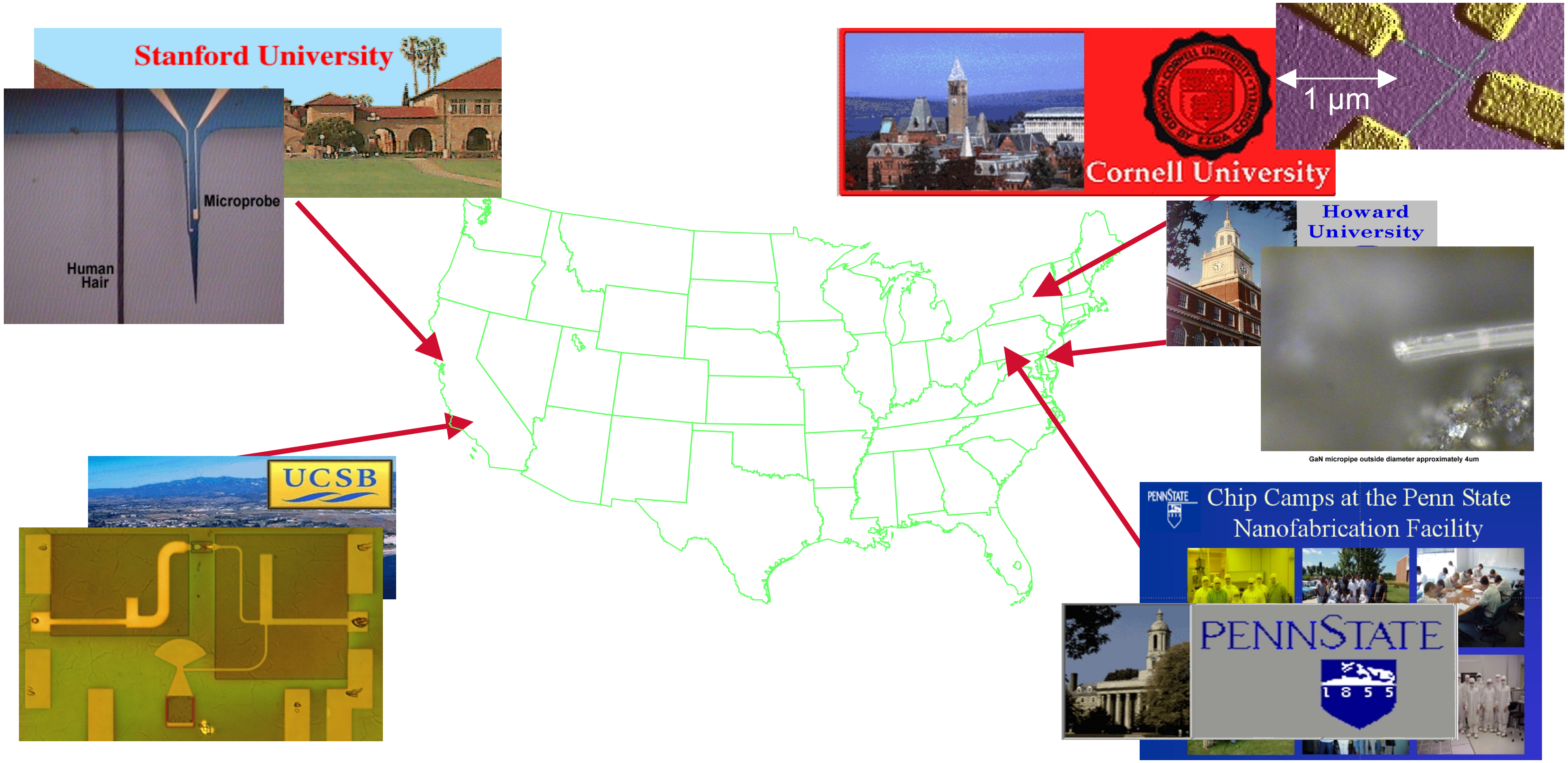
The National Nanofabrication Users Network



Sandip Tiwari

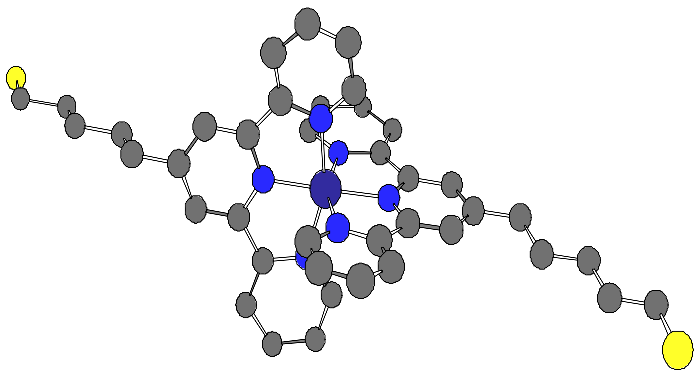
April 30, 2002

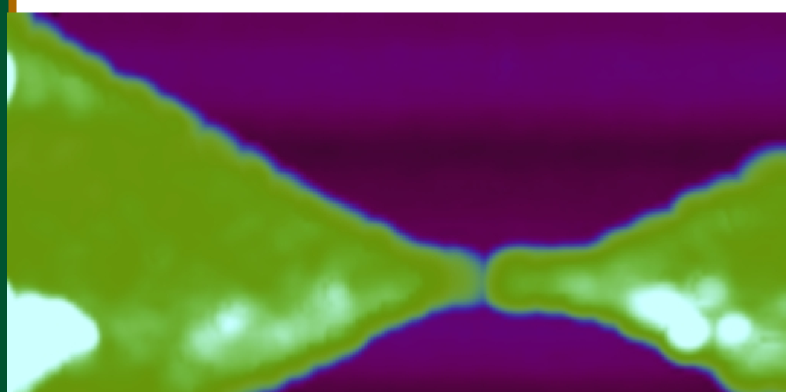
National Nanofabrication Users Network

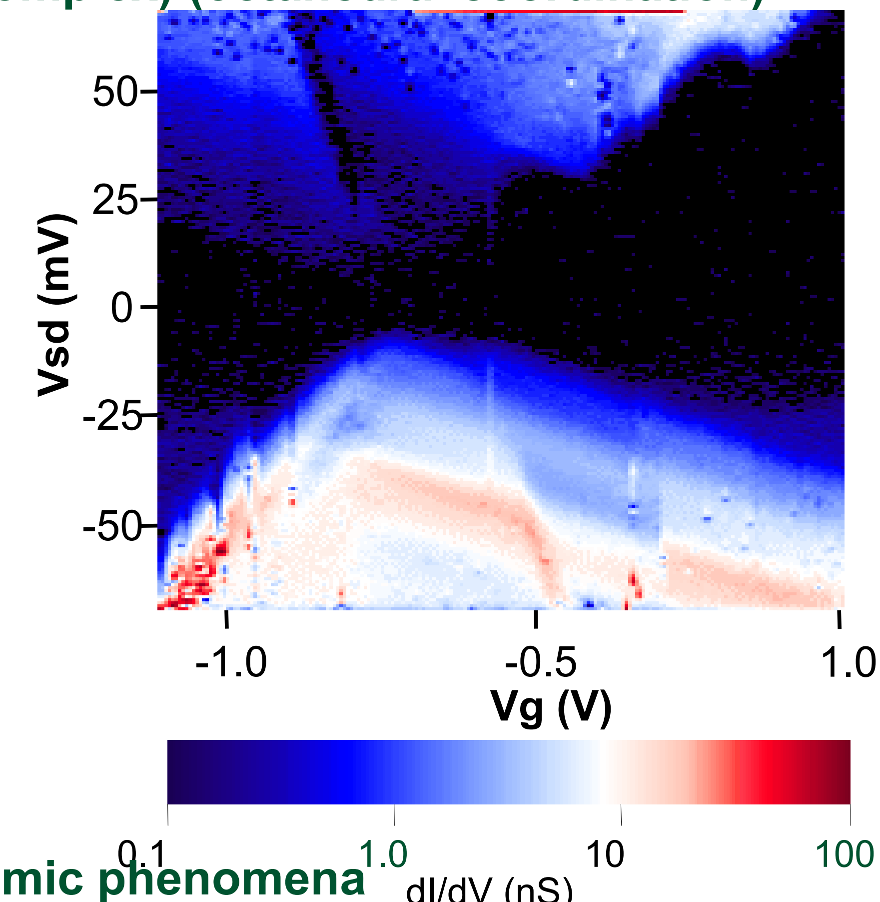
Single-Electron Effects in Molecules

McEuen, Ralph, Abruna et al. (Cornell)

- two 4'-(5-Mercaptopentyl)-2,2':6',2''-terpyrindinyl thiol (or tpy-SH) with Co atom (bis-tpySH Co complex) (octahedral coordination)







- First observation of atomic phenomena using direct electron transport measurements

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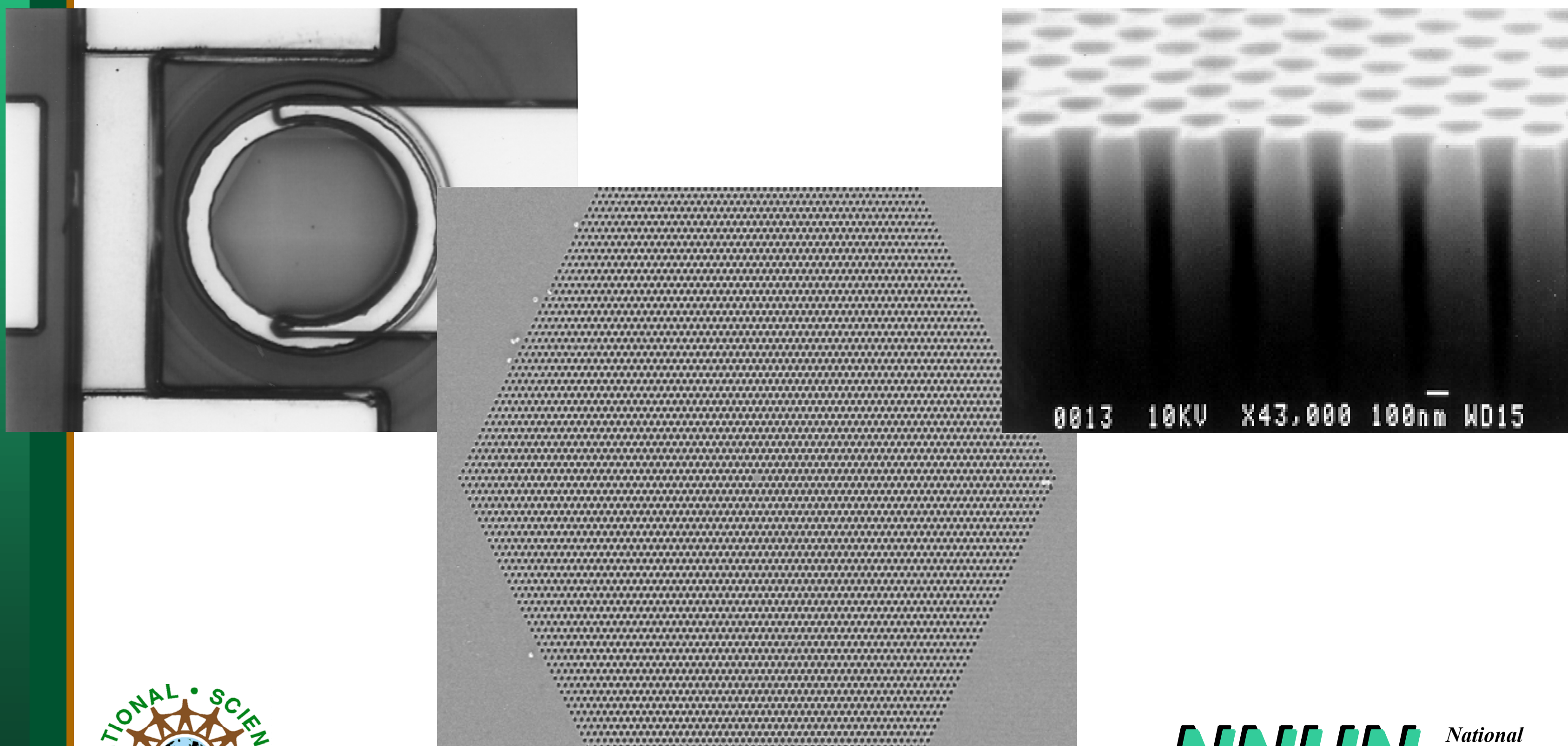
Photonic Crystal Microcavity Devices

P. Bhattacharya (U. Michigan)

- **VCSEL Lasers in InP-based system with oxide confinement using photonic crystal microcavity**



NNUN *National Nanofabrication Users Network*

DNA Prism:Continuous Fractionation of Genomic DNA

R. Austin (Princeton)

- **Pulsed electrophoresis in a hexagonal array with alternating-angle electric field**

