Self Assembly and Biologically Inspired Processes in Applied Nanotechnology: Current and Emergent Developments

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SILICON VALLEY NANO VENTURES

Nano Electronics & Photonics Forum

INSTITUTE FOR GLOBAL FUTURES

Primary Areas of Interest – Nano Electronics and Photonics Forum

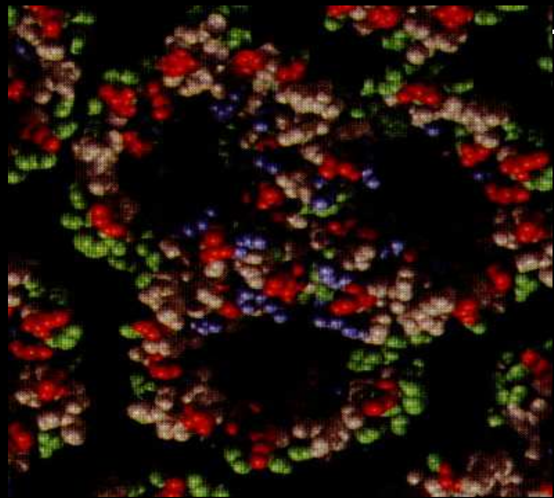
- Molecular Switches, Gates, Sensors
- Nanowires and Interconnect Systems
- **Self Assembly Enabled Fabrication**
- **Nanobiological Materials and Processes**
- Memory and Reconfigurable Architectures
- Electro-Optical Materials and Nanostructures
- Bandgap, Nonlinear, & Other Photonic Systems
- Quantum Devices & Spintronics
- Nanostructured materials with Novel Photonic and / or Electronic Properties
- Nanoprinting, Imprinting, "Soft" Lithography, & Molecular Deposition

Self Assembly
Process Development Trajectories

- Enhance “Friendliness” to Novel Materials in “Traditional” Micro-litho Fab Facilities
- Integrated Biological and Non-Biological NanoStructures
- Supra-molecular Synthesis
- Integrated / Inter-related Techniques for Patterning Matter
- Chemical Handles for Attachment to Surfaces
- Fabrication processes approaching ZIP – Zero Inventory Production – capacity
- Utilizing Biology as a Foundry

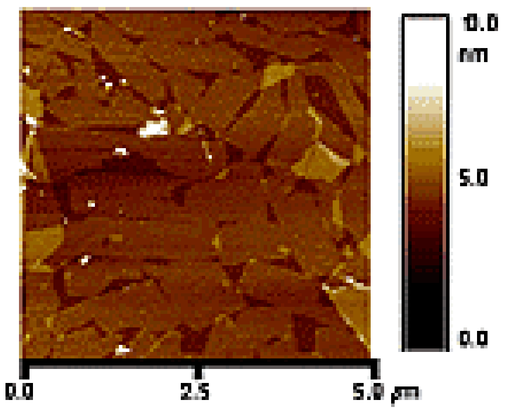
Self Assembly and Biologically Inspired Processes

- Why Self Assembly?
- Why Biology?
- Market Models, Economic Considerations
- Example Technology Developments
- Future Trends
- Conclusions

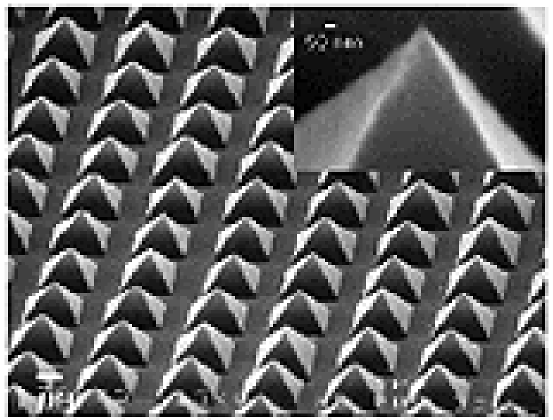


Why Self Assembly? – Functional Attributes, Target Goals

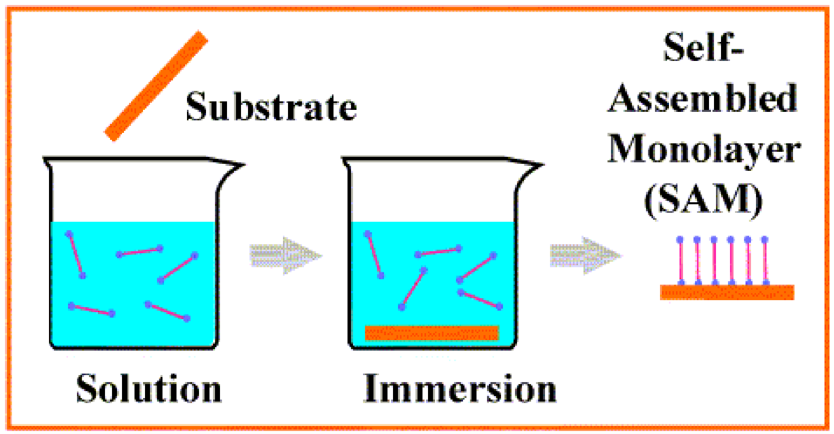
- Just as needed fabrication processes
- Functional Diversity
- Low cost, disposable device technology
- Highly adaptable

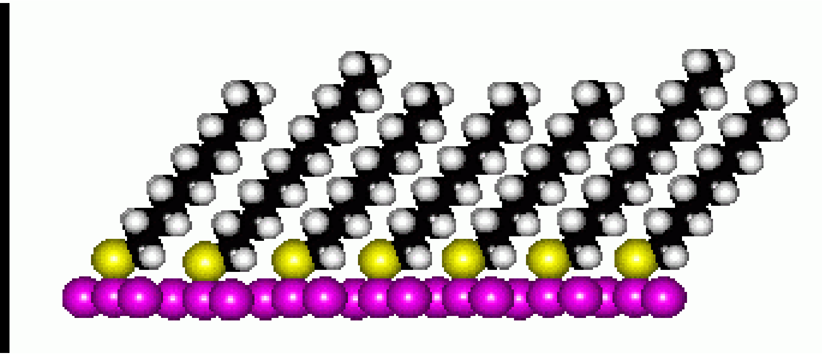


AFM image of a self-assembled monolayer of 1 nm thick [Ti Nbo$_5$]$_x^{x-}$ sheets on Si/So$_x$/ [Al$_{13}$O$_4$(OH)$_{24}$(H$_2$0)$_{12}$]$^{7+}$



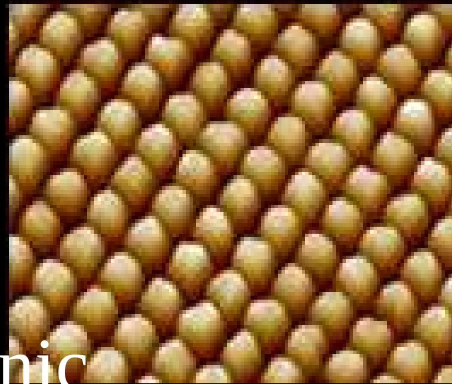
SEM micrograph (22 x 17 µm, inset is 1 x 0.67µm) of an array of silicon pyramidal tips fabricated by sol-gel micro-molding.

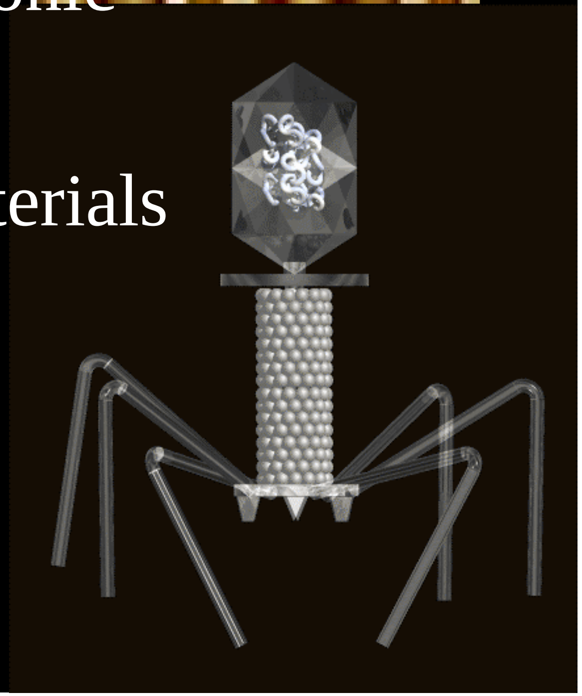


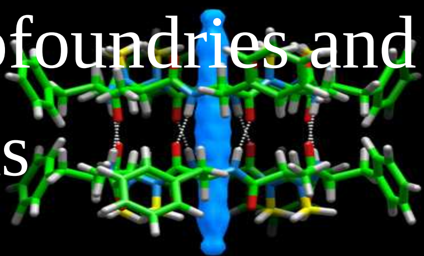


Examples of Nanofabrication Enabled by Self Assembly and Biologically Inspired Processes

- Self organizing / assembling nanocrystals and quantum dots
- SAM (Self Assembled Monolayers)
- Integrated 2D and 3D photonic and electronic structures
- Genetic “magnification” of biological materials with electronic and photonic properties
- Living organisms as biofoundries and nanomechanical systems

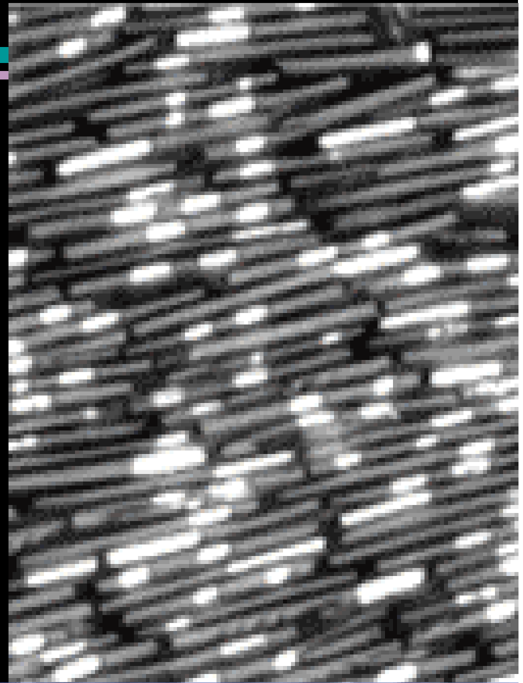


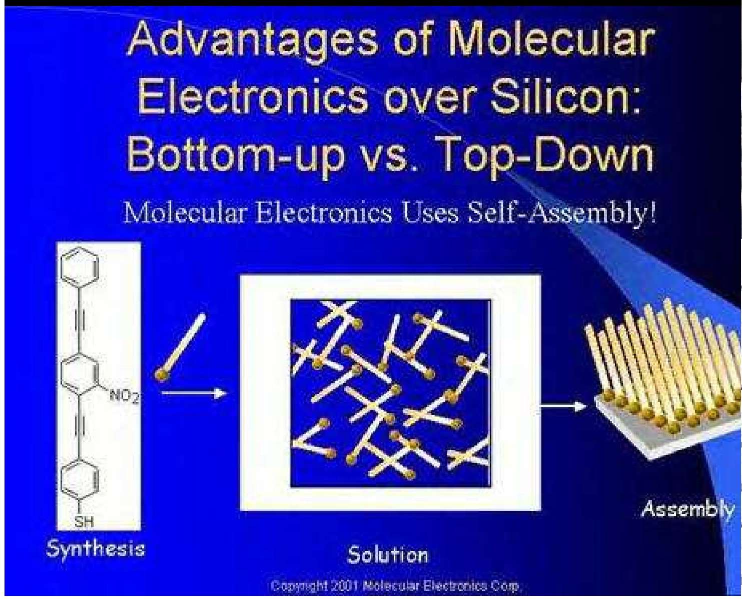




Self Assembly Reaching into Applications

- Integrated Electronics / Electro-optics
- Sensors / Distributed Detection
- Self Assembling Mirrors / Photonics
- RFID / nano-barcode



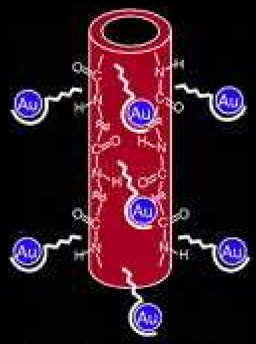
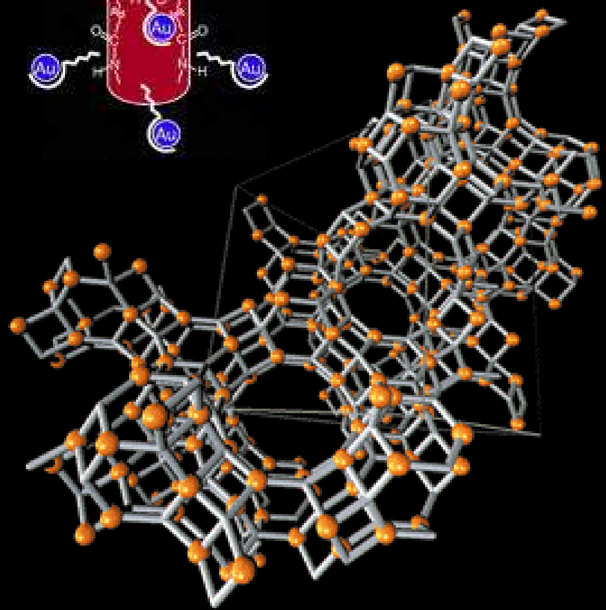
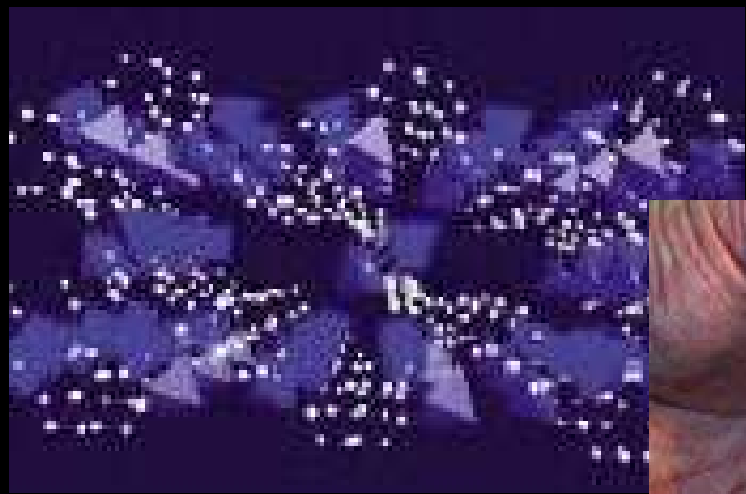


Source: University of California, San Diego

The red sides of these tiny mirrored particles are attracted to water, and their green sides are repelled by water. This causes the particles to encase the drops of oil in this container of water.

