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*The Second U.S.-Korea Forum on Nanotechnology:
Nanomanufacturing Research and Education*

**Nano-Scale Manufacturing:
Top-down, Bottom-up and System Engineering**

Cheng Sun, Xiang Zhang

Center of Scalable and Integrated Nanomanufacturing (SINAM)
University of California, Berkeley

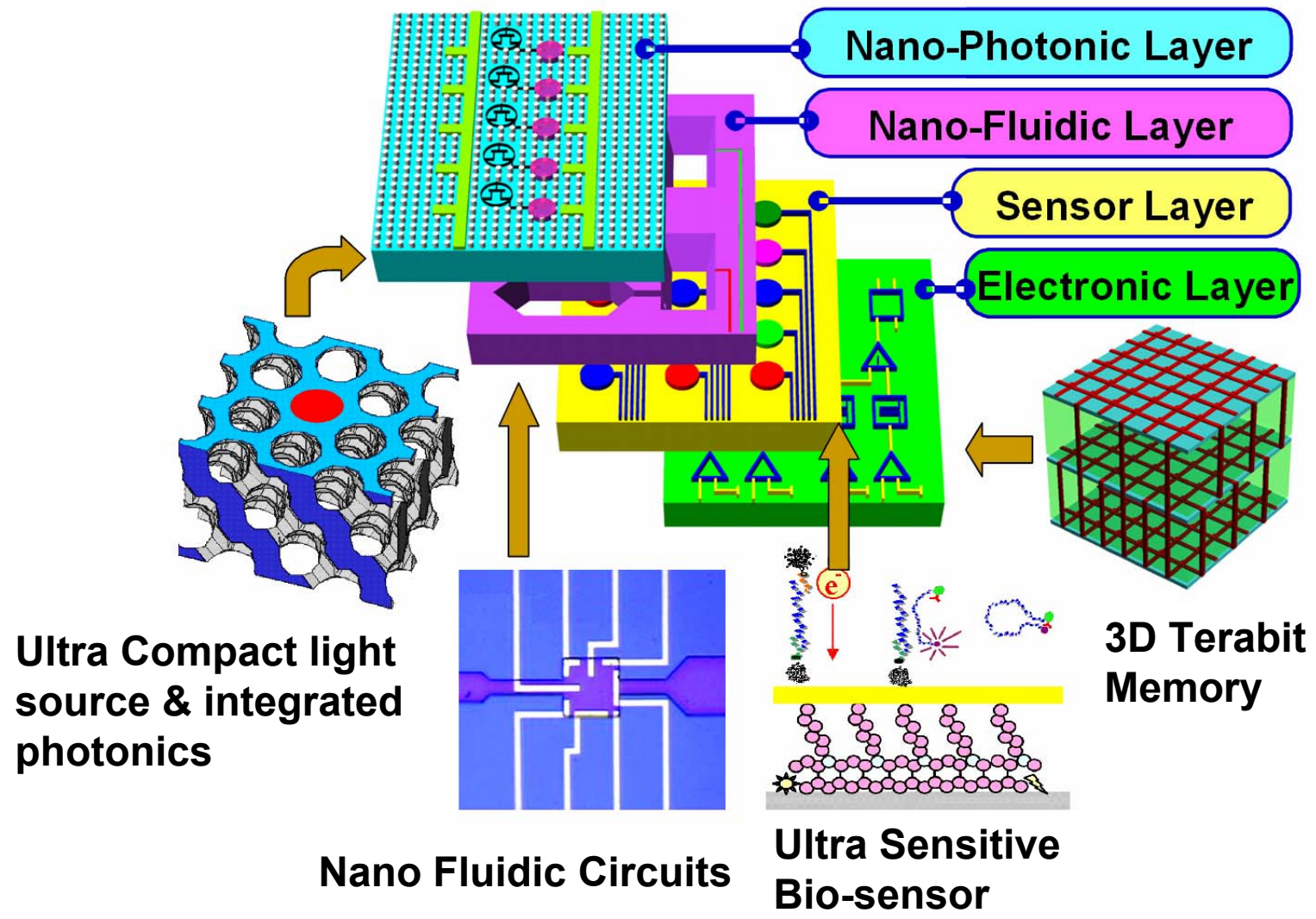
*Los Angeles, CA
February 17-18, 2005*



NSF Nanoscale Science and Engineering Center (NSEC)