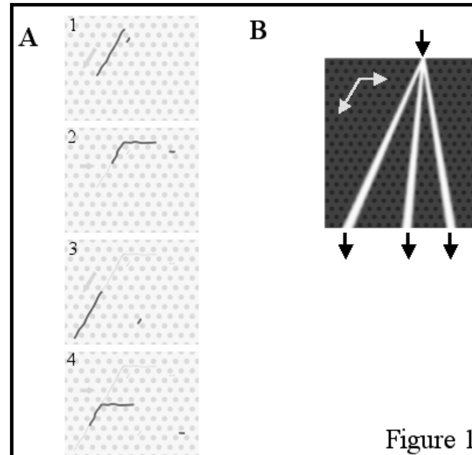


Figure 1

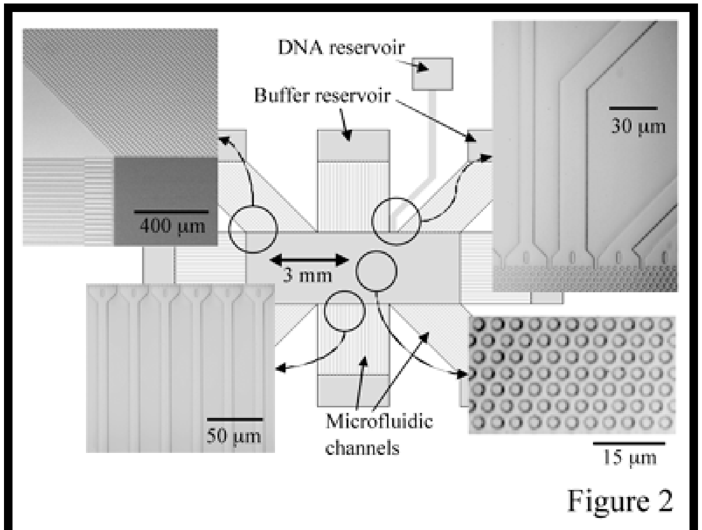


Figure 2

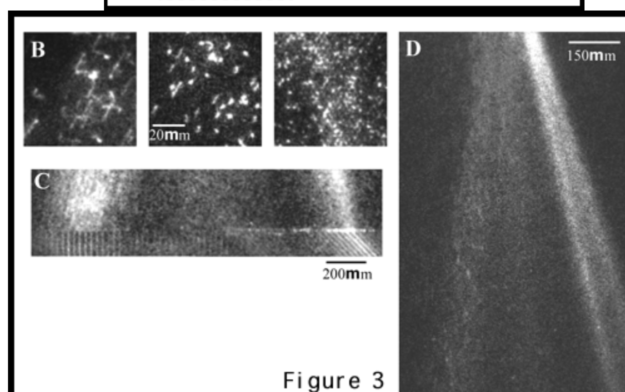
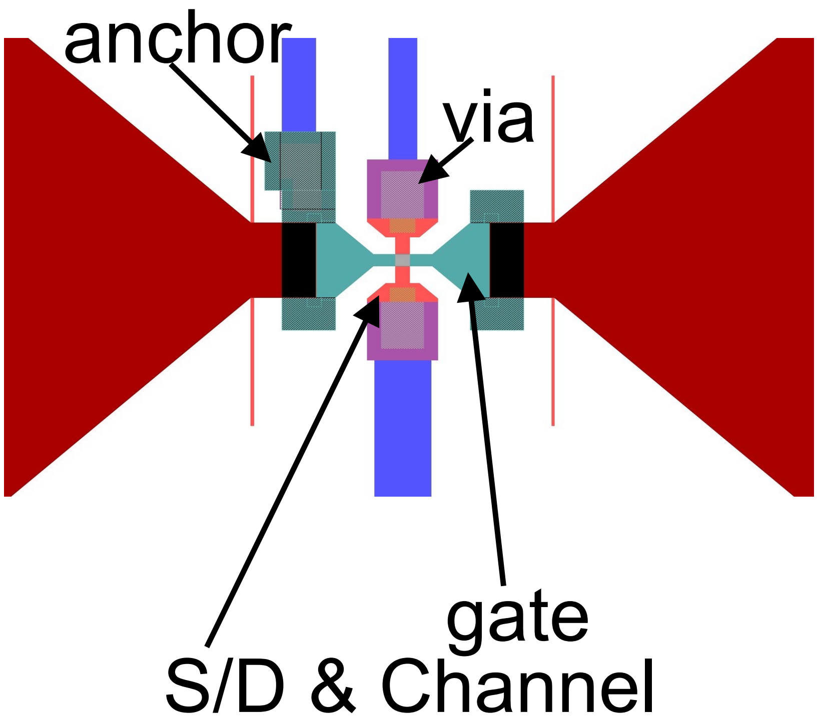


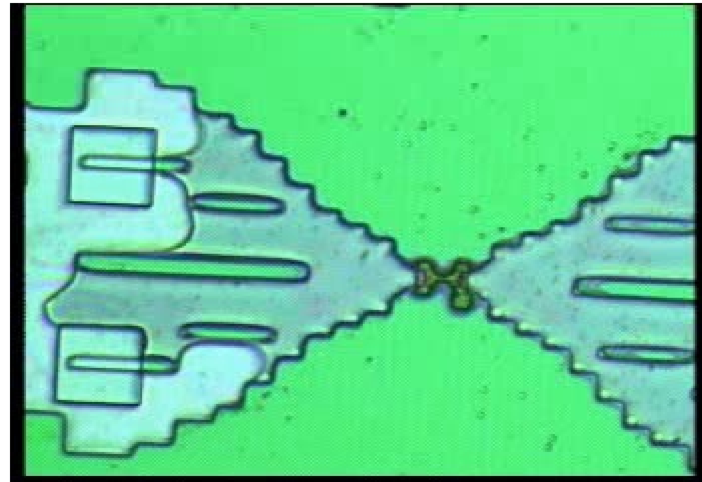
Figure 3

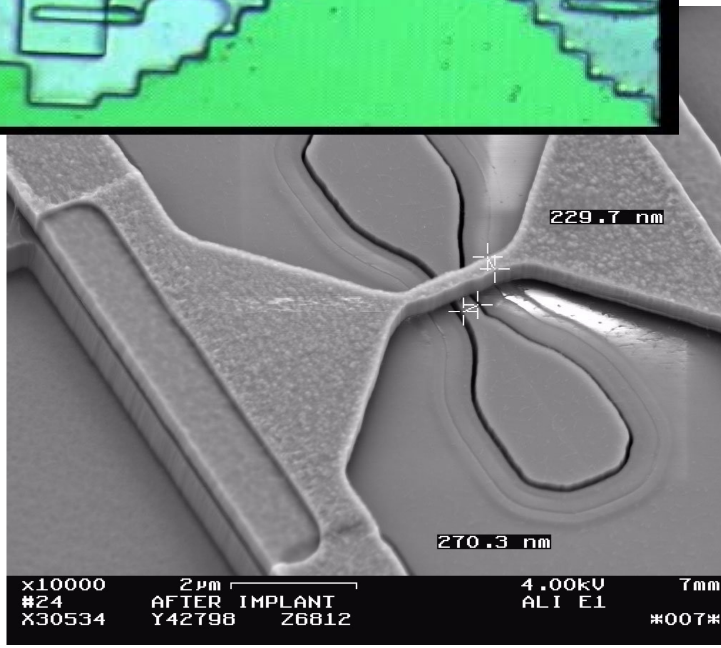
National
Nanofabrication
Users Network

Single Charge Sensing in Fluidics

S. Tiwari (Cornell)







- **First direct active gain assisted sequencing**

National Nanofabrication Users Network

NNUN: Network Mission

The challenge for nanotechnology:

How can the interdisciplinary science and engineering in this vast areas of industrial and economic significance, with its strong research content, high experimentation cost, and broad knowledge needs, be accomplished with broad participation?

- Provide the nation's researchers with effective and efficient access to advanced nanofabrication equipment and expertise to enable top-quality research in nanotechnology across all disciplines
- Expand the applications of nanotechnology
- Broad spectrum of activities to support development of the scientists, engineers, and the work-force of future

National Nanofabrication Users Network

NNUN: Network Strategy

- **Effective research resource**
  - Networked partnership of state-of-art facilities with common and complementary infrastructure leveraging large user base
  - Training and open access
  - Expertise and support for simple and complex integrated experiments
  - Focus on user needs, ease of use, and access
- **Applications of nanotechnology**
  - Bridge between disciplines through technical liaison and catalysis of new developments
  - Education through web, workshops, short courses, …
  - Dissemination of results and technology transfer
- **Education and Outreach**
  - Top quality graduate students excited by accomplishments and advanced research
  - Undergraduate education through research and training locally, as well as through web-resources

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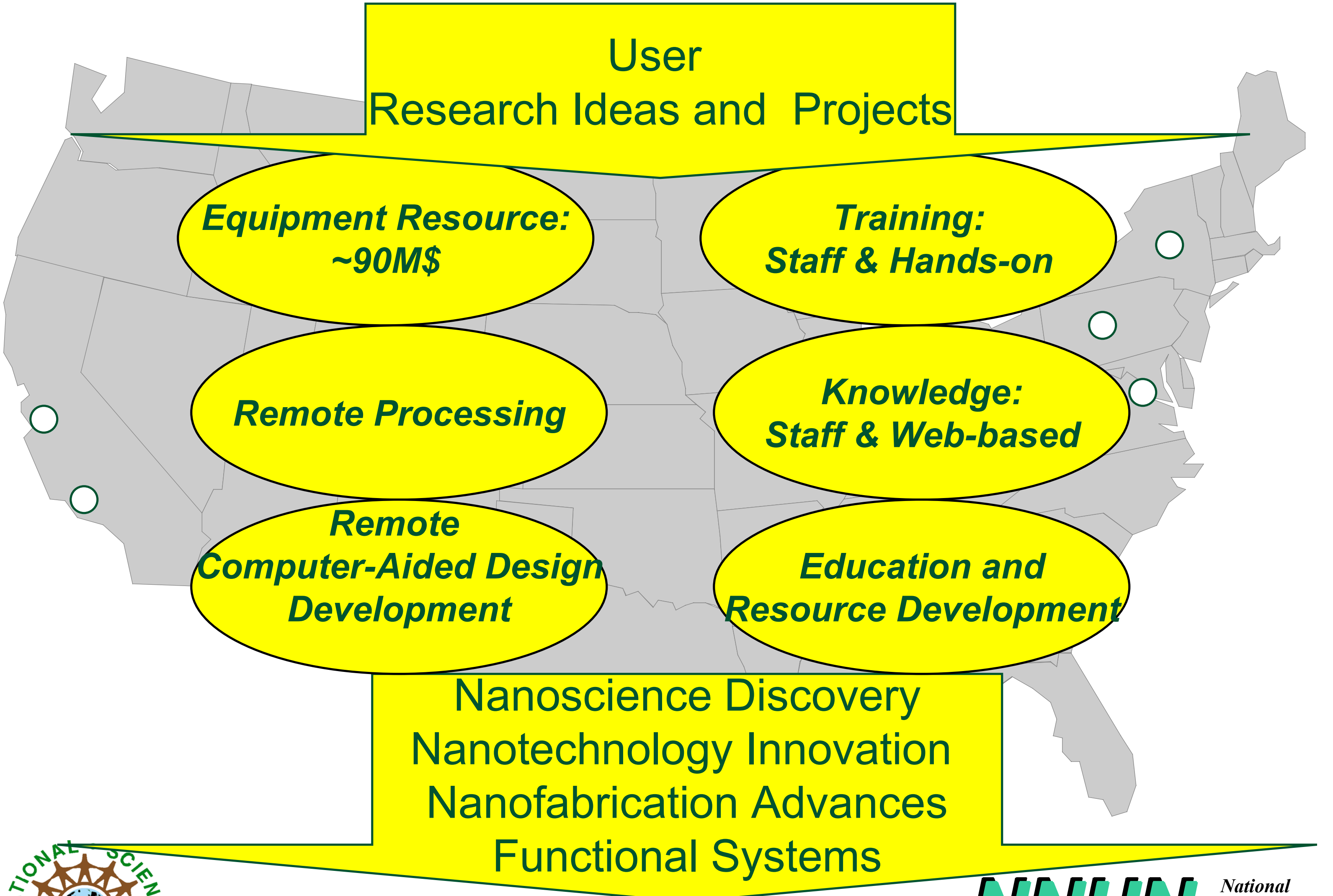
NNUN Approach



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NanoTechnology

Nanofabrication Processes
Nanobiology
Nano and Microelectronics
Optics and Optoelectronics
Nano and Micromechanics
Nano and Microfluidics
Solid State Physics & Chemistry at nano-scale
- *Magnetics*
- *Ferroelectrics*
- *Soft-materials*
- *Quantum Structures*

Nanostructure Science
Biophysics
Chemical Sensors
Molecular Applications
Self-assembled Structures
Polymers
Materials Science
Nano-Crystals

Patterning:
Lithography
nm: Electron Beam and Probe-based lithography
>150 nm: Optical
Embossing
Dry etching

Material:
Dopant diffusion
Dopant implantation
Magnetic, ferroelectric, dielectric, … materials
Polymers and resists

Structural:
Depositions
Growth of films – hot and other physical processes
Contacts