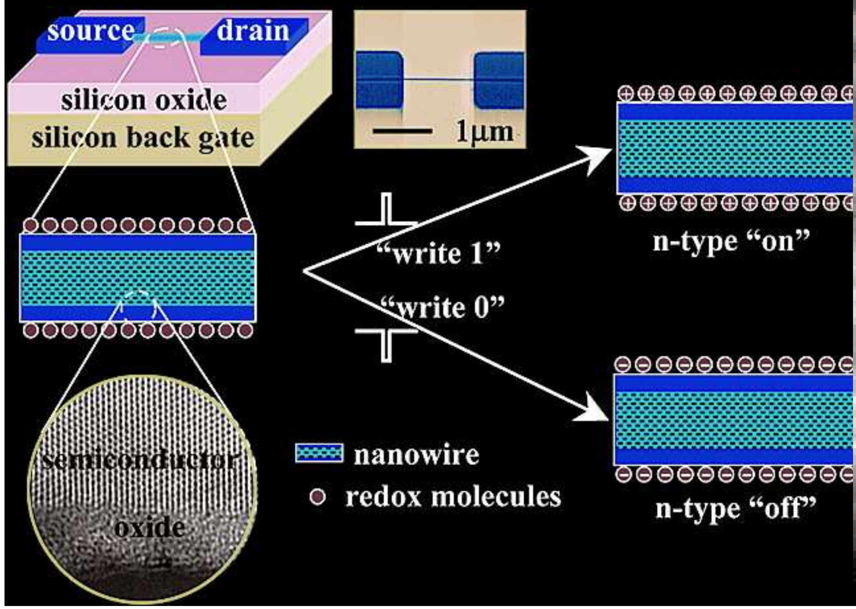
The Emergent NanoEconomy
- Self Assembly

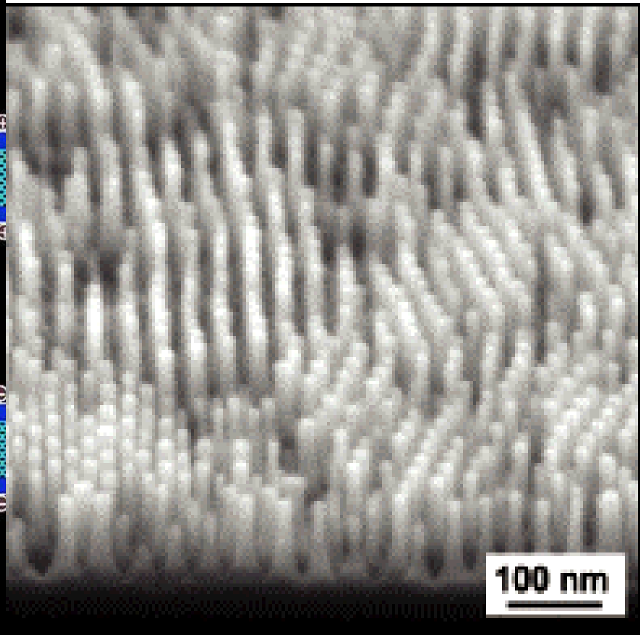
- Moore’s 1st Law is Not Relevant, Moore’s 2nd Law is
- Systems Approach to an Emergent Industrial Infrastructure
- Enabling Access to New Markets that Could Not Otherwise Exist


Integrating Current Technology and Fabrication Infrastructure Commitments with Emergent Nanofoundry Capacity

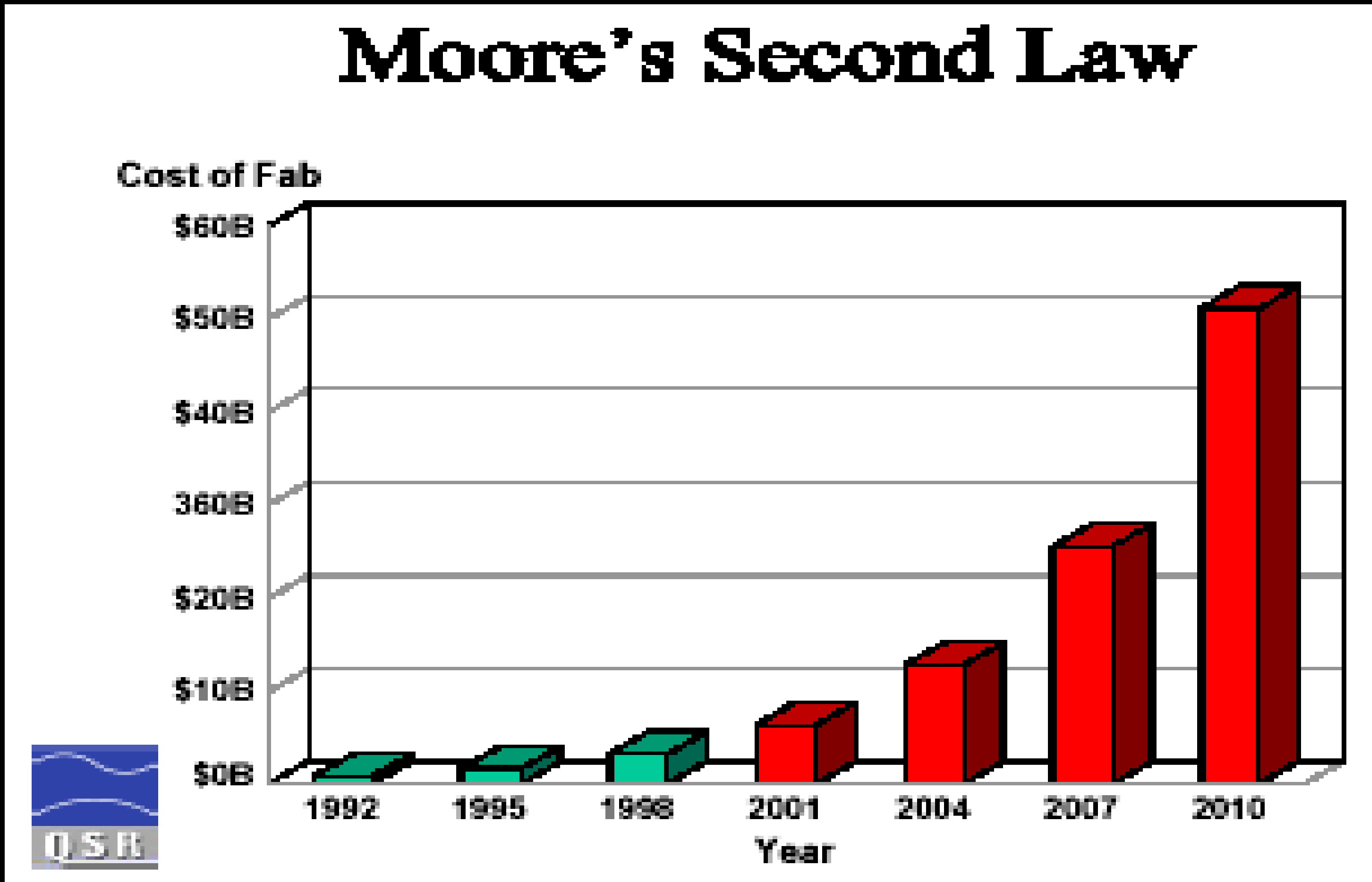
- Microscale top down silicon / CMOS becomes the “circuit board” for bottom up self organizing nanostructure systems
- Integrated “operational ecologies” of fluidics, optics, mechanical, electrical, chemical modalities
- Transition from 2D platforms to 3D manifolds





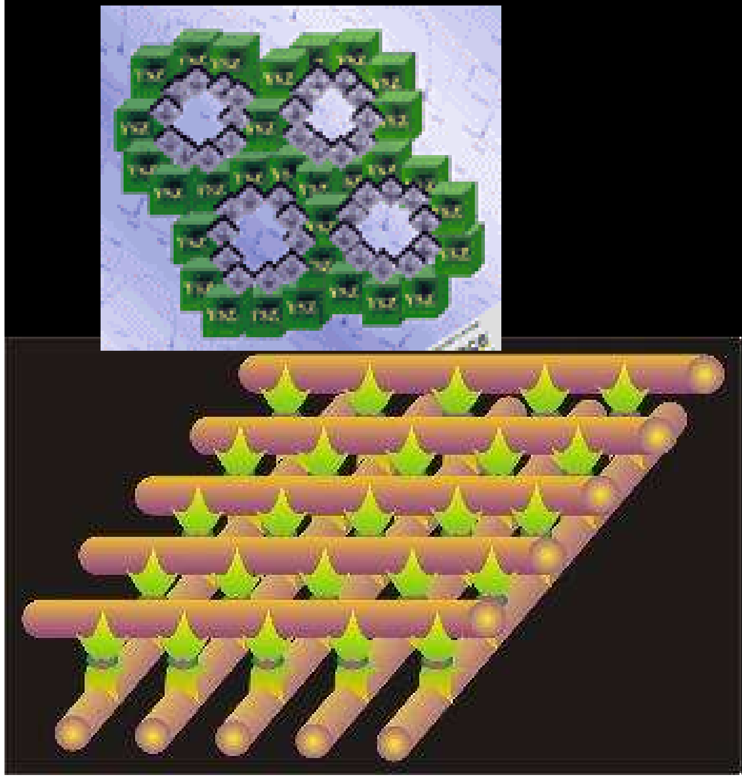
IBM combined diblock co-polymer thin films with conventional silicon processing to form these 20-nm- diameter self-assembled silicon pillar arrays. The polymer films are easily integrated with semiconductor fabrication.

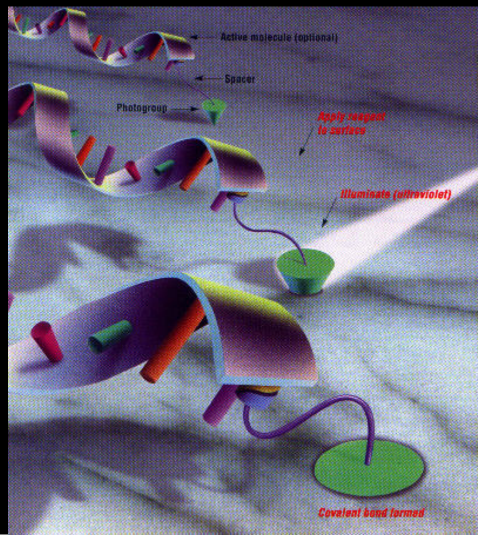
The Emergent NanoEconomy

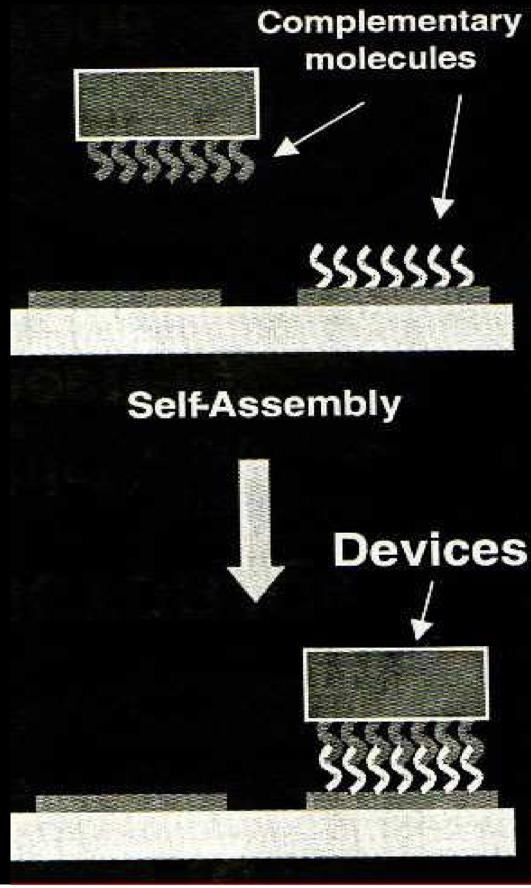


The goal is process integration

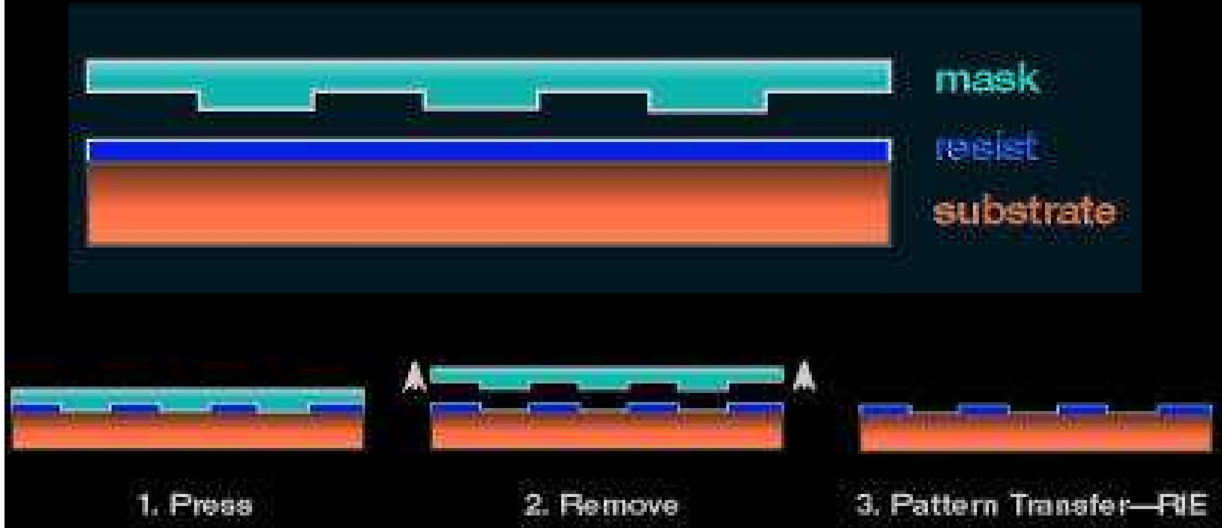
- Self Assembly / Self Organization
- Biolithography / “Soft” lithography
- Supra molecular manipulation

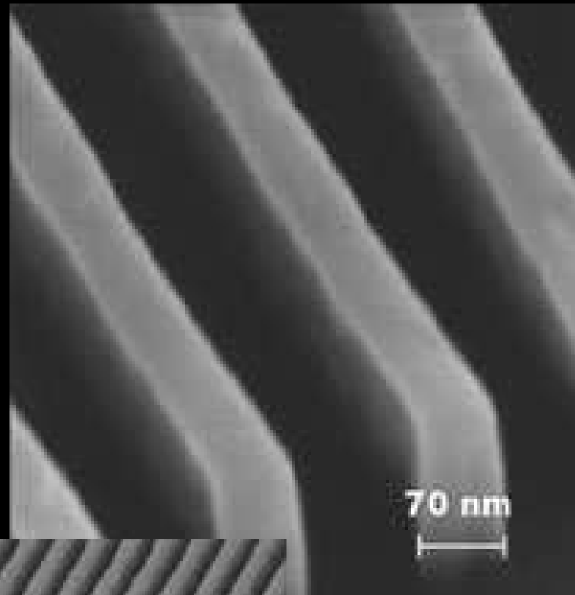


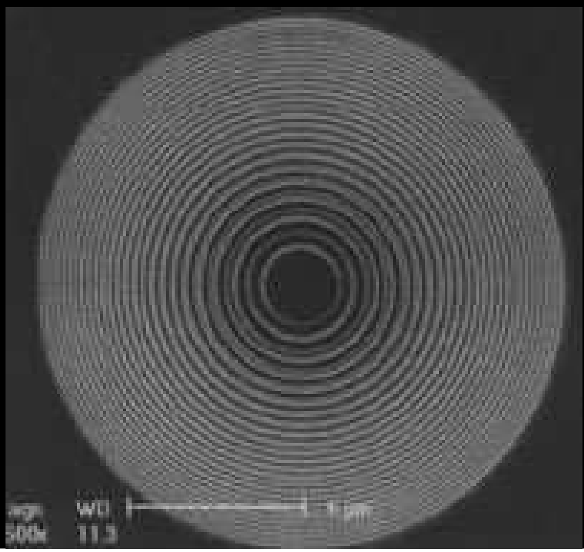


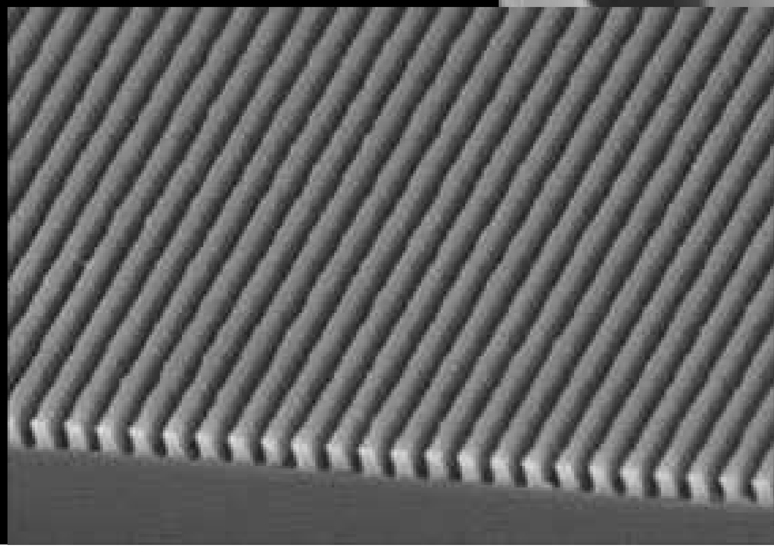


Synergistically Enabling Foundry Processes in Photonics, Electronics, Fluidics – NanoImprinting