Future Integrated Nano-Systems



Nano-Manufacturing Grand Challenges

State of Art

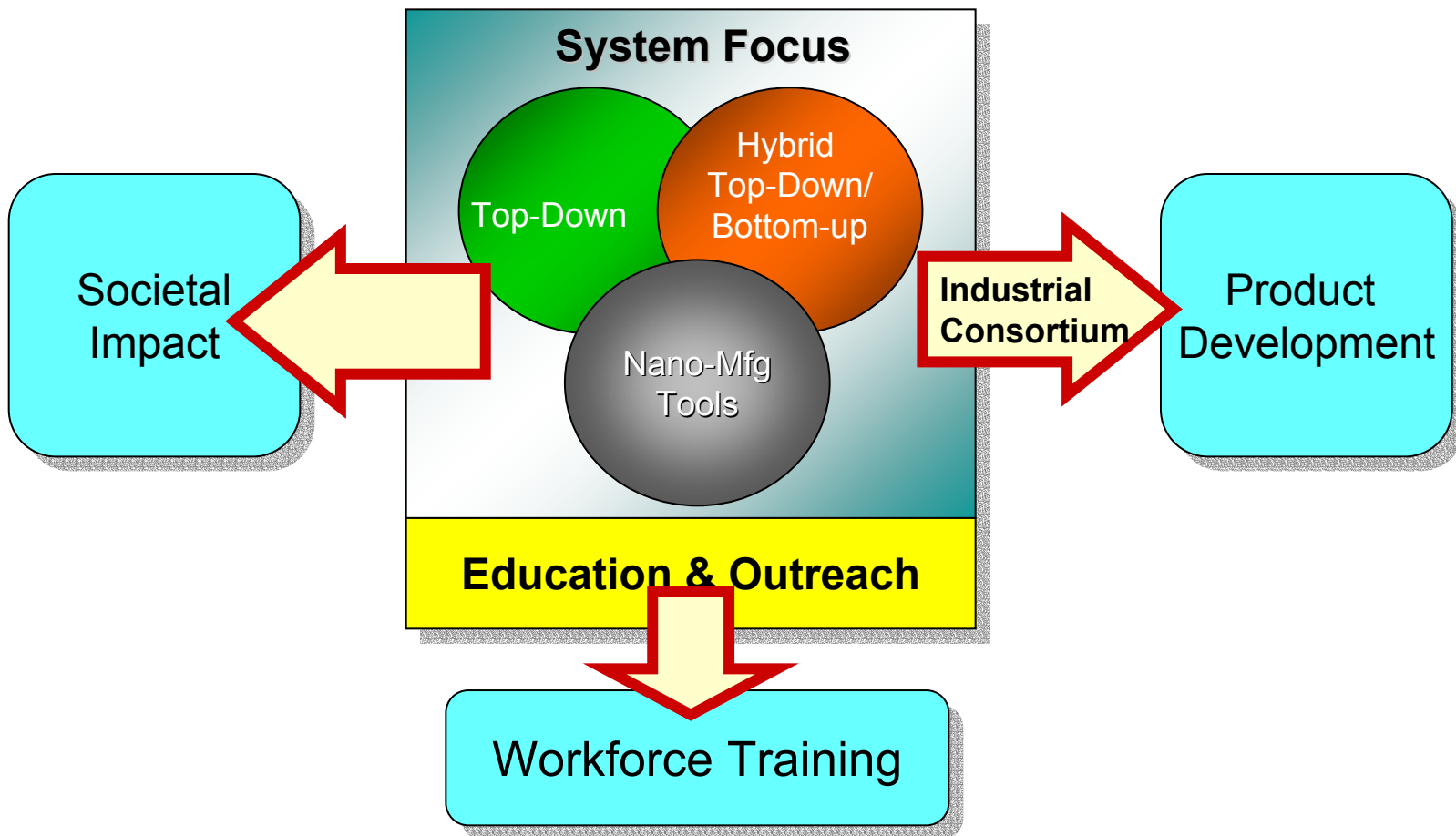
- Prohibitive cost (EUV > \$25M/tool), low speed (EBL)
- Not suitable for 3D (nanoimprint, soft lithography)
- Prone to defects (self-assembly)

Technological Barriers

- Dimension below 20 nm → High density devices
- 3D complex nanostructures → Low power, high speed (Rent's law)
- Heterogeneous integration → Multiple functionality

Center of Scalable & Integrated Nanomanufacturing

Vision: *To Develop A New Nano-Manufacturing Paradigm that Enables the Quantum Leap from Lab Science to Industry floor*



Core Research Competence

Physical Science

Stoddart, Osher

Materials

Hahn, Chen,
Frechet, Maynard

Manufacturing

Dornfeld, Prinz, Hocken,
Tsao, Lavine, Zhang

Design & Modeling

Grigoropoulos,
Caflich, Goodson

Devices

Heller, Majumdar,
Ho, Yablonovitch

1+1>2!



IRG I. Top-Down Nano-manufacturing

Participants: Zhang (*lead*), Yablonovitch, Frechet, Goodson, Osher, Grigoropoulos

Critical Challenges

Semiconductor Manufacturing at a crossroads

- 50 nm resolution limit
- Lacking 3D capability

Goal

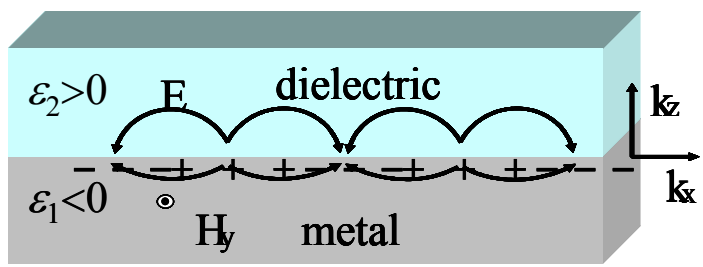
3D nano-manufacturing with 1-20 nm resolution

