“The Virginia MEMS and Nanotechnology Training Academy - A proposed strategy for rapid workforce development in MEMS and Nanotechnology for the Commonwealth of Virginia ”

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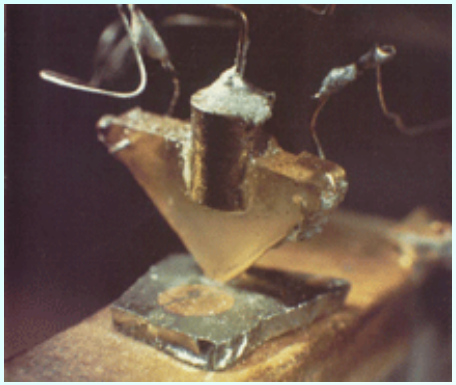
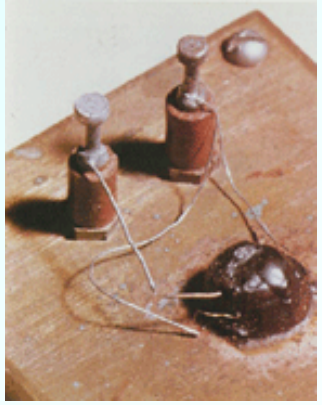
Integrated Circuits: The First Silicon Revolution

- 1945 - Transistor invented
- 1951 - Junction transistor invented
- 1950 - The grown junction transistor
- 1954 - First commercial silicon transistor
- 1955 - First field effect transistor
- 1958 - Integrated circuit invented
- 1959 - Planar technology invented
- 1960 - First MOSFET fabricated
- 1961 - First commercial ICs
- 1963 - First MOS IC
- 1963 - CMOS invented
- 1965 - Moore's law
- 1969 - BiCMOS invented
- 1970 - 1st NMOS IC
- 1971 - First Microprocessor

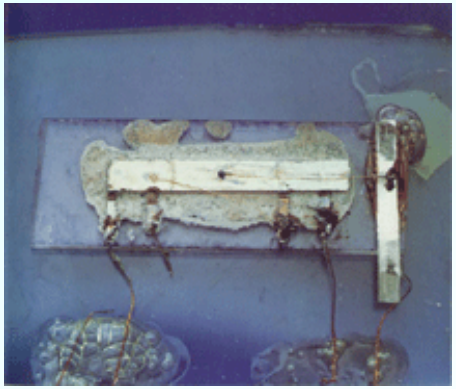


1945 - Transistor invented

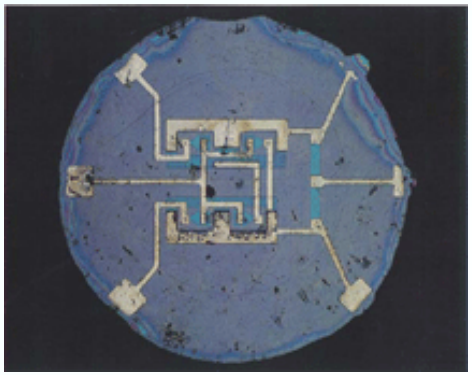
1951 - Junction Transistor invented

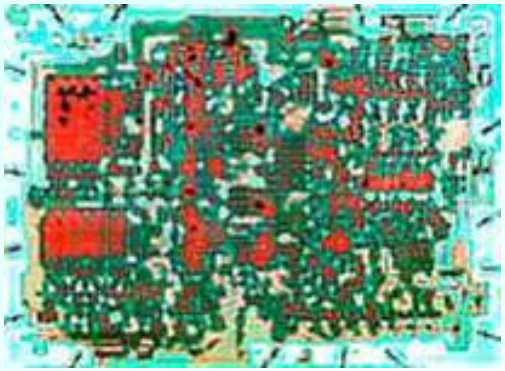


1959 - Planar technology invented



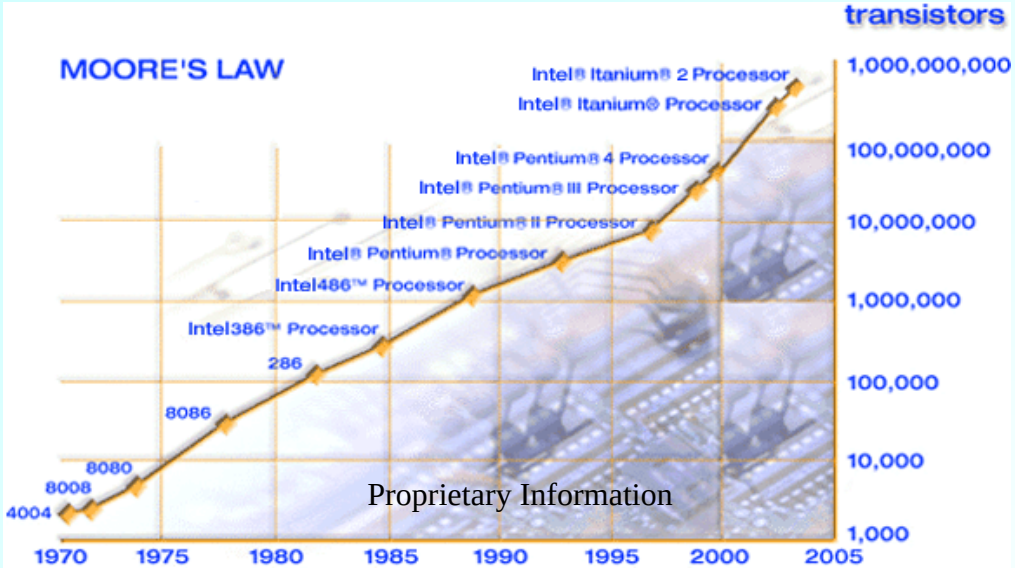
1958 - Integrated circuit invented





1971 - First Microprocessor - Intel

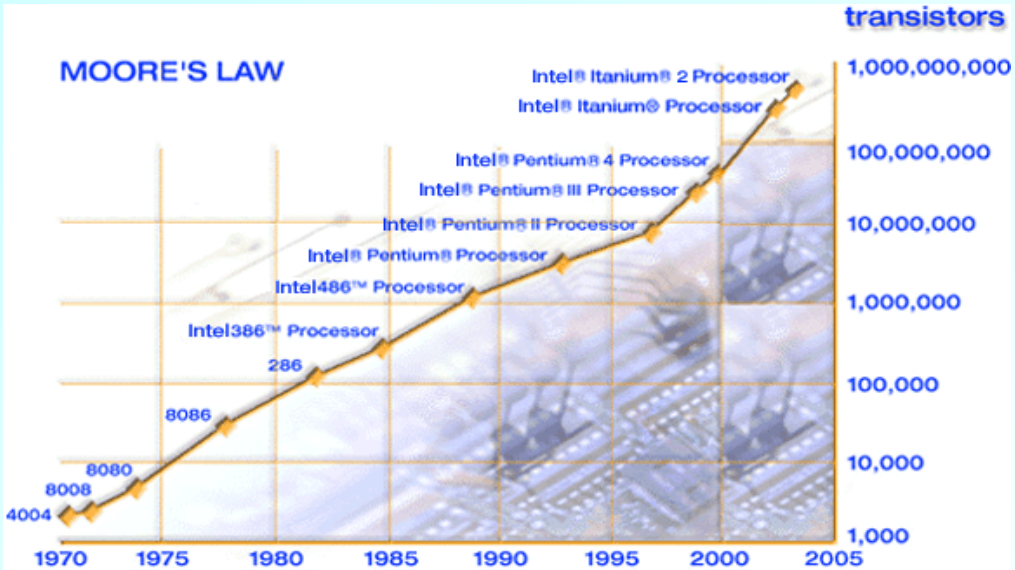
Integrated Circuits: The First Silicon Revolution



Until the present time the integrated circuits industry has measured its progress by the number and size of the transistors that can be packed onto a single slab of silicon or microchip.

In the future, the important metrics will be: how capable a chip is; how powerful it can understand and influence its environment; and how it can assist and enlighten its user.

Integrated Circuits: The First Silicon Revolution



Until the present time the integrated circuits industry has measured its progress by the number and size of the transistors that can be packed onto a single slab of silicon or microchip.

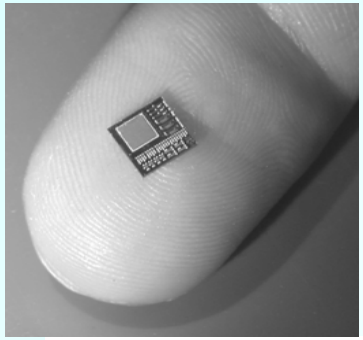
In the future, the important metrics will be: how capable a chip is; how well it can understand and influence its environment; and how it can assist or enlighten its user.