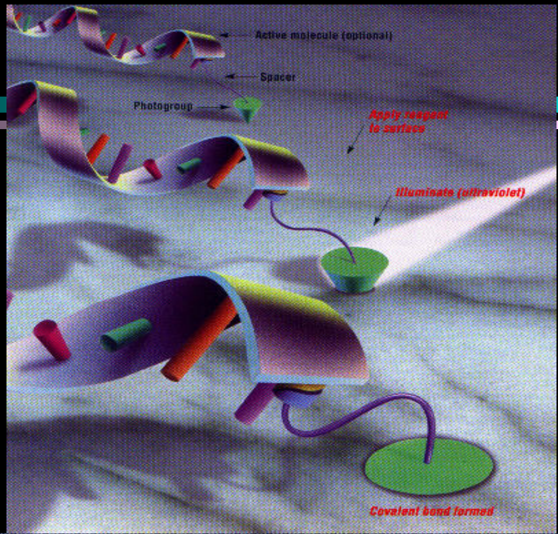


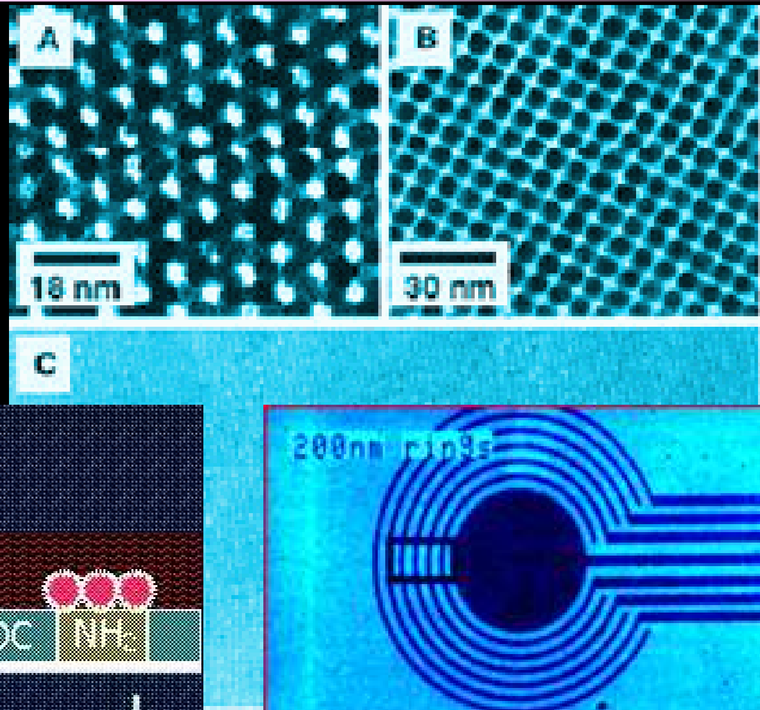


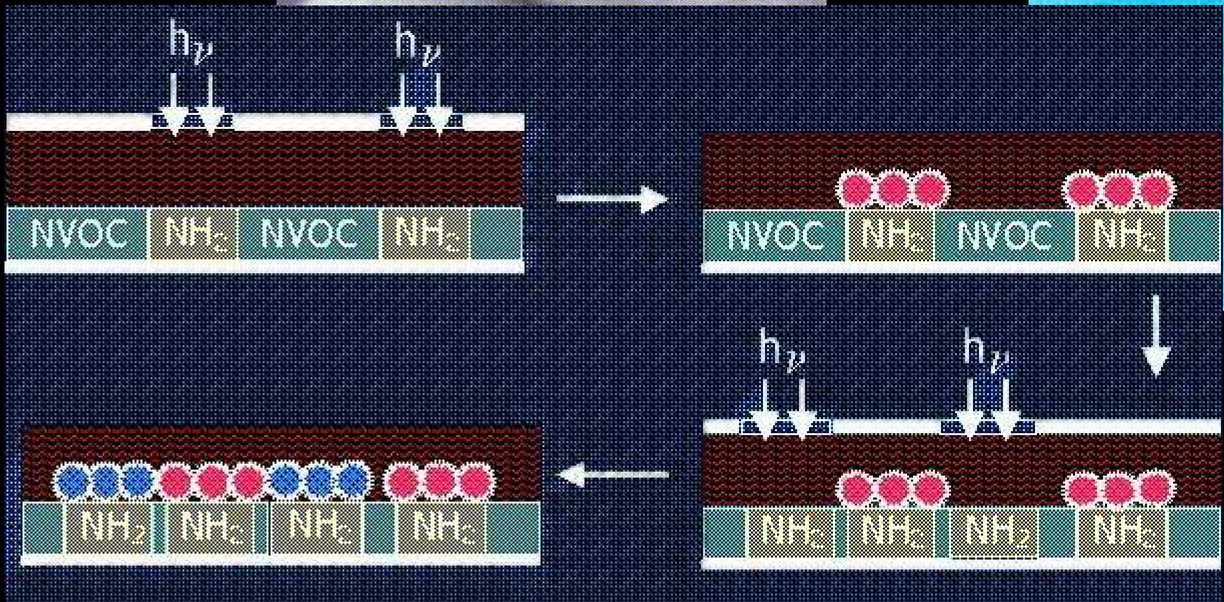


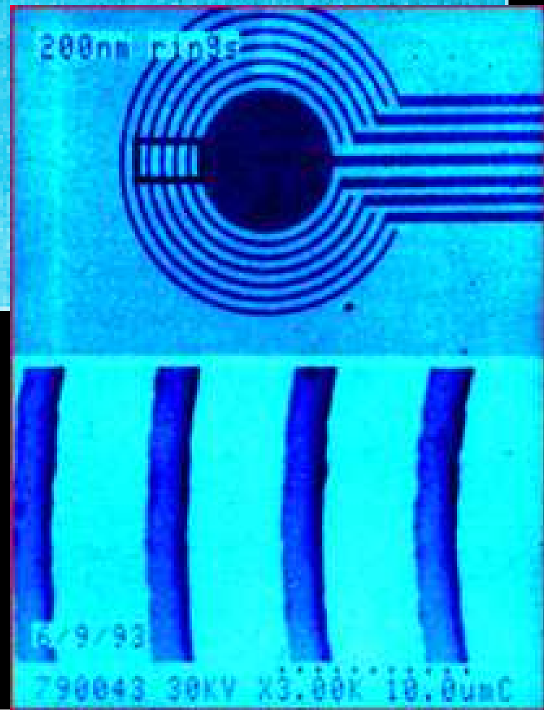


Biolithography – Directed Biochemical Assembly









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Combinatorial / Synergistically Inter-relatable Process Modalities

- Self-assembled DNA / carbon nanotube "nanobiotronic" devices

U of South Carolina - Seminario, Agapito, Figueroa

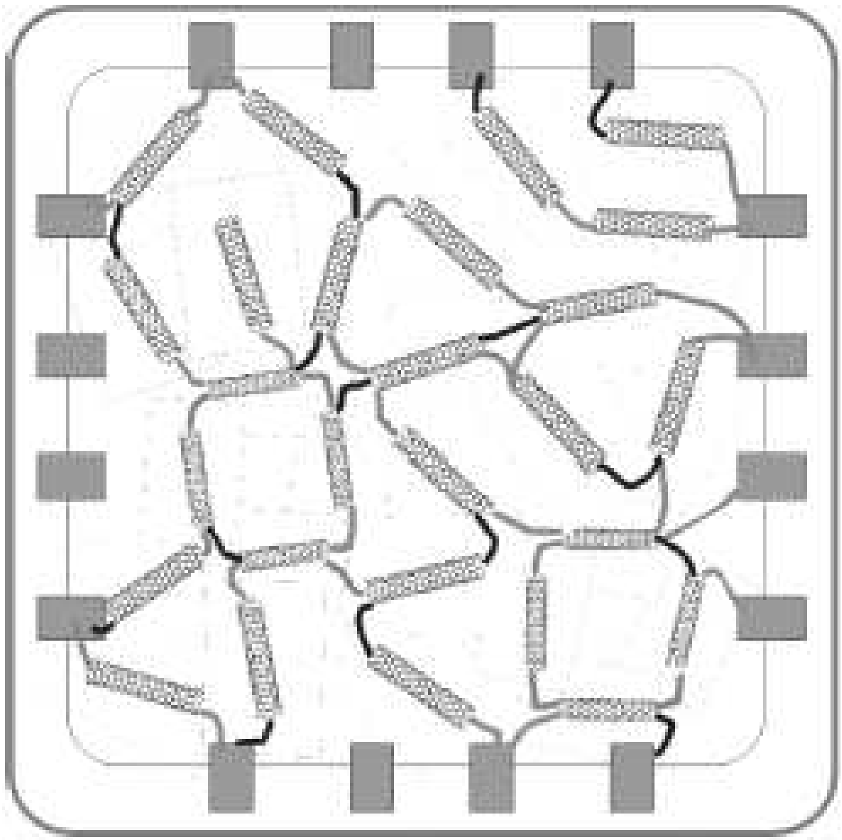
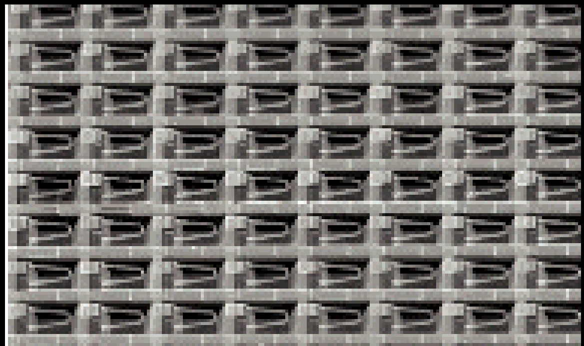


Fig. 1. A bionanochip, based in polygons made of carbon nanotubes and interconnecting DNA fragments.

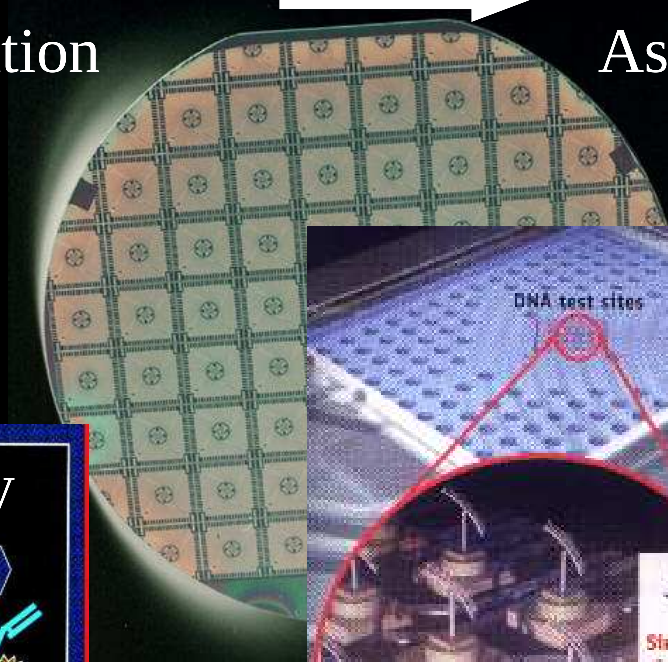
Define “Tools”

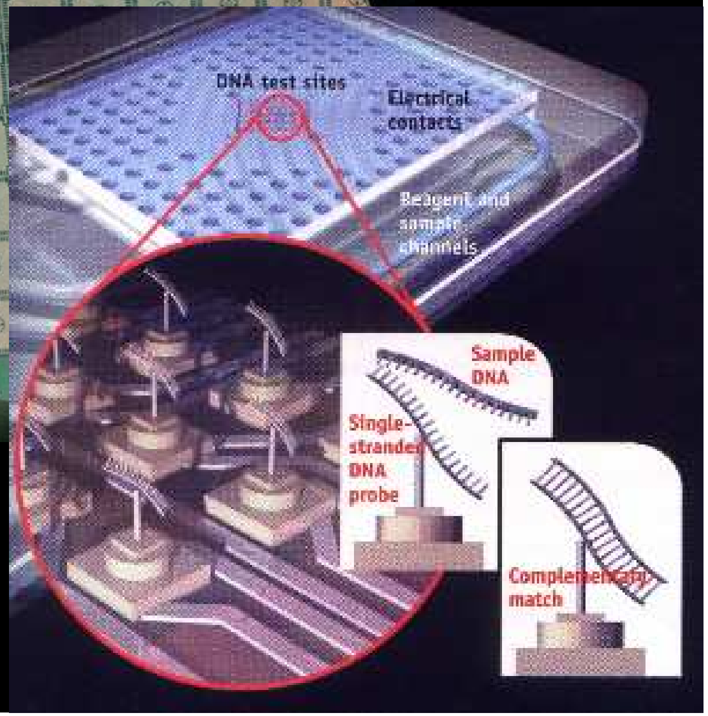
Goal of the tool is to manipulate molecules and pattern matter

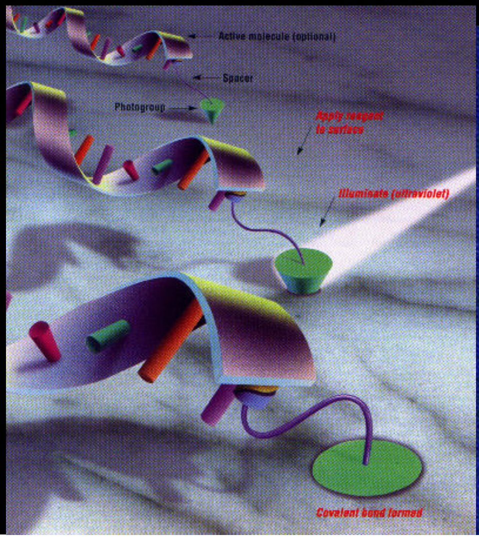
AFM devices / arrays



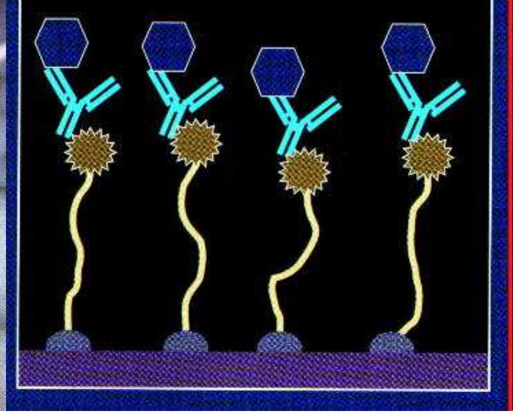
Electro-Molecular Manipulation → Heterogeneous Assembly





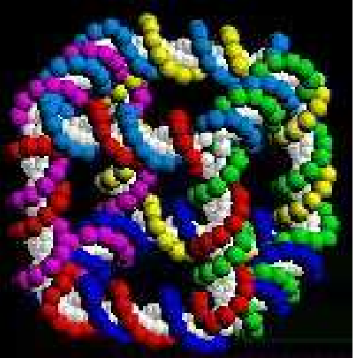


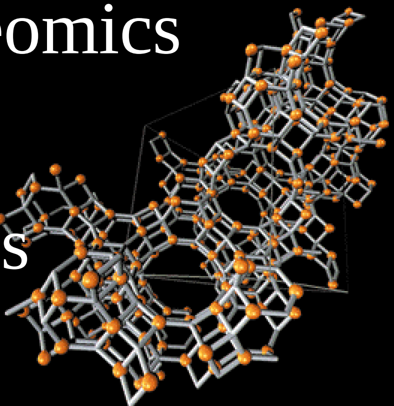
Biolithography

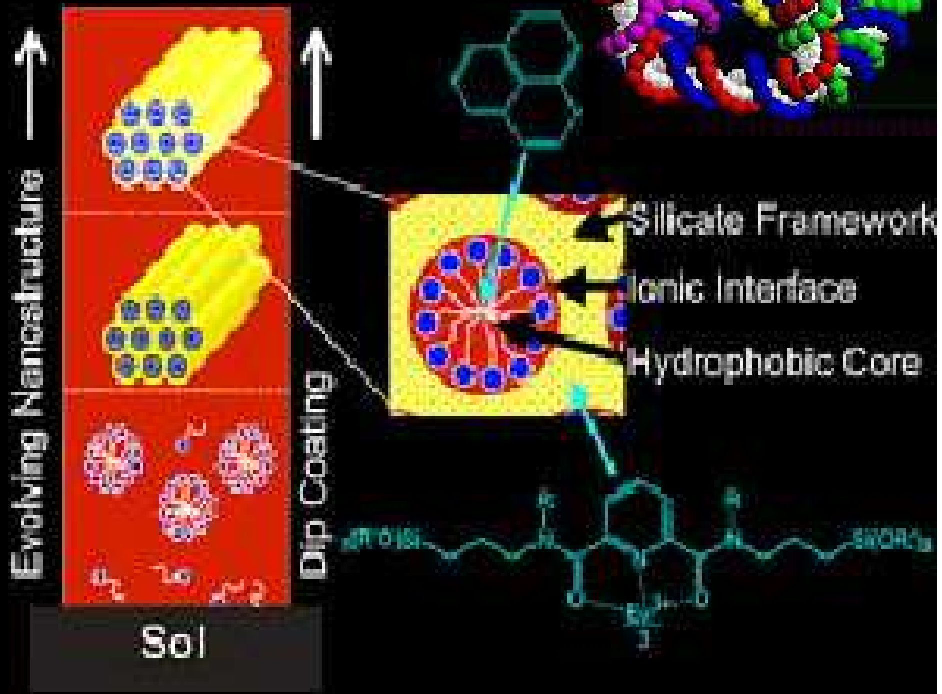


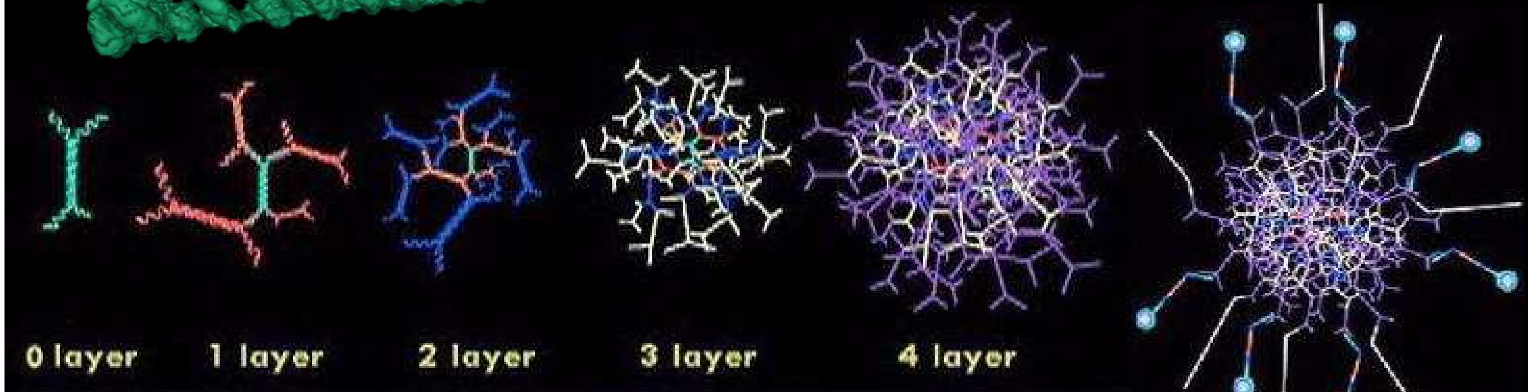
Molecules as Tools – Not Just Endproducts