Approaches:

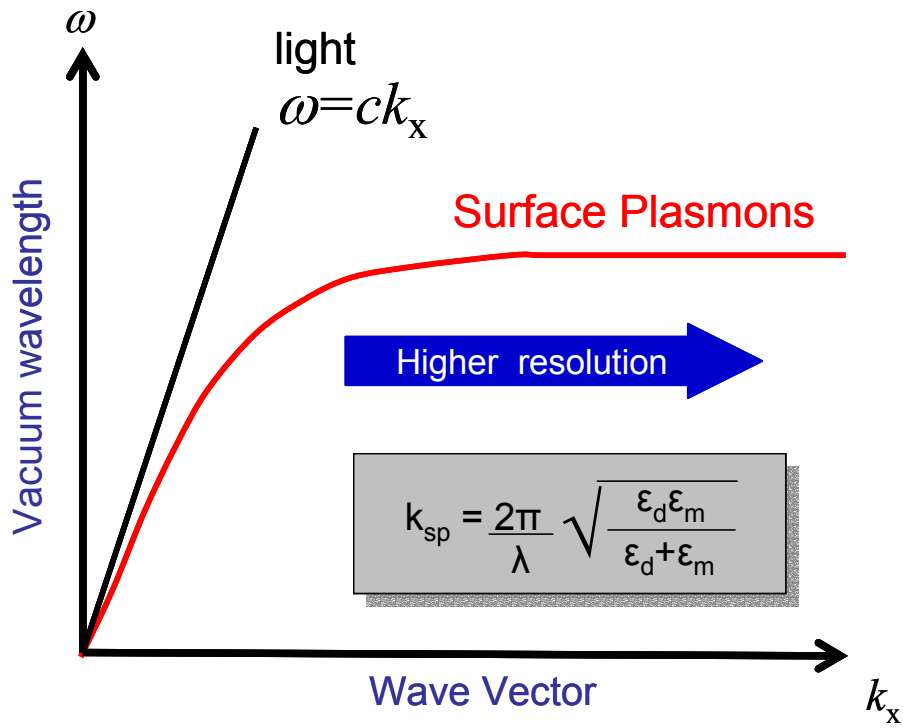
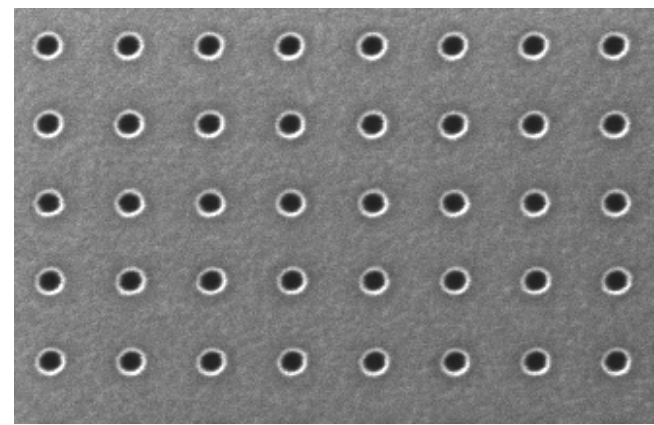
- Plasmonic Imaging Lithography (PIL)
- Ultra Mold Imprinting Lithography (UMIL)

Plasmonic Imaging lithography

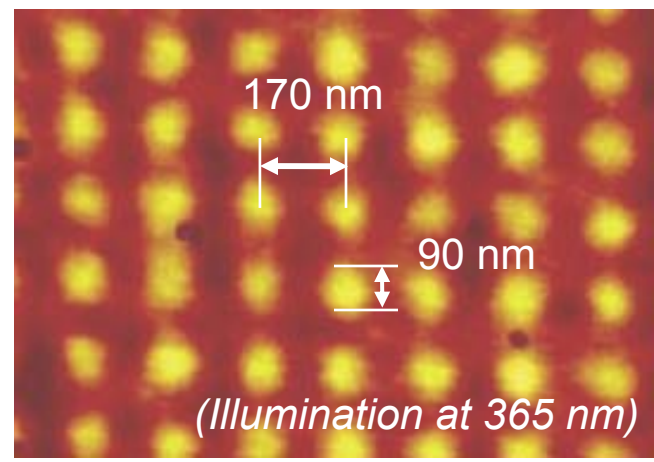
Surface plasmon: **Optical wave frequencies, with X-ray wavelengths!**