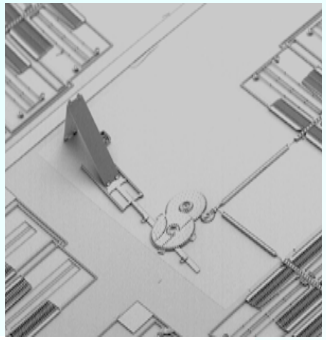
MEMS: The Second Silicon Revolution

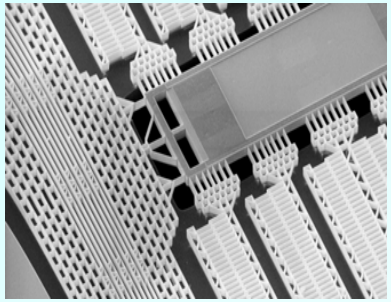
Hallmark of MEMS is the integration of mechanical structures and multifunctional materials with microelectronics

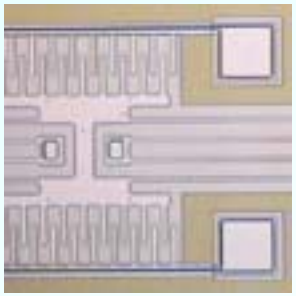
MEMS combines the capabilities of perception, computation, and actuation

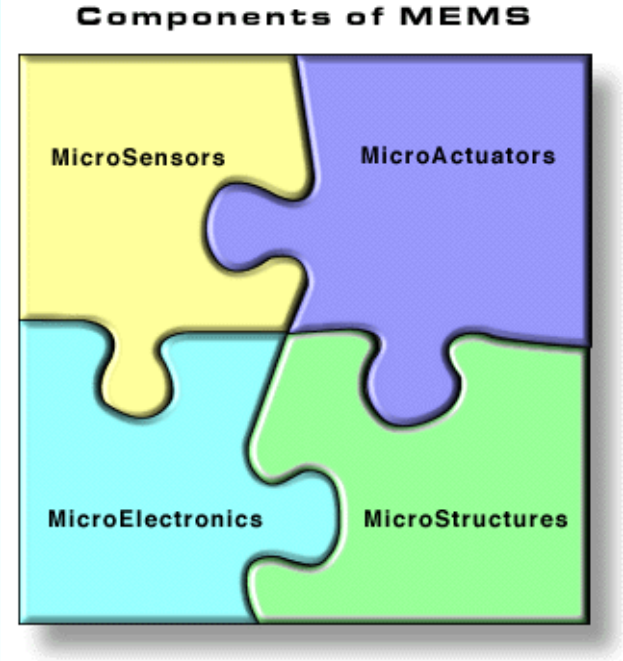
- Sensors perceive environment
- Electronics process sensory information and make decisions
- Actuators control the environment





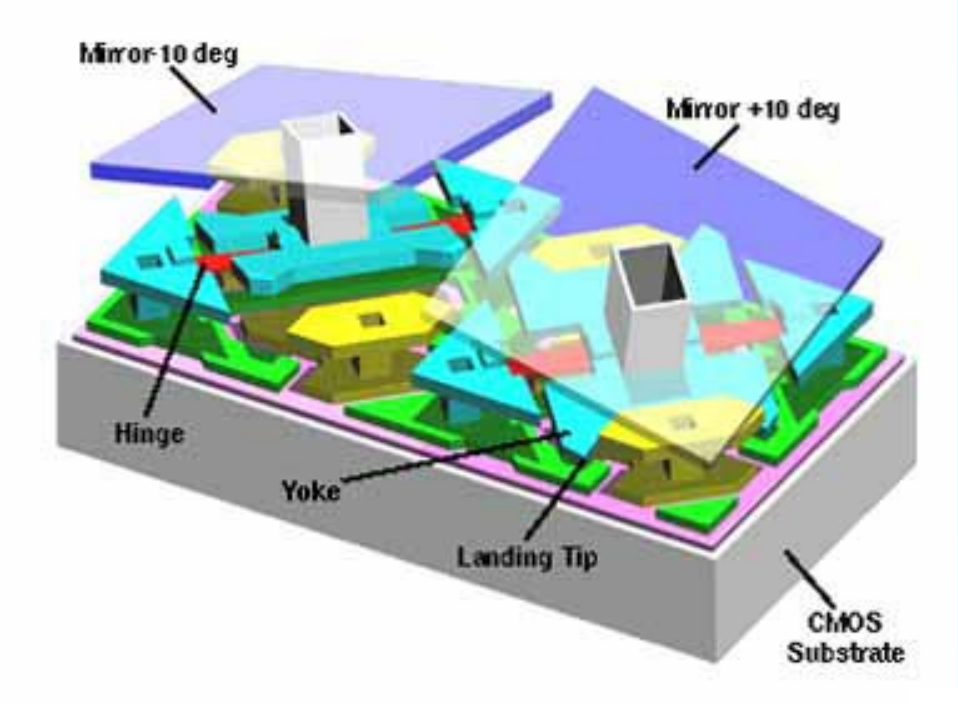




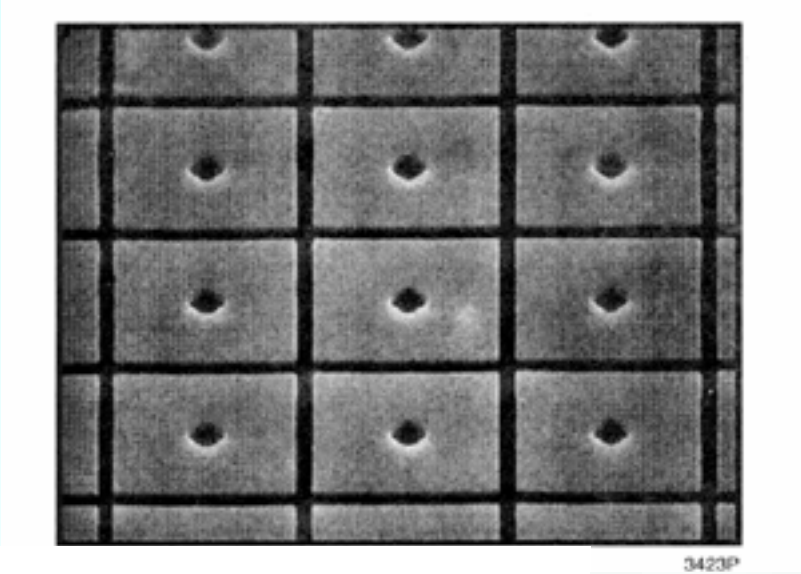


<u>MEMS enables revolutionary new system applications!</u>

TI Digital Light Processor



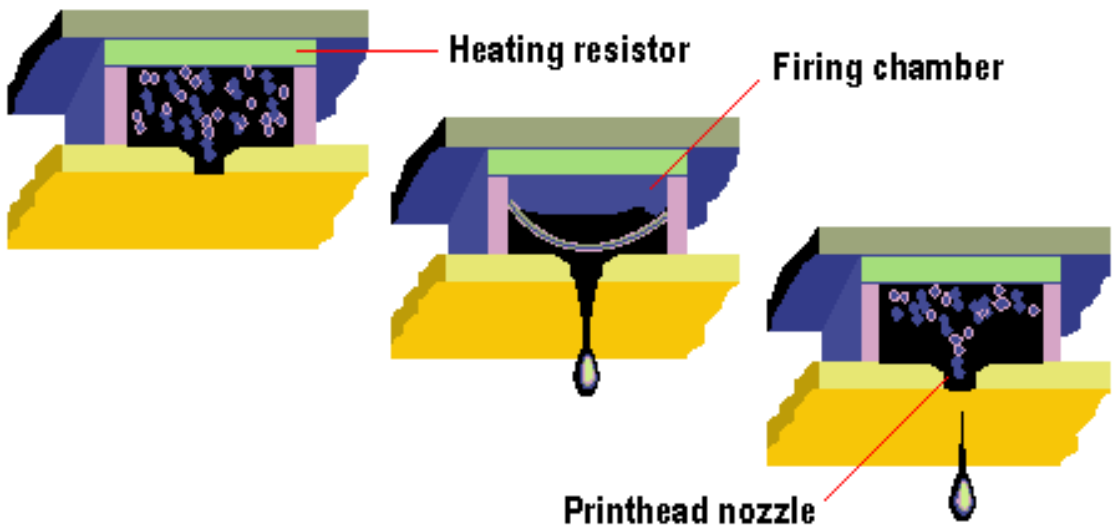
SEM of DLP chip surface



Distinguishing features of DMD MEMS technology:

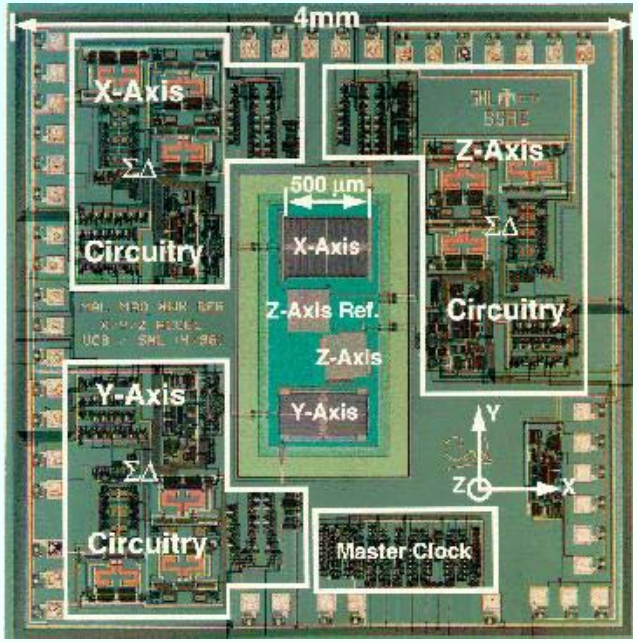
- Number of moving parts - 0.5 to 1.2 million
- Mechanical motion - Makes discrete contacts or landings
- Lifetime requirement - 450 billion contacts per moving part
- Address voltage - Limited by 5 volt CMOS technology
- Mechanical elements - Aluminum
- Process - Low temp., sputter deposition, plasma etch
- Sacrificial layer - Organic, dry-etched, wafer-level removal
- Die separation - After removal of sacrificial spacer
- Package - Optical, hermetic, thermal vias
- Testing - High-speed electro-optical before die separation

InkJet Technology



- Today's inkjet printers use print heads with 300 to 600 nozzles
- Each nozzle is about one-half the diameter of a human hair (70 um)
- Nozzles deliver between 8 to 10 picoliters (a picoliter is one million millionth of one liter) in each cycle
- Dot sizes range between 50 and 60 um in diameter
- Printer resolution varies between 300 and 600 dpi with 1200 dpi is becoming increasingly available
- Print speed is function of frequency of firing of nozzles and width of print head swath, which are typically 12MHz and 0.5 inch, respectively.
- This gives a print speed of 4 to 8 pages per minute for monochrome and 2 to 4 ppm for color
- Presently over a $15B per year business and growing

Inertial Sensor Technology

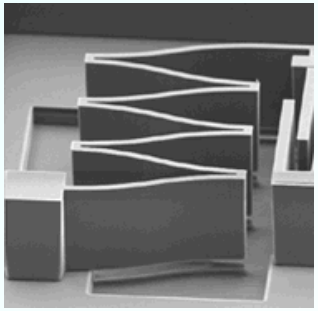


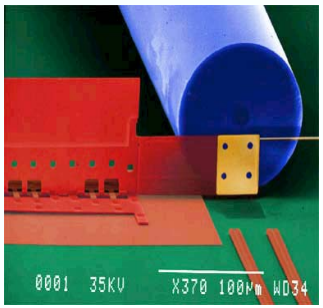
MEMS Inertial Sensors

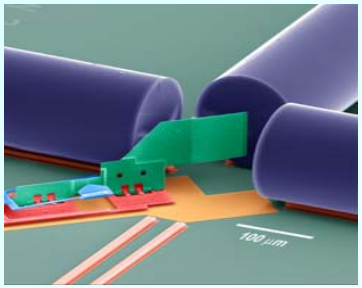
- Largest market is automotive crash airbags, average car has over 6 sensors for front and side crash protection
- Other accelerometer applications include: joysticks, shoes, missiles, etc.
- Automotive sensors are typically +/- 50 g, have self test capability
- Devices ranging from far less than 1g to over 100,000g are available
- New technology for micromachined gyroscopes which will allow better handling of cars is becoming available

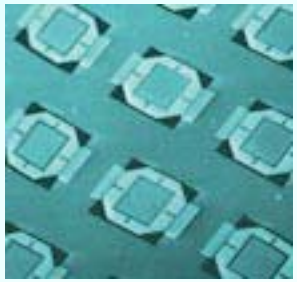
The Importance of MEMS Technology - A $5B a Year Business!