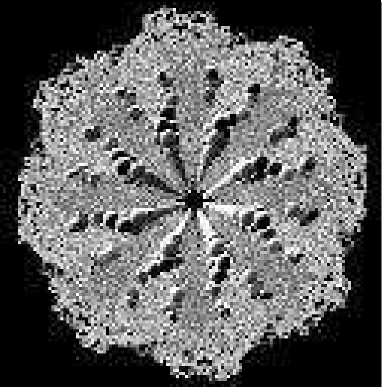
- Nanotubes - carbon, polymer, protein, etc.
- Structural proteomics
- Dendrimers
- Organometallics
- Zeolites





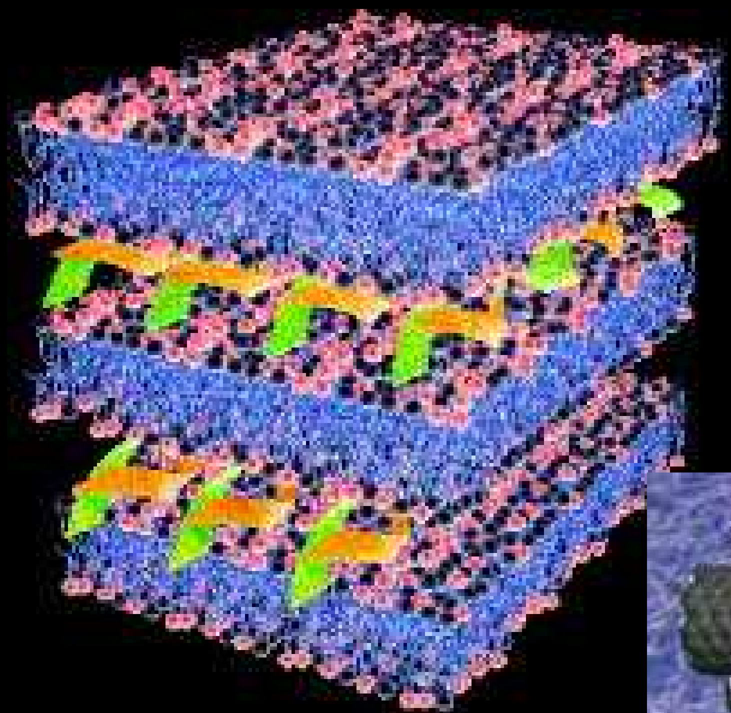


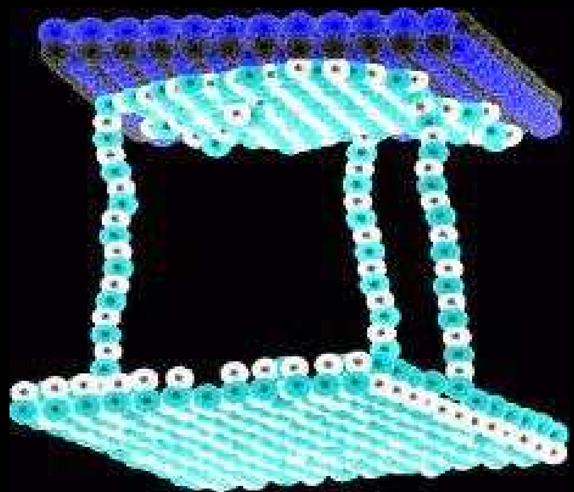


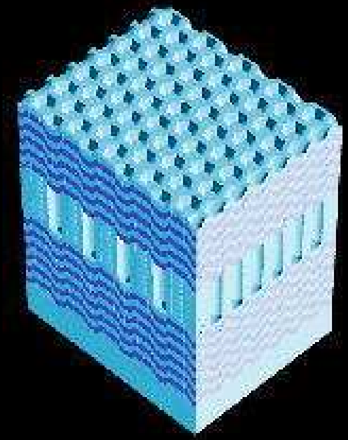


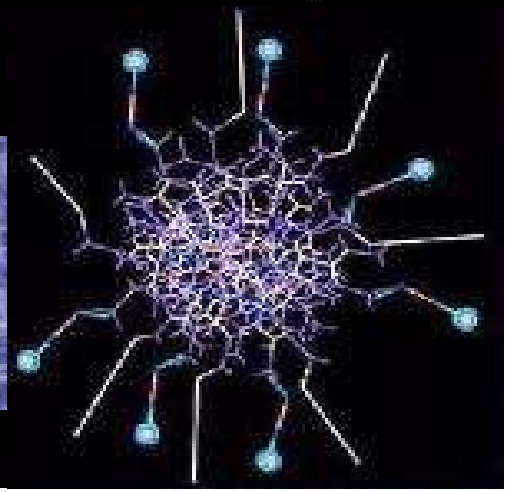
Complimentary Chemistries in Molecular Components

- Integration of organic and in-organic dopants with carbon nanotubes, dendrimers, various molecular structures



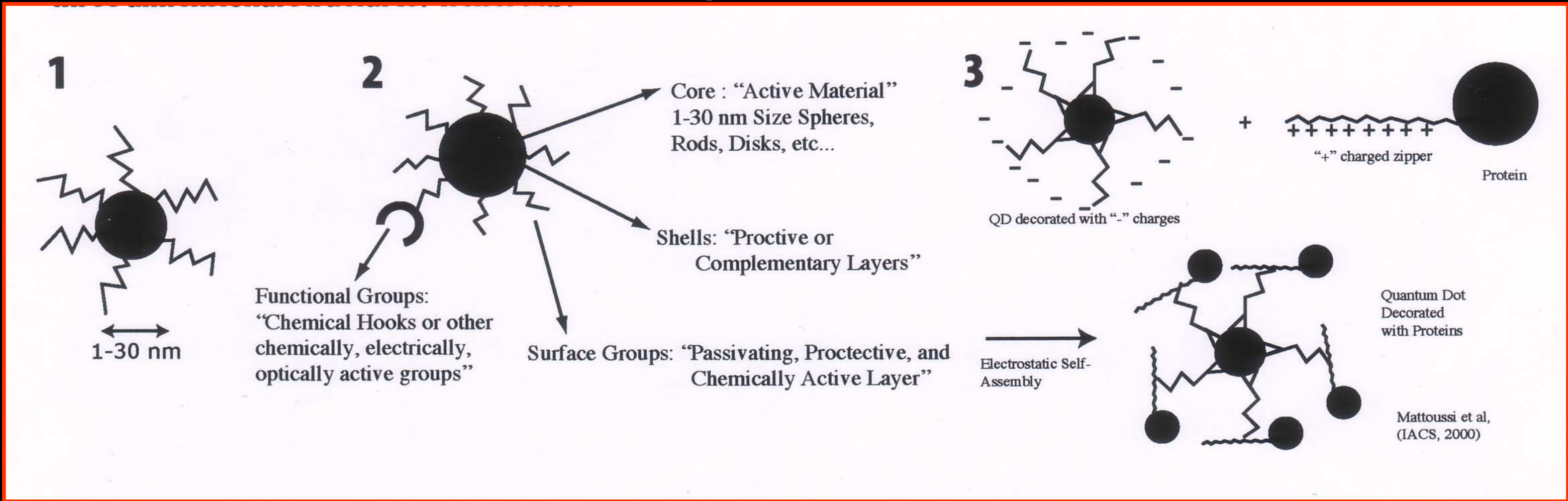




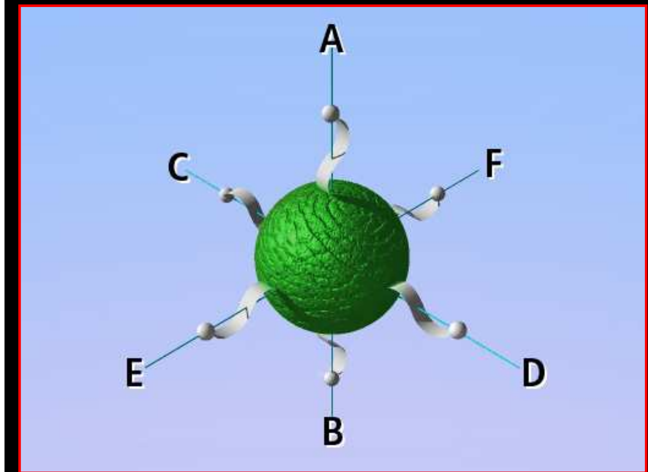


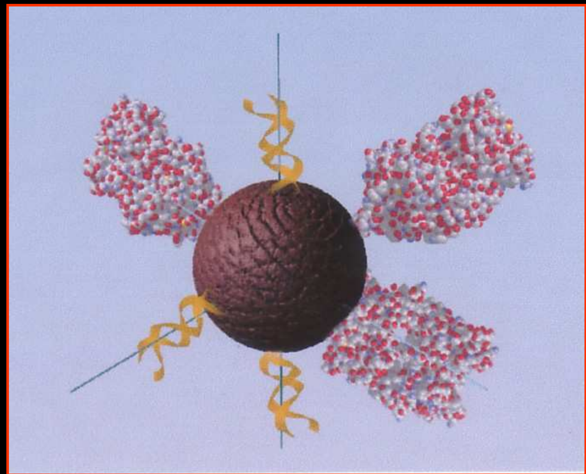
Objective: Improved Processes for Manufacturing High Precision Functionalized Nanostructures

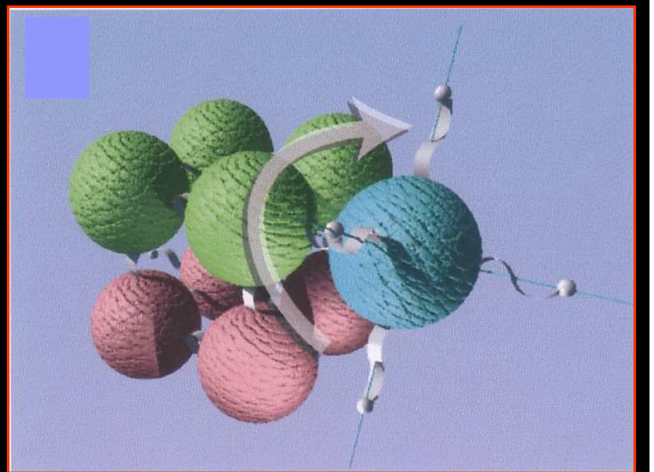
Present strategies for nanofabrication



Target future nanofabrication goals

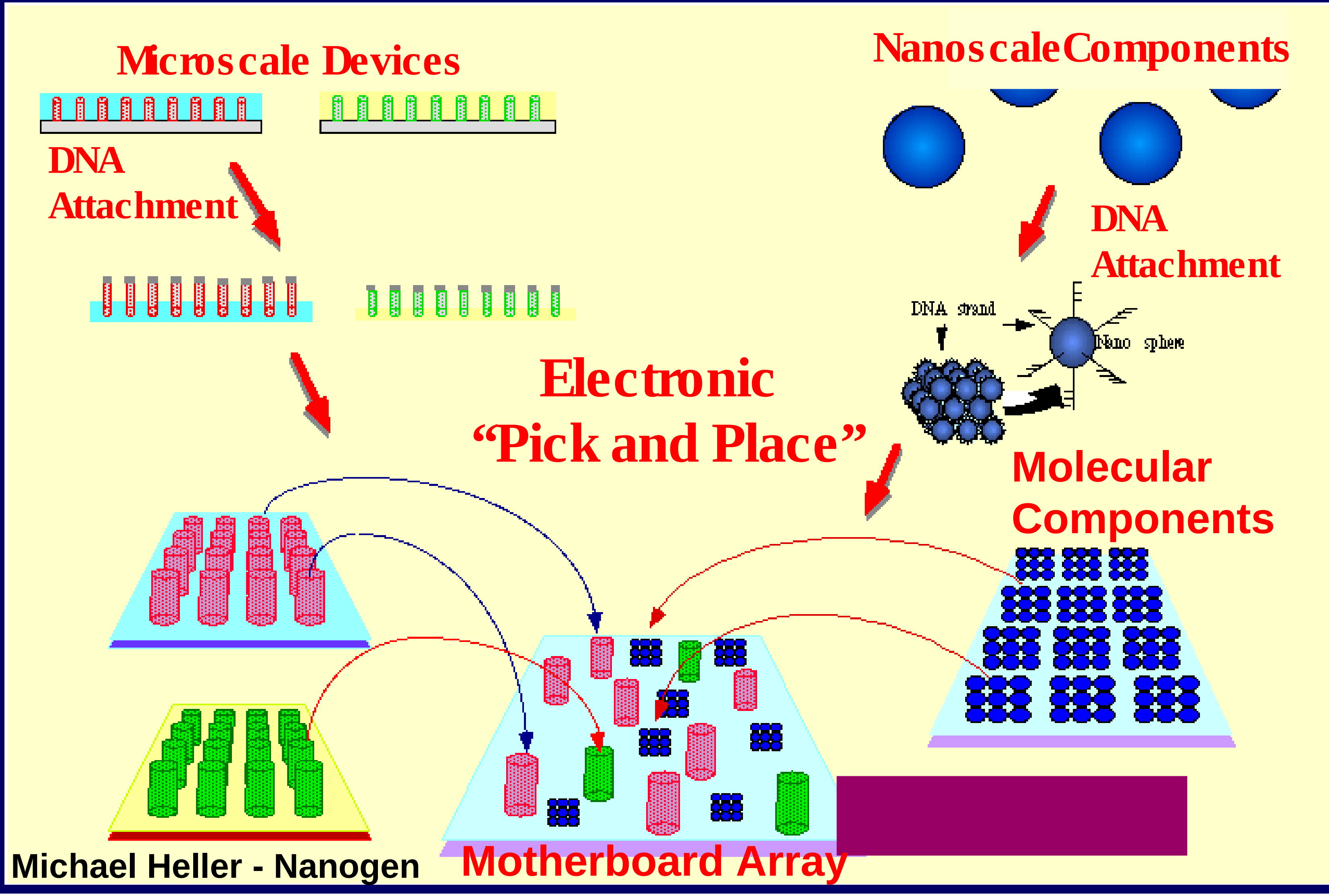






20 nanometers

Heterogeneous Integration Process for Micro/Nanofabrication – Synergy of Top-Down with Bottom-Up Processes



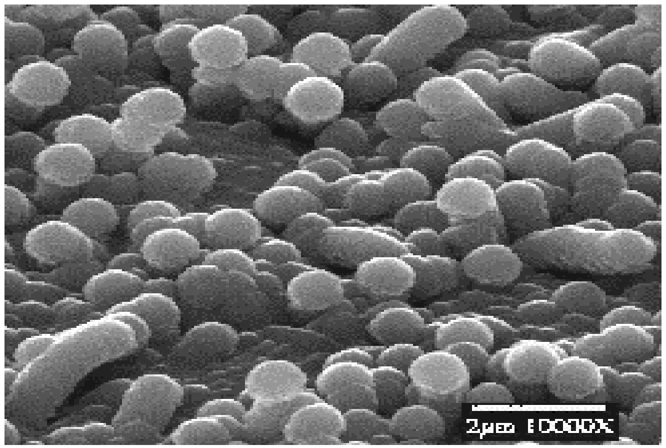
Michael Heller - Nanogen

Self Assembly as a Foundry Process

Self-assembly is the most practical and realizable approach to fabricate arrays of nanodevices with the sub-100nm size features in short-term (the conventional lithographic methods of microsystem processing offer very limited control over the fabrication on the sub-100 nm scale)

Spontaneous self-assembly

This approach relies on structural disorder at the interface between the two materials with different physical properties (heteroepitaxy, fluctuations of the dopant concentration, etc.)