Physical:
Characterization at nano-scale: AFM, STM, AFM, BEEM, …
Optical Probing
Electronic Probing

Self-Organized/Synthesis
Block-Copolymers
Nanocrystal synthesis
Self-assembly processes

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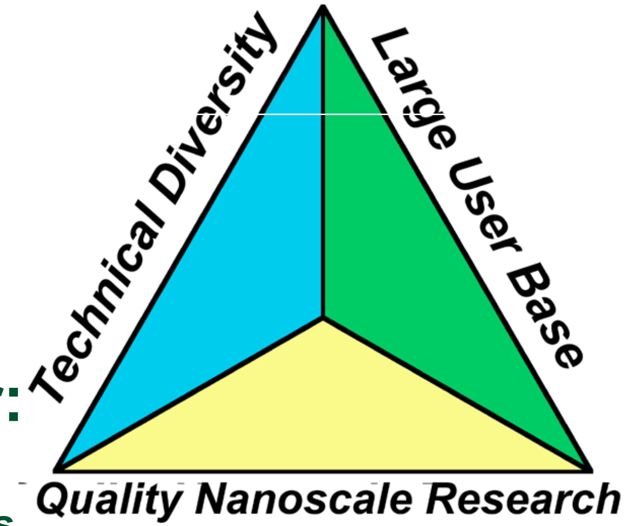
NNUN Operational Characteristics

- Productive experimental resource for:
  - New and traditional approaches to nanofabrication
  - New applications of nanofabrication
  - Leading edge technology
  - Catalyst for new developments
- Unique educational resource for:
  - Training for students (graduate and undergraduate) and scientists and engineers
  - Dissemination of results and transfer of technology
- Efficient use of national resources
  - Critical mass



National Nanofabrication Users Network

Strength of the Network Concept

- Networked expertise
  - Complementary & common expensive research resource (equipment, knowledge, staff) with enhanced capability
  - Shared knowledge dissemination and outreach
- Integrated access (http://www.nnun.org) with user / project coordination
  - Critical mass of users at sites and across network
- Shared learning – processes, facility operation, etc., and transfer of successes
- Enhanced visibility and interactions with community
  - Networked Research Experience for Undergraduates
  - Workshops
- Equipment & software compatibility (evolving) and back-up
- Joint resource development

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NNUN National Nanofabrication Users Network

NNUN Culture

- Fair and open access for any research project of merit to all equipment and processes
  - Strong university support and infrastructure
  - Strong faculty and staff commitment to sharing and promoting outside usage
  - Strong internal research program for providing critical research mass and knowledge
- State-of-the-art experimental facility with
  - Flexibility (wafers, processes, materials)
  - New techniques
  - On-site training for users
  - Skilled support personnel to assist users

NNUN National Nanofabrication Users Network

NNUN Facilities

- State-of-the-art equipment and process expertise
  - Physical and Chemical Techniques: Electron, optical, and mold-assisted lithography; dry and wet chemistry patterning; deposition techniques; semiconductor hot processes; surface-oriented processes; specialized processes such as wafer bonding, selective chemistries, ion-implantation, other doping techniques; characterization; etc.
- Flexible equipment: wafers, processes, materials, etc.
- Acceptance of experimental risks associated with multitude of processes and materials
- Rapid adaptation and development of new techniques and openness to new ideas
- A structure that allows complexity of many processes and many tools to be coordinated for integrated success
- NSF provides ~36% of funds which principally support staff; user fees, etc. fund remainder

NNUN National Nanofabrication Users Network

NNUN Snapshot

- Network activity growing extremely rapidly
  - Number of users (~20% growth rate; doubling in 4 years)
  - In other measured parameters - fees, hours, etc.
- New disciplines growing rapidly
  - Healthy balance between disciplines
    - Science and engineering
    - Smaller equipment-specific projects and larger integration projects
- Instrumental in several key research breakthroughs
  - Strong quality of this research
- High levels of measured user satisfaction
  - Strong user research support
- NNUN supported the experimental education of over 1100 graduate and undergraduate students in 2001
  - ~ 300 PhD awards depended on NNUN resources
- NNUN supported effort of >120 small companies during 2001
  - ~25 companies seeded by research from NNUN

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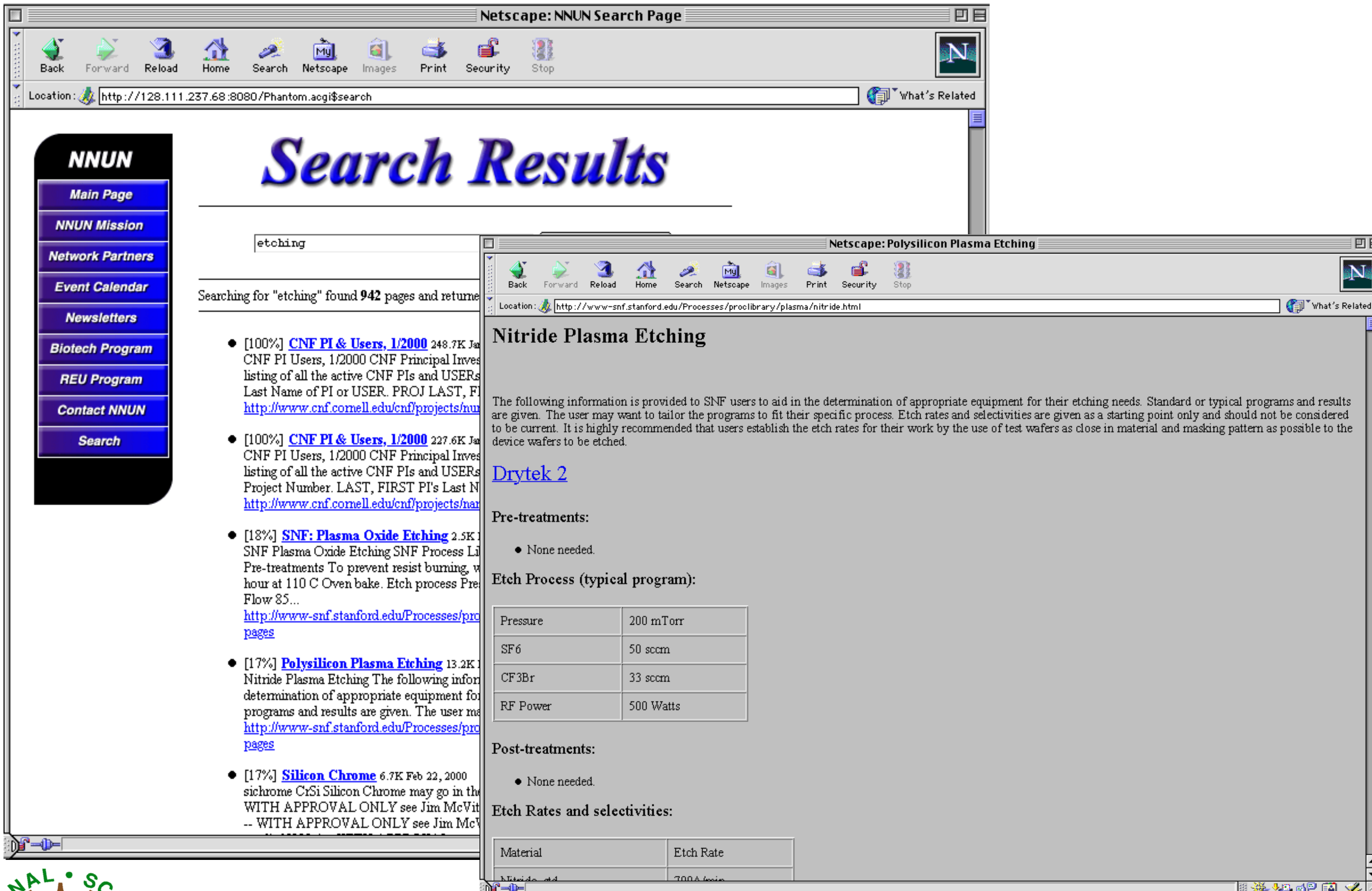
NNUN National Nanofabrication Users Network

NNUN (http://www.nnun.org) Web Access

- Information delivery
- Entry point for all sites
- Events
- Courses
- Processes
- Research
- Training
- Equipment
- …

NNUN National Nanofabrication Users Network

Search Results



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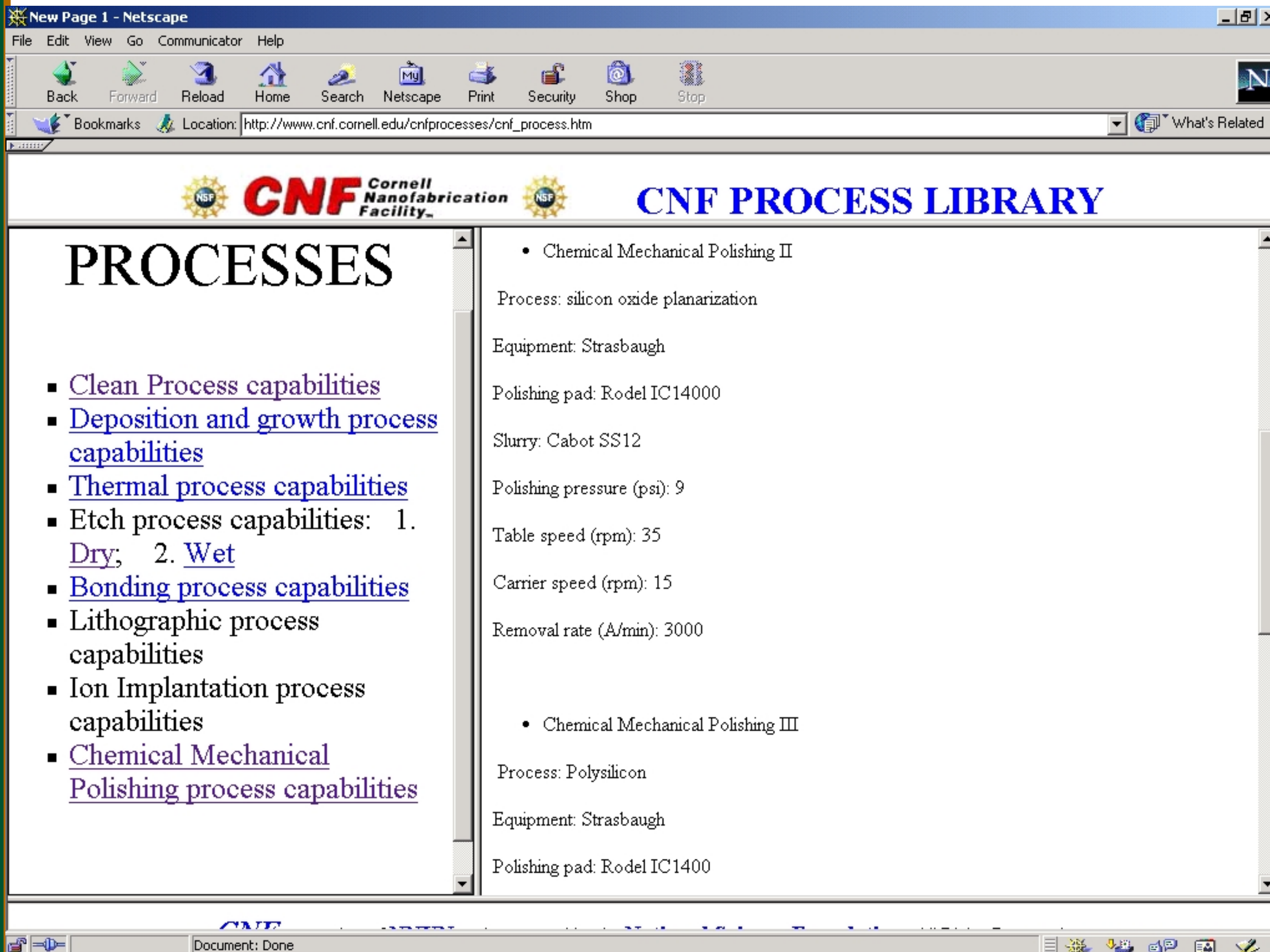
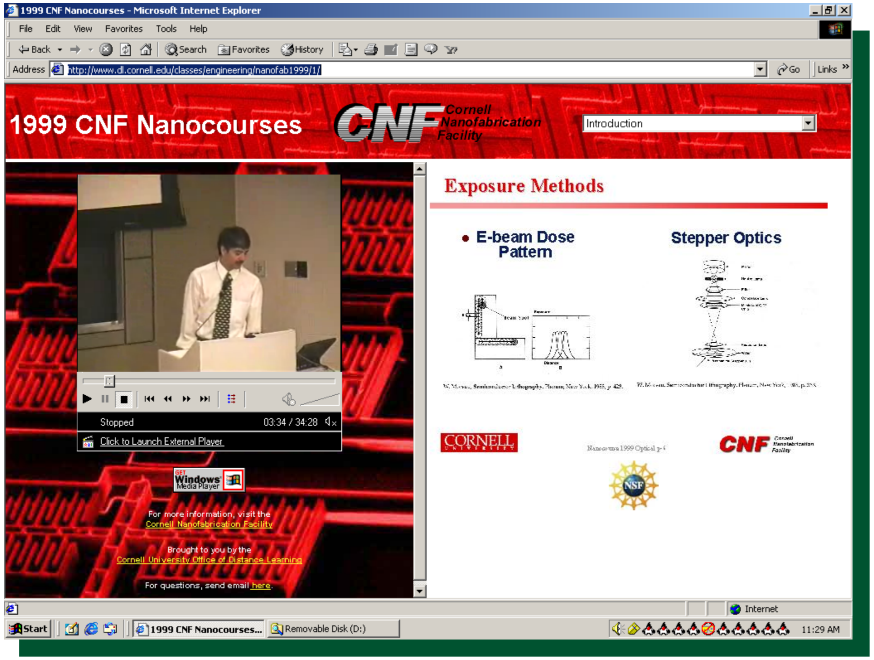
Technical Education and Use