Mask fabricated by FIB

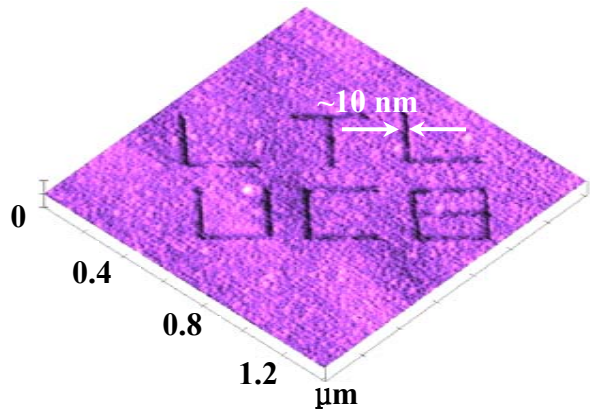


90nm features



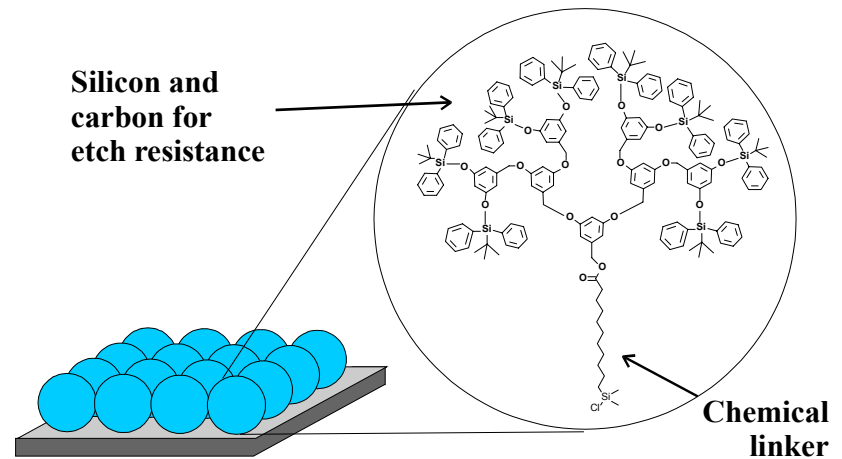
Characterization, Modeling and Material Engineering

Nanolitho Characterization Platform

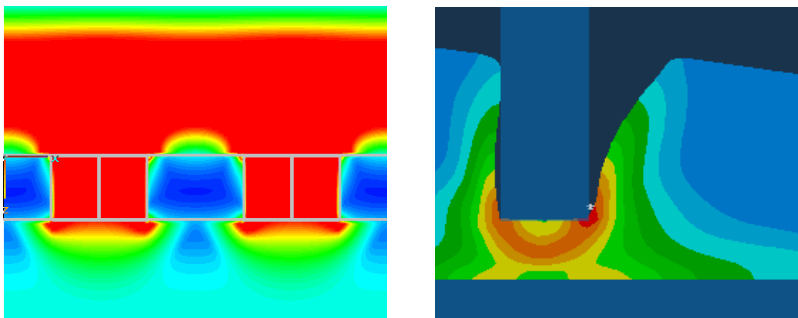


[Grigoropoulos, UCB]

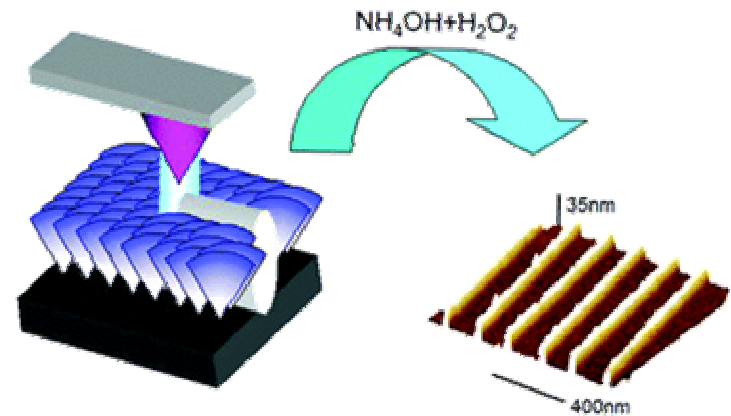
Materials issues at very small dimensions:
Dendrimer molecules as “molecular pixels”



Process Modeling



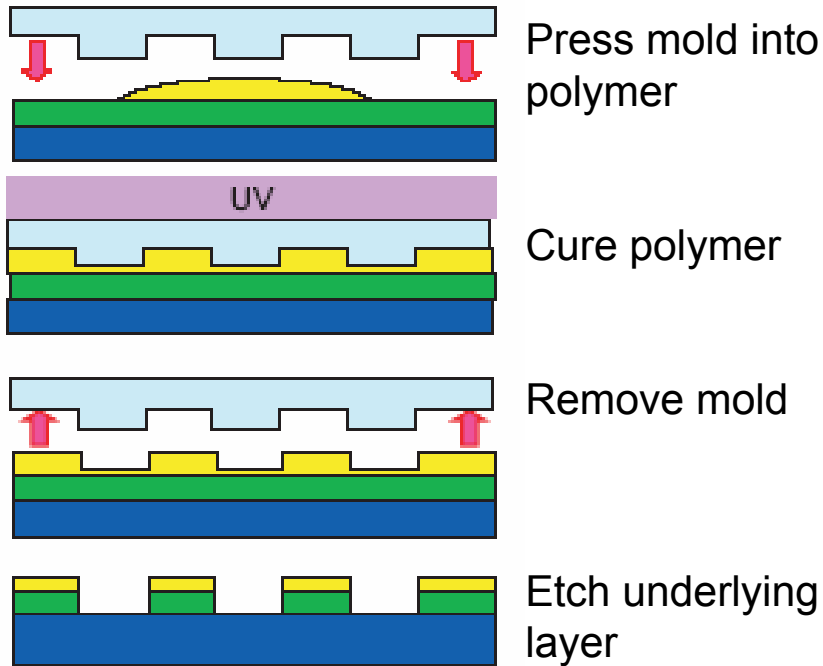
[Grigoropoulos, Zhang, UCB ; Hahn, UCLA]