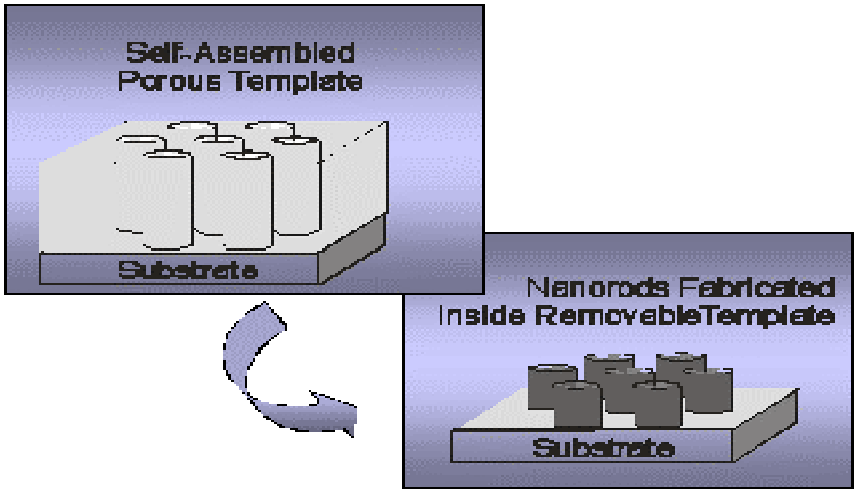


Self-assembled Si nanowires grown by magnetron sputtering

(E.A. Guliants and W.A. Anderson, "A Novel Method of Structure Control in Si Thin Film Technology", *197th Meeting of The Electrochemical Society*, Toronto, ON, May 2000)

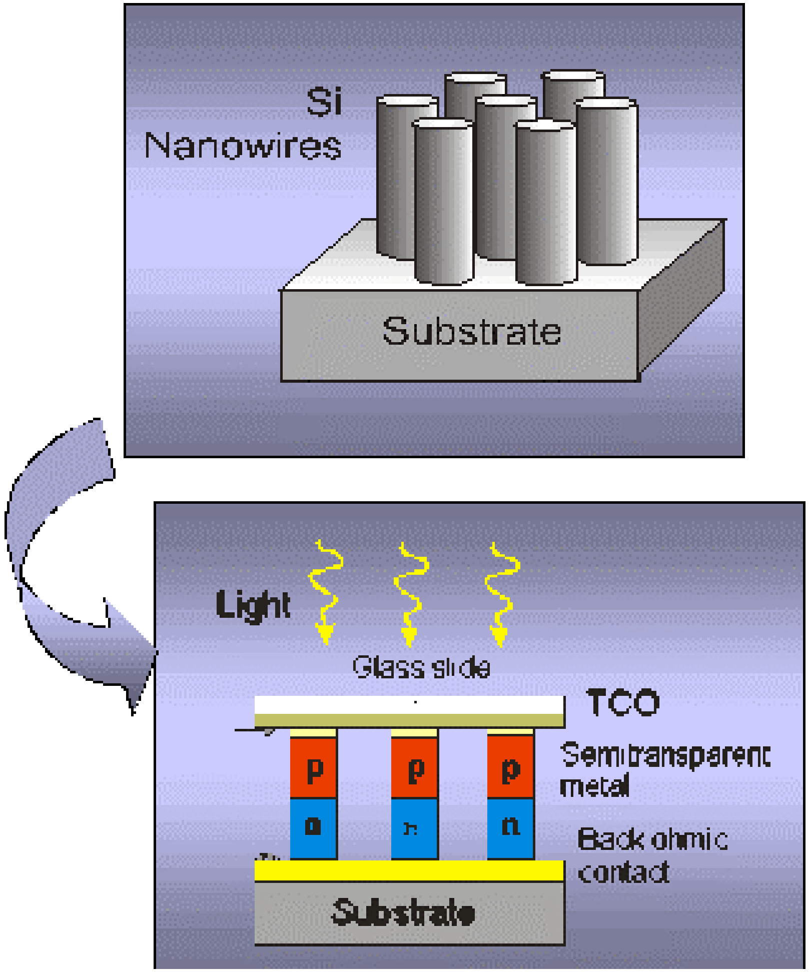
Controllable self-assembly

Involves self-assembly of the tools for fabrication of nanostructures and nanodevices, such as masks or templates.

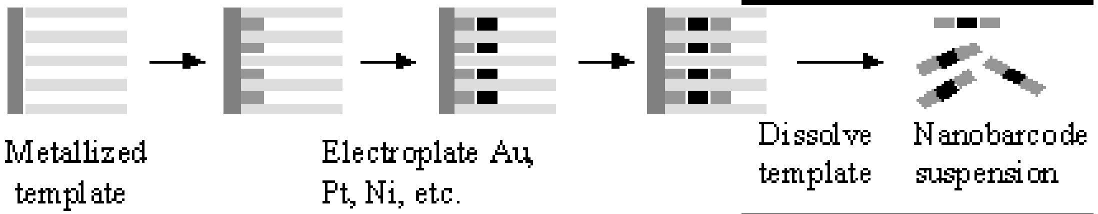


Periodic Nanostructures

Some of the potential applications of periodic nanostructures are:



- Quantum effect dots
- Resonant tunneling diodes
- Single-domain/bit magnetic storage media
- Single electron transistors (SETs)
- Light-emitting diodes (LEDs)
- Photodetectors
- Quantum well optoelectronic devices
- Quantum cellular automata
- High-density memory



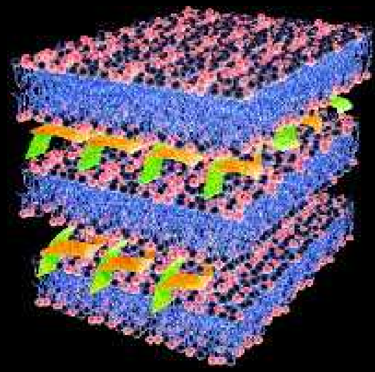
Schematic of a Si photodetector array fabricated on periodic Si nanowires

Biology as a mechanism for material production, patterning, and fabrication

Key Properties:

Photonic
Electronic
Mechnical
Chemical

Living Systems as Biofoundry



Genetic Magnification

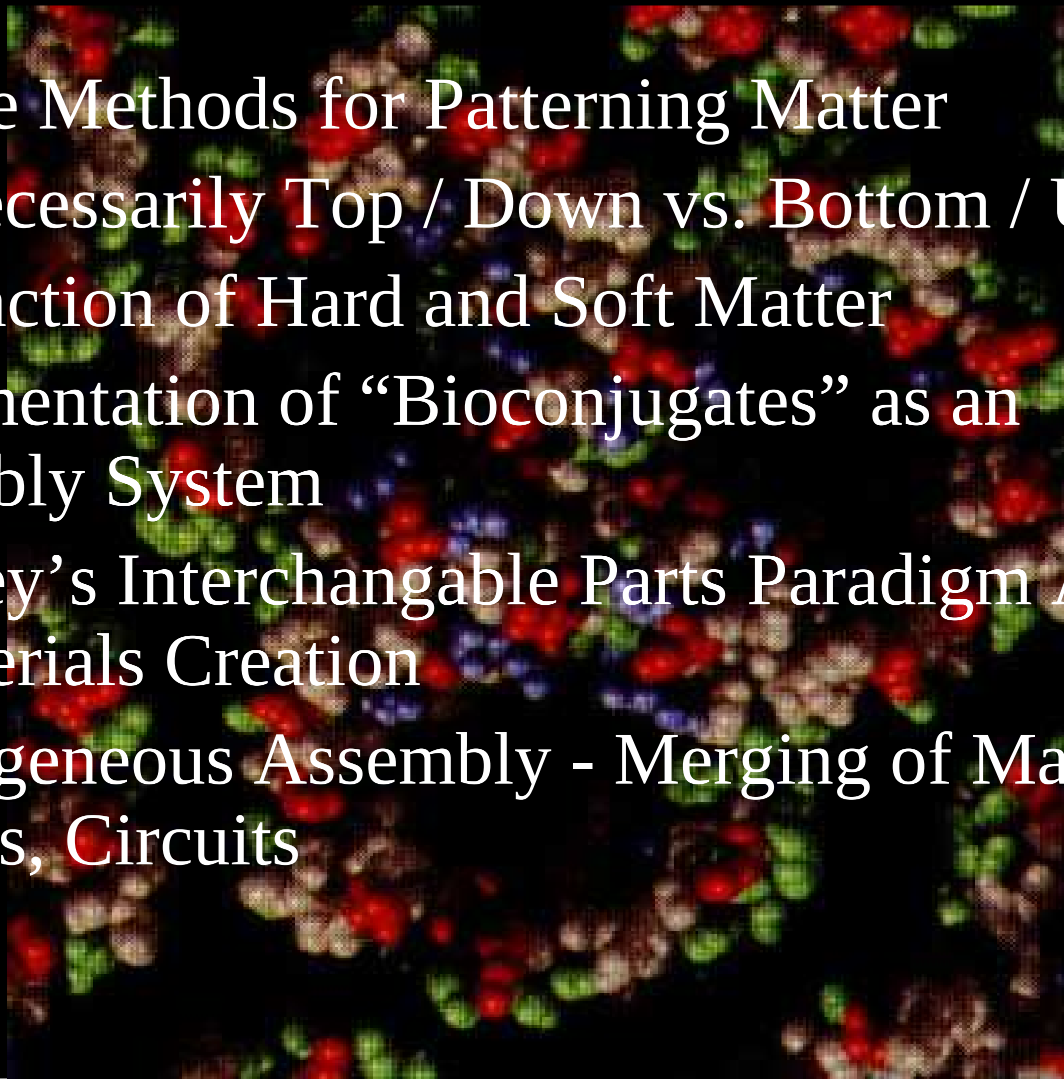
Dynamic Agent

Controlled Replication

Material Patterning / Structural Systems

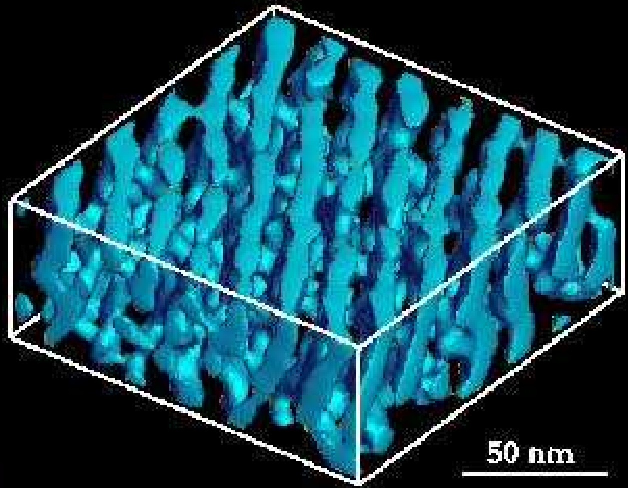
Materials Harvest / "Biocomponents"

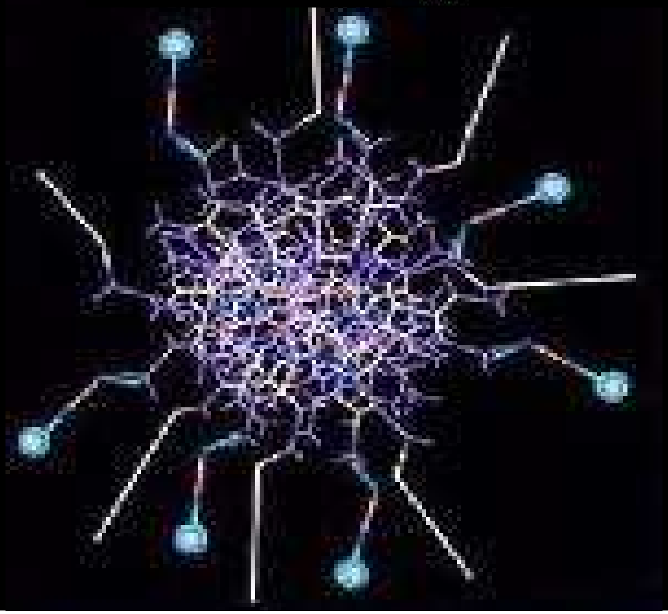
Self Assembly Enabled Process Modalities
Key Points of Consideration

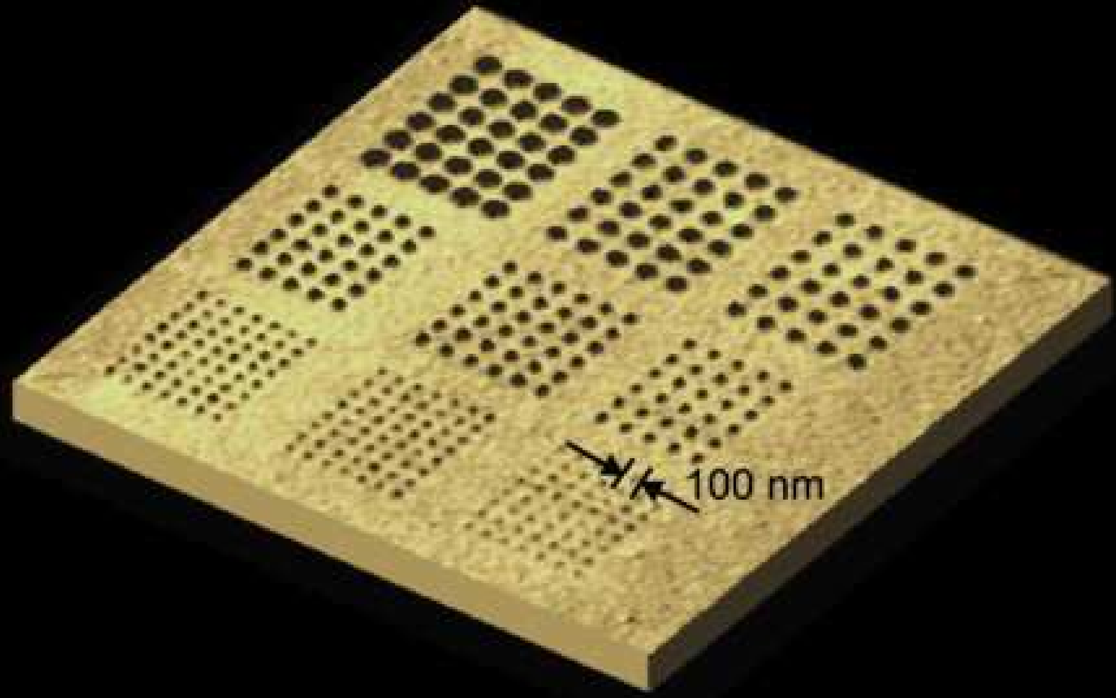


- Diverse Methods for Patterning Matter
- Not Necessarily Top / Down vs. Bottom / Up
- Conjunction of Hard and Soft Matter
- Implementation of “Bioconjugates” as an Assembly System
- Whitney’s Interchangable Parts Paradigm Applied to Materials Creation
- Heterogeneous Assembly - Merging of Materials, Devices, Circuits

Diversity of Tools –
Integration of "traditional" and biologically enabled or inspired processes and materials