National Nanofabrication Users Network

Technical Outreach: Nanocourses

- Nanofabrication technology courses for new users
  - Lithography
  - Vacuum techniques
  - Plasma techniques
  - Thin Film techniques
  - Hot processes
  - New techniques
  - Characterization
- Presented by staff in short course format with printed notes
  - 24 lecture hours



Available in streaming video on web

http://www.cnf.cornell.edu/nanocourses/nanocourse.html

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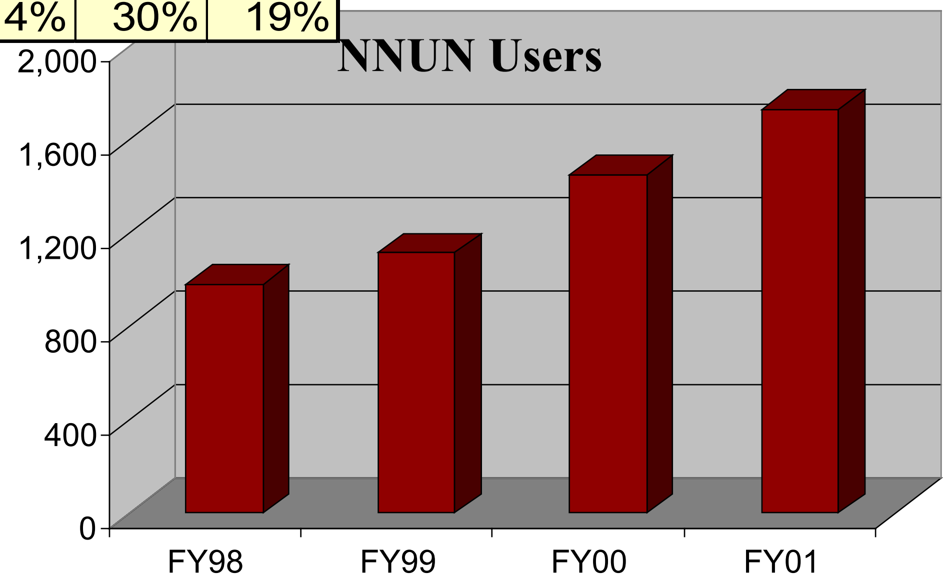
NNUN Users

	FY98	FY99	FY00	FY01
NNUN Users	981	1,114	1,449	1,729
NNUN Annual User Growth Rate		14%	30%	19%

(Unique User: same individual through the year is counted as 1 user.)



- **A doubling of users in 4 years**
- **A similar large increase in small-company usage**

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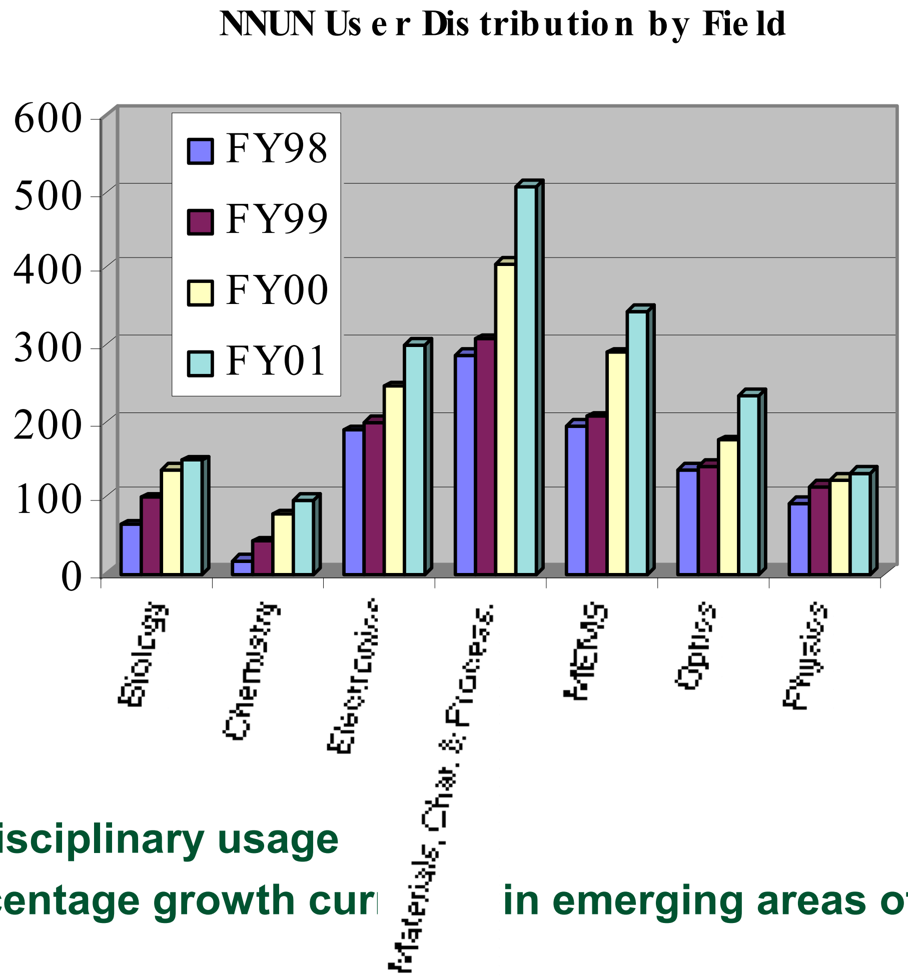
NNUN User Base by Discipline



- Large interdisciplinary usage
- Largest percentage growth currently in emerging areas of biology and chemistry

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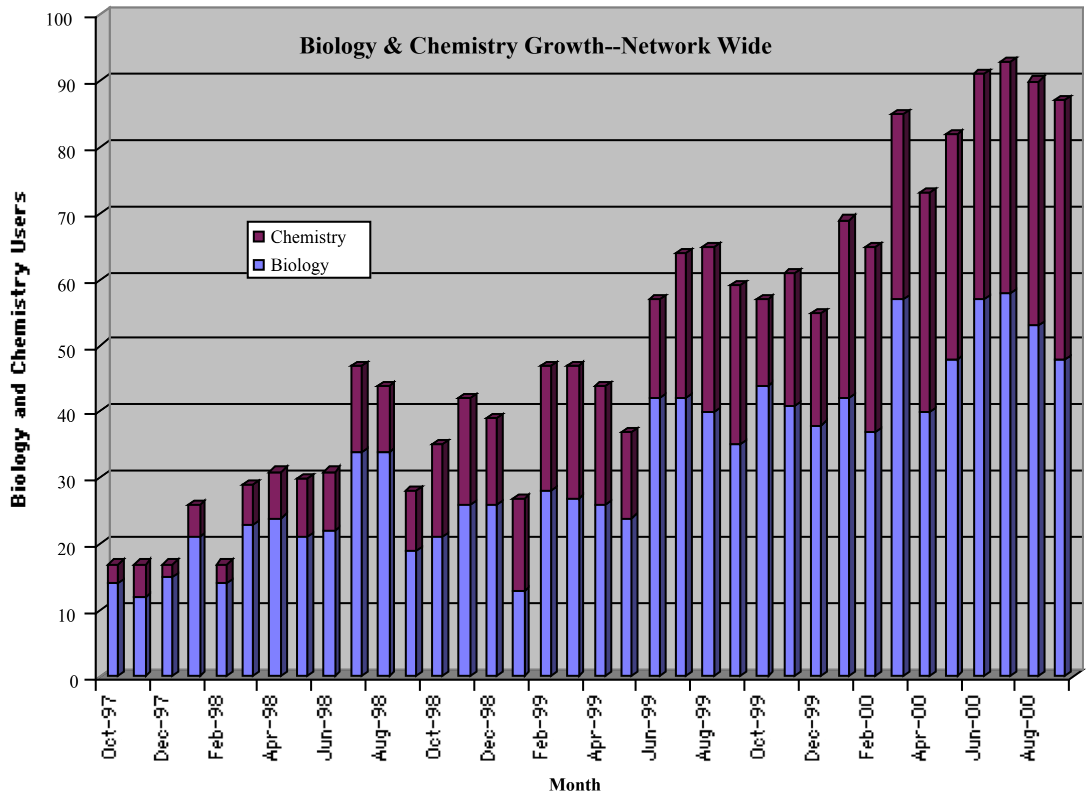
Trend in NNUN Biology and Chemistry Users



- Strong steady growth reflecting broad interest in biology and chemical applications
- NNUN helped through domain experts and development of capabilities

National Nanofabrication Users Network

User Distribution Snap-Shot

Data by zip-code without weighting for number of users from the zip-code

- **Diverse user base from across the nation reflecting the distribution of high tech industry, many of the major universities, and the distribution of NNUN sites.**

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How to Use NNUN

- Check http://www.nnun.org
- Visit and search on projects, resources, capabilities of the facilities (visit individual sites)
  - Look at projects, reports, etc. at sites
- Contact us through user program managers of the sites
  - IP is not an issue because we ask you not to tell us your confidential information, but there are few voice and e-mail technical and administrative exchanges
  - But, you need to tell us sufficient details of what you wish to accomplish
    - Establish the appropriateness of our capabilities
- Send short project description and MOU
- Start project in 2-6 weeks
- Some projects can also be accomplished remotely

NNUN Experience

- NNUN is a very effective use of resources and very successful in execution of nanostructures science and engineering research
  - the variety of nano-science and -technology demands and consequent compromises make networked universities (with critical mass) as the appropriate location
- Research in nanostructures requires coordination of multiple fabrication, synthesis, and characterization tools (typically 20-30 time-sensitive process steps, but could be as high as 200 in electronics/systems)
  - Complexity of execution increases at a faster rate with projects
- Requires expensive equipment (lithography tools, e.g., are $1-5M) that require distributed networking
  - Cost of new instrumentation has increased at a rapid pace during the past years
  - Cost of service contracts is high
  - New users at nano-dimensions => increased capital needs
- Requires expert staff
  - Need to be competitive with industry
  - Staff needs to be user-oriented with strong research skills

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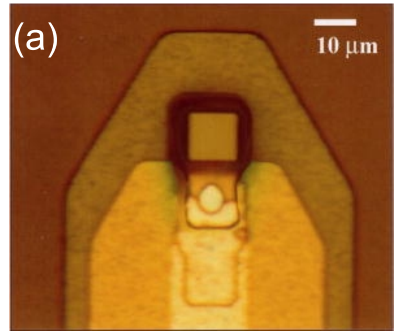
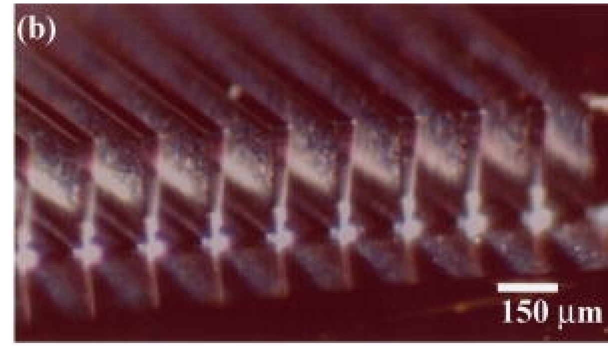
Microvolume Field-Effect pH Sensor for Scanning Probe Microscope

Quate et al. Stanford

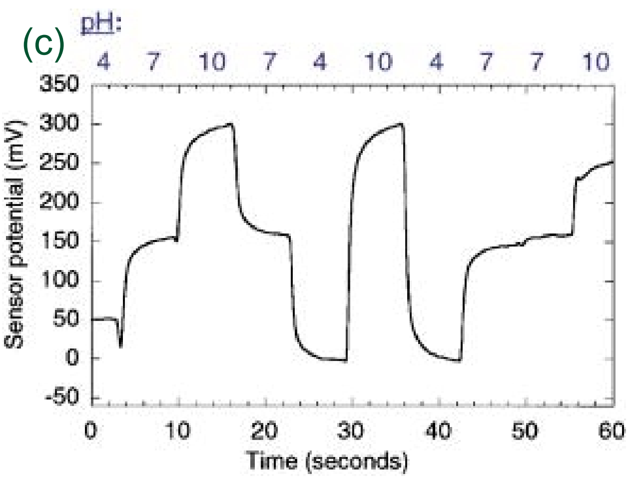
The scanning probe potentiometer (SPP) is a pH-sensitive, micron-sized field-effect sensor, capable of measuring pH gradients over a surface (top view, (a)).