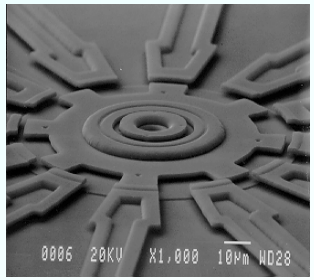
- Inertial Measurement - Accelerometers, gyroscopes, seismic sensors, vibration sensors, etc.
- Microfluidics - Gene chips, lab on a chip, chemical sensors, flow controllers, microvalves, micropumps, micronozzles, biosensors, etc.
- Optical MEMS - Optical switches, displays, modulators, multiplexers & de-multiplexers, adaptive optics
- Pressure Measurement- Auto sensors, medical sensors, industrial sensors, etc.
- RF Technology - RF switches, filters, variable capacitors, inductors, antennas, phase shifters, scanned apertures, etc.
- Other - Printers, data storage, magnetometers, pico-satellites, safe and arm fuses, actuators, etc.

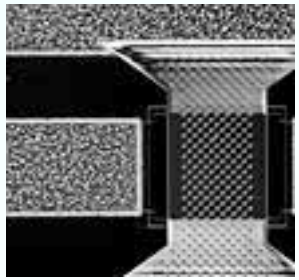








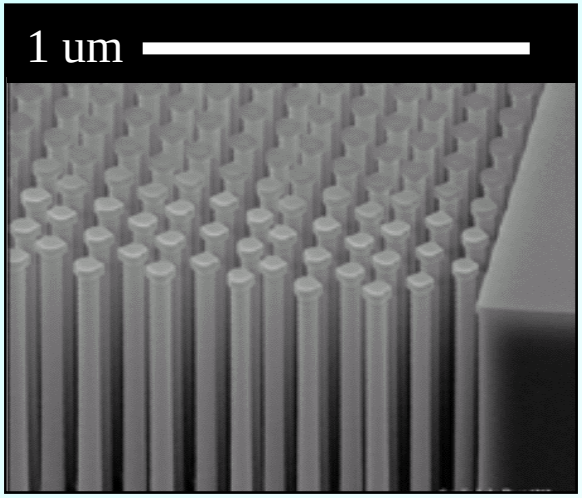


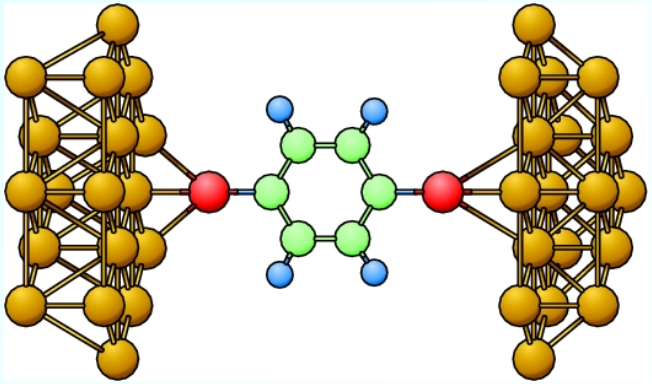


Nanotechnology

The ability to manipulate matter at the atomic or molecular scale

Two basic approaches: top down and bottom up.





Top down

Similar to Microfabrication, but on a smaller scale

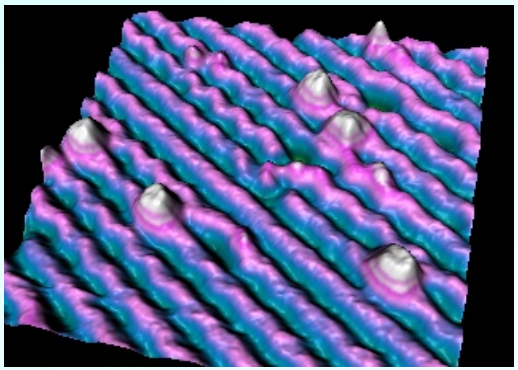
Bottom up

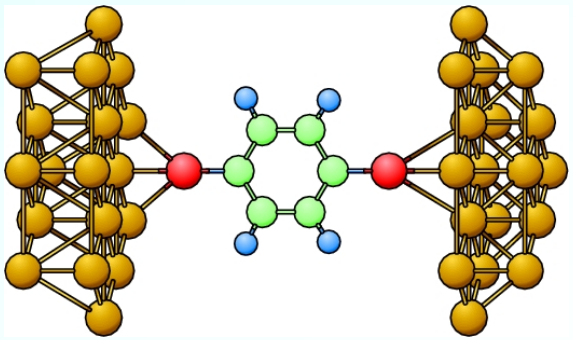
Chemistry, Biology, Materials Sciences, etc.

The Importance of Nanotechnology

Nanotechnology promises to allow us to:

- Put essentially every atom in the place and position we desire (positional control for assembly)
- Make almost any structure consistent with the laws of physics that we can specify in molecular detail
- Have manufacturing costs not greatly exceeding the cost of the required raw materials and energy (massive parallelism)





Nanotechnology could apply to everything!

Nano Time Line

Nano Now

- Nanoscale particles and thin films in electronic devices
- Pharmaceuticals and drugs
- Cutting tools and wear resistant coatings
- Pigments in paints
- Jewelry, optical and semiconductor wafer polishing

Nano 2007 - 2010

- Drug delivery, biomagnetic Separation, and wound healing
- Flame retardant additives
- Propellants and high energy materials
- Biosensors, transducers, and detectors
- Functional designer fluids

Nano 2012 +

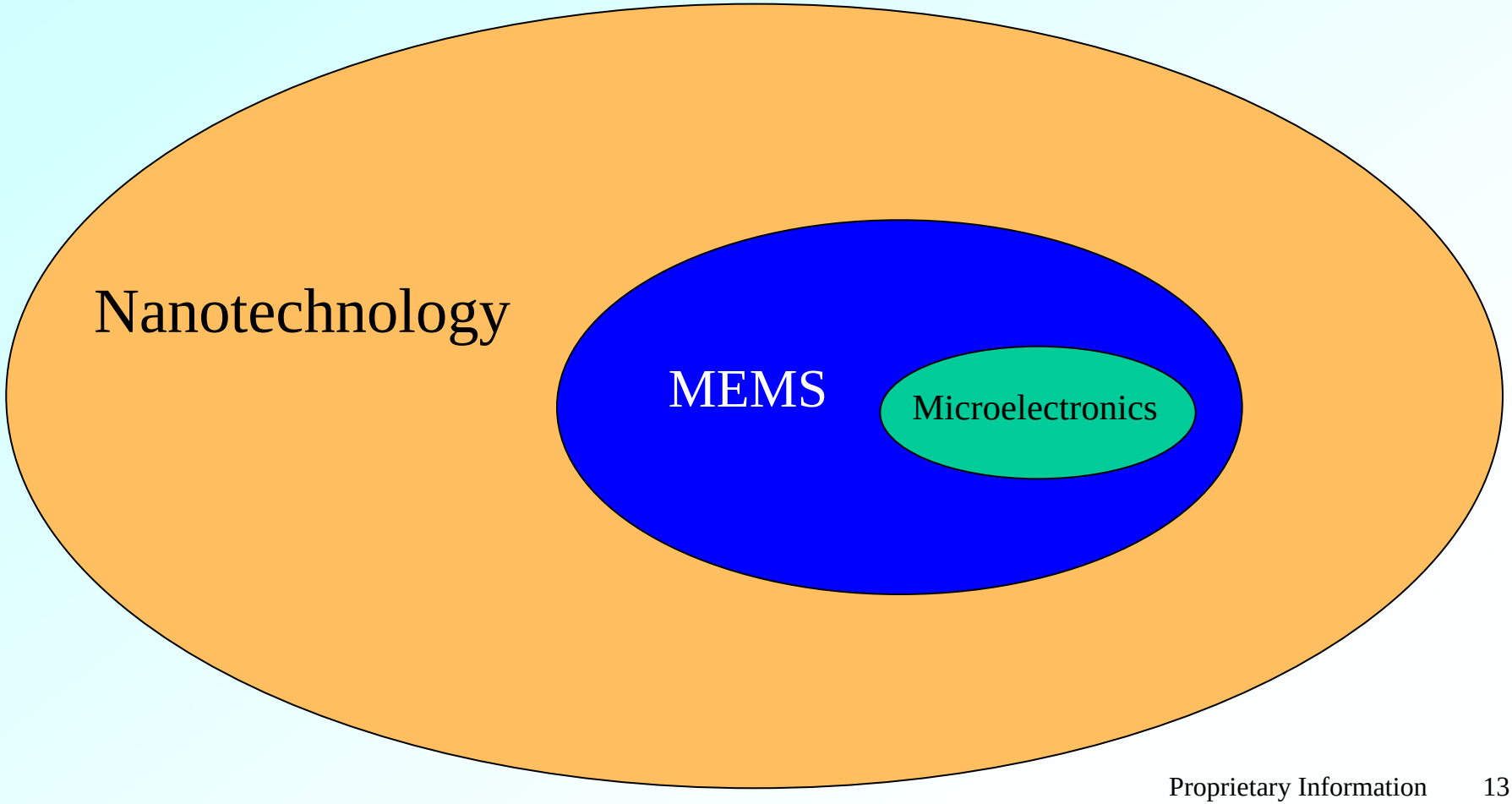
- NEMS-based devices
- High-end flexible displays
- Nano-optical, nanoelectronics, and nanopower sources
- Nano-biomaterials as artificial organs
- Ultra-sensitive sensors

