Introduction to the Stanford Nanofabrication Facility and Research Examples

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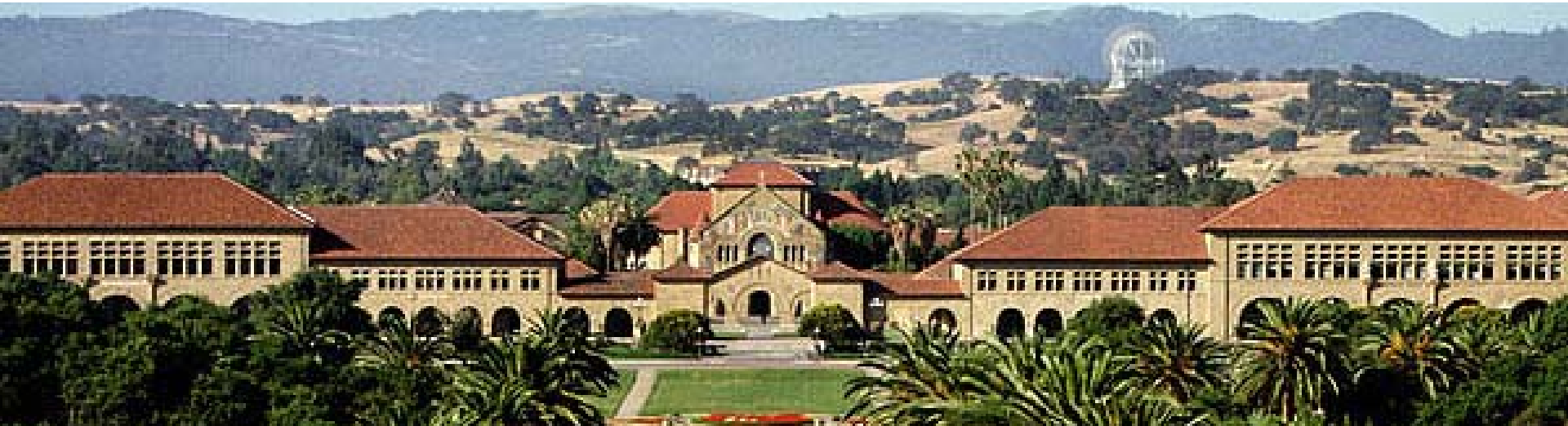


Agenda

- location of the Stanford Nanofabrication Facility
- NNIN – National Nanotechnology Infrastructure Network
- overview of SNF
  - vision, mission, strategy
  - organization
  - equipment resources
- research examples (primarily from Stanford)
  - nanotubes, nanowires
  - optical devices
  - silicon based devices
  - new semiconductor materials
  - fundamental physics
  - MEMs/NEMs
  - magnetic devices
  - miscellaneous
- success stories
- finances