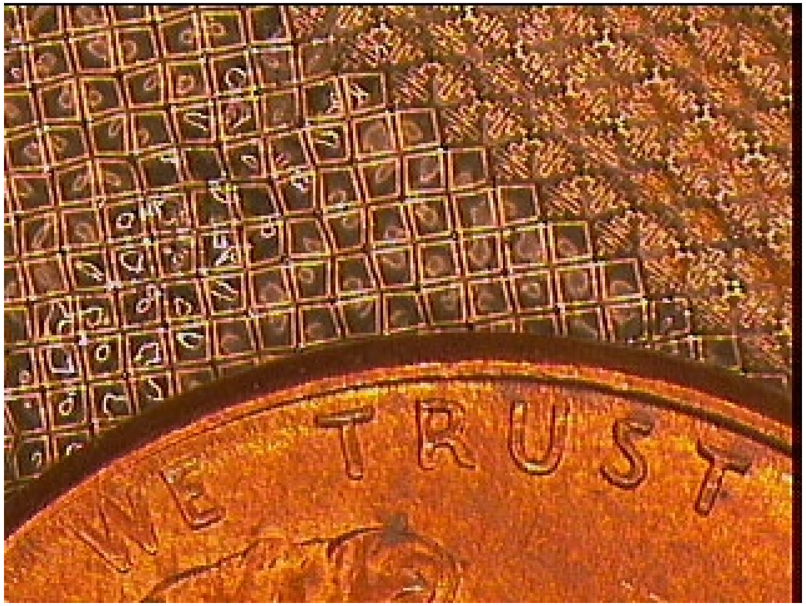
Multiple solutions of varying pH were introduced from microfabricated channels into a reservoir (cross-section, (b)). Because of the laminar flow conditions, the streams will not mix in the reservoir.

The SPP was scanned across the reservoir, successfully detecting the different pH's associated with the individual streams.



A Sensor System to Measure Contact Stress Distributions in the Human Knee
M. Hull, UC-Davis

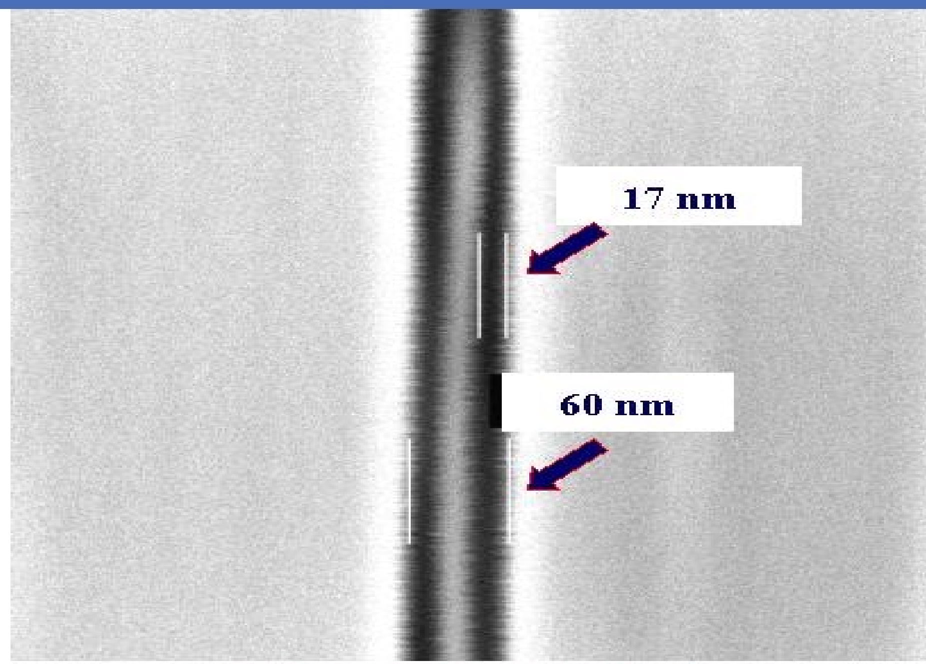
- 1500 independent sensors to measure normal stress
- Flexible and extensible 2-D sensor array that conform to complex knee cartilage curvatures
- Sensor array <70 μm thick
- 30 x 50 mm array
- Novel stress sensor design and processing



Sensor array on Silicone rubber backing is shown with a penny

Reduction of Dimensions using SAM

Molecular Ruler for Scaling Down Nanostructures
Formation of Precisely Defined Electrode Spacings



FE SEM Image of a metal wire ~17 nm wide between parent electrodes from an initial gap of 60 nm (with 20 nm ruler spacing)

PS Weiss

A. Hatzor & P. S. Weiss, submitted to *Science*

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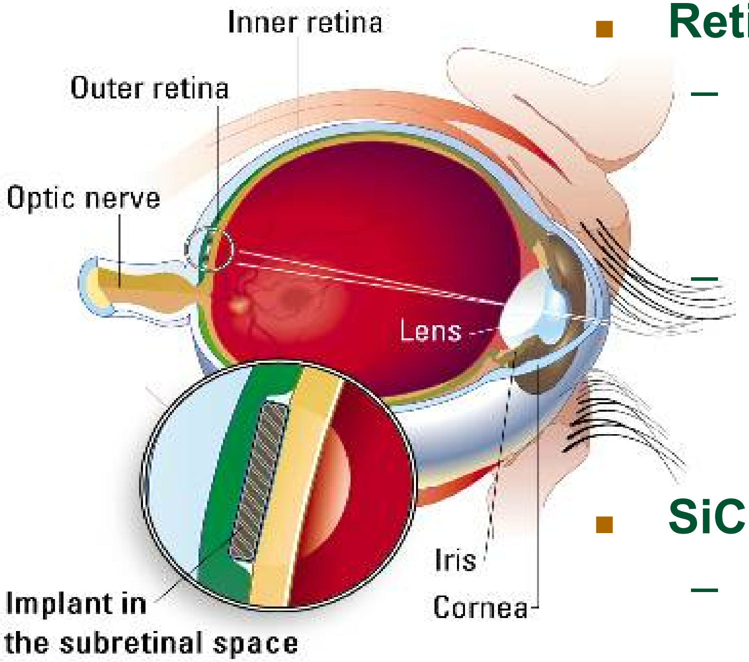
Artificial SiC Retina
Chow & Chow (Optobionics)

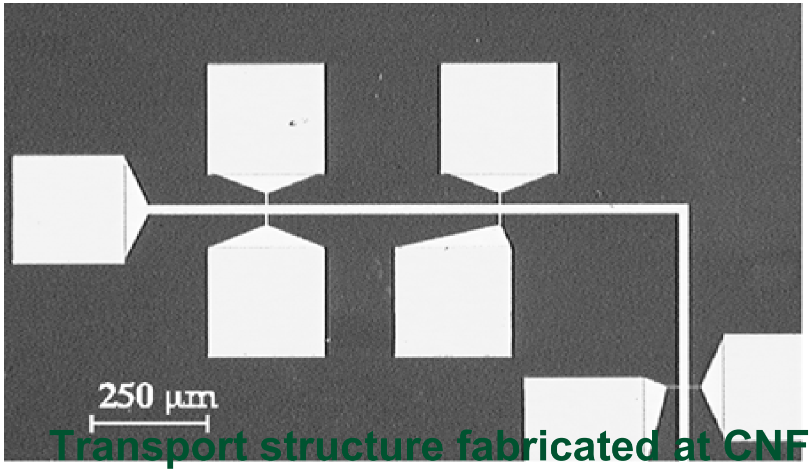


- Retina Disease
  - AMD age-related macular degeneration-injury to the photoreceptor layer
  - RP retinitis pigmentosa- injury to the photoreceptor layer usually hereditary in nature and produce "tunnel vision"
- SiC retina
  - highest sensitivity in the blue region
  - compatibility
  - higher output voltage
  - inert

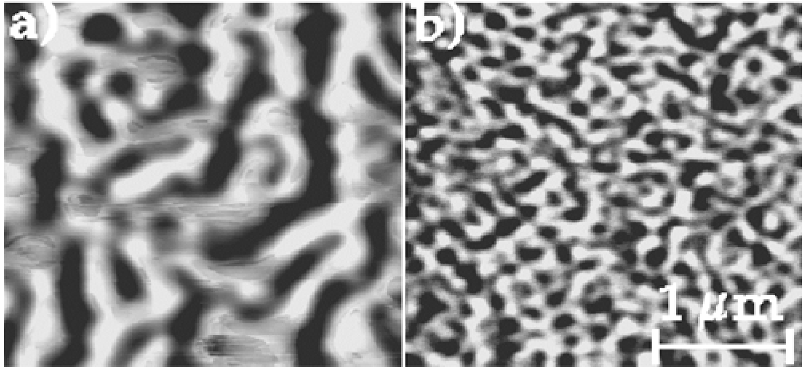
Properties of Small Scale Magnetic Structures

Jun Yu and Andy Kent, NYU

- Control of magnetic domain configurations in small structures with nanometer scale domain wall widths
- Ordered $L1_0$ Fe Pt has among the highest know magnetic anisotropy energy of any ferromagnetic material
- First evidence for intrinsic domain wall scattering contribution to resistivity in a transition metal ferromagnet.



Transport structure fabricated at CNF



MFM images of ordered films

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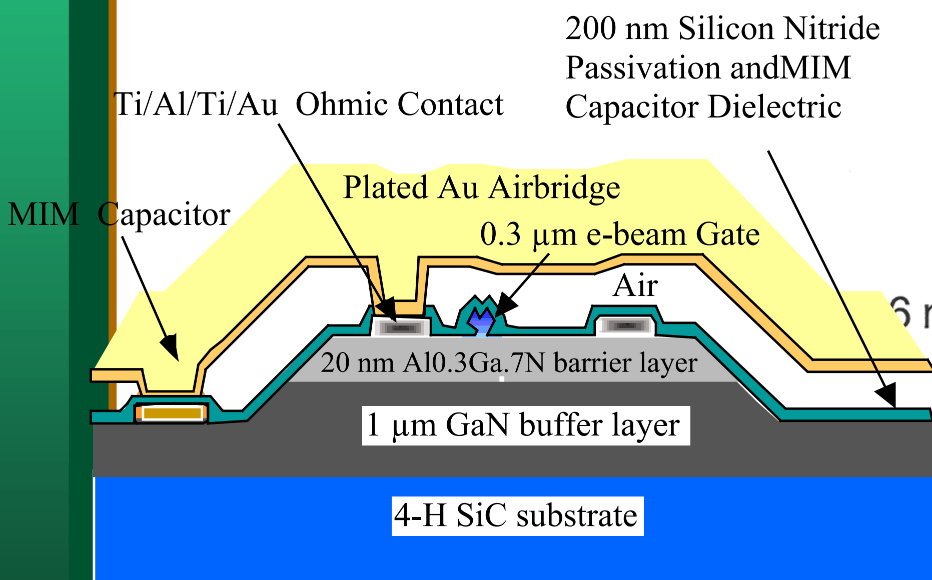
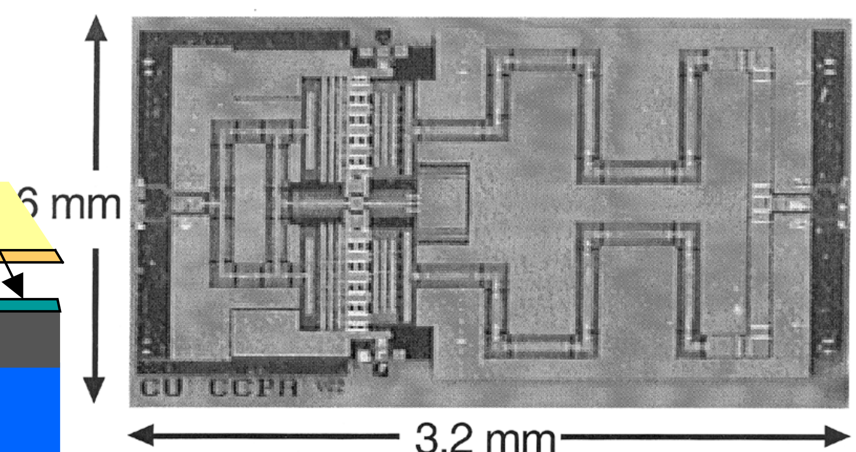
High Speed Large Bandgap Transistors and Circuits

L. F. Eastman et al. (Cornell)

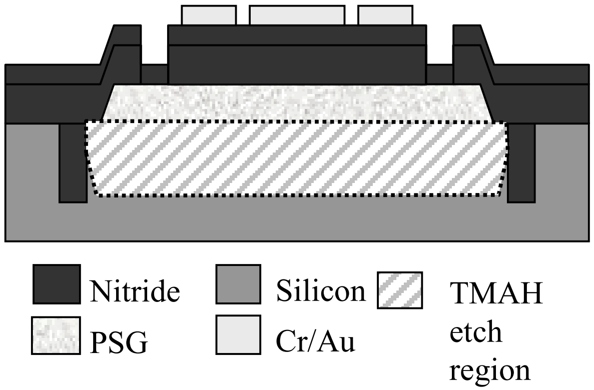
- **Dopant free AlGaN/GaN HEMTs and circuits on SiC substrates with 10.7 W/mm of RF power at 10 GHz and >5W of total power**