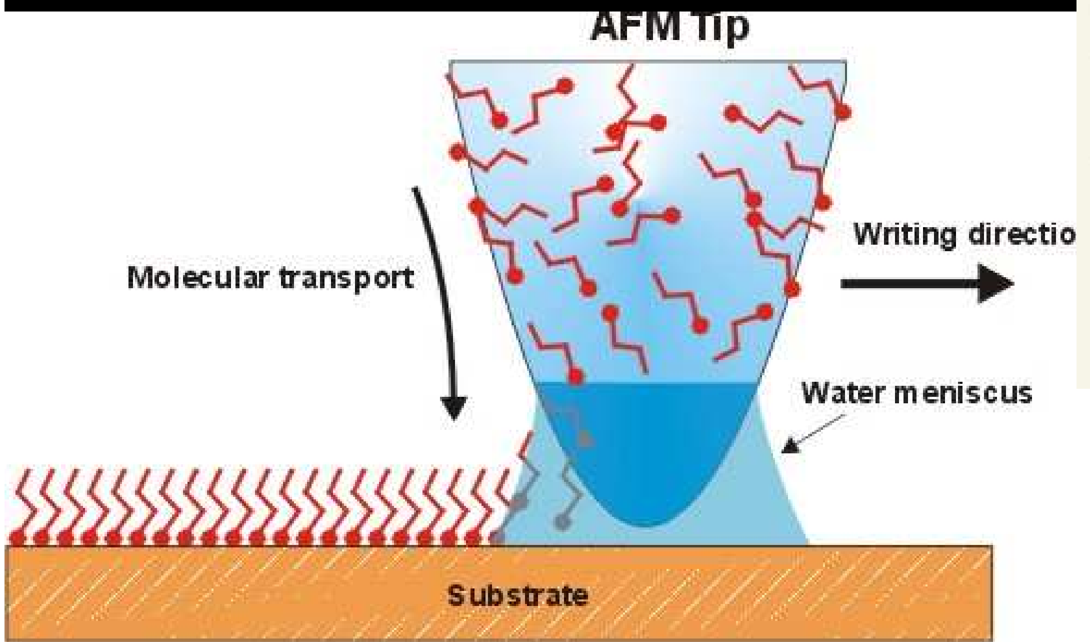


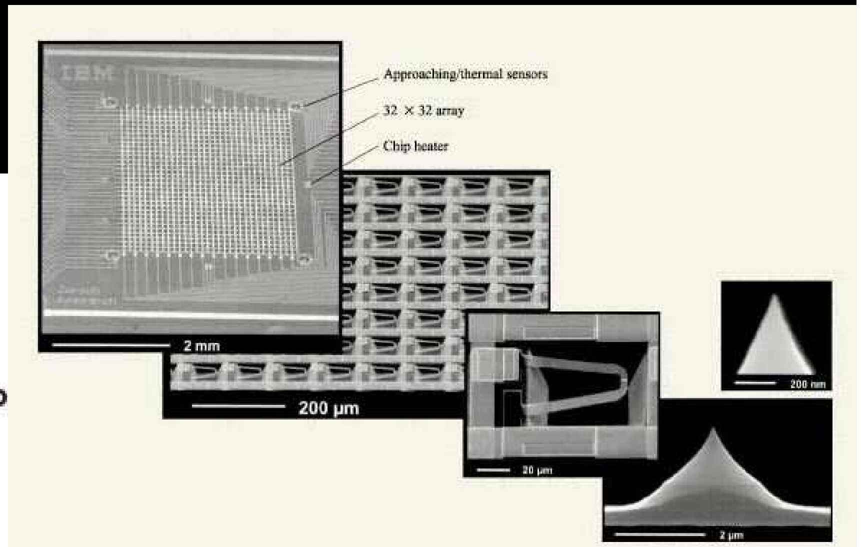




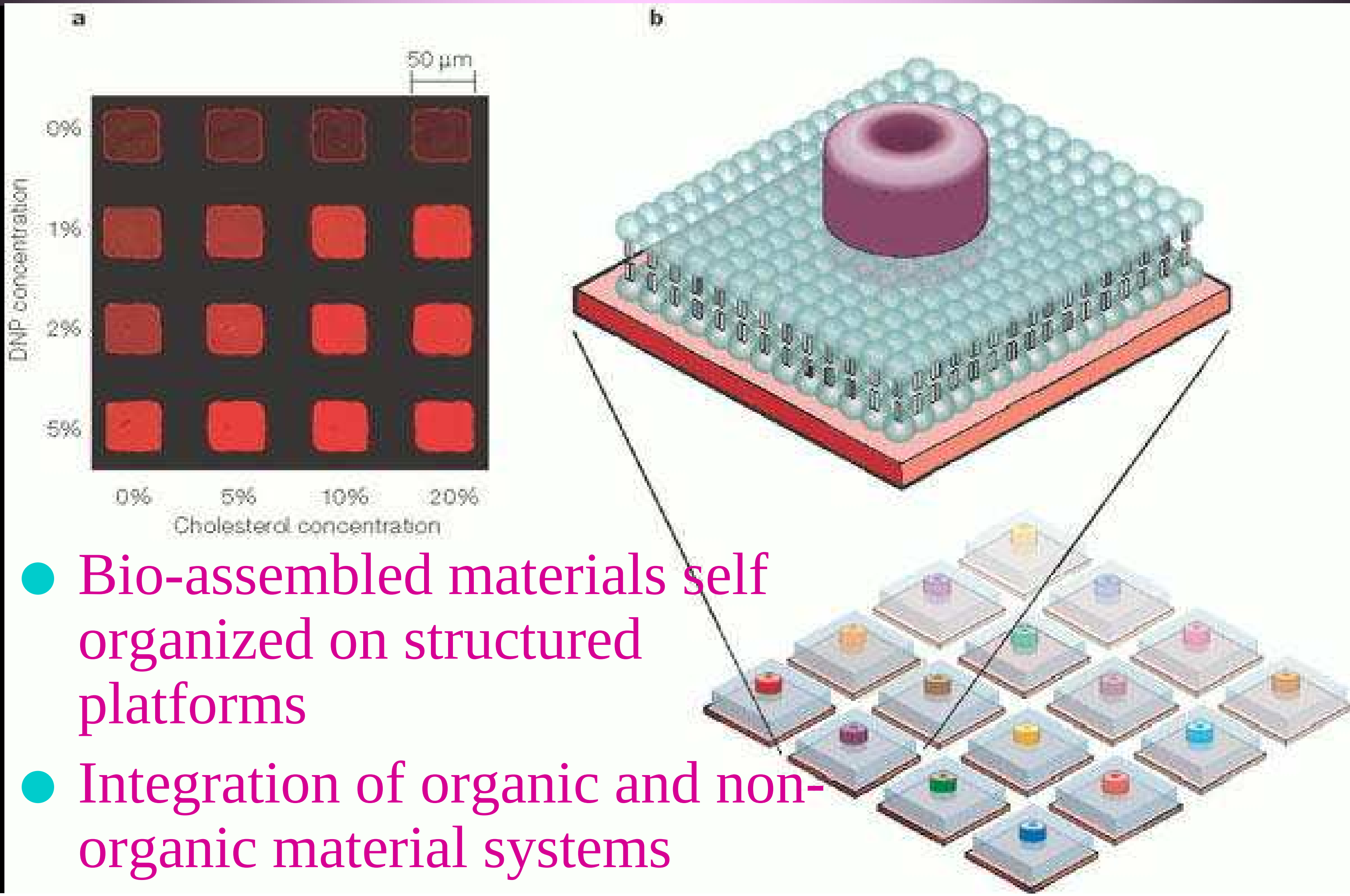
Complimentary Chemistry Enabling Process Example – NanoPrinting AFM arrays

- Massively parallel molecular deposition





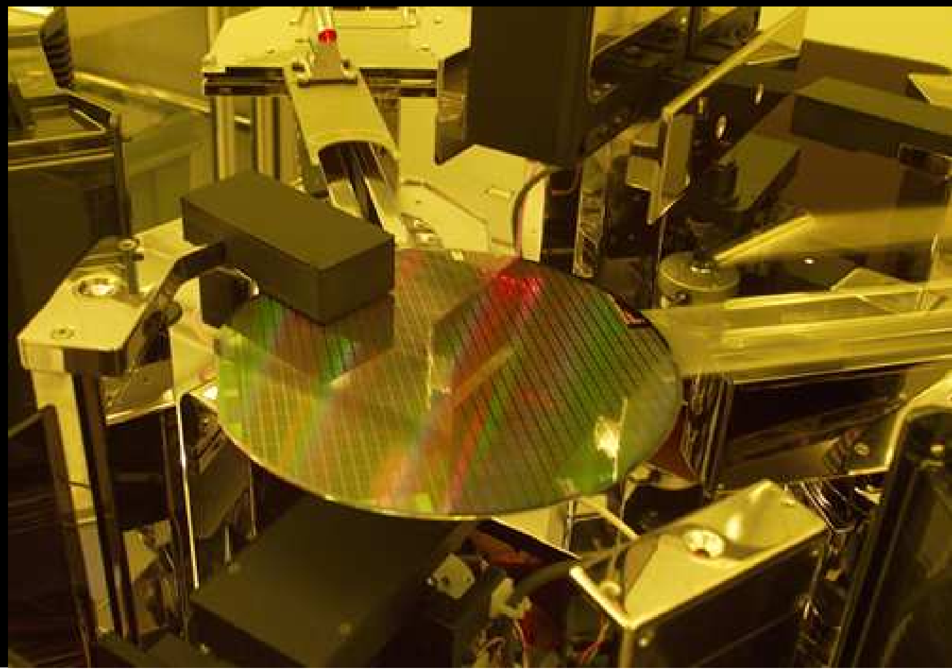
Integrated Biofoundry Processes



- Bio-assembled materials self organized on structured platforms
- Integration of organic and non-organic material systems

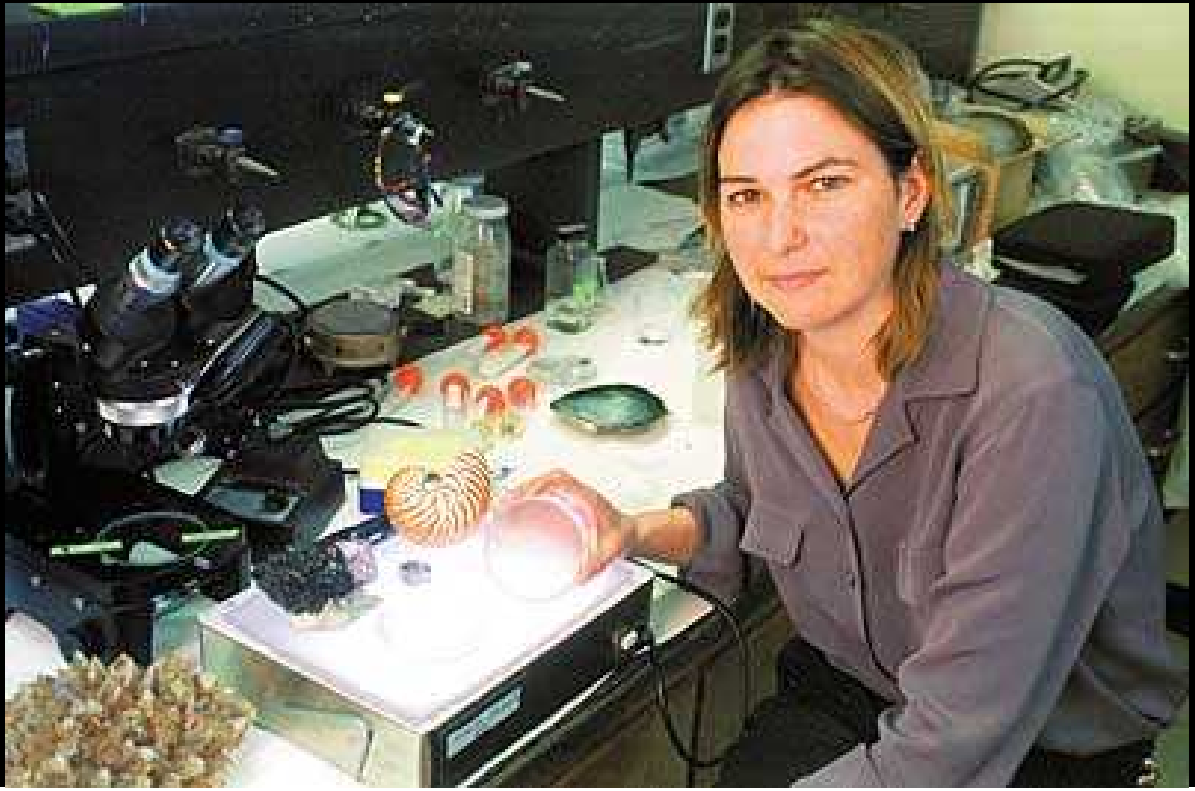
Define Foundry - Current

- Monolithic, Centralized
- Volume Dependant Amortization
- Rigid Fabrication Parameters
- Highly confined range of materials



Define Foundry: Biologically Enabled Self Assembly Fabrication
SemZyme - Cambrios

- Extremely diverse range of materials
- Highly adaptive, polymorphic
- Just as Needed Fabrication