Stanford Hospital
Emergency
Parking Struct. 3
Parking Struct. 4
Stanford Athletics Sand Hill Fields
PASTEUR DR
WELCH RD
OAK RD
Parking Struct. 5
Park & Ride Lot
Lucas Ctr./MSLS
Health Res. & Policy (Redwd)
Ctr. for Clinical Sciences Research (CCSR)
Clinic
School of Medicine
Med School Office Bldg
Beckman Center
Fairchild Aud. Center
James H. Clark Center
Anatomy
Cantor Center for Visual Art
Rodin Sculpture Garden
Parking Struct. 1
CAMPUS DR WEST
ROTH WY
MUSEUM WY
LOMITA DR
PALM DR
Chemical Biology Lorry Lokey
Keck Science
Organic Chem
Mudd Chem Bldg
Stauffer I
Stauffer II
Stauffer III
Old Chem Bldg
STOCK FARM RD
Support Services Area
Cordura Hall
Ventura Hall
Gates Computer Science
Gilbert BioSci
Herrin Hall and Labs
The Oval
Frost Amphitheater
Frances Arrillaga Alumni Center
Littlefield Center
Knight
MEMORIAL WY
Graduate School of Business South
Memorial Hall/Aud.
Bakewell Ford Plaza
Landau Economics
Ford Center
Burnham Pavilion
Band Shack
Sand Volleyball
Tennis Court
Parking & Transportation Services
Police Services
Fire Station
BONAIR SIDING
Jordan Quad
Cogan Facility
Allen Ctr. for Integrative Systems
David Packard Elect. Engr.
William R. Hewlett Teaching Center
Serra Grove
SERRA MALL
Sequoia Hall
Varian Labs
W.R. Hewlett and D. Packard Quadrangle
Memorial Court
Dohrmann Grove
Art Gallery
Main Quad
Memorial Church
Cummings Art
Hoover Tower
Hoover Bldg
Hoover Mem. Bldg
Green Library East Wing
Green Library
Encina Hall
Encina Commons
Schwab Residential Center
Manzanita Park
Manzanita Dining Commons
Lantana
Cedar Terrace
Moore Materials Resch.
McCullough
Skilling
Burand
Green Earth Sciences
Roble Modules
Godzilla
Roble Field
Roble Pool
Roble Gym
Bamboo
Mitchell
Terman Engineering
Thornton
Starkey Mech. Engr.
Fire Track
Fire Station 610
Old Union
Clubhouse
Bookstore
Canfield Court
Koret Park
School of Education
Meyer Library
Calvez Module
Crothers Hall
Crothers Memorial Hall
Toyon Hall
Branner Hall
Kimball Hall
Sweet Hall
Stern Hall
Wilbur Hall
Wilbur Field
Wilbur Modules
Mirrielees
Baina Houses
Cowell Houses
Sterling Quad
Lyman Grad. Res.
Governor's Corner
West Campus Tennis Courts
Lagunita Court
Roble Hall
New Guinea Grdn
Kennedy Grove
Stanford Humanities Center
Tresidder Union
Dinkelspiel Aud.
White Plaza
Post Office
Faculty Club
LAGUNITA DR
Law School
Braun Music Ctr
Kresge Aud.
Rogers
Mariposa Oven
Student Services Center
SHC Annex
Bechtel Int'l Center
Golf Driving Range
Lake Lagunita
MAYFIELD AVE
Florence Moore Hall
Levin Field
Pearce Mitchell Houses
Golf Pro Shop
Lathrop Gate House
JUNIPERO SERRA BLVD
LINKS RD
ALTA RD
National Bureau of Economic Research
Artist's Studio
Center for Advanced Study in the Behavioral Sciences
Observatory
To Interstate 280 via Page Mill R
To Foothill Expressw
CAMPUS DR EAST
ESCONDIDO RD
ESCONDIDO MALL
SANTA TERESA ST
GOVERNOR'S AVE SOUTH
GOVERNOR'S AVE
PANAMA ST
PANAMA MALL
SEARSVILLE
Biology Greenhouses
Carnegie
Bleeker Barnes Labs
Python
Barnes
Bus Parking
Galvez Field
G.A. Richards Press Box
NELSON RD
Park & Ride Lot
Varsity Lot
Ticket Office
Cobb Track & Angell Field
Track House
PAC 10 Plaza
Chuck Taylor Grove
Klein Clubhouse
Athletics
Sunken Diamond
Avery Aquatic Center
Taube Family Tennis Stadium
Arrillaga Plaza
Arrillaga Family Sports Ctr.
Maples Pavilion
Elliot Field
Artif. Turf
SAM MACDONALD MALL
AVERY MALL
NELSON MALL
GALVEZ ST
ALVARADO ROW
ARGUELLO MALL
LASUEN ST
LANE A
LANE B
LANE C
BOWDOIN ST
SAN FRANCISCO CT
S.F. TERR
SALVATIERRA ST
VALPARAISO AVE
CONSTANZO ST
MAYFIELD

The National Nanotechnology Infrastructure Network (NNIN)

The SNF is a member of the NNIN, an integrated partnership of thirteen university user facilities, supported in part by National Science Foundation.

- University of California at Santa Barbara
- Cornell University
- Georgia Institute of Technology
- Harvard University
- Howard University
- University of Michigan
- University of Minnesota
- University of New Mexico
- North Carolina State University
- Penn State
- Stanford University
- University of Texas at Austin
- University of Washington

http://www.nnin.org

members of original NNUN

NNIN Vision and Mission

To enable rapid advancements in science, engineering and technology down to the nano-scale by efficient access to nanotechnology infrastructure.

NNIN Strategy

to provide:

- comprehensive science and engineering resources for the nanoscale.
- expertise, processes, and process support – *not just equipment.*
- on-site and remote use.
- an integrated national resource through the web infrastructure.
- distributed technical specialization and complex integration resources.
- geographically distributed sites.
- external user-focussed commitment backed by strong internal strength.

Stanford Nanofabrication Facility Vision

To be one of the top fabrication infrastructures for nanotechnology research and education in the world measured in terms of quality and quantity of work in nanotechnology.

Raith 150 electron beam system

SVG develop track

SNF Mission

To provide a fabrication infrastructure which helps both academic and industrial users accomplish their experimental research goals.

SVG resist coat track

Lam TCP 9400 poly etch system

To provide an environment in which users can try innovative ideas for scientific research, engineering research, and development of innovative products.

SNF Strategy

- to provide user operated experimental capabilities with advanced equipment and effective training in order to maintain a safe working environment.
- to acquire, in a timely manner, necessary equipment and process capabilities.
- to balance the budget with NSF/NNIN funding and user fees while establishing a process for new equipment acquisition.
- to enable close coupling and information exchange between academic and industrial users.
- to strengthen resources as necessary in order to meet the demand for new technical knowledge and new skills.
- to increase the use of nanofabrication in non-traditional areas.
- to provide an incubator facility for start-up companies.

The Nanofab's Philosophy

- the lab is open to all – Stanford academic, non-Stanford academic and industrial users.
- there is a dynamic community of researchers who support one another. There is an active problem discussion list.
- there are consultants who work with users that don't want to come to Stanford to get their project done in the lab.

Tylan furnace

Zygo optical profilometer

- each user is responsible for his or her own intellectual property.
- it is a cost effective and efficient way to try out new ideas.
- by terms of the NSF agreement only R&D can be done, no manufacturing.