[Frechet, Grigoropoulos, UCB]

Ultra Molding Imprint Lithography

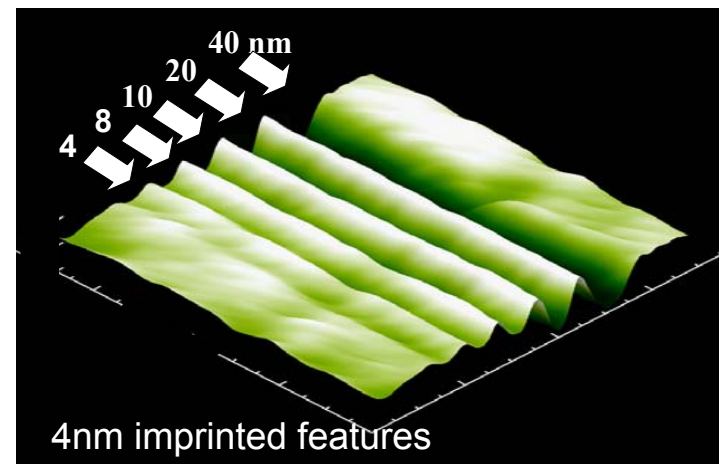
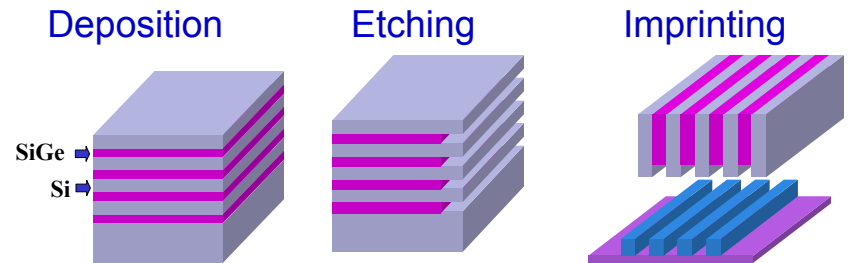
Conventional Nanoimprint Lithography



L.J. Gou, J. Phys. D, 2004

Ultra Molding Imprint Lithography

Sub-10 nm mold fabricated using Superlattice of alternating SiGe and Si multilayers.



[Chen, Hahn, Tsao, UCLA; Wang, HP; Hocken, UNCC]



IRG II. Hybrid Top-down and Bottom-up Nanomanufacturing

Participants: Ho (lead), Chen, Majumdar, Caflisch, Stoddart, Heller, Maynard

Critical Challenges

Self-assembly CANNOT:

- Heterogeneously assemble pattern for devices
- Avoid “defects” due to thermodynamic nature

