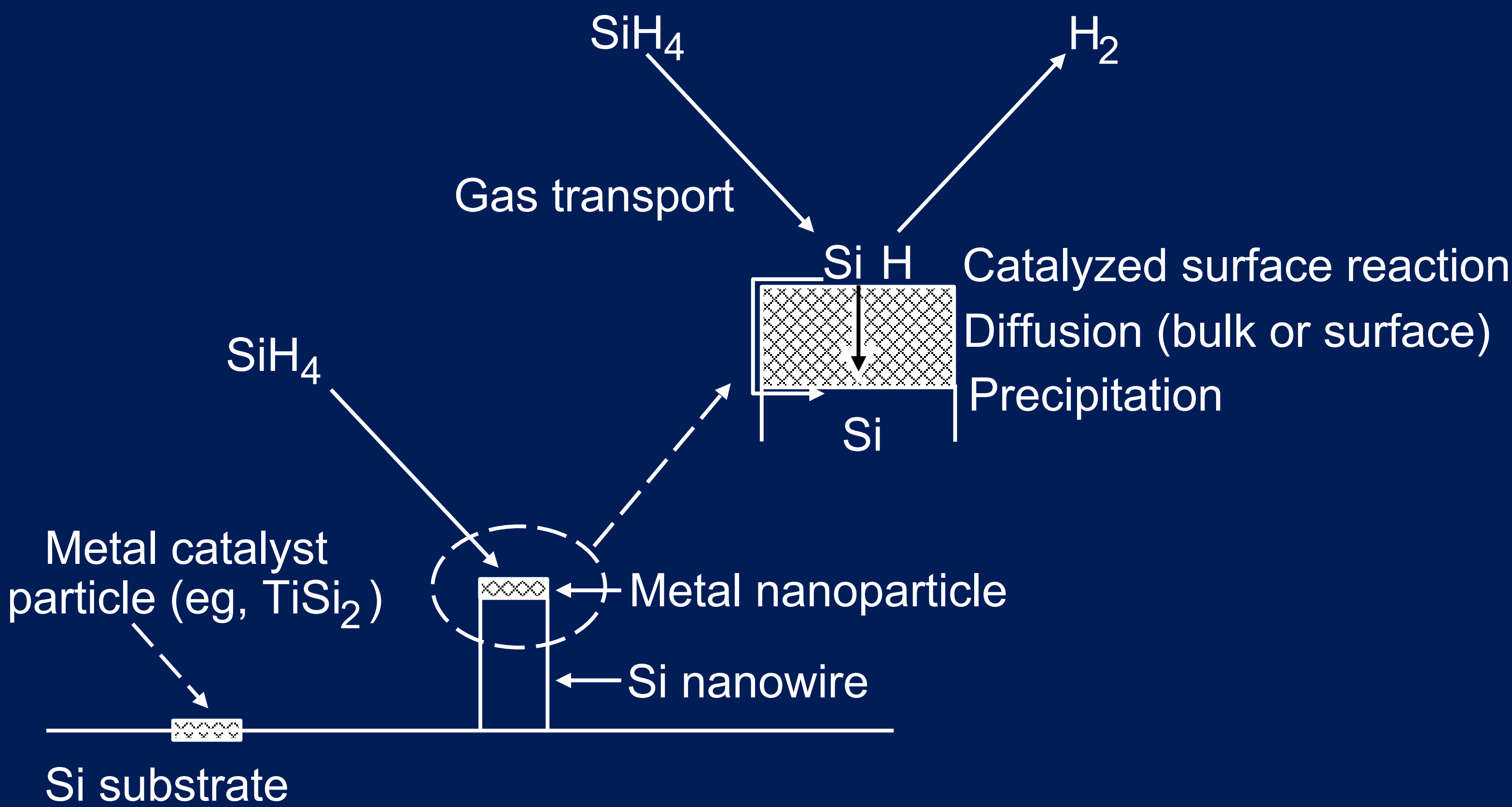
= 90 % (2004)