User's Perspective on SNF's Value

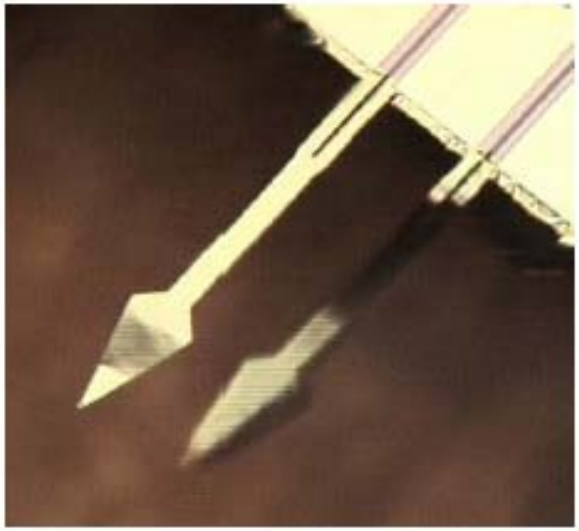
- the SNF plays a vital role in the incubation of new technologies
  - most foundries have $50k+ barrier to entry - access gap
  - flexibility to try non-conventional processes
  - variety of equipment
  - hands-on opportunities appealing to Ph.D. founder types
  - home turf advantage to [Stanford] grads
  - SNF's secret weapon: today's academic users are tomorrow's industrial users
- excellent work environment
  - friendly and knowledgeable staff
  - supportive learning environment
  - collegial atmosphere
  - most users are good citizens

Dr. Alissa Fitzgerald
A. M. Fitzgerald & Associates, LLC
655 Skyway Rd., Suite 118, San Carlos, CA 94070
www.amfitzgerald.com

NNIN

The Stanford Nanofabrication Facility

- SNF is part of the infrastructure of Stanford's Center for Integrated Systems, but does not receive direct funding from CIS.
- there is 10.5k ft^2 (1k m^2) of class 100 cleanroom space with separate floors for fan deck and support equipment.
- primarily 4" wafer processing although some 6" equipment is available.
- over 200 active labmembers in any given month. 120 Stanford academic users, 20 non-Stanford academic users, and 60 industrial users.



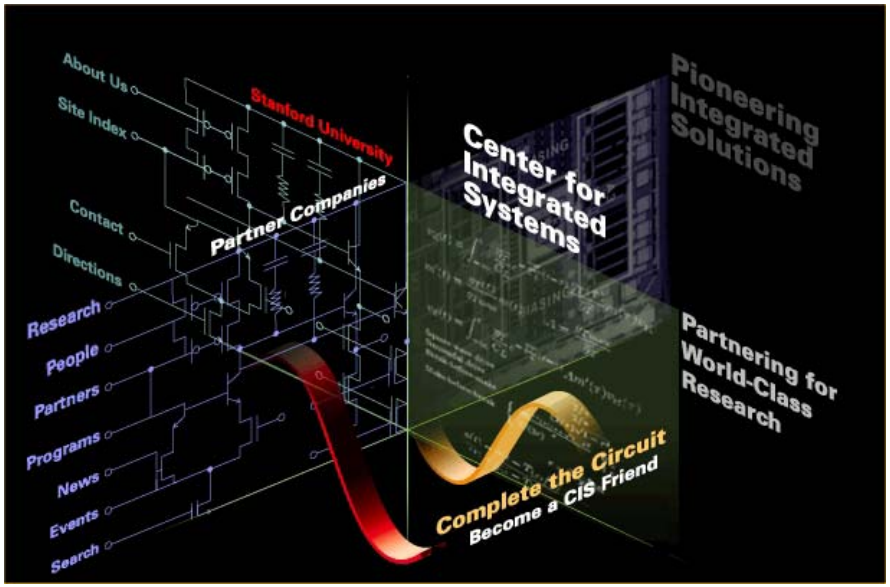
70 nm thick low mass cantilevers

Michael Bartsch and Professor Thomas Kenny, Stanford

- industrial users are primarily from small, local startups, but also several large companies (Intel, HP, IBM, Hitachi, and others).