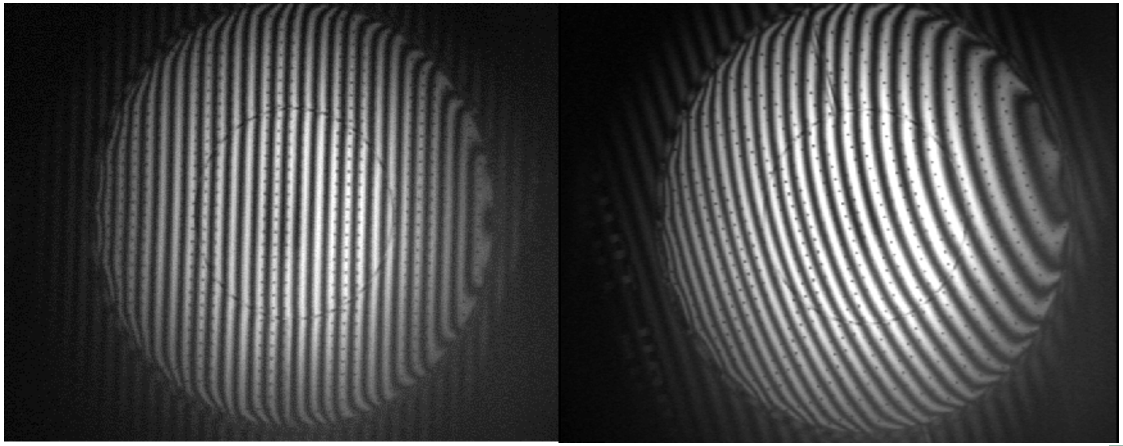


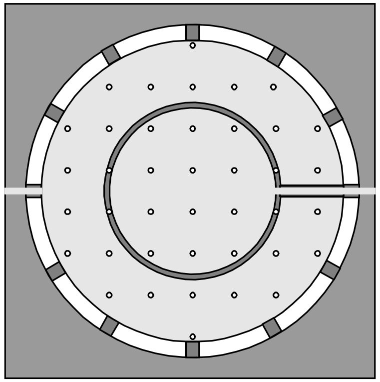
Deformable Silicon Nitride Mirrors for Focus Control
David Dickensheets (Montana State University)

- 1mm diameter mirror with 36-360 mm focal length control at zero primary spherical aberration using deep sub-wavelength dimensions
- Active bias control



Cross Section


Interference images of 1mm mirror. a) 0 volts applied.
b) 65 volts applied to center and outer electrodes.


Top View

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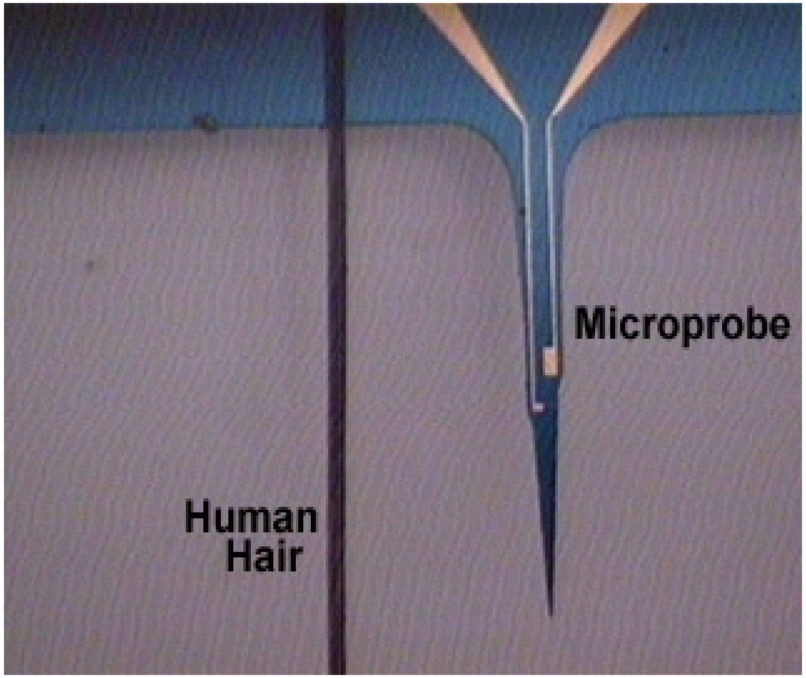
Integrated Sampling Devices for Bioanalysis
W. H. Smart (Kumetrix)

- A Silicon Microsampling Device for bioanalysis of ultra-small dimensions.
- Advantages
  - Small,flexible micro-needles and probes offer painless insertion
  - Small size allows for nonrestrictive attachment to the body for continuous monitoring of an analyte, such as lactate
  - High volume, low cost production of devices



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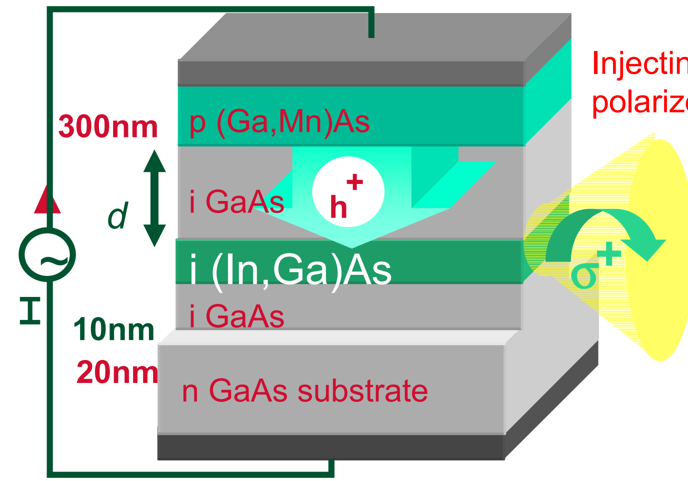
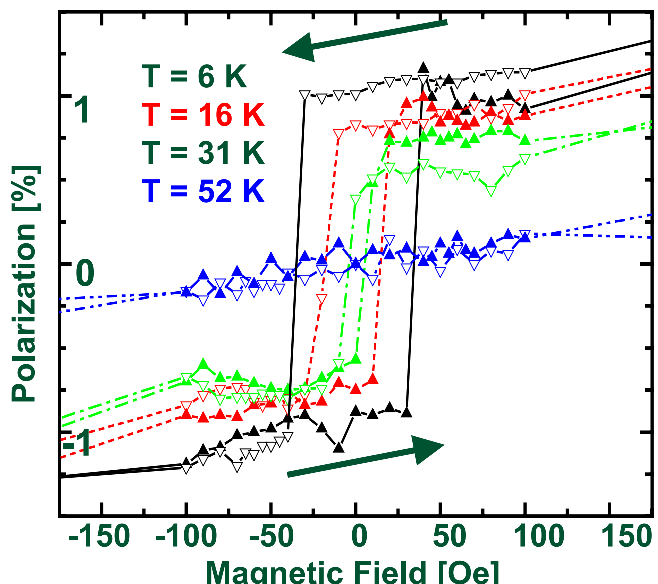
Spin-Polarized Light Emitting Diodes
D. Awschalom (UC-Santa Barbara)



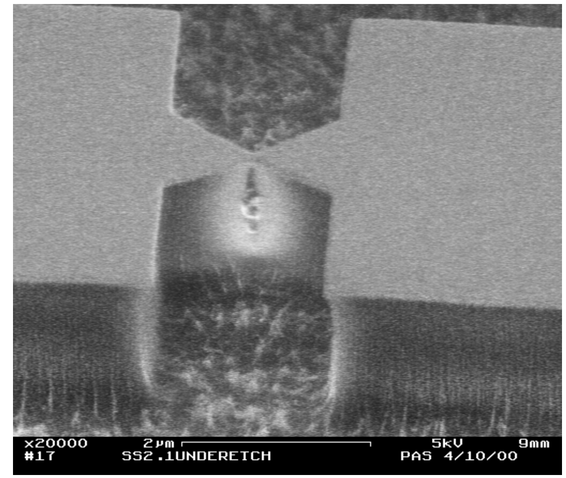


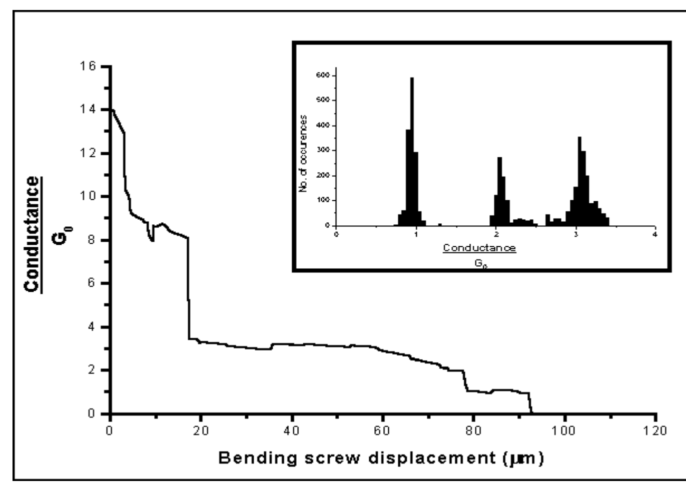
- (Ga,Mn)As - a p-type, hole-induced ferromagnetic semiconductor, readily grown on GaAs
- Spin-polarized holes injected from (Ga, Mn)As, transported > 200 nm to recombine in (In,Ga)As
- Polarization of emitted light tracks magnetization below Tc of (Ga,Mn)As

Atomic Scale Break Junctions for Molecular and Nanostructural Measurements

Dan Ralph, Cornell

- **Mechanically controllable break junctions fabricated by e-beam lithography on flexible substrates**
- **Conductance quantization can be observed at low temperature as the wire is stretched to atomic dimensions**
- **Used for measurements of properties of magnetic tunneling devices and transport characteristics of single molecules and small nanostructures**





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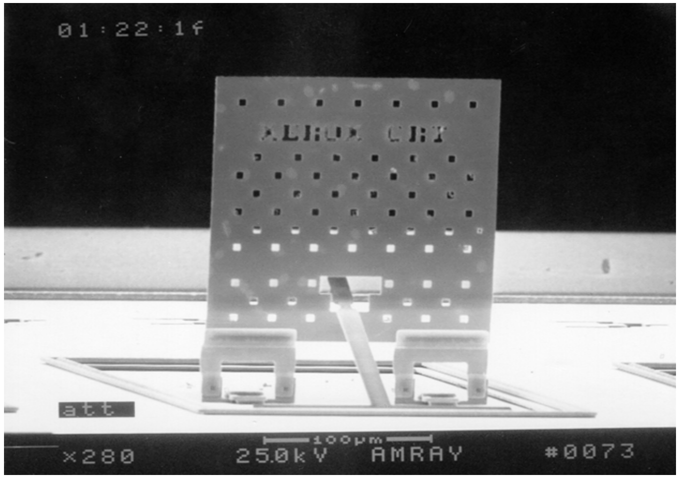
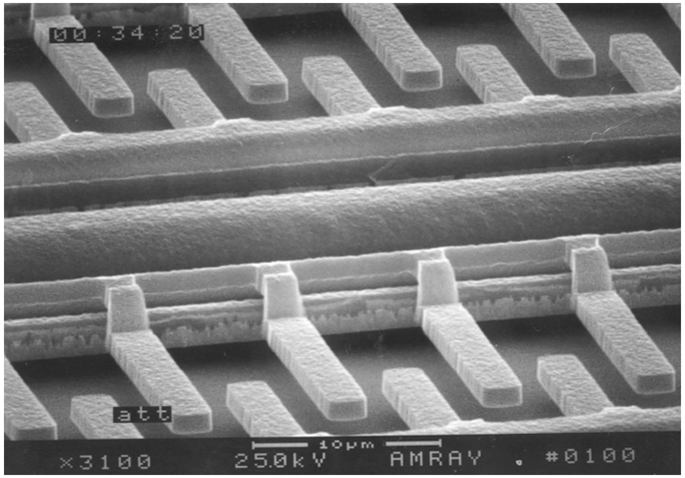
MEMS technology for Advanced Imaging Systems

Alex Tran, Xerox

- 3 level poly-silicon on SOI MEMS process for optical and microactuators
- High quality optical components together with micro-dimensional MEMS components
- Polysilicon provides mechanical elements only
- Applications to optical imaging and optical communications