* MEMS only
after Colibrys

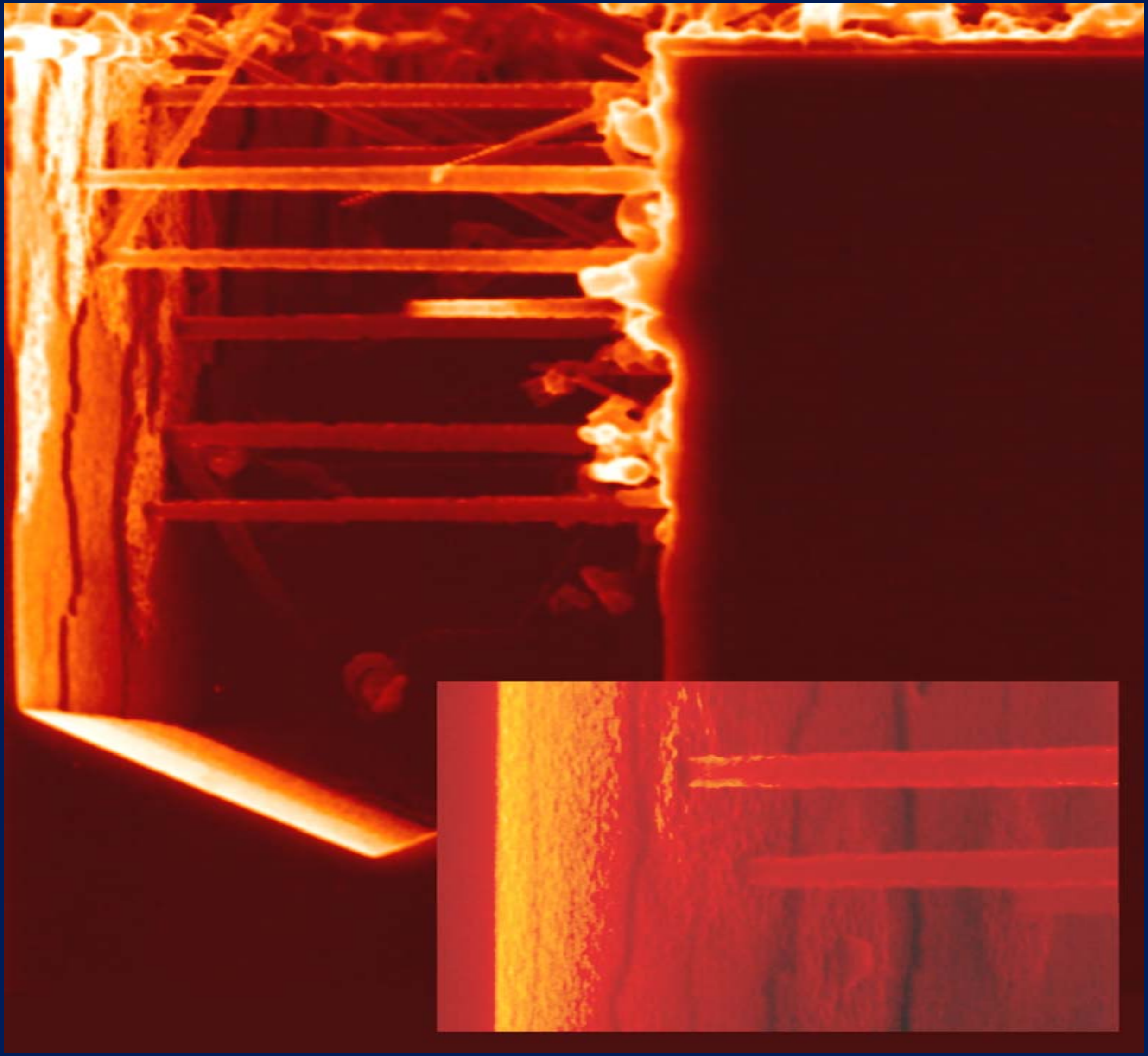
NT: Nanowire Sensors



NT: Nanowire Sensors

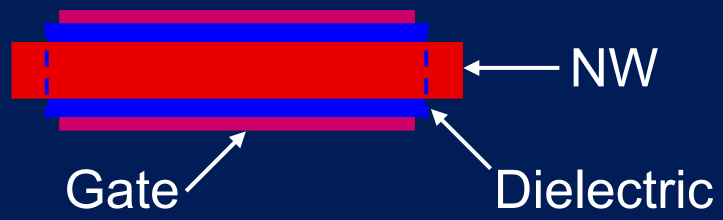


NT: Nanowire Sensors

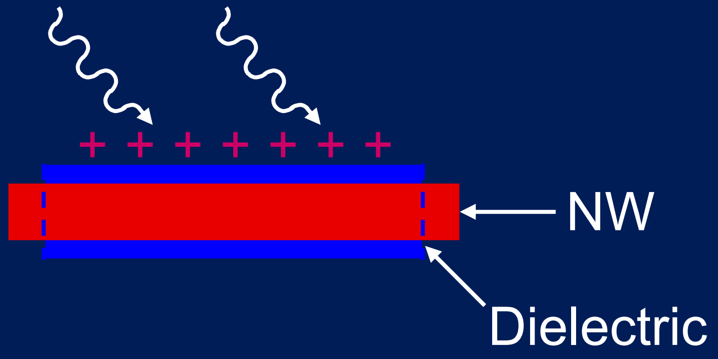


NT: Nanowire Sensors

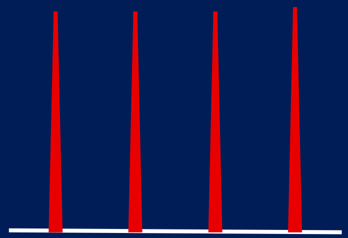
MOS Transistor



Chemical Sensor



Electron Emitters



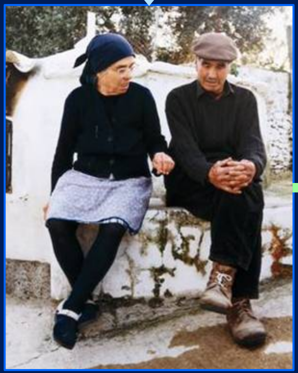
NT: Nanowire Sensors Application

Customer Needs/Pain Points

1. Integration of current and historical health information into a form that enables *faster* and *less costly* actions
2. Remote access to real-time data

Professional Care Givers

Longs Drugs



People

Home Monitor

Secure Infrastructure

Integrated health sensing system to enable timely health decisions, reducing health-care costs and human suffering.

Market Statistics

1. 20+% of population > 60 years and growing larger
2. Healthcare is 15% of US GDP and growing larger
3. $30,000,000,000 WW Home Medical Devices (2000)

Technologies That Need Improvement