CIS Member Companies

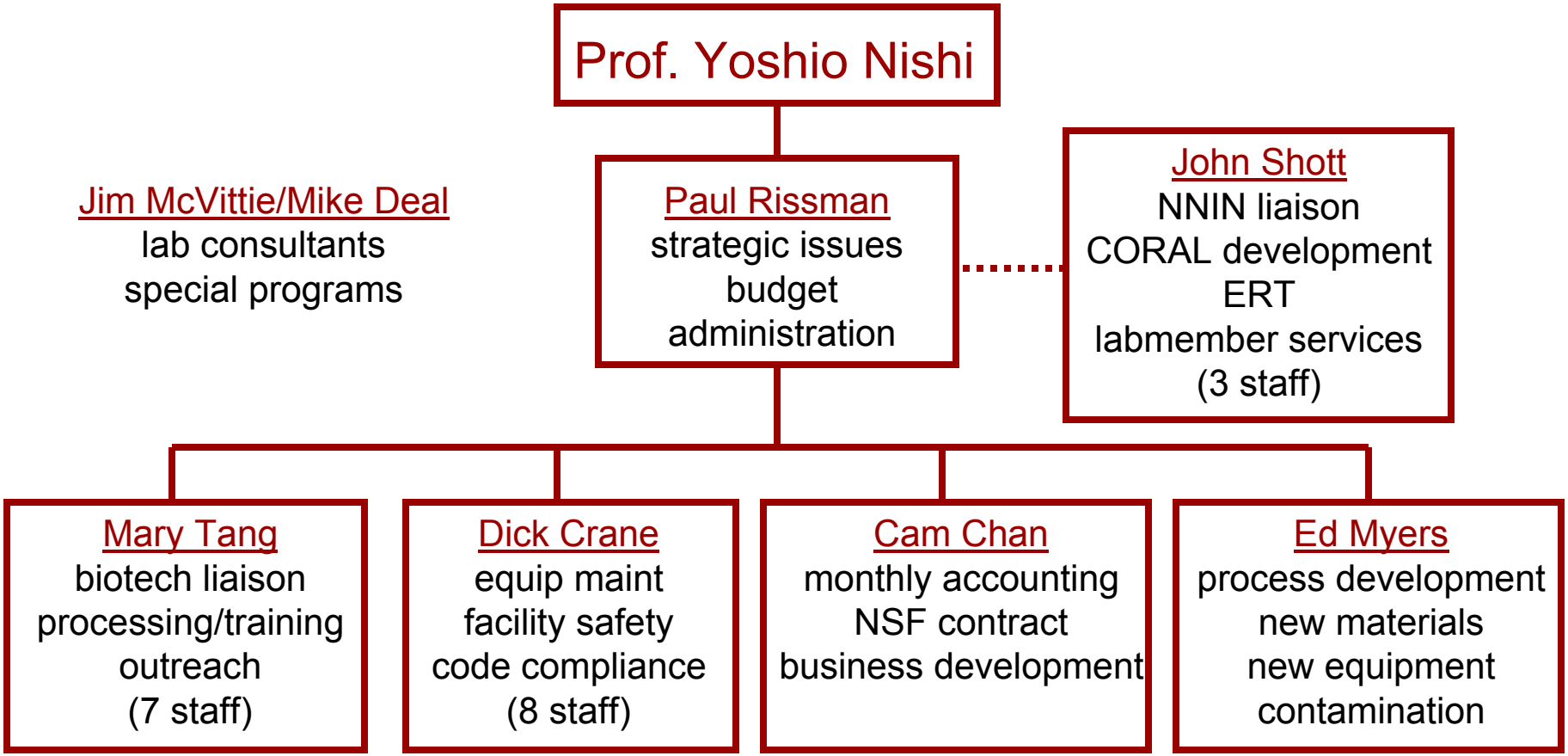
- Advanced Micro Devices
- Agilent Technologies
- Analog Devices
- Applied Materials
- Canon
- Ebara Corporation
- Hewlett-Packard Company
- Hitachi Ltd
- IBM Corporation
- Infineon
- Intel Corporation
- LG Electronics, Inc.
- National Semiconductor Corporation
- Panasonic



- Philips
- Renesas Technology Corporation
- Robert Bosch Corporation
- Texas Instruments, Incorporated
- Toshiba
- TSMC

NNIN

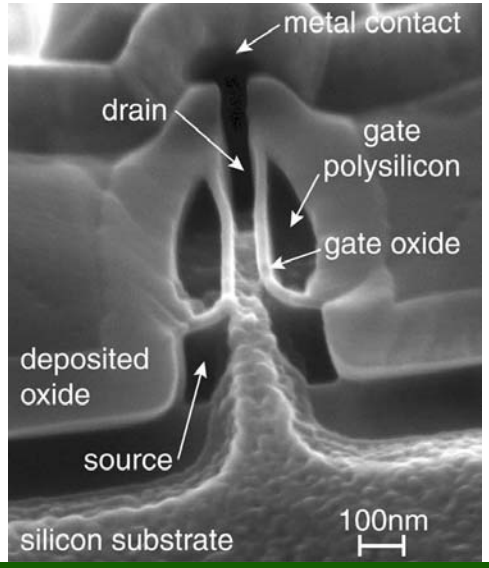
SNF Organization

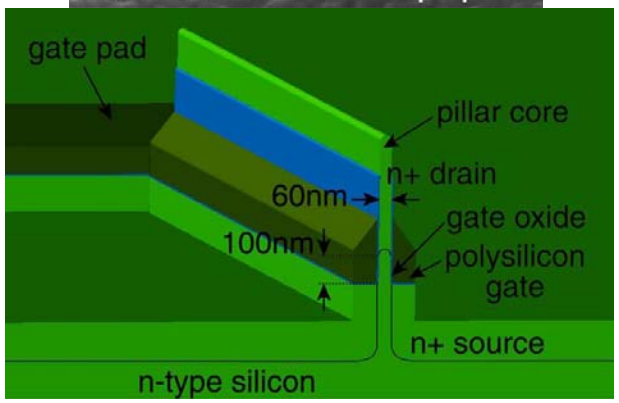


total lab headcount - 25

Special Programs

- remote users program
- symposia and workshops
- CIS new user grants program (for Stanford and non-Stanford faculty)
- summer research internships for undergraduate students and high school teachers
- participation in educational curriculum development
- social and ethical issues in nanotechnology