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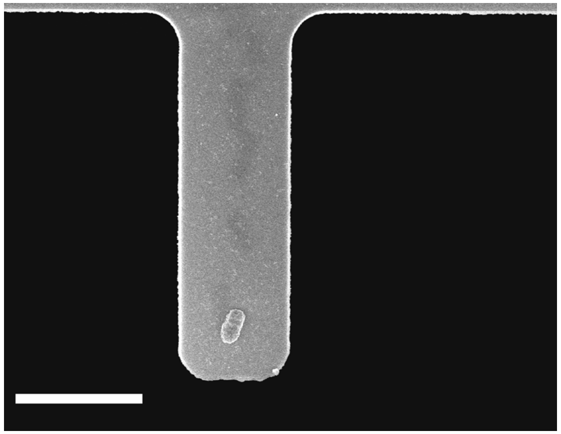
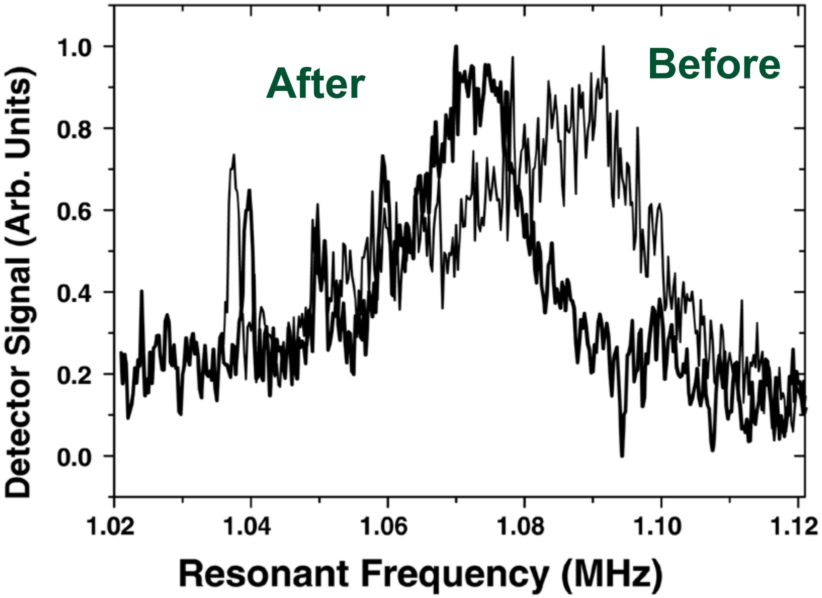
Single Cell Detection using Mechanical Oscillations
H. Craighead (Cornell)

- **Highly sensitive resonant sensing using nano-mechanical silicon nitride cantilever beams.**
- **Detects specific binding of E. Coli antibody monolayers**



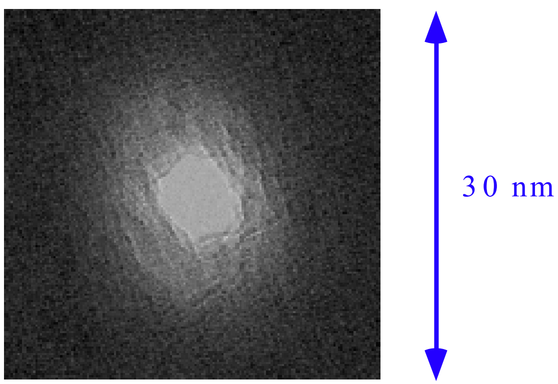


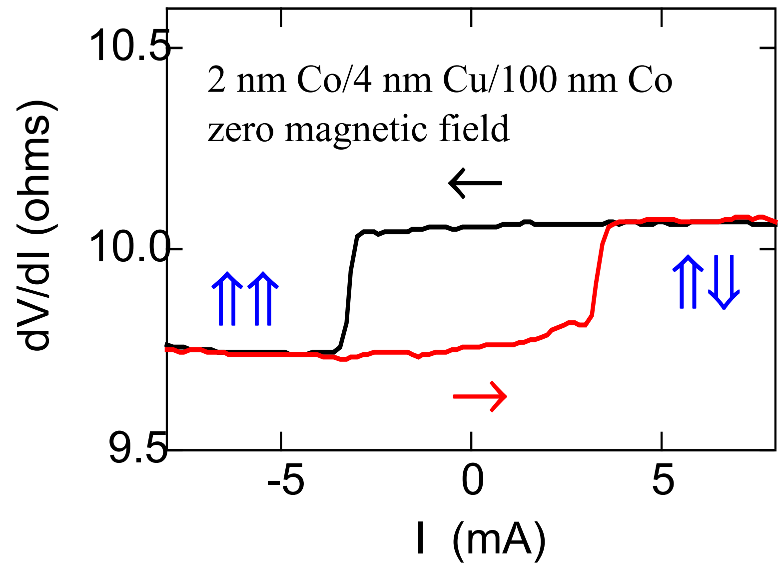
Nano-Magnetics: Spin-Torque Effects

D. Ralph et al., Cornell

Demonstration of torque by spin-polarized current causing single-domain switching

- measured in nanostructures





Ralph et al.

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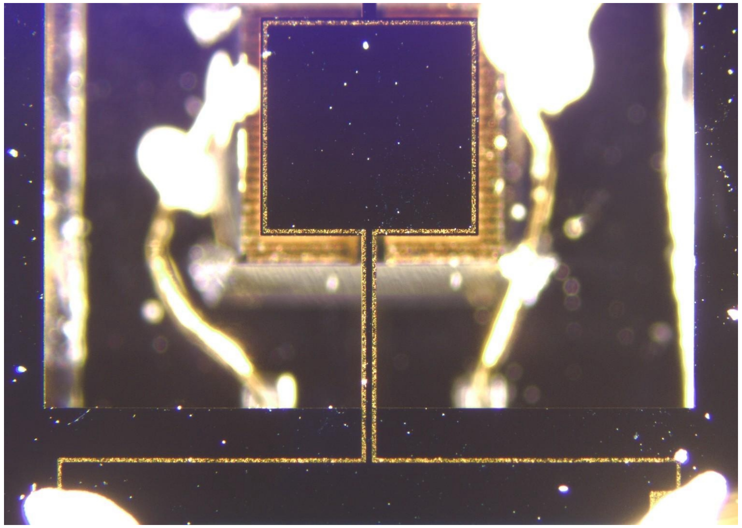
Torsional Magnetometer

M. J. Naughton (Boston College)

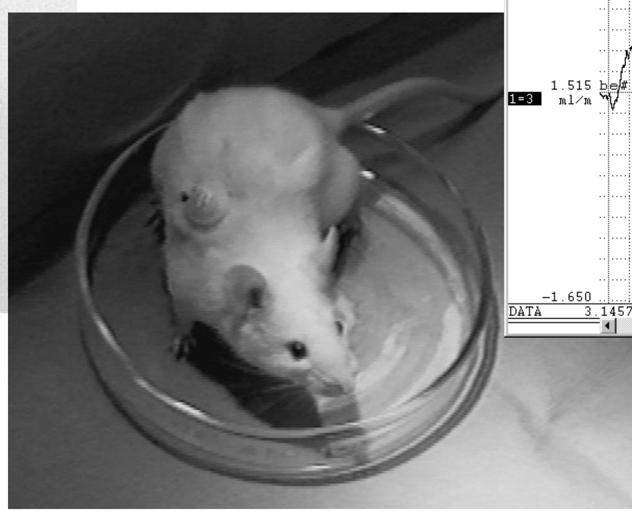
- High sensitivity magnetometer using small metal loops, with isotropic torque rejection, for measurement of uniform magnetic fields.

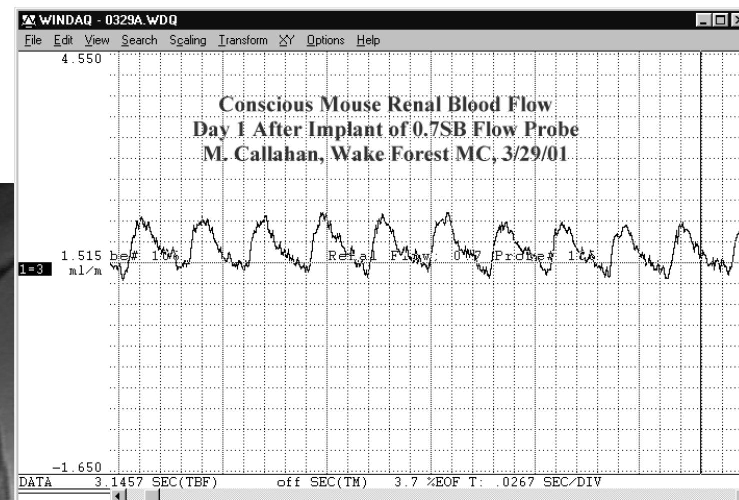


Micro-Machined Flow Probe

C. J. Drost et al. (Transonic Systems)

- Miniature blood flow monitoring system using photoepoxy based two-layer probe.
- Smallest transit time flow probe
- Used to monitor arterial blood flow into kidney





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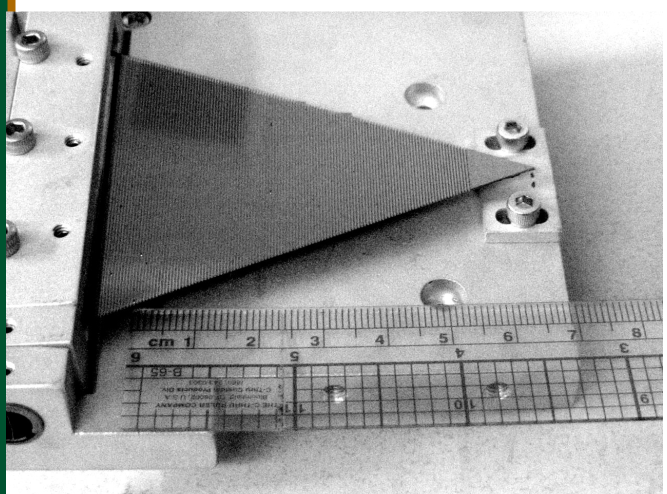
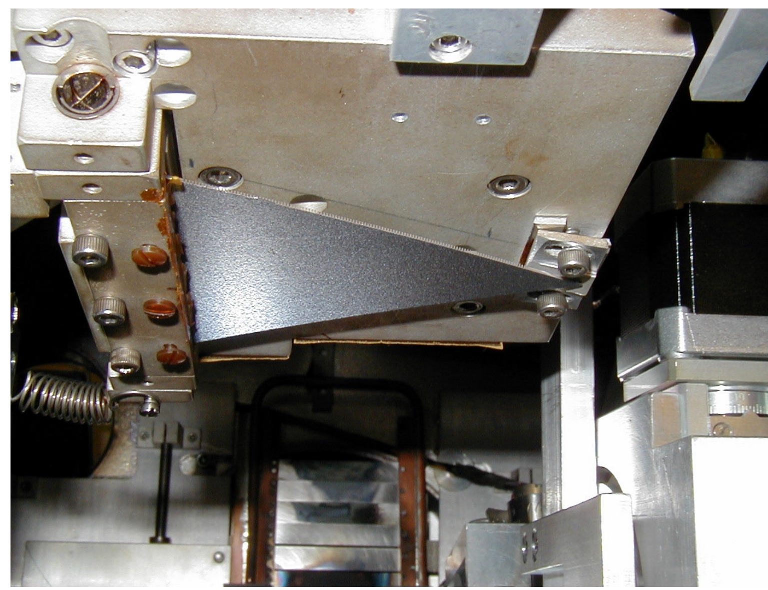
Micro-Fabricated X-Ray Optics

K. Finkelstein et al. (Cornell)

- **Use of deep (650 um) trenches and rib structure in X-ray lenses.**
- **Achieved 1.3×10^{12} photons/second at 9KeV into a 1×1 mm^2 spot without compromising energy resolution.**

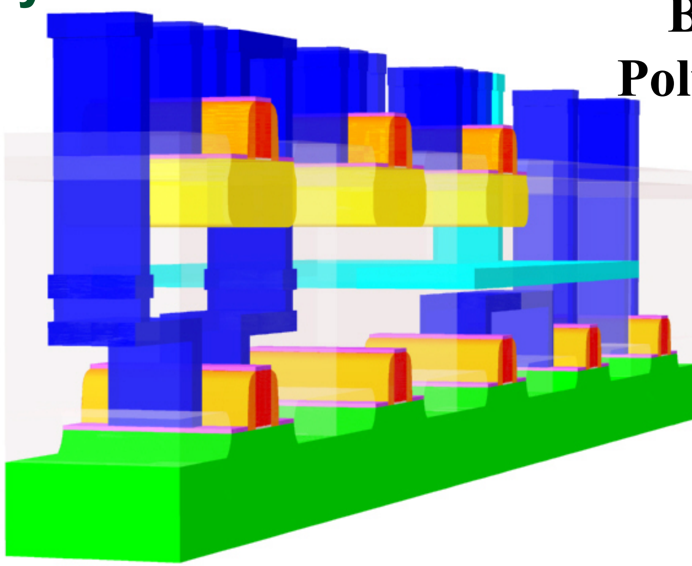




Silicon 3D Electronic Integration

L. Xue, C. Liu and S. Tiwari, Cornell

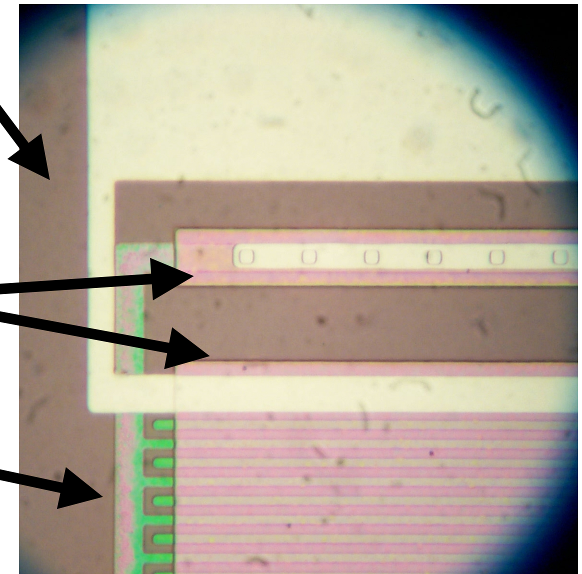
- New low temperature single-crystal silicon layering technique
- First demonstration of low temperature multi-layer electronics