Source: “Small Wonders, Endless Frontiers” A Review of the National Nanotechnology Initiative, National Research Council

Proprietary Information

How these Technologies Compare

In terms of diversity of fabrication approaches and materials used:



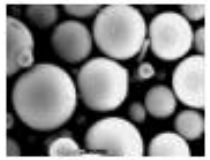
The Scale of Things – Nanometers and More

Things Natural

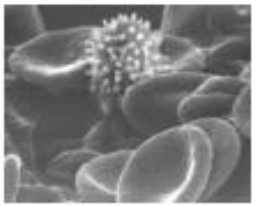
Dust mite
200 µm

Ant
~ 5 mm

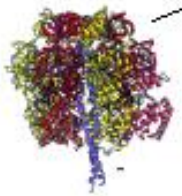
Human hair
~ 60-120 µm wide



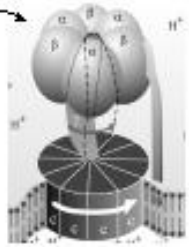
Fly ash
~ 10-20 µm



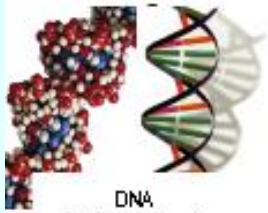
Red blood cells
with white cell
~ 2-5 µm



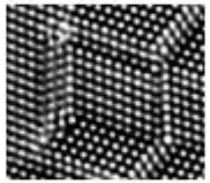
~10 nm diameter



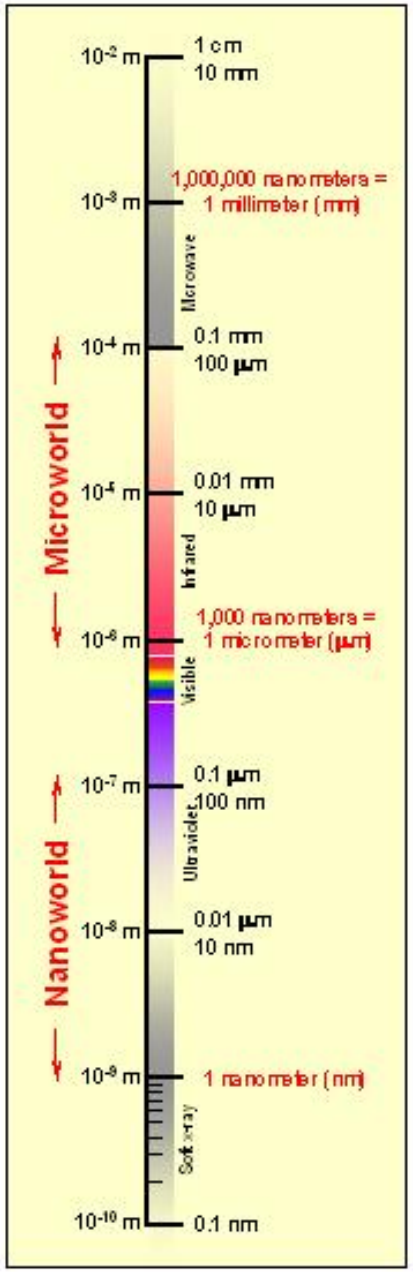
ATPsynthase



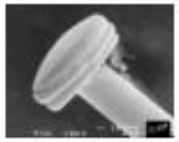
DNA
~2-12 nm diameter



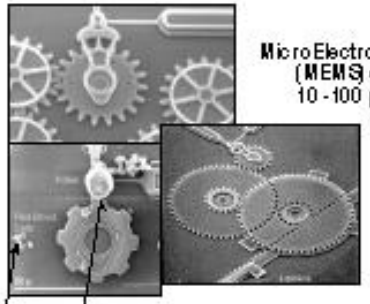
Atoms of silicon
spacing ~tenths of nm



Things Manmade

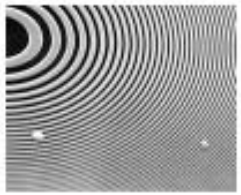


Head of a pin
1-2 mm

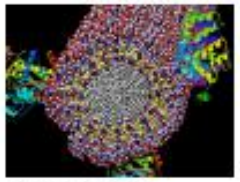


MicroElectroMechanical
(MEMS) devices
10 - 100 µm wide

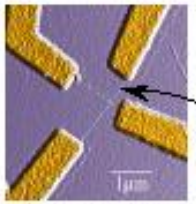
Pollen grain
Red blood cells



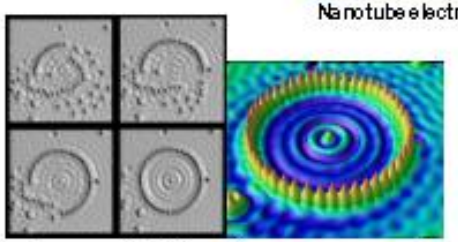
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



Self-assembled,
Nature-inspired structure
Many 10s of nm

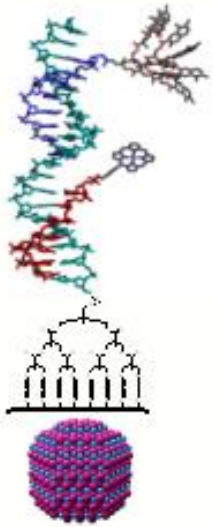


Nanotube electrode

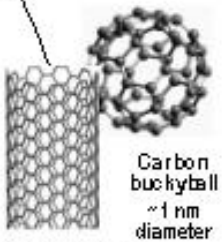


Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14nm

The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

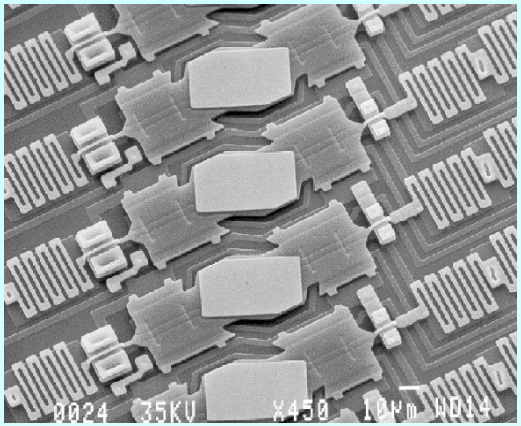


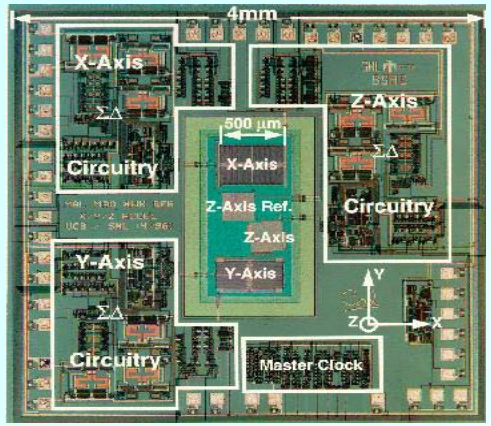
Carbon
buckyball
~1 nm
diameter

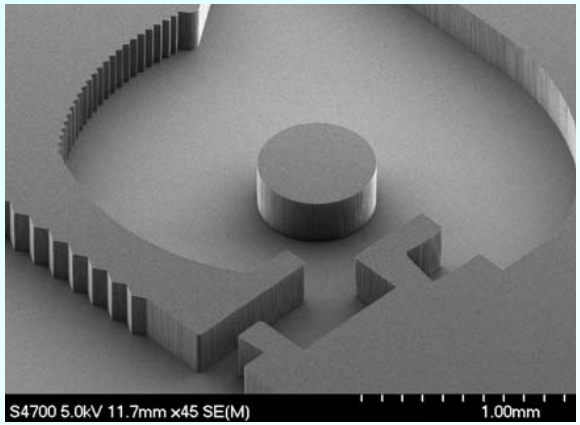
Carbon nanotube
~1.3 nm diameter

Proprietary Information

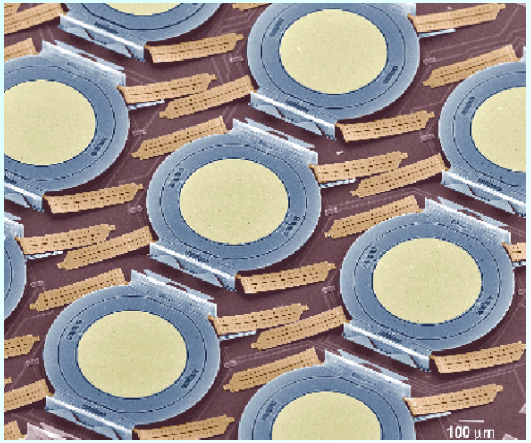
MEMS and Nanotechnology technologies have enormous economic potential!