Goal

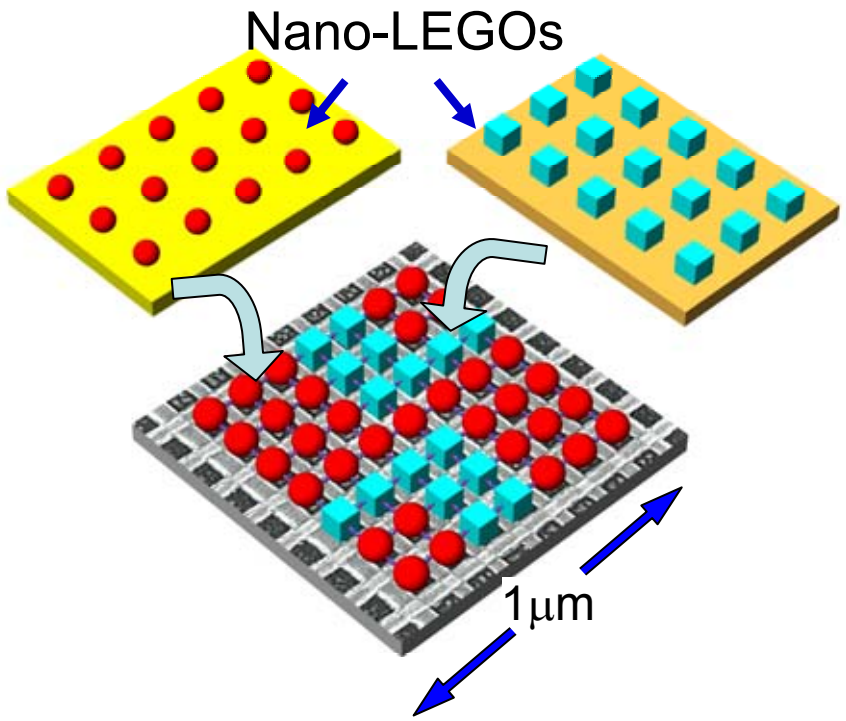
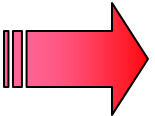
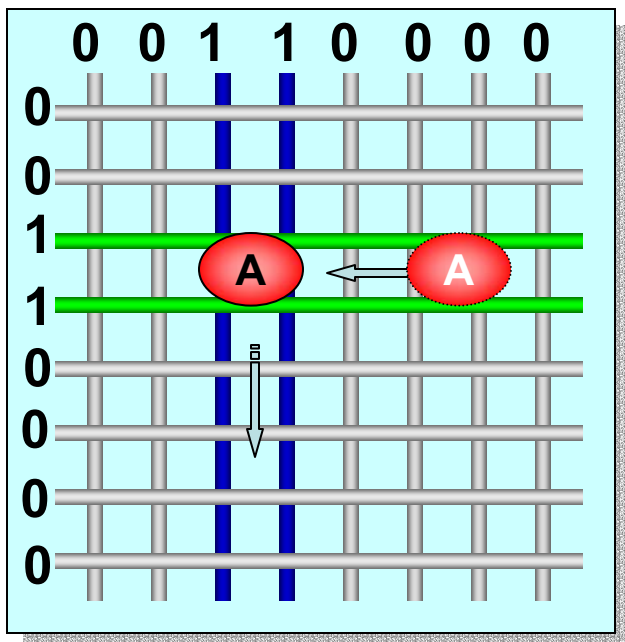
Massive and parallel integration of heterogeneous nano-LEGOs into devices

Approaches

- Hybrid Top-down and Bottom-up technologies

Field-Assisted Parallel Nano-Assembly (FAPNA)

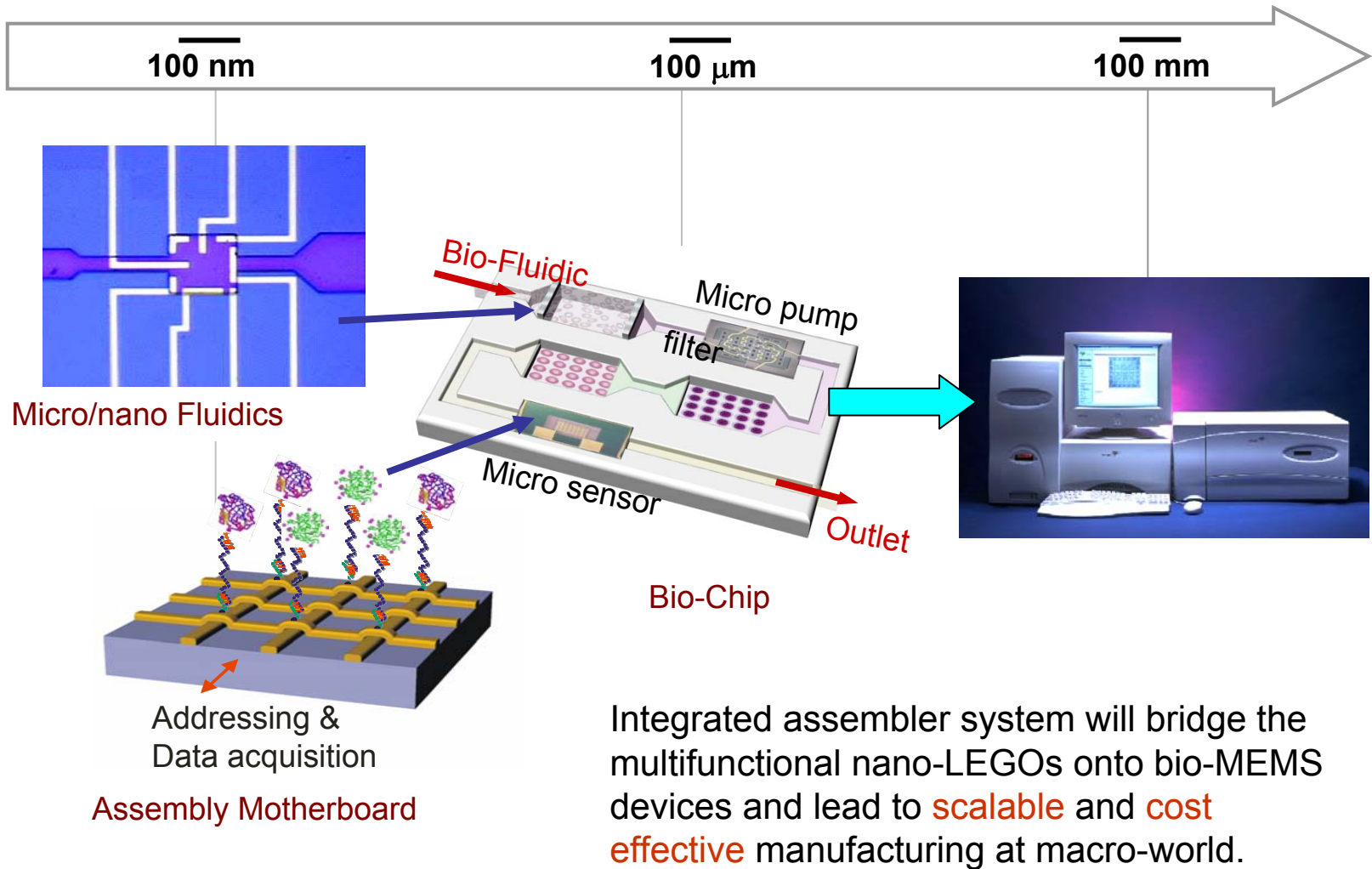
Electronic
"Pick and Place"