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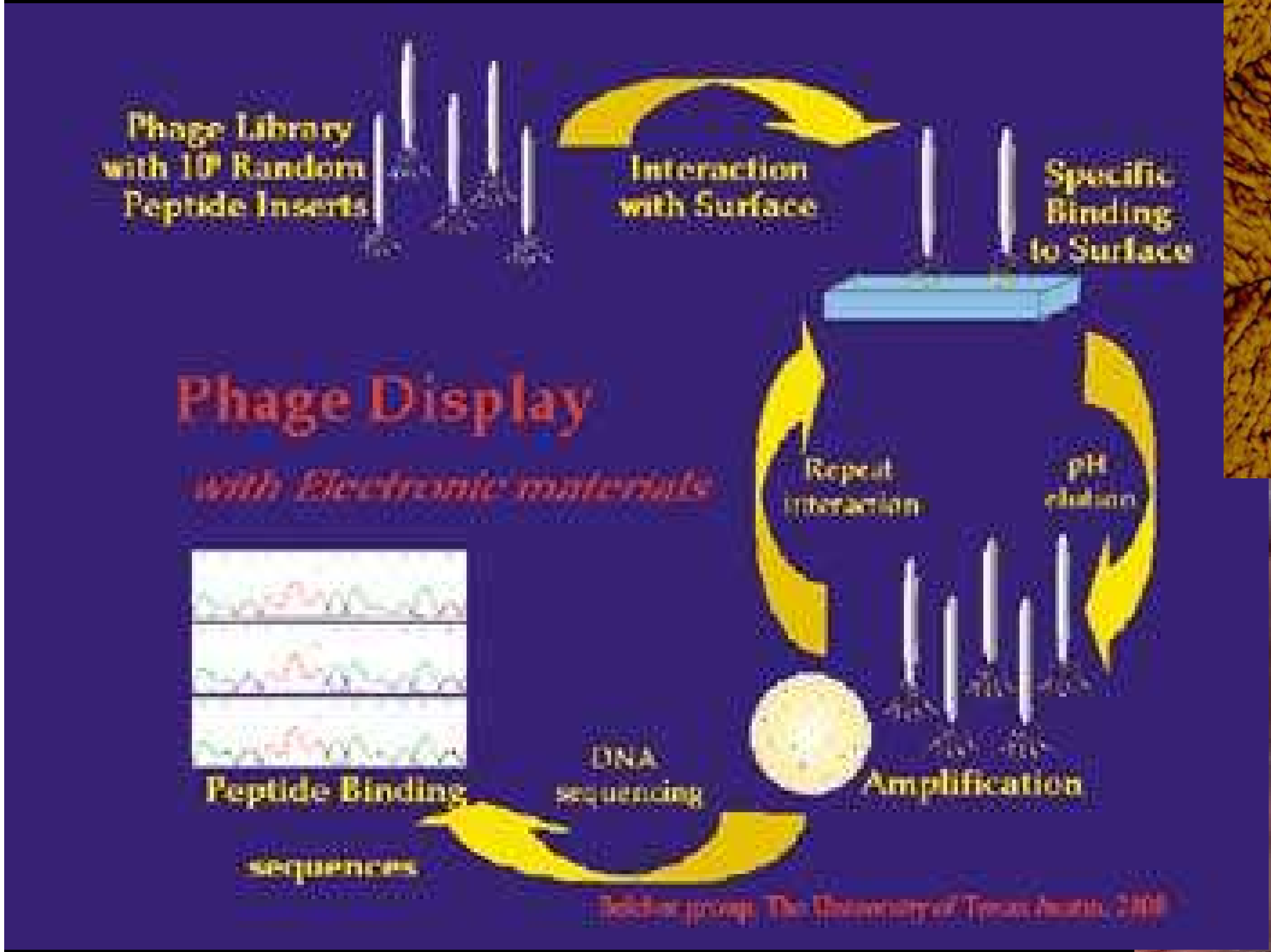
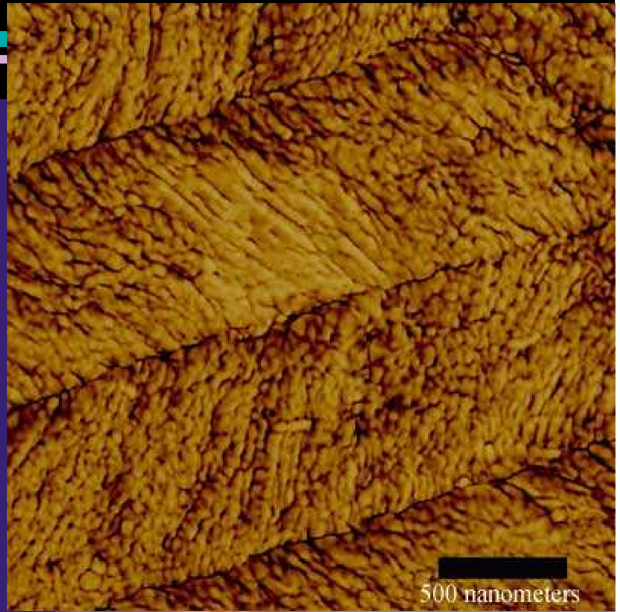
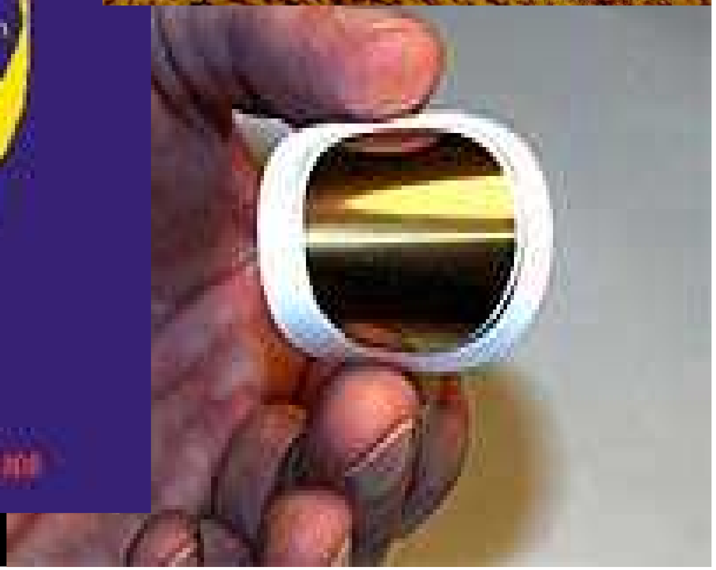
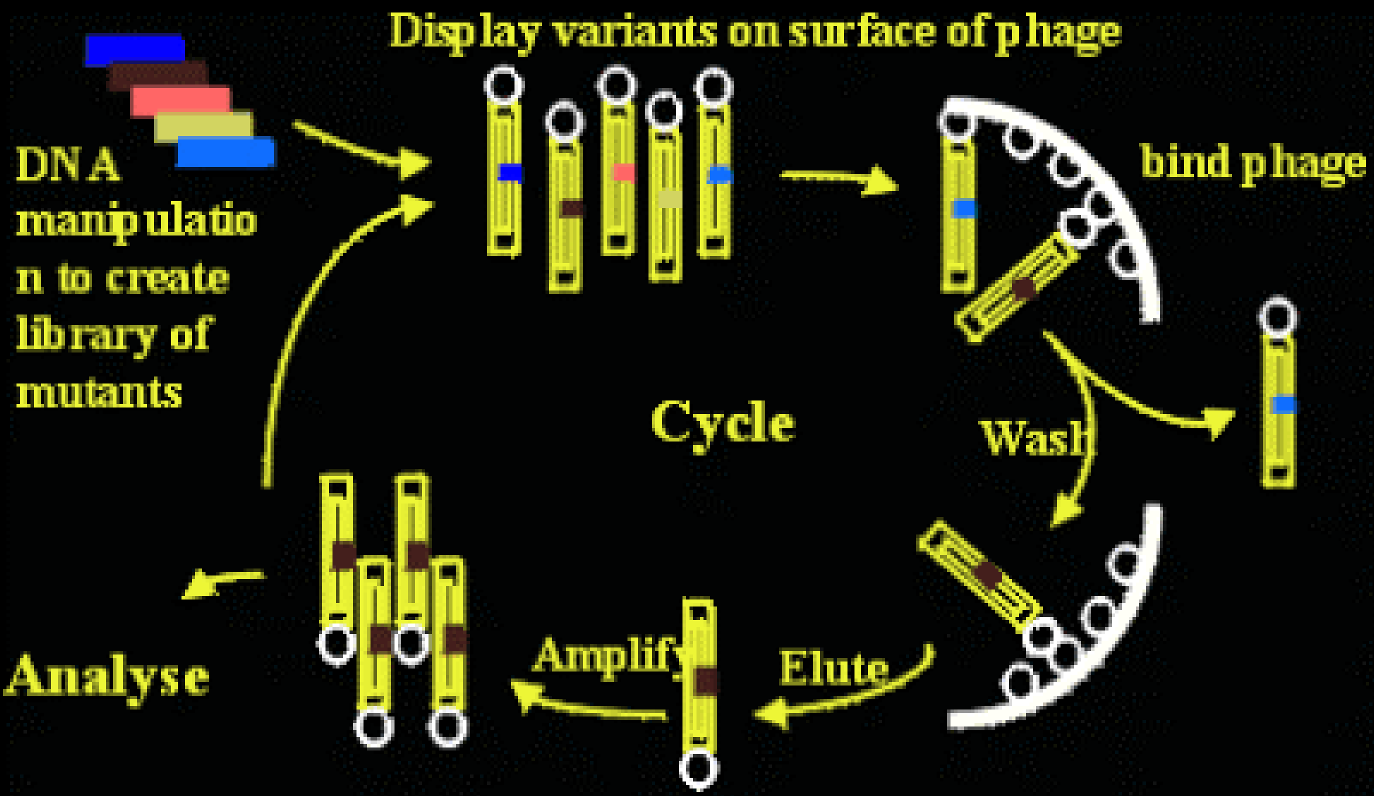
Define Foundry - Future







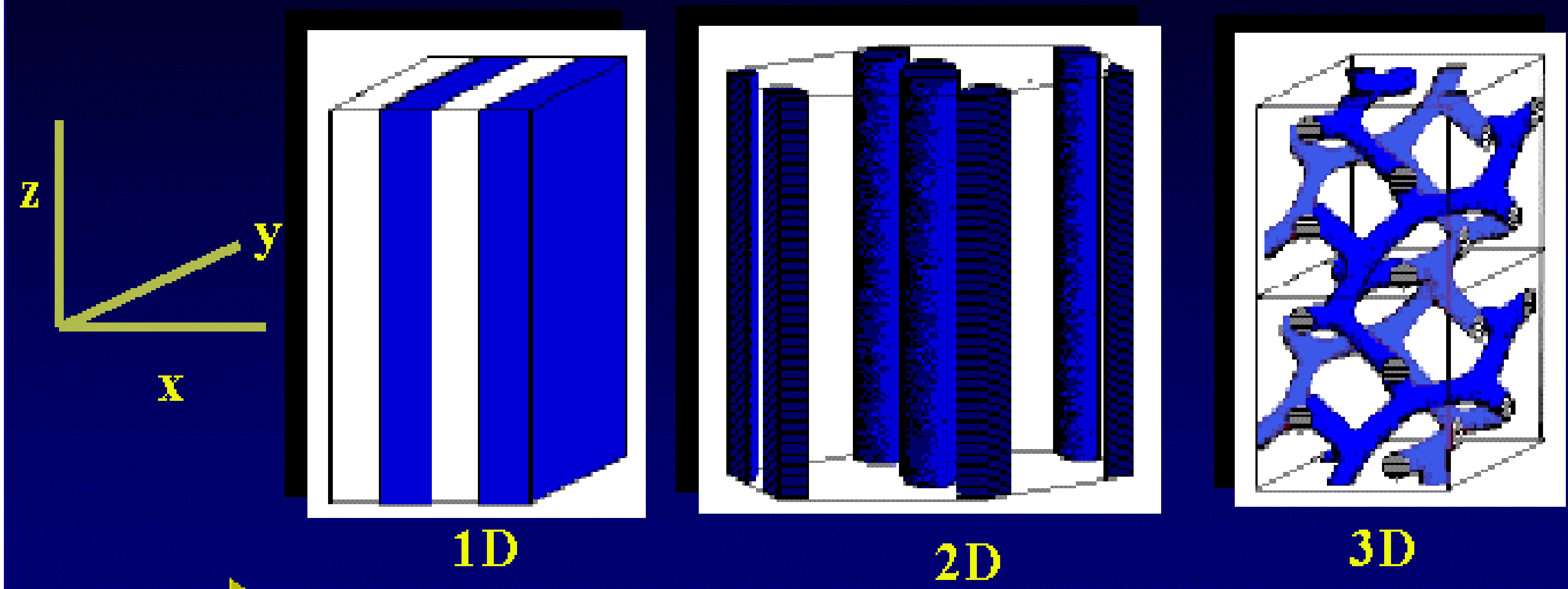
Define Foundry
Living Systems as BioFoundries



Phage Display Methods (A. Bradbury *et al*, LANL, *Nature Biotech.* 18 (2000) 75; *J. Immunol. Methods* 253 (2001) 233.)

PHOTONIC BAND GAP MATERIALS

- <u>Concept</u> : To produce periodic differences in refractive indicies in a material.



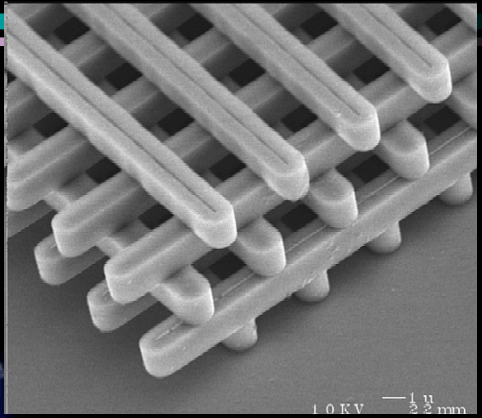
Prevent propagation of e-m radiation wthin a specified frequency range in certain directions.

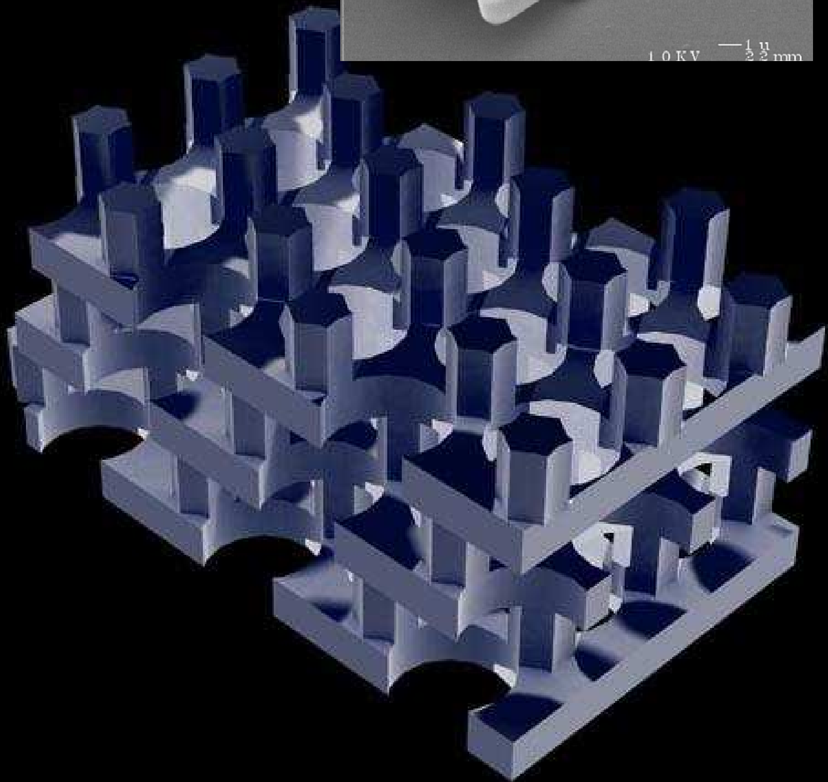
COMPLETE REFLECTION

Fink Y., Winn J.N., Fan S., Chen C., Michel J., Joannopoulos J.D., Thomas E.L., "A Dielectric Omnidrectional Reflector, *Science*, 282, 1679-1682, 1998.

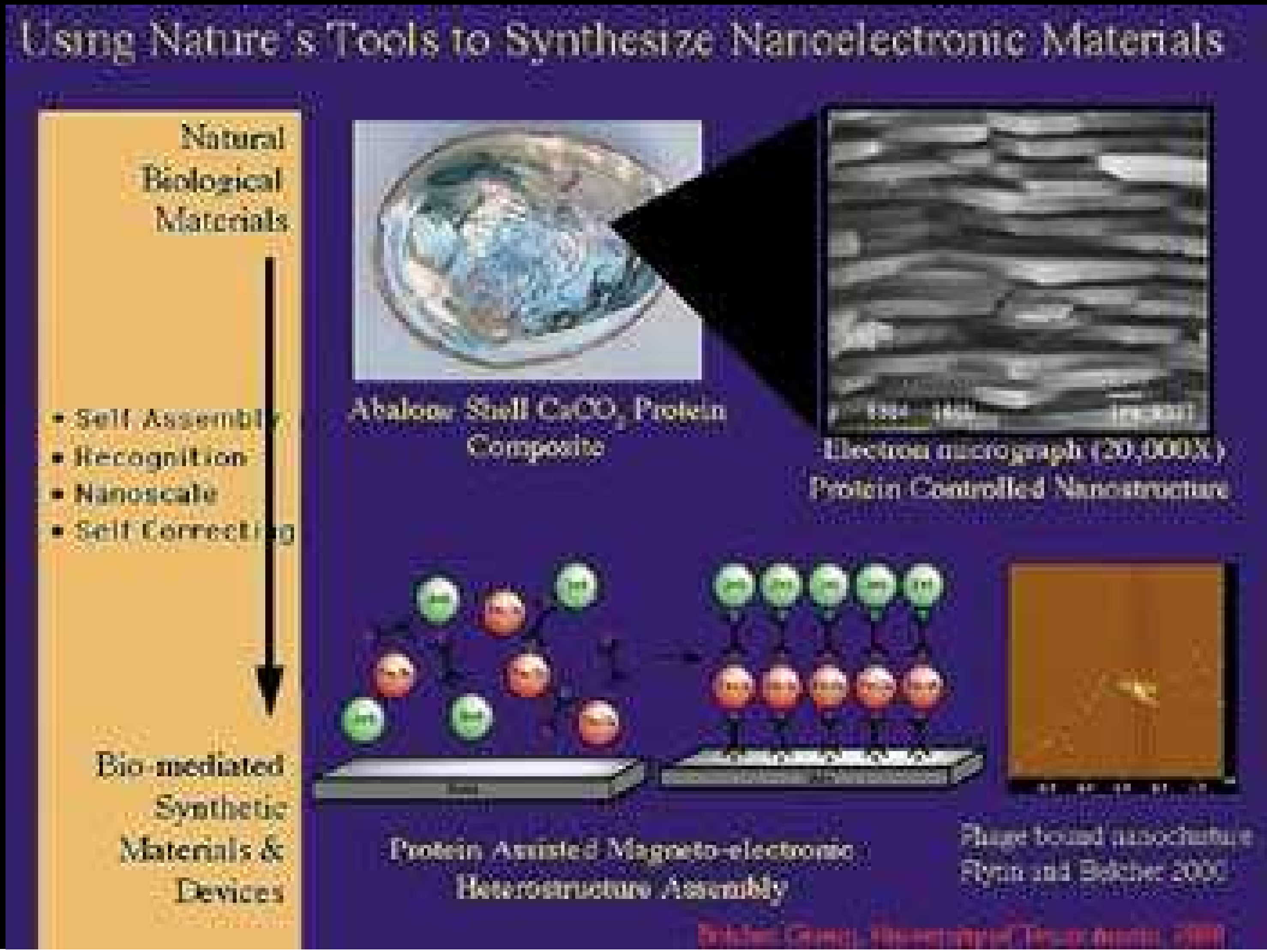
Photonics BandGap Materials - the Self Assembly Approach?