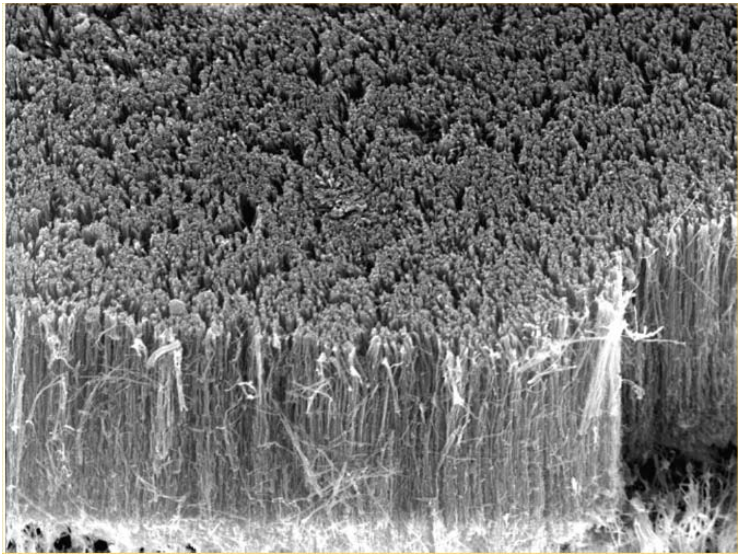




pillar transistor – Teresa Kramer and Professor Fabian Pease, Stanford

Interdisciplinary Workshops/Symposia

- BioMEMS
- E-Beam Lithography for Nanostructure Fabrication
- Biomedical Applications of Nanofabrication
- DNA Microarray Workshop
- Plasma Etching Workshop
- Nanosafety - Dec. 2, 2004 at Georgia Tech
- Foundry Day – Prototype to Product – October 20, 2005 at Stanford

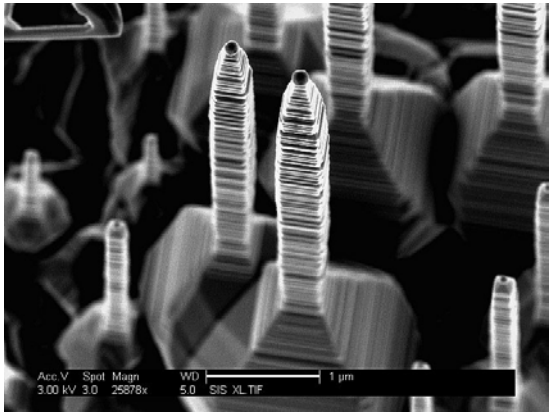


carbon nanotubes

Stanford Nanocharacterization Laboratory (SNL)

contacts – Ann Marshall, Richard Chin, Professor Robert Sinclair

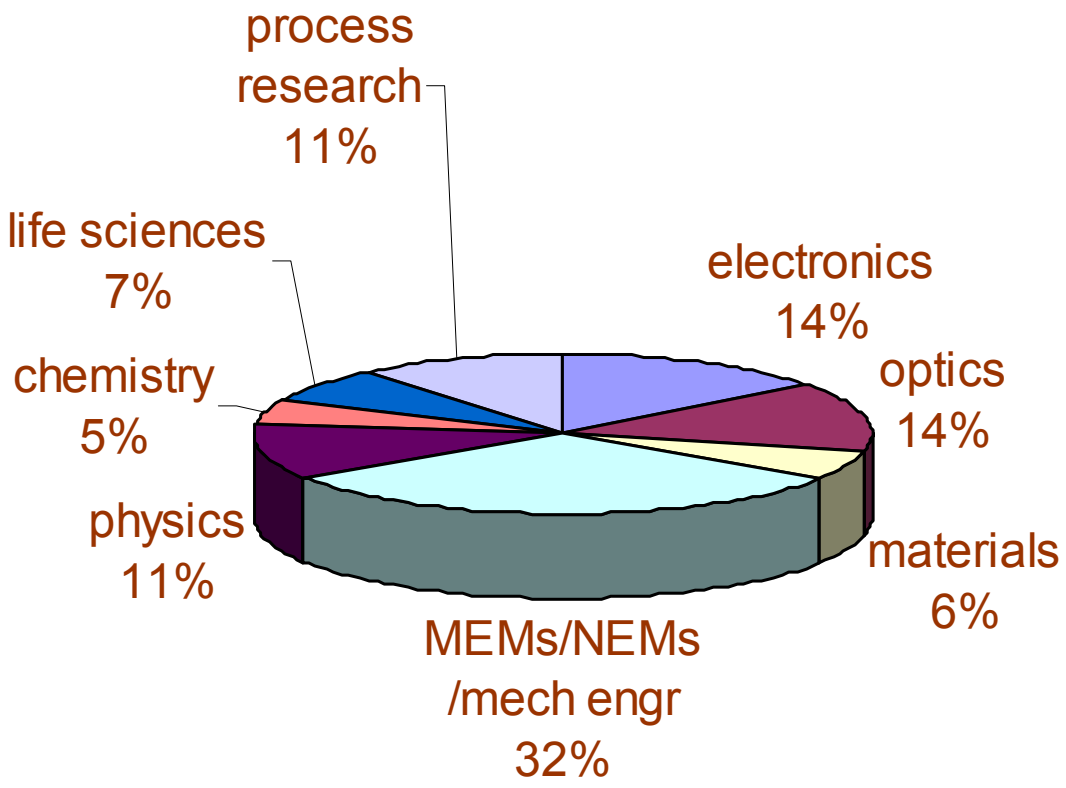
- associated with SNF through NNIN grant
- high resolution scanning electron microscopes (SEM)
- focussed ion beam (FIB)
- high resolution transmission electron microscope (TEM)
- high resolution Auger electron spectroscopy (AES)
- x-ray photoelectron spectroscopy (XPS)
- secondary ion mass spectroscopy (SIMS)
- specimen preparation equipment
- x-ray diffraction laboratory