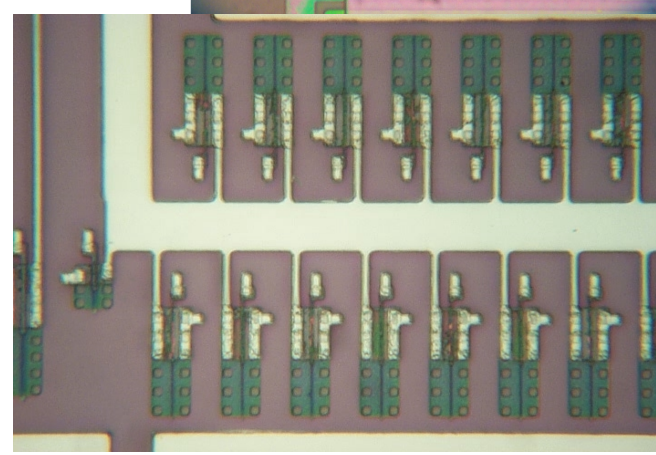


LOCOS in top silicon layer

Top single-crystal silicon layer

Buried Poly-Silicon





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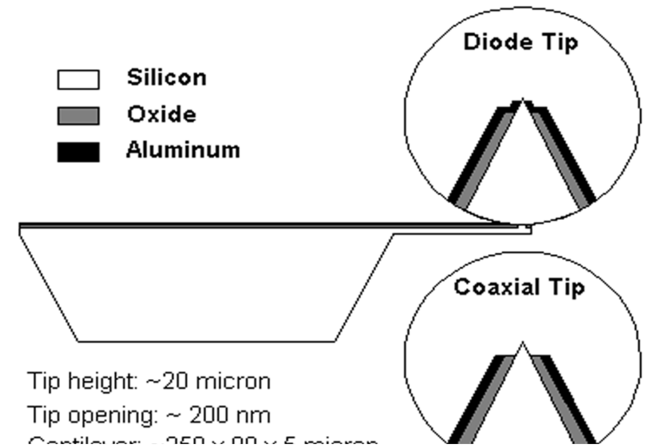
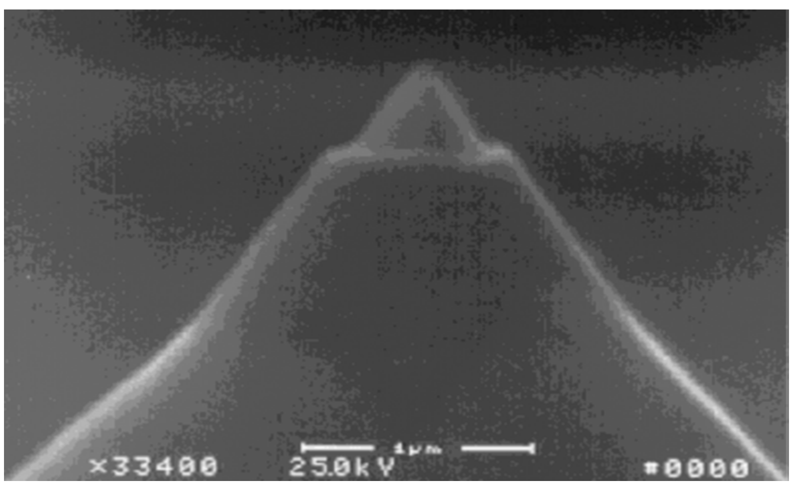
Multifunctional Scanning Force Microscope Tips

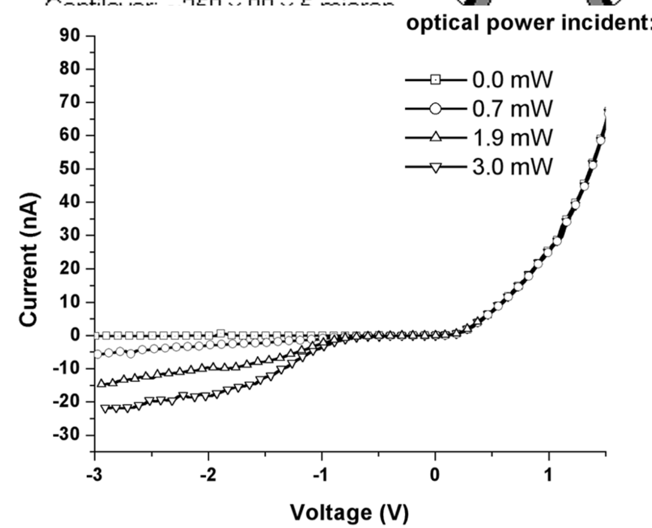
Andreas Koglin, Bjoern Rosner, Dan van der Weide, U. Wisconsin

- **Schottky diode tips for photon and thermal detection**
- **Coaxial tips for high frequency probing of electric fields**





Photodiode tip



Photodiode tip

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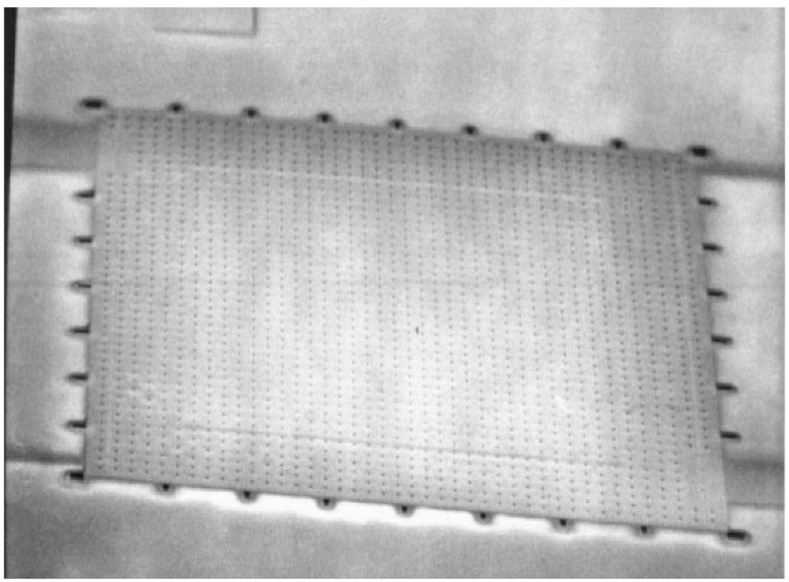
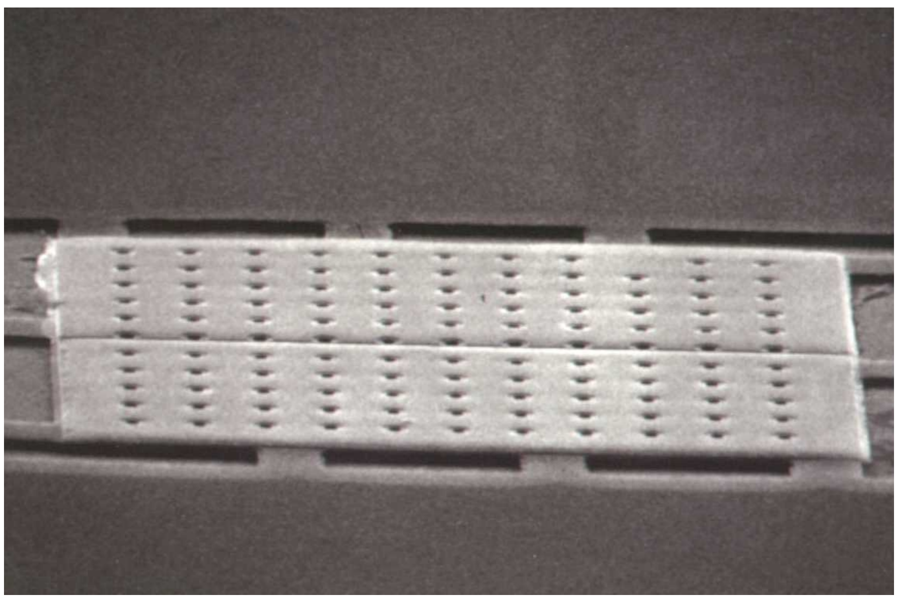
Broadband 0.3 um to 100 um Uncooled Bolometer

D. P. Butler et al. (SMU)

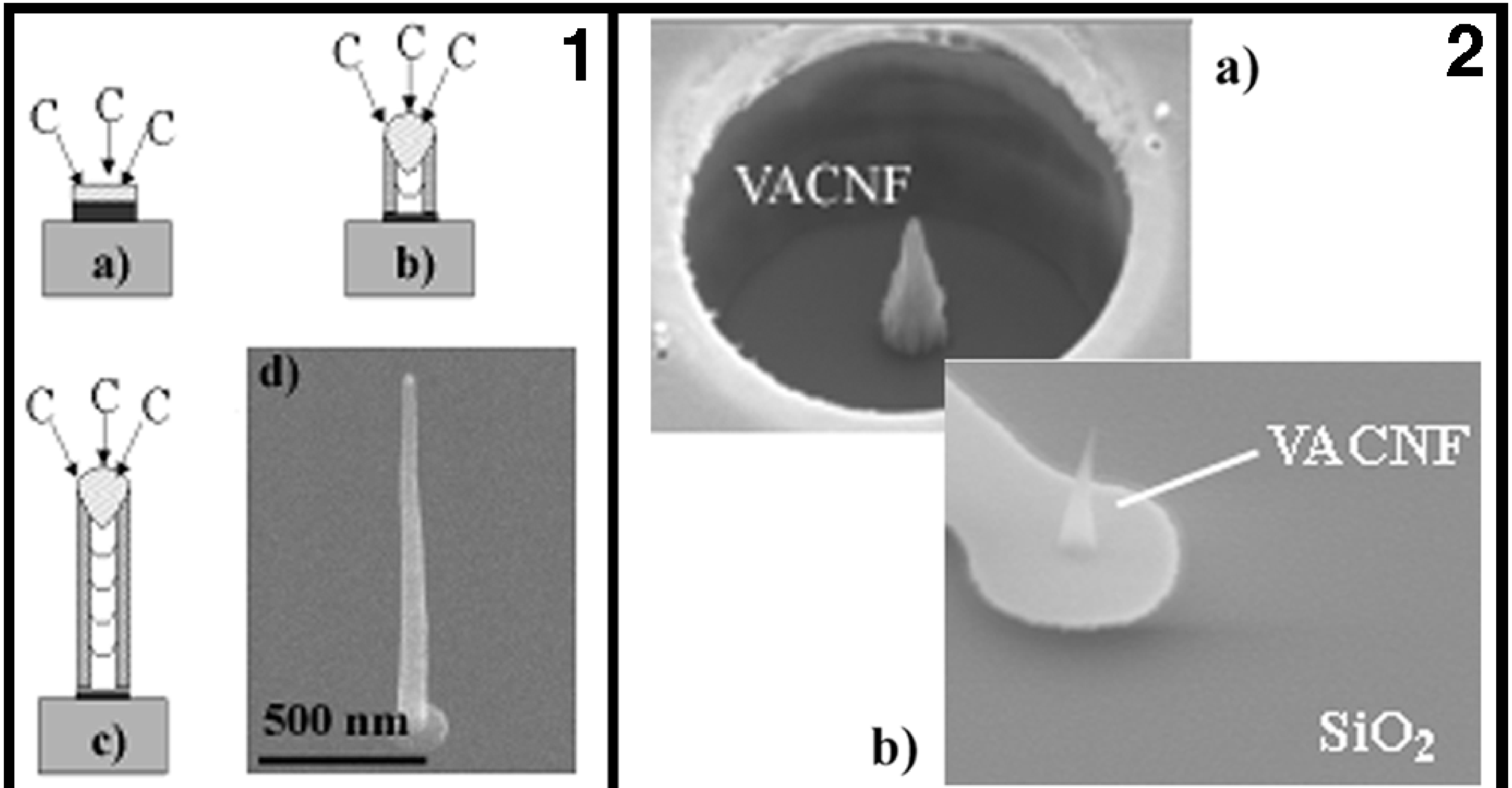
- **Y-Ba-Cu-O based uncooled IR detector with a broad spectral response**





Carbon based Nanostructures
Guillorn & Simpson (U. Tenn.)

- **Reproducible field emission from nanotubes and fibers**



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