- Biologically enabled self-assembly

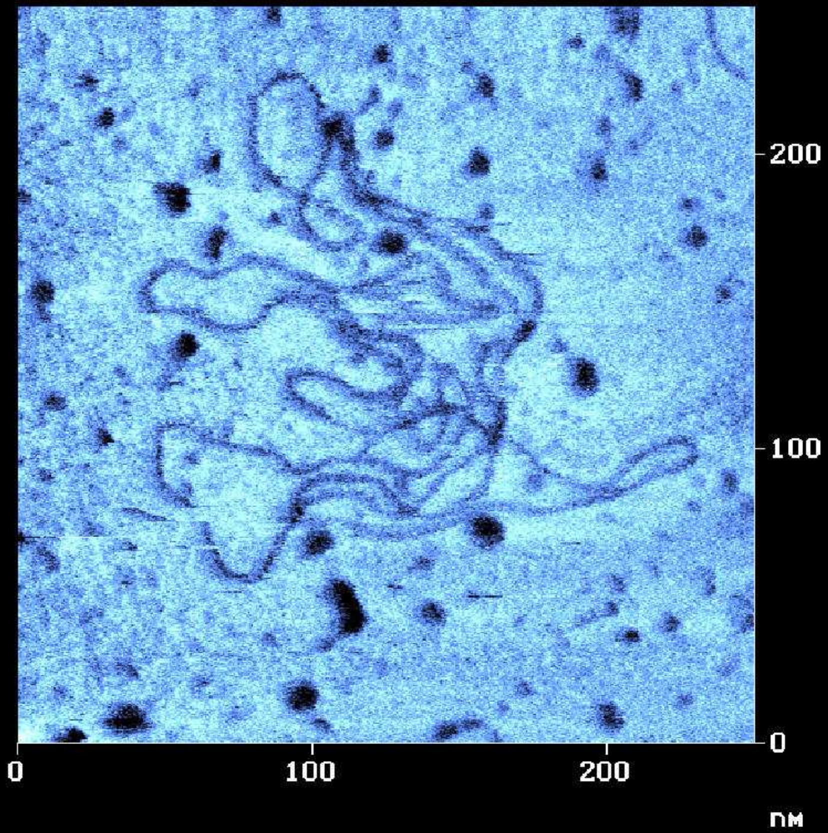


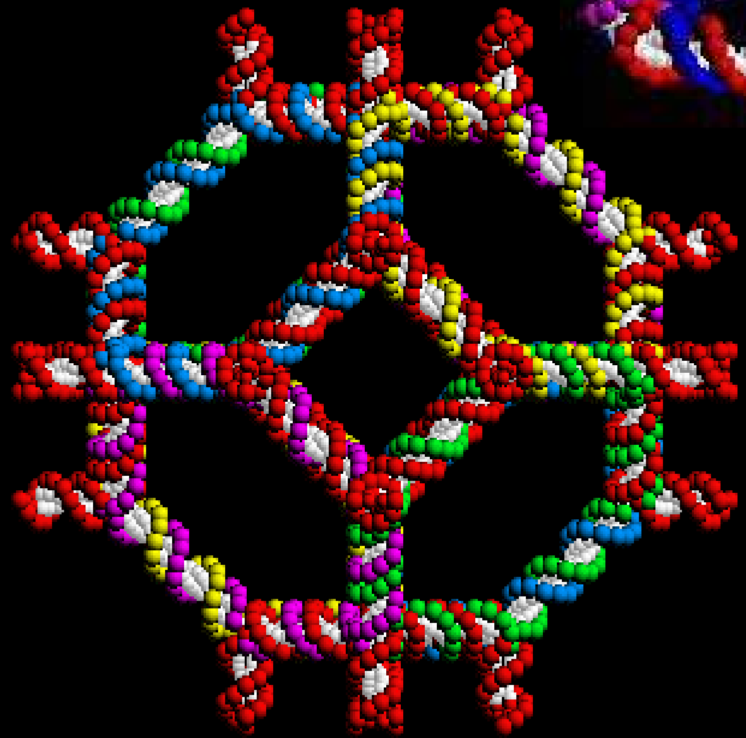


Define Foundry - Future

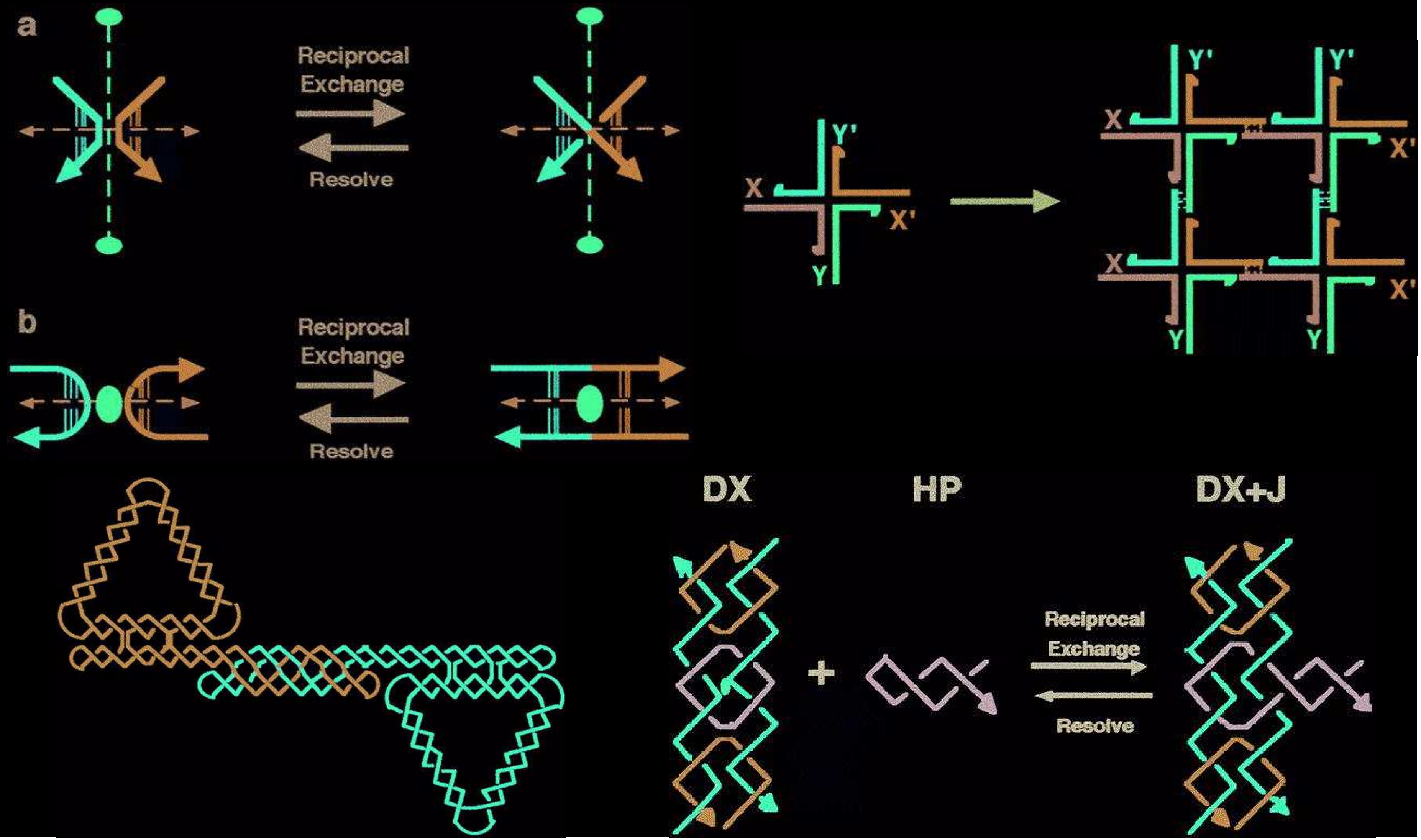


Structural Proteomics - Proteomic Assembly

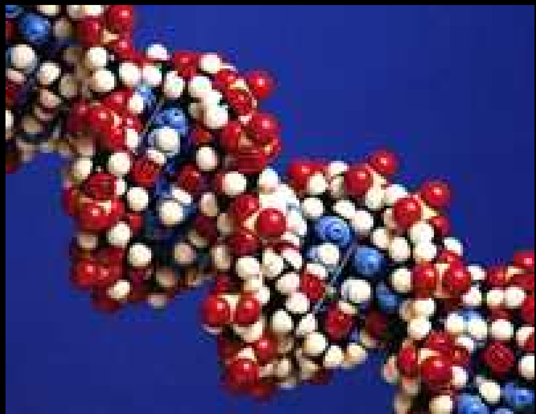


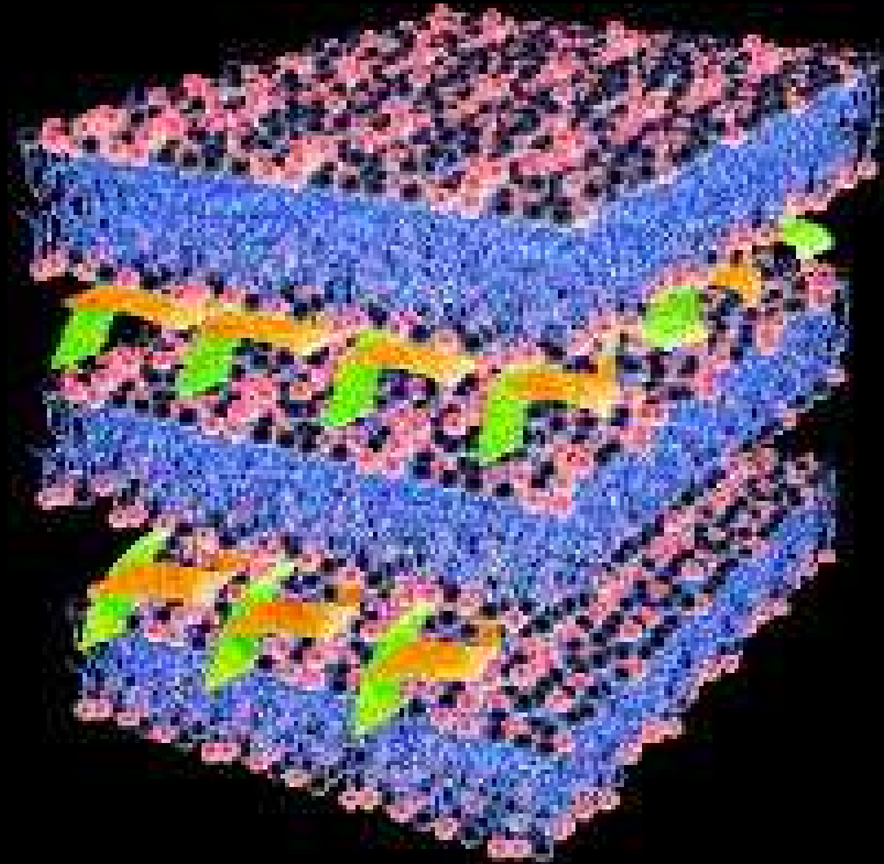


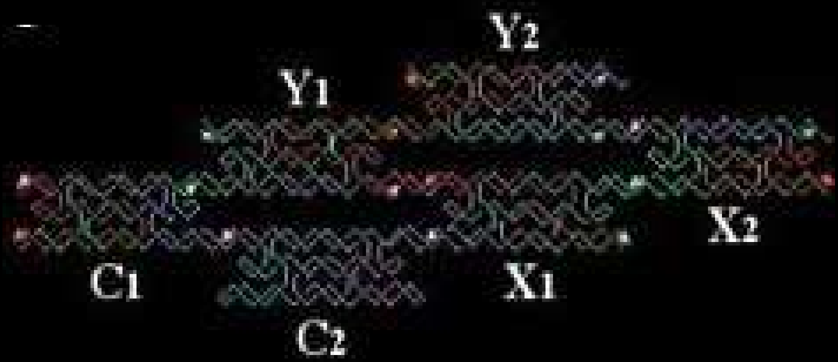
Structural Proteomics - Proteomic Assembly



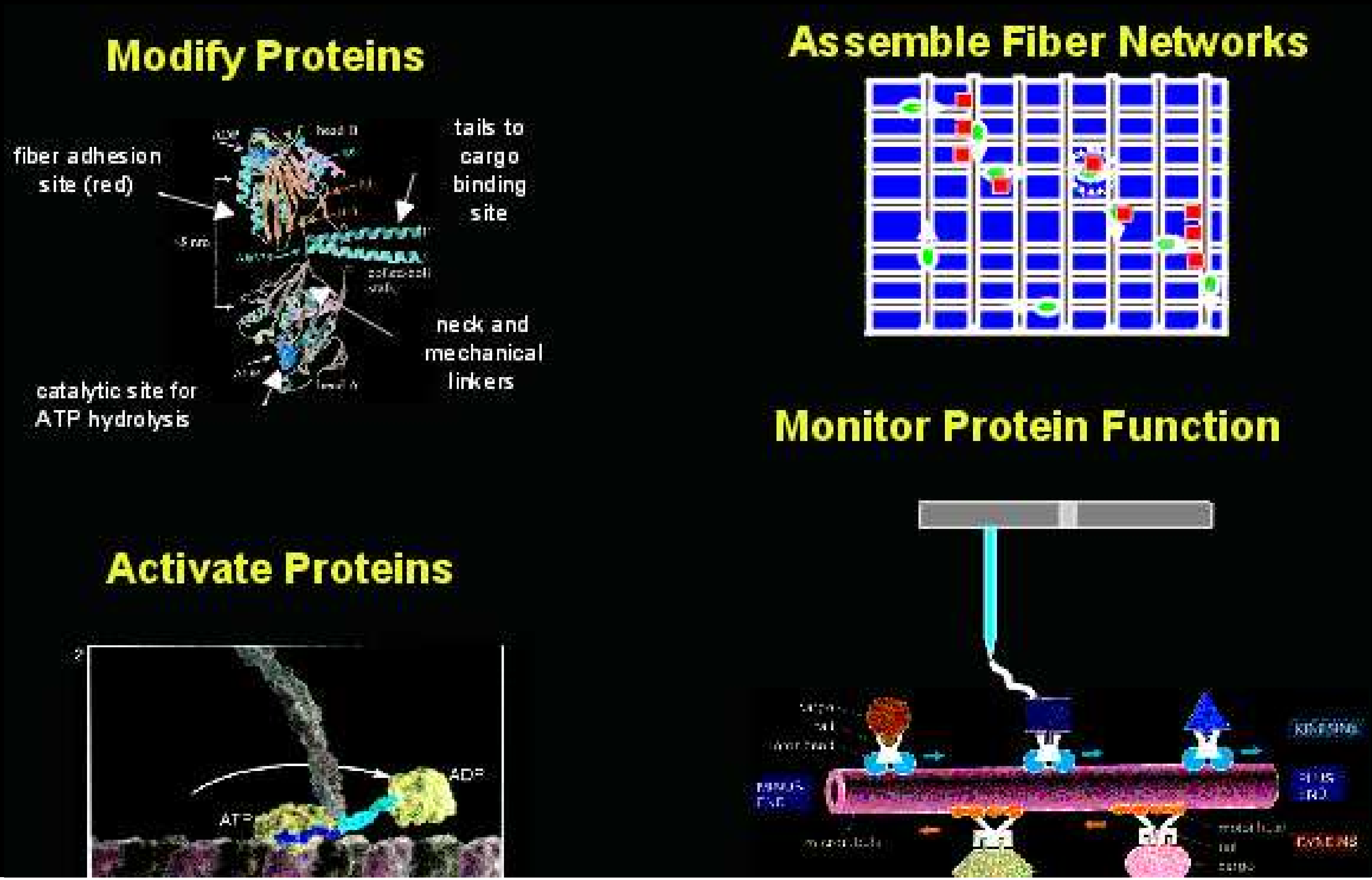
Structural Proteomics - Proteomic Assembly







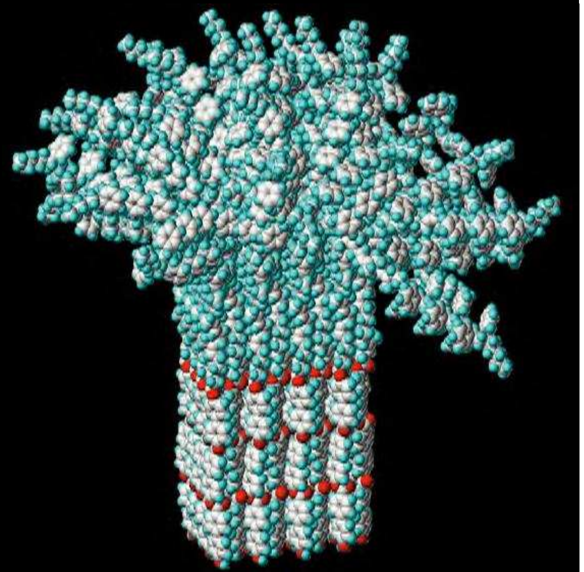
Structural Proteomics - Proteomic Assembly



Nano Electronics & Photonics Forum

Conference Oct 26, 2004, Palo Alto

www.NanoSIG.org/nanoelectronics.htm



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