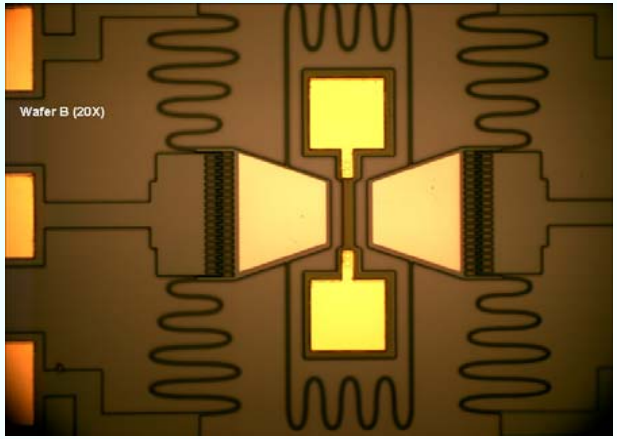


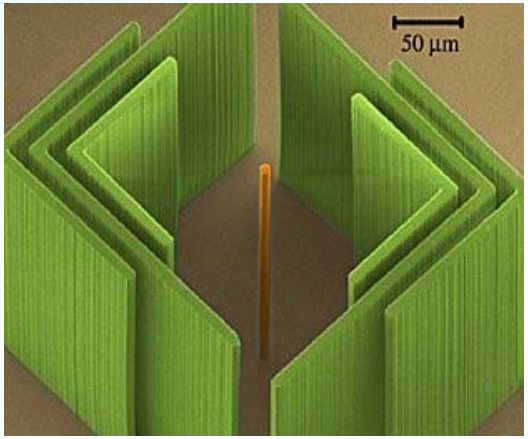




But, organizations need trained staff and access to implementation resources to exploit the opportunities offered by these technologies.







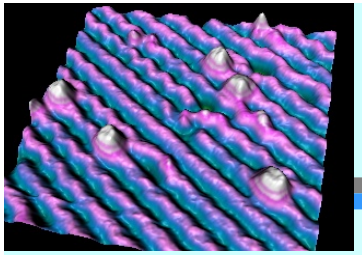
Proprietary Information

The approach taken by most states

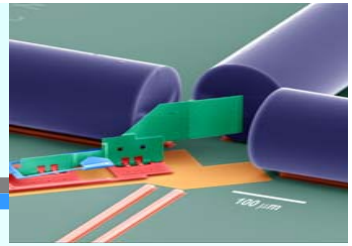
is to build a fabrication facility

<u>Some important considerations:</u>

- Enormously expensive to build facility ($10M's to $100M's)
- Enormously expensive to operate and maintain ($10M's per year)
- Impossible to have all the relevant implementation technologies
- Fabrication methods are in constant flux, enormous cost for constant equipment and staff upgrading
- Not one example where a "shared-use" facility has broken even
- Too many of these facilities and more are being announced every week

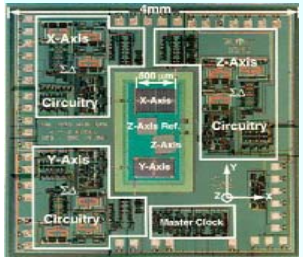


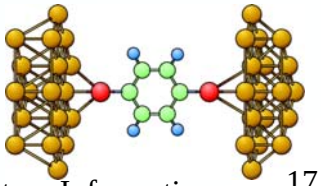
Our Goal:



To establish a world-class training infrastructure for MEMS and Nanotechnology developers in the Commonwealth of Virginia. Features:

- A MEMS and Nanotechnology "training academy" for companies doing business in the Commonwealth of Virginia
  - Classroom teaching of the fundamentals of MEMS and Nanotechnology taught by experts in the field
  - Courses will cover both design and fabrication and will provide extensive "hands-on" training in product and technology development
- Leverage the extensive investments made by DARPA and others in establishing the technical and personnel resources of the MEMS and Nanotechnology Exchange
- Graduates will be in position to utilize the extensive capabilities and resources of the MEMS and Nanotechnology Exchange for research and product development in organizations around Virginia



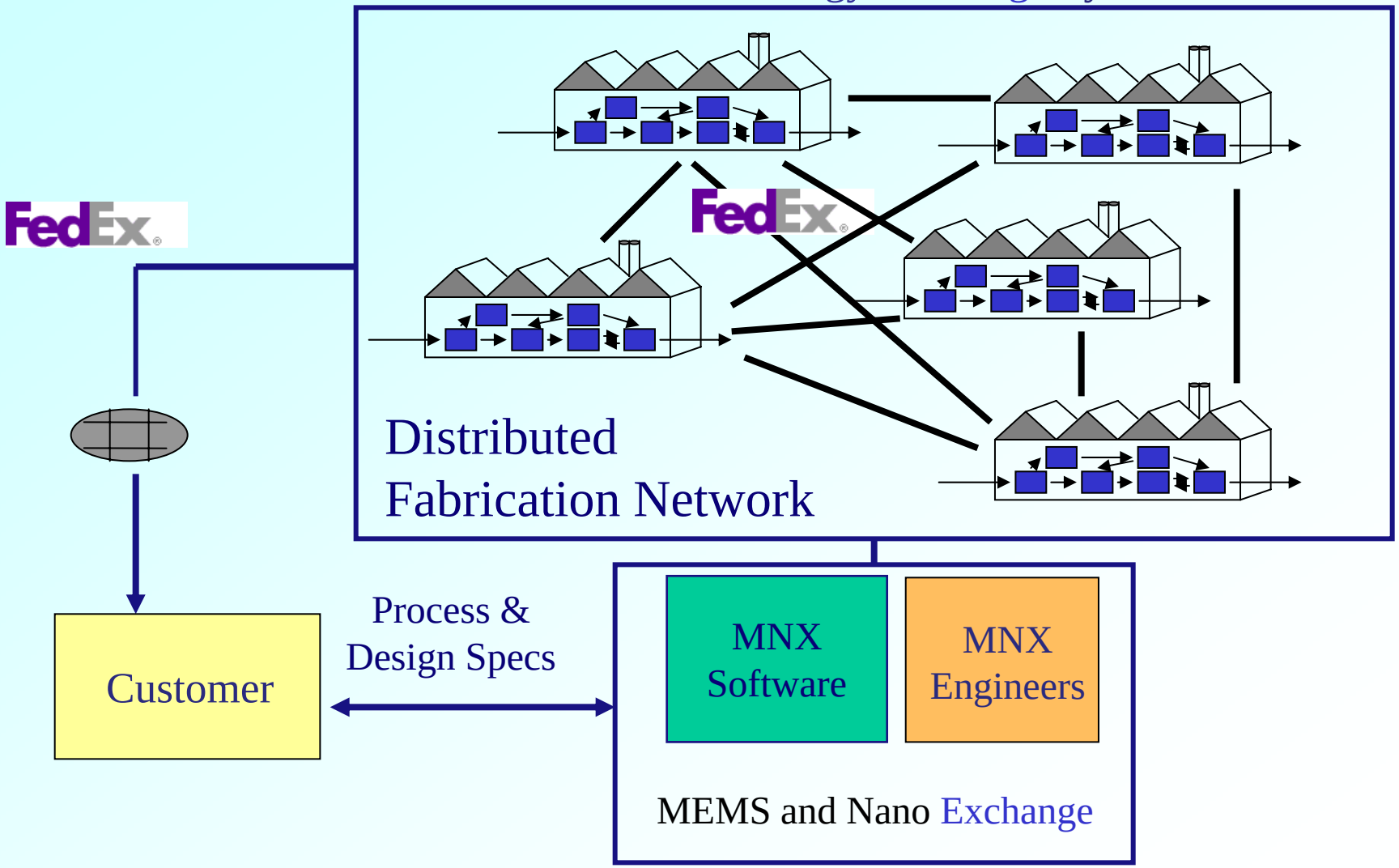


What is the MEMS and Nanotechnology Exchange ?

- A large national-wide network composed of the nation's best and most respected fabrication and processing sites which collectively offer the most diverse and comprehensive array of techniques and technologies available in the world for implementing MEMS and Nanotechnology devices
- A "trusted intermediary" between MEMS and Nanotechnology researchers and the network of fabrication facilities - providing quick and low-barrier access to basic research and product R&D
- An exceptional team of technical experts (who collectively have nearly 50 years of experience and all of which have PhDs) to assist users
- A sophisticated software system that organizes, manages, and tracks all relevant process, fabrication site, and user information
- An established and operating national-level system (started in 1999 with DARPA support)

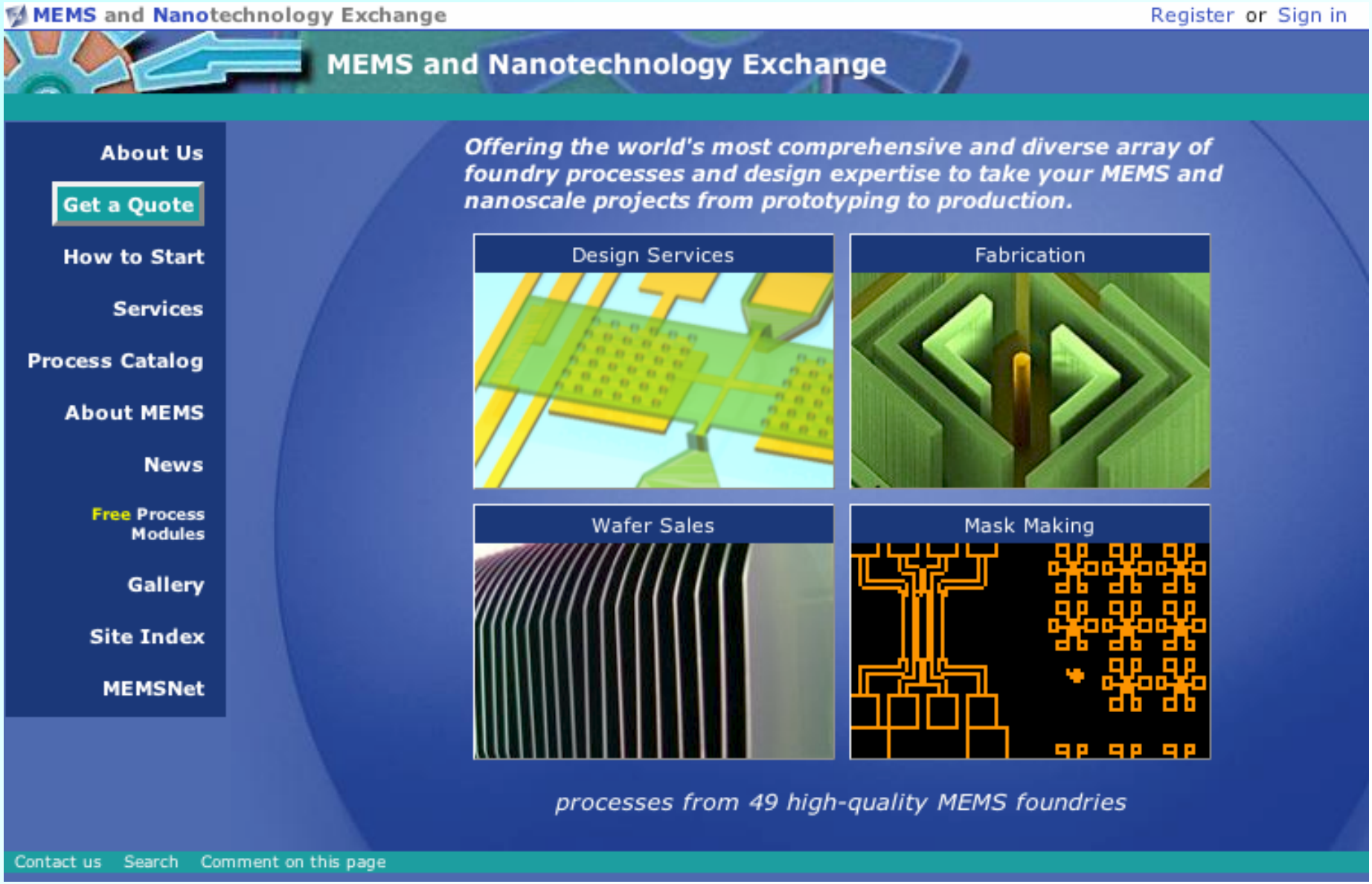
How does it look?