Nanotechnology and Electronics

Batteries

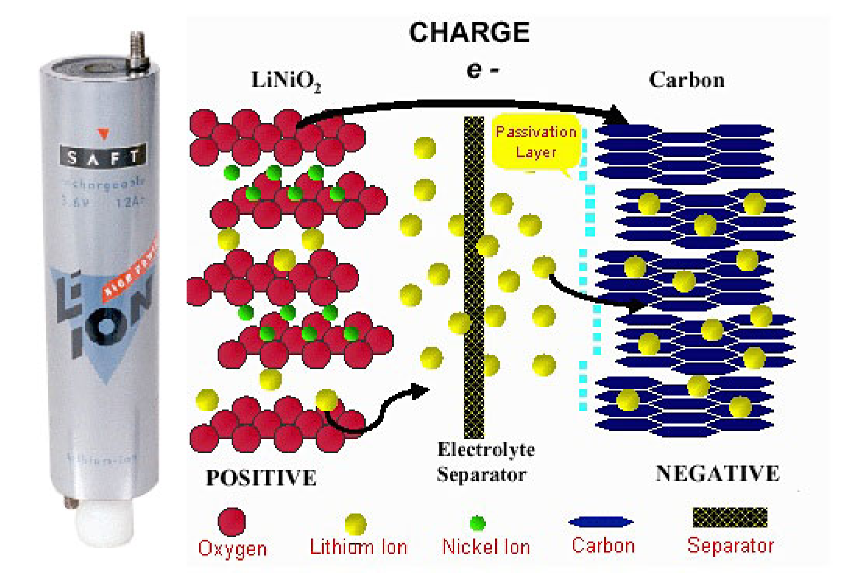


Photo Courtesy of SAFT America

- Wants
  - Higher energy density
  - Longer life
  - Lower weight
  - Environmentally sound
  - Lower cost

Nanotechnology and Electronics

Conclusions:

- Evolution over time
  - Shrinking dimensions – more functionality in same space
  - Faster computation
  - Lower cost if device size shrinks
- Multifunctional portable devices will be common
- Revolutions
  - Molecular Electronics may supplant Semiconductors
  - Probe-Based Storage may supplant disk drives
- Other evolving electronics technologies
  - Displays – LCD is king – OLEDs in small displays
  - Sensors – Motion sensing evolving – Chemical sensing
- Battery technology needs improvement

Acknowledgments

Ferroelectric Probe Storage	Pioneer	Takanori Maeda
MEMS motors	HP	Peter Hartwell *et al*
Cross – Bar Memories	HP	S. Y. Wang *et al*
MRAM	HP	Tom Anthony *et al*
Nanowire Sensors	HP	Ted Kamins *et al*

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