nanowires – Professor Yoshio Nishi and H. Jagannathan, Stanford

SSI S-Probe monochromatized XPS spectrometer

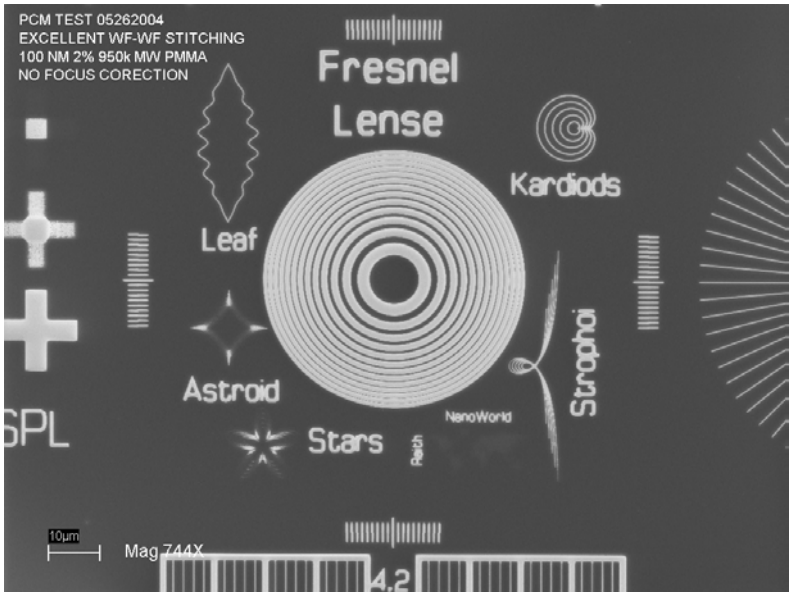
Areas of Research at SNF



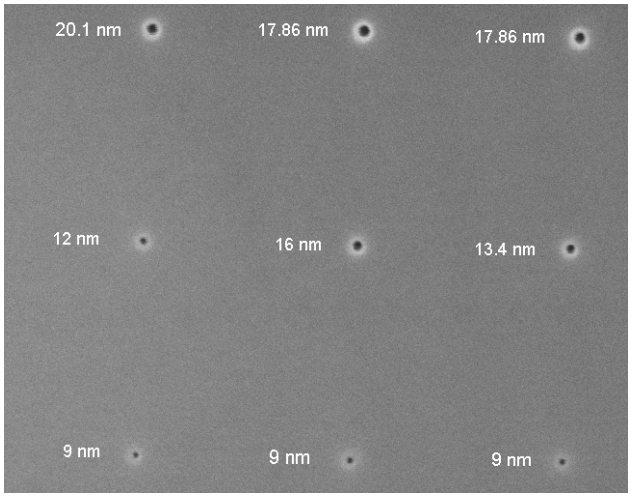
data for calendar year 2004

E-Beam Lithography Resources

- Hitachi HL 700F direct-write electron beam system.
  - medium throughput
  - resolution limited to ~150 nm
- Raith direct-write electron beam system.
  - low throughput
  - high resolution down to 10 nm



