Introduction to the Stanford Nanofabrication Facility and Research Examples

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presented to the IEEE Santa Clara Valley Solid State Circuits Society
January 19, 2006
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
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-focused 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.

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.
- 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
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 ft² (1k m²) 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.
- 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
SNF Organization

Prof. Yoshio Nishi

Paul Rissman
- strategic issues
- budget
- administration

Jim McVittie/Mike Deal
- lab consultants
- special programs

Mary Tang
- biotech liaison
- processing/training
- outreach
  (7 staff)

Dick Crane
- equip maint
- facility safety
- code compliance
  (8 staff)

Cam Chan
- monthly accounting
- NSF contract
- business development

John Shott
- NNIN liaison
- CORAL development
- ERT
- labmember services
  (3 staff)

Ed Myers
- process development
- new materials
- new equipment
- contamination

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
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

- 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.
- 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 – $\text{Al}_2\text{O}_3$
- 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

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