Nano-LEGOs: DNA/RNA, Proteins, cells, nanoparticles, molecules

[Chen, Ho, Maynard, UCLA; Heller, UCSD]

Hybrid Top-down and Bottom-up Nanomanufacturing





IRG III Manufacturing System Engineering

Participants: Tsao and Prinz (lead), Dornfeld, Hocken, Hahn, Caflisch, Lavine

Critical Challenge

- Scaled-up nano-manufacturing for high throughput and high yield

Goal

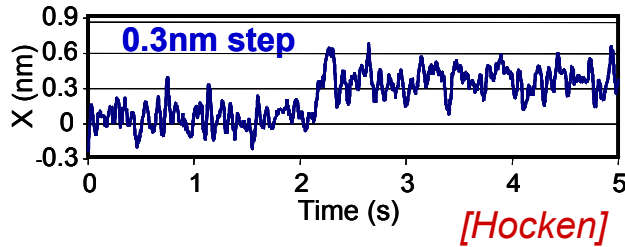
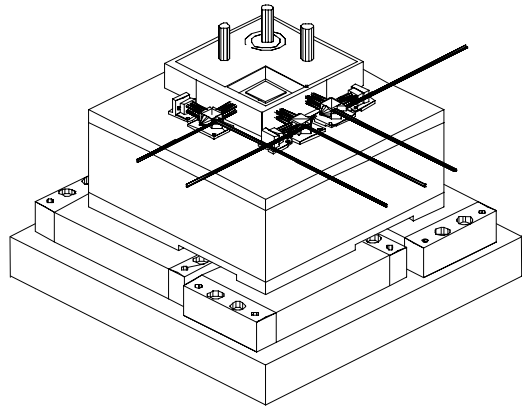
Develop Nano-manufacturing cluster tool

Approaches

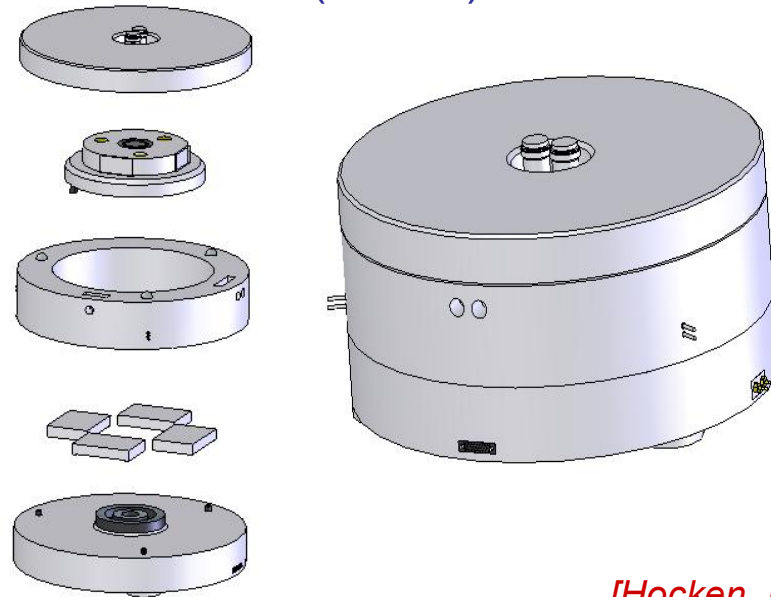
- Design for nano-manufacturing
- Tooling and metrology
- Reliability and scalability

NanoManufacturing Platform - UMIL

UNCC 3D Sub-atomic Measuring Machine

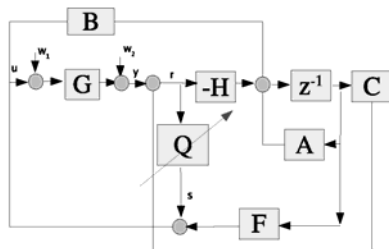


Multiscale Alignment and Positioning System (MAPS)