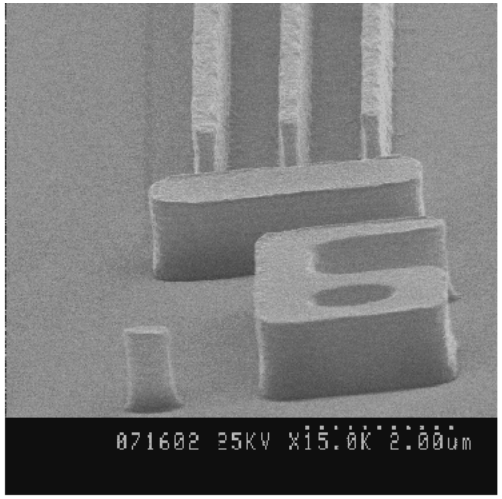
Raith resolution test pattern



9 nm holes imaged on Raith

Optical and Imprint Lithography Resources

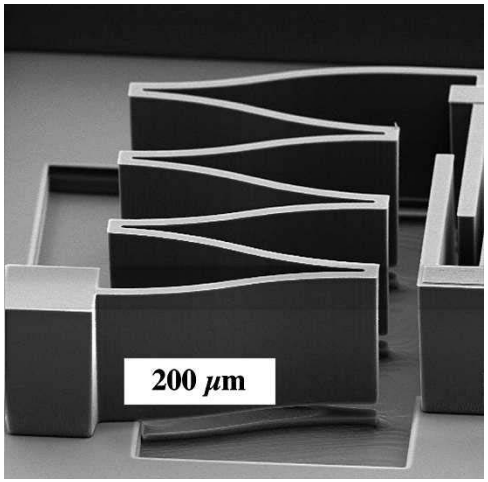
- optical steppers - Nikon body 4 and body 9 (5:1), two Ultratech 1000s (1:1)
- contact printers with backside alignment - two Karl Süss MA-6 systems, EV Group 620 aligner
- EV Group nano-imprint system
- in-house maskmaking - Micronic Laserwriter
- SVG spin/develop track, DNS spin/develop track, manual spinners
- suite of resist processes



Nikon Body 4
0.6 μm lines.

Etch Resources

STS etcher

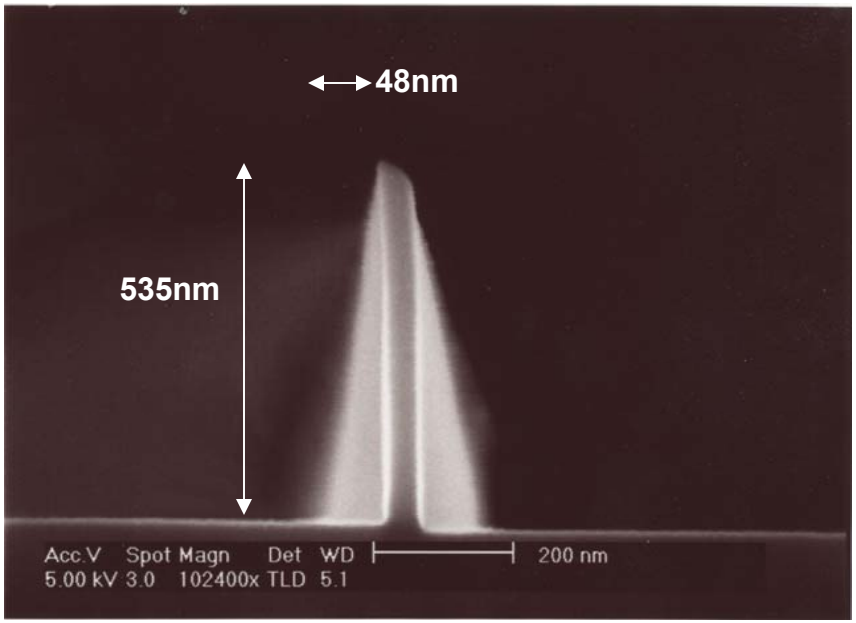


spring transducer
Klaasen, et al., Stanford

- deep silicon etch – two STS Multiplex ICP reactive ion etch systems.
- silicon/poly etch - Lam Research TCP 9400.
- nitride/oxide/silicon/polymer etch – Applied Materials 8100.
- metals/oxide/nitride/silicon/resist strip - Applied Materials 5000 cluster tool.
- GaAs/films etch – PlasmaQuest ECR etcher.
- miscellaneous materials – three Drytek 100 etchers.
- resist strip – Matrix and Gasonics

Thin Films Resources

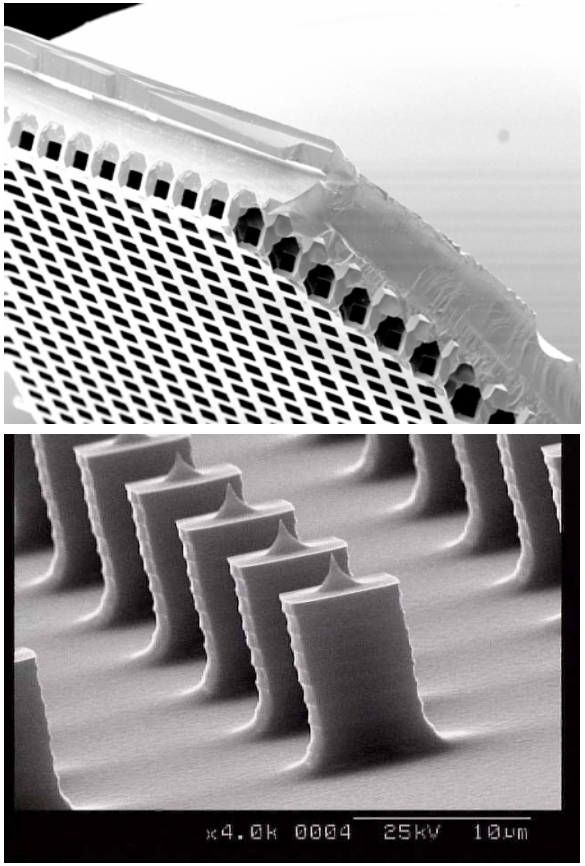
- gate oxide growth
- LPCVD of poly, nitride,
- low temperature oxide
- low-stress nitride
- low stress PECVD of dielectrics
- ASM Epsilon II single wafer epitaxial reactor - silicon, silicon/germanium, germanium
- atomic layer deposition system – Al_2O_3
- metal sputtering and evaporation - Cu, Al, AlSi, W, Ti, Au, Cr, Pt, NiCr
- sputtering of some dielectrics and ferromagnetic materials



high aspect ratio nitride spacer
Hoon Cho and Professor Krishna Saraswat, Stanford