The MEMS and Nanotechnology Exchange System

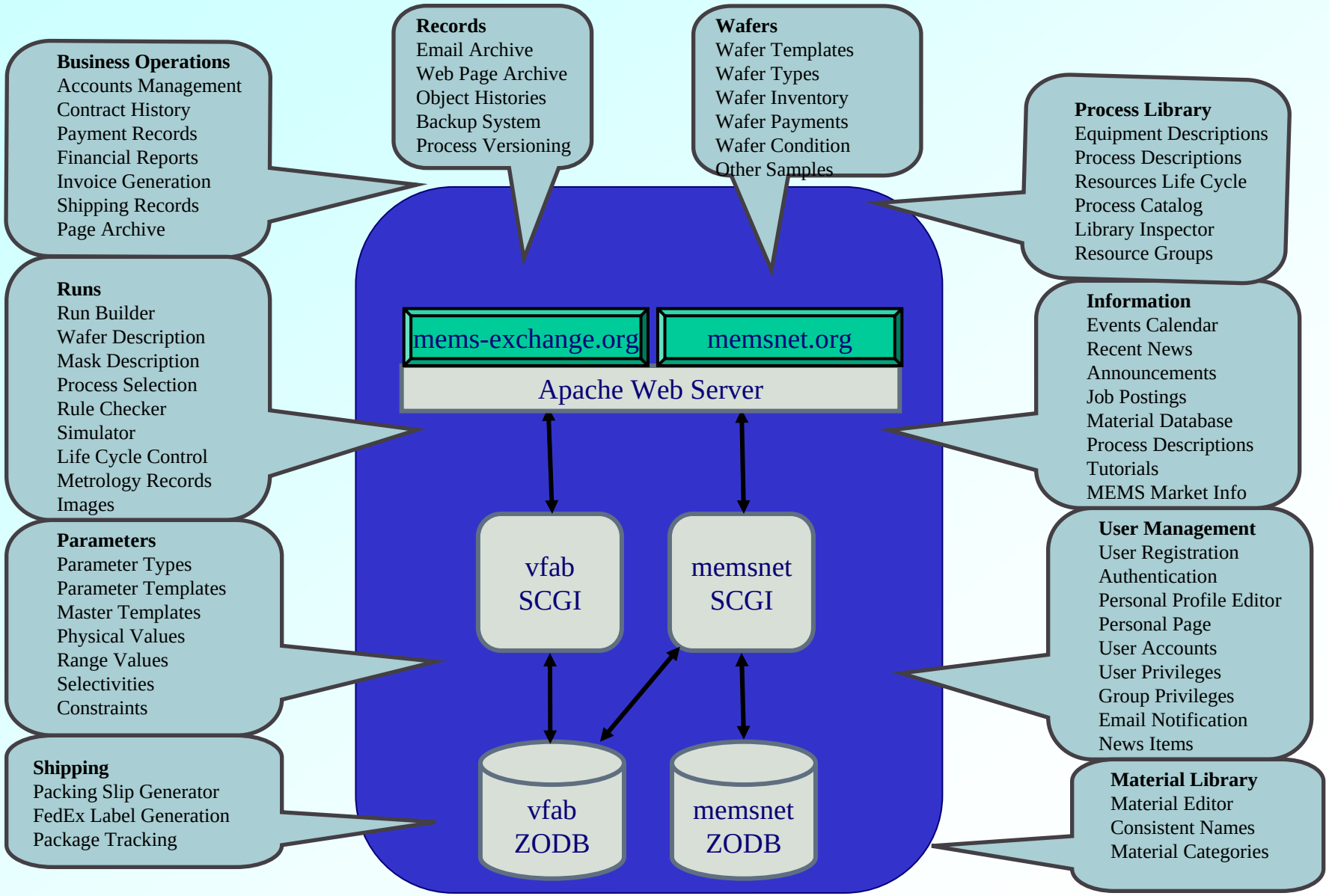


MEMS and Nanotechnology Exchange Home Page

http://www.mems-exchange.org



The Software System



Proprietary Information

Process Catalog - Many Thousands of Processes!

A base process represents a single operation on a single item of equipment.

Silicon Dioxide RIE	Side: front
Fab site	Commercial
Process characteristics:	
Depth Depth of material removed by etch process	1.0 µm 0 .. 2 µm
Ambient Ambient to which substrate is exposed during processing	oxygen/carbon tetrafluoride
Edge profile Free form text field for description of edge profile	vertical
Etch rate	400 Å/min
Material	silicon dioxide
Selectivity Primary material removal rate divided by removal rates of secondary materials (i.e., factors by which primary material is removed faster than secondary materials)	photoresist (category): 1.5, silicon dioxide: 1
Sides processed	either
Temperature	25 .. 70 °C
Wafer diameter	100 mm
Equipment	Unaxis RIE
Equipment characteristics:	
Batch sizes	100 mm: 4, 150 mm: 1
Wafer geometry Types of wafers this equipment can accept	1-flat, 2-flat, no-flat
Wafer materials List of wafer materials this tool can accept (not list of all materials, just the wafer itself).	silicon, silicon on insulator
Wafer thickness List or range of wafer thicknesses the tool can accept	300 .. 1100 µm

Process Run Builder - your on-line shopping cart

Run 2215 - View - Mozilla

File Edit View Go Bookmarks Tools Window Help

http://www.mems-exchange.org/run/2215/

Search

Home | Bookmarks | Instant Message | WebMail | Radio | People | The MEMS Exc... | Yellow Pages | Download | Calendar | Channels | RealPlayer Ho...

Run 2215

Cancel review

Comment

Copy to new run

Masks (7)

Aluminum 1
Aluminum 2
N+ contacts
N+ posts
Nichrome heater
Nitride 1
Nitride 2

Wafers (4)

6in bump mems (4)

Steps (35)

1. Mac
2. Pattern Generation
3. Oxidation
4. LPCVD
5. Lithography
6. PR strip
7. Sputter
8. Strip
9. Lithography
10. PR strip
11. Sputter
12. Strip
13. PECVD
14. Lithography
15. Dry etch
16. Strip
17. Sputter
18. Lithography
19. Electrodeposition
20. Strip
21. Wet etch
22. Deposit
23. CMP
24. Al sputter
25. Lithography
26. Dry etch
27. Strip
28. SiN PECVD
29. Lithography
30. Dry etch
31. Strip
32. Sputter
33. Lithography
34. Dry etch
35. Strip

Step 1 [Add Review]

Consulting [see recent changes]

Price	$1600.00
Time	8 hour
Number of items	1

Step 2 [Add Review]

1X LPG L10 mask

Price	$7992.50				
Batch size	1	Critical dimension tolerance	0.5 µm	Defect density	0 > 5.0um
Magnification	1	Mask coating	chromium	Mask material	soda lime
Mask plate dimension	7x7x0.12"	Min feature size	3 µm		
Number of items	7				
Processing instructions	Make masks from customer CAD layout.				

Step 3 [Add Review]

Wet Thermal Oxidation — Side: both

Price	$467.50				
Material	silicon dioxide	Refractive index	1.45	Rush service	no
Thickness	0.1 µm				
Wafers	Group	Processed			
	6in bump mems (150 mm)	4 of 4			

1 Piranha clean — both

2 HF etch (10:1) — both

Material silicon dioxide

3 Wet Thermal Oxidation — both

Material silicon dioxide Refractive index 1.45

Step 4 [Add Review]

Low-stress silicon nitride LPCVD (<350 MPa) — Side: both

Price	$2280.00				
Batch size	25	Measured film thickness variation (+/- %)	10	Material	silicon nitride
Refractive index	2.15 .. 235	Residual stress	150 .. 350 MPa	Temperature	810 °C
Thickness	0.15 µm				
Wafers	Group	Processed			
	6in bump mems (150 mm)	4 of 4			

Step 5 [Add Review]

Contact photolithography (Automated) [see recent changes] — Side: front

Price	$392.04				
Alignment side	front	Alignment type	flat	Batch size	1
Magnification	1	Perform hardbake	none	Perform linewidth metrology	no
Perform microscope inspection	no	Perform stylus profilometry	no	Resist thickness	1.4 µm
Wafers	Group	Processed			
	6in bump mems (150 mm)	4 of 4			
Allowed wafer diameter(s)	75 mm, 100 mm				

1 HMDS Vapor Prime — both

Proprietary Information

Process Simulation and Rule Checker

- Constructs and displays cross section schematics that follow the processing description.
- Provides visual representation of processing description for designer to check against expectations.
- Analyze results of process simulation to detect processing mistakes.
- Examples
  - Make sure that wafer dimensions are compatible with equipment used in every processing step.
  - Make sure that photoresist strips happen where needed.