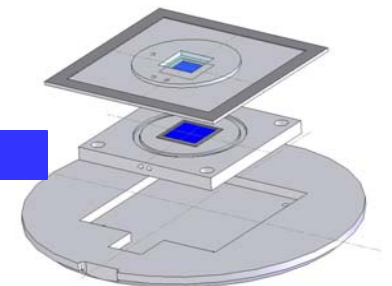
[Hocken, UNCC]

Dynamic Positioning Control



[Tsao, UCLA]

Imprinting Module



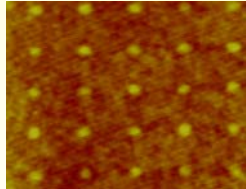
[Chen, UCLA]

The Ultimate Imprint Machine
 1 nm Alignment Precision
 Sub – 5 nm Imprinting Precision

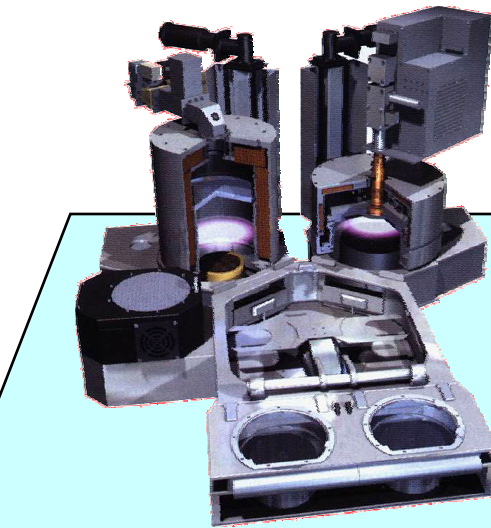
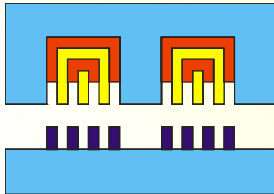
SINAM NanoMFG Technologies and Tools

Top-down NanoMfg

Plasmonic Imaging
Lithography

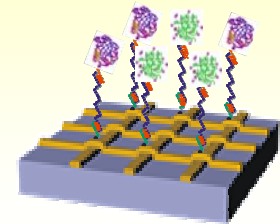


Ultra Mold Imprint
Lithography



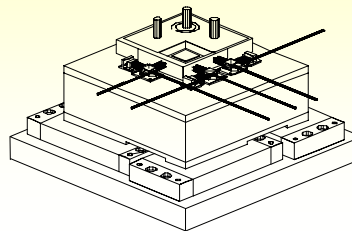
System Level Focus and Testbed

Hybrid Top-down & Bottom-up

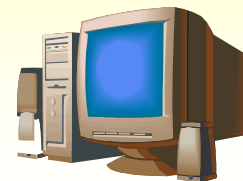


Design for Nanomanufacturing

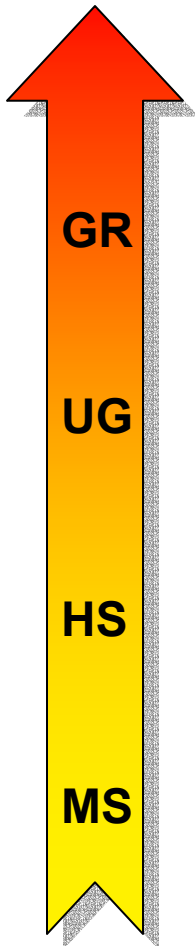
Metrology



3D nano-CAD



Integrated Educational Program



Graduate Young Investigator Program

- Enhancing **interdisciplinarity** and connections between faculty

Interdisciplinary Curricula

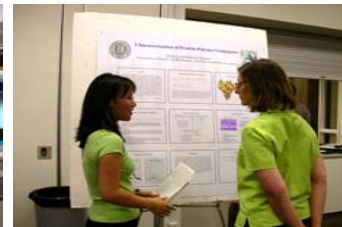
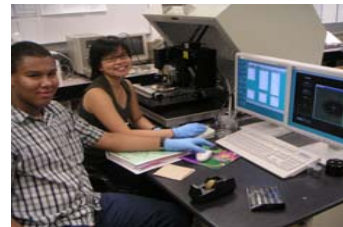
- **Five** interdisciplinary, research-integration courses developed by SINAM faculty

Nano-Manufacturing Summer Academy/REU

- **Six** undergrad and **Three** high school students into faculty labs, integrating research into their education

Discover Nanotechnology (Grades 7-12)

- SINAM is developing an education module using Nano- manipulator



SINAM Collaborative Network

SINAM Industrial Collaborations

- ❑ *HP Lab*
- ❑ *RAND Corporation*
- ❑ *Boeing Company*
- ❑ *Northrop Grumman*



Establishing Broad Collaborative Network

- ❑ *National Institute of Health*
Focus: Muscle Molecule assembly
- ❑ *Semiconductor Industrial Association*
Focus: Nanoelectronic Research Initiative and collaboration with SIA members
- ❑ *Center for Nanoscale Mechatronics and Manufacturing*
Focus: International collaboration in the Nanomanufacturing