Analytical Tools

- scanning electron microscopes
  Hitachi S-800 – out of fab
  Hitachi 4160 – in fab
- Digital Instruments atomic force microscope
- Zygo optical profilometer
- ellipsometer, profilometers
- spectrophotometer
- resistivity mapping
- film stress gauge

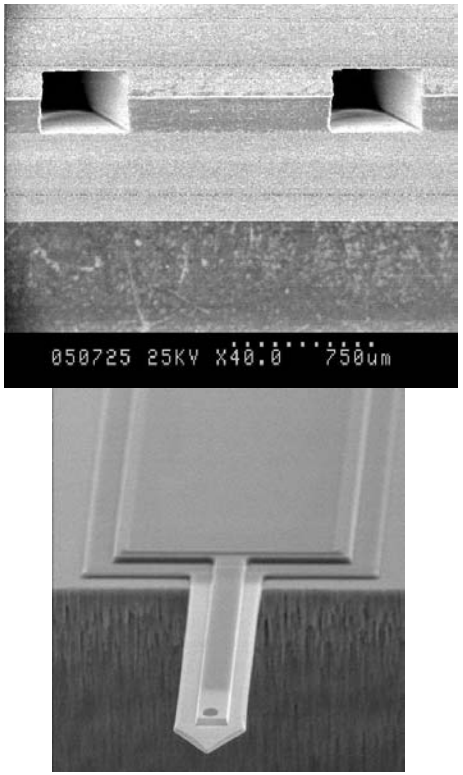


3-D cell network substrate and microelectrode array
Rainer Fasching, Kyle Hammerick, Eric Tao,
Professor Fritz Prinz, Stanford

Miscellaneous Equipment

- wafer aligner/bonder - EV Group, Karl Süss
- Tousimis critical point dryer
- HF vapor etch
- thermal bonding
- wafer saw
- chemical mechanical polishing for dielectric materials

Glass
Silicon
Glass



flow channel system cross section (top) and injector needle (bottom) Stefan Zappe, John Zhang and Professor Olav Solgaard, Stanford

Coral Laboratory Management Software

Window Equipment Actions Reservation Actions History Actions Staff Actions

Stanford Nanofabrication Facility

- E-Beam, SEM & Mask Making
  - ebeam
  - masksrub
  - micronic
  - raith (jwc)
  - sem4160
  - semhitachi
- Optical Photolithography
- Chemical Vapor Deposition
- Metalization & Sputtering
- Dry Etching
- Annealing, Oxidation & Doping
- Wet Benches
- Wafer Bonding and Sawing
- Characterization & Testing
- Facilities

Reservations | History | Maintenance | Policy | Equipment Status Summary | Staff Charges

raith History

	Fri, JAN 21	Sat, JAN 22	Sun, JAN 23	Mon, JAN 24	Tue, JAN 25	Wed, JAN 26	Thu, JAN 27	Fri,
0:00	joshuar	ryantu	englund	englund	edo	ifushman	ajavey	jrgol
0:30	joshuar	ryantu	englund	englund	edo	ifushman	ajavey	jrgol
1:00	joshuar	ryantu	englund	englund	edo	ifushman	ajavey	
1:30	joshuar	ryantu	englund	englund	edo	ifushman	ajavey	
2:00		ryantu	englund	englund	edo	ifushman	ajavey	
2:30		ryantu	englund	englund	edo	ifushman	ajavey	
3:00		ryantu	englund	englund	edo	ifushman	ajavey	
3:30		ryantu	englund	englund	edo	ifushman	ajavey	
4:00		ryantu	englund	englund	edo	ifushman	ajavey	
4:30		ryantu	englund	englund	edo	ifushman	ajavey	
5:00		ryantu	englund	englund	edo	ifushman	ajavey	
5:30		ryantu	englund	englund	edo	ifushman	ajavey	
6:00		ryantu	englund	englund	edo	ifushman	ajavey	
6:30		ryantu	englund	englund	edo	ifushman	ajavey	
7:00		ryantu	englund	englund	edo	ifushman	ajavey	
7:30		ryantu	englund	englund	edo	ifushman	ajavey	
8:00		ryantu	englund	englund	edo	ifushman	ajavey	
8:30		ryantu	englund	englund	edo	ifushman	ajavey	
9:00		ryantu	englund	englund	edo	ifushman	ajavey	
9:30		ryantu	englund	englund	edo	ifushman	ajavey	ryan
10:00	ryantu	ryantu	englund	englund	edo	ifushman	ajavey	ryan
10:30	ryantu	ryantu	englund	ryantu	edo	ifushman	ajavey	ryan
11:00	ryantu	ryantu	englund	ryantu	edo	jiencao	ajavey	ryan
11:30	ryantu	ryantu	englund	ryantu	edo	jiencao	ajavey	ryan

- equipment reservations, use tracking, billing
- user training and qualification, remote access
- equipment problem and shutdown reporting

NNIN