Detailed View of Process Run

Step 9

Contact photolithography -no hardbake- (front-front align) (Shipley 1827) [see recent changes]	Side
	front

Fab	Academic	**Status**	completed (2003-04-02)
Material	Shipley 1827	**Resist thickness**	2.7 µm
Wafers	**Group**	**Processed**	**MOS clean**
	Au/Ge (100 mm)	1 of 1	**No**
	NiCr (100 mm)	1 of 1	**No**

1 Dehydration bake [see recent changes]	both
2 HMDS prime	front
3 Photoresist coat (Shipley 1827)	front

Thickness 2.7 µm

4 Photoresist softbake (hotplate) [see recent changes]	both
5 Contact front-front align	front

Wafer group(s) Au/Ge, NiCr **Alignment type** align to mask **Mask** align R935-CONTACTS to R935-LEADS

Marks on mask R935-CONTACTS	**Corresponding marks on wafer (from R935-LEADS)**
X: -31.79 mm, Y: 0.195 mm **Description:** CONT -> LEAD (Left)	X: -31.79 mm, Y: 0.195 mm **Description:** CONT -> LEAD (Left)
X: 31.1 mm, Y: 0.195 mm **Description:** CONT -> LEAD (Right)	X: 31.1 mm, Y: 0.195 mm **Description:** CONT -> LEAD (Right)

6 I-line exposure	front
7 Photoresist develop (Shipley 1827) [see recent changes]	both

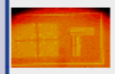
Files

r935_cont_align.jpg (75.1 KB, image/jpeg)

935_AuG_right_cd.JPG (34.4 KB, image/jpeg)

935_AuGe_Left_cd.JPG (29.4 KB, image/jpeg)

935_AuGe_left_Device.jpg (32.9 KB, image/jpeg)


935_right_AuGe_device.jpg (36.8 KB, image/jpeg)

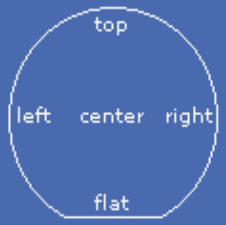
Metrology Entry in Run Card

Step 1.2

Stylus profilometer step measurement

Wafers	Group	Processed
	My Wafers (100 mm)	10 of 10

Measurement sites



Add row

Wafer ID	Surface Label	Site	Roughness (avg)	Roughness (rms)	Step height
dummy	front	load	top	µm	µm	µm
W001	front	n/a	center	µm	µm	µm
"	"	"	"	µm	µm	µm
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	
"	"	"	"	µm	µm	

Comment

Save Cancel

For processing steps that include any metrology, the fabrication/processing site staff enter data as they collect it.

This data feeds back into the processing steps in the process run card.

4 Microscope inspection

Metrology	Etched features look good - bottom is nice and flat; reached.

5 Stylus profilometer 1-D step measurement

Depth	0 .. 1000 µm

Metrology

	Min	Max	Mean	Std Dev	Error
Step height [um]	354	375	361.7	11.59	n/a

Wafer ID	Surface	Site	Step height
W001	front	left	375 µm
"	"	center	356 µm
"	"	right	354 µm

Proprietary Information

Integrated Shipping

Wafers being shipped

Available	Selected
My Wafers: W001	My Wafers: All wafers
My Wafers: W002	
My Wafers: W003	
My Wafers: W004	
My Wafers: W005	
My Wafers: W006	
My Wafers: W007	
My Wafers: W008	

The wafers that will be included in this shipment

Other things being shipped

Other items being shipped that need to show on the packing slip

Sent from

MEMS Exchange

The originating facility for this shipment

Ship to

MEMS Exchange

The destination facility for this shipment

Delivery Notification Email

mhuff@mems-exchange.org

A notification email will be sent to this email address once the package has been delivered

Comments

Any other information that needs to show on the packing slip

Shipping weight

2.0 lb

Shipping weight in lbs of the box that will be shipped

Fedex Drop-off Type

Regular Pickup

The system provides for generating packing slips and Fed Ex shipping labels, as well as notification to Fed Ex of intended shipment. Also allows tracking of every individual item in network.

FROM: John Smith (123)456-7890
2002 Micro Drive
Reston, VA 20191

FedEx Express

FedEx Revenue Barcode

TO: **Christy Short (703)262-5368**
MEMS Exchange
1895 Preston White Drive
Suite 100
Reston, VA 201915434

CAD#: 1206413
SHIP DATE: 16AUG04
WEIGHT: 2 LB

Ref: Run 1352-1

DELIVERY ADDRESS (FedEx-EDR)

STANDARD OVERNIGHT

TUE
A1
Deliver by:
17AUG04

TRK # 7902 4147 5540 FORM 0201

IAD

201915 -VA-US

19 BCBA

CLS060704

Packing Slip Run 1352-1

Date 2004-08-16 13:59

10 Wafers My Wafers: 10 of 10

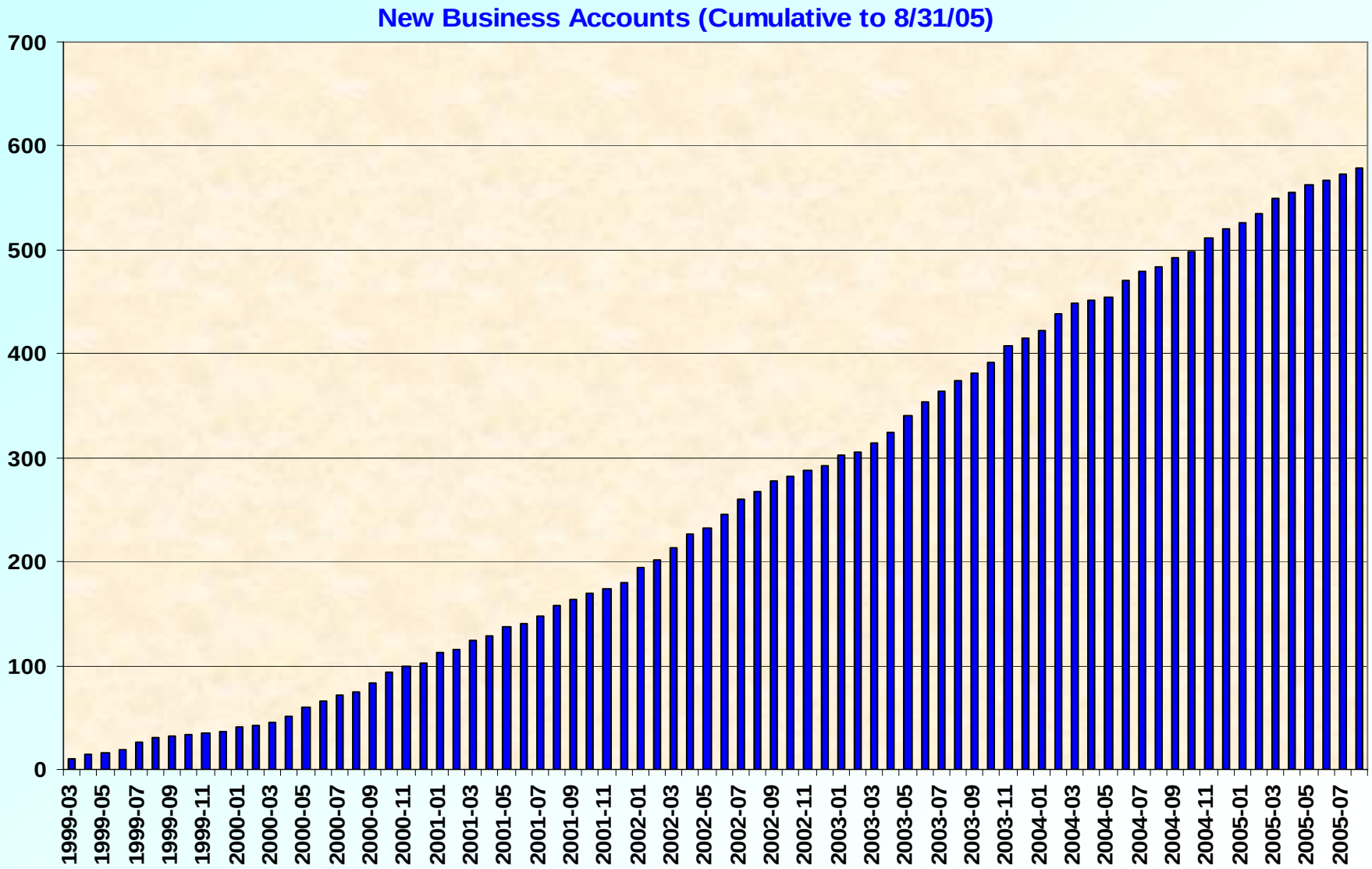
From John Smith
2002 Micro Drive
Reston, VA 20191
US
1234567890

To Christy Short
MEMS Exchange
1895 Preston White Drive
Suite 100
Reston, VA 20191-5434
US
(703) 262 5368

Recent MEMS and Nanotechnology Exchange Stats (as of September 12, 2005)

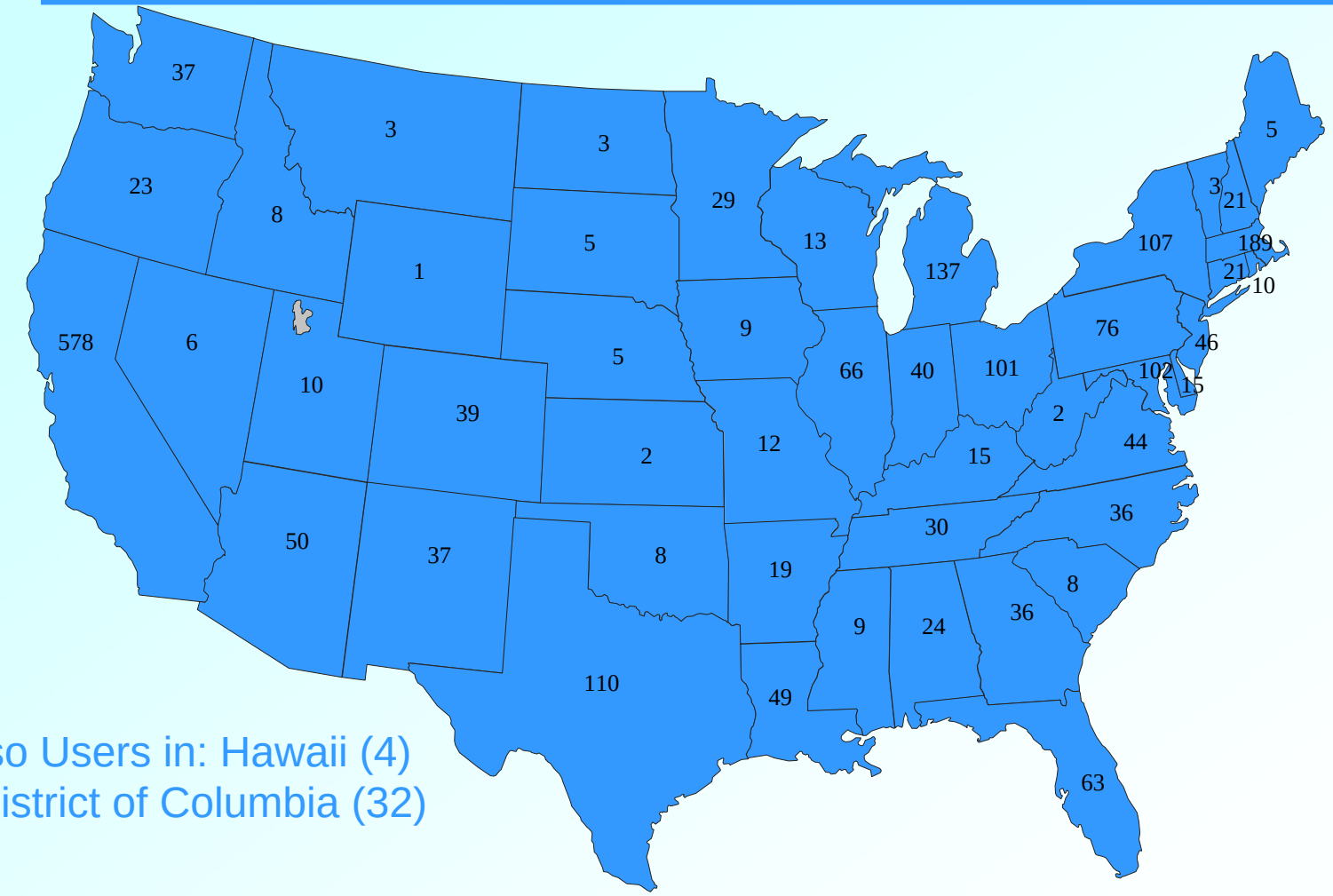
- Total Number of Fabrication Sites Enlisted to Participate in Program: 54
- Number of processes in catalog: >3500
- Number of Organizational Business Accounts : 580
- Number of Individual Customers (Persons) using Exchange: 4530
- Compounded Annual Growth Rate in New Business Accounts & Customers: > 30 %
- Number of Process Runs or Projects Submitted to Exchange for Implementation: 1350
- Current workload of new projects is about 45 and climbing.
- Number of substrates and square area of silicon or other substrate material processed: 18,278 and 358,706 square inches, respectively
- Revenue and income up over 200% over last 12 months.

Growth in the Number of Business Accounts



Some of the organizations using the MEMS Exchange

Where are the MEMS and Nanotechnology Exchange Customers?



Also Users in: Hawaii (4)
& District of Columbia (32)

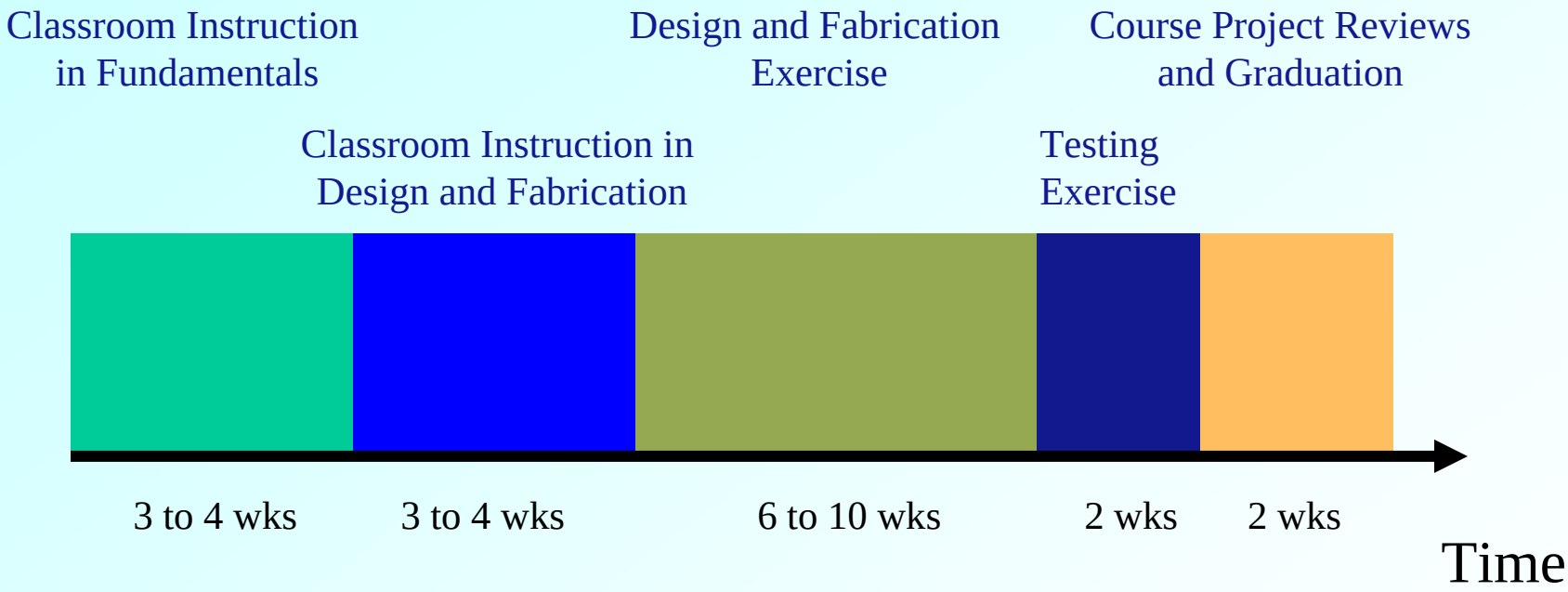
Customers from all 50 States in United States
Projects range from basic research to product development
The complexity of processes ranges from low to very high

Proposed strategy for MEMS and Nanotechnology ***Training Academy***

Leverage the extensive resources and capabilities of the MEMS and Nanotechnology Exchange, which can provide:

- Intensive classroom teaching in fundamentals (possibly performed in conjunction with others)
- Classroom instruction in design, fabrication, tools, testing, etc.
- Facilities for hands-on laboratory and design work
- Classroom teaching with real-life design and implementation exercises performed through the Exchange
- Small classroom sizes (highly interactive) with aggressive schedules to suit business schedules and interests
- Provision for office space at the Exchange to enable interaction with experts during design, fabrication, and testing exercises

Possible Course Schedule:



Intensive Course for nominally 10 students over 16 to 22 weeks

- Classroom Instruction - 2 to 3 days per week
- Design and Fabrication Exercise - 1 - 2 days per week
- Testing Exercise - 1 to 2 days per week
- Project Reviews - 1 or more days per week depending on interest

What exists and what needs to be put into place to make the training academy a reality?

What already exists: Intellectual resources of Exchange staff, extensive infrastructure for designing, fabrication, and testing of the Exchange, office space for students, lab and testing space - a complete operational system!

What needs to be put into place: development of a classroom curriculum, developments of design and fabrication exercises, acquire computers and design tools for student use, augment testing capabilities of Exchange, assign staff to teach, pull in some additional talent from MEMS and Nano community to help teach, advertising and marketing to get the word out to companies in Virginia

Tangible Benefits to Virginia:

- Graduates will go back to their home companies fully proficient in developing technologies and products using MEMS and Nanotechnology

- Will enable their companies to quickly and effectively exploit the benefits of these technologies

- Graduates will have gained real-life design and fabrication experience

- Graduates will know how to exercise the MEMS and Nanotechnology Exchange or other implementation avenues to their company's benefit in the future

- Students will interact with students from other companies and organizations interested in these technologies

- Will enable Virginia to quickly advance in these important technologies (smarter approach than building another expensive fabrication facility) without enormous and continuing expenditures

- Will allow Virginia to create a vibrant MEMS and Nano business environment

Proprietary Information

What are the program cost elements?

- Develop Course (one time cost) - 16 to 24 weeks, 3 Exchange staff plus outside experts,
- Course Instruction - 16 to 22 weeks, 3 Exchange staff plus outside experts,
- Fabrication and Testing - Shared fabrication runs or individual fabrication runs for each class depending on need
- Course updating - 6 to 8 weeks every year, 3 Exchange staff plus outside experts
- Class room space, office space, lab use - 16 to 22 weeks
- Computers, design tools, and new testing equipment
- Desirable funding amount to set up about $1M (for MNX cost only) with possibly some smaller on-going support needed

Summary of Proposed Strategy

- The Commonwealth of Virginia contributes $500K over two years to establish the MEMS and Nanotechnology Training Academy and get it started
- Local Governments (such as Fairfax County EDA) contributes $250K over two years
- Participating companies contribute $125K per year
- MEMS and Nanotechnology Exchange makes available space, facilities and expertise
- Plan can include teacher training and liaison with Virginia Universities for basic training