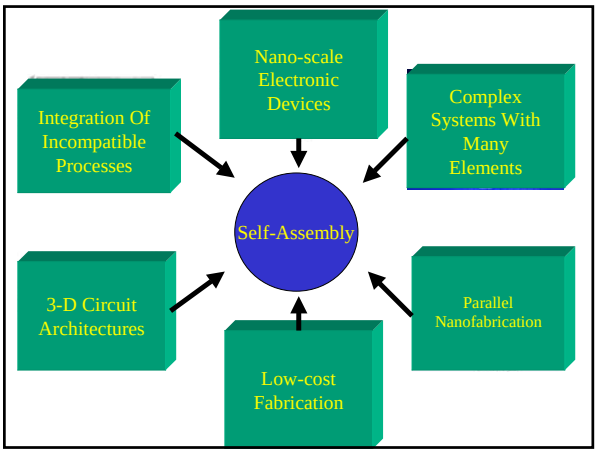
University of Washington
Electrical Engineering

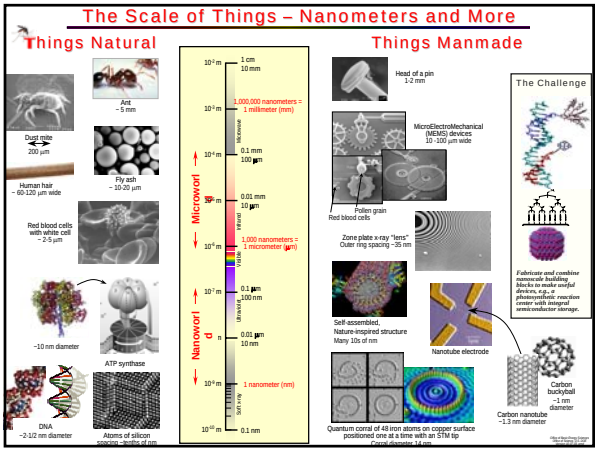
UNIVERSITY OF WASHINGTON

Self-Assembly for Nano and Micro Manufacturing

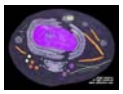
Babak A. Parviz

UC Berkeley, October 24th 2005

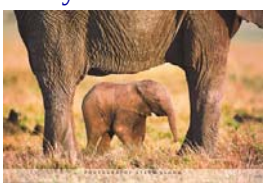




Self-Assembly



Single cell

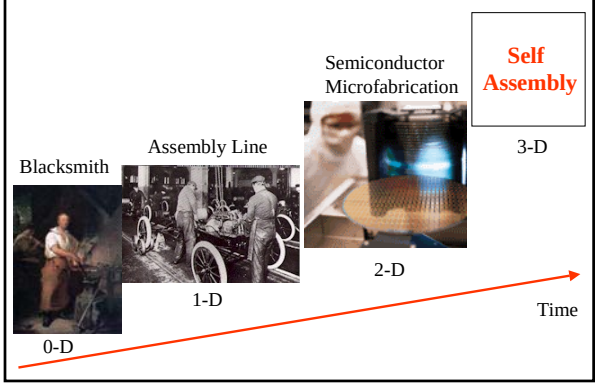


The complete "system"

Complex (many elements)
Three dimensional
Nano-scale precision
Can span many orders of magnitude (interfacing with micro and macro)
Self-reorganization and self-healing

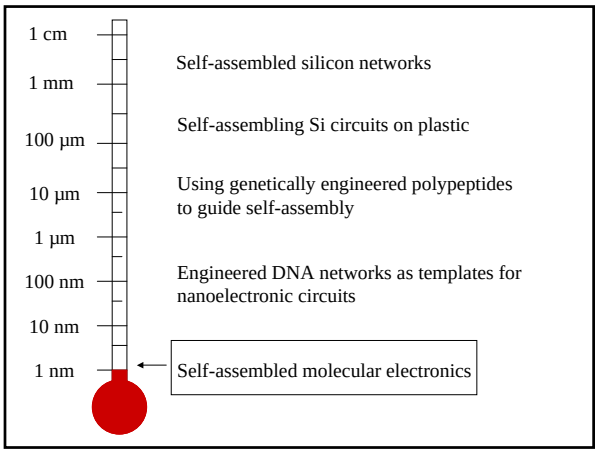
A fundamentally different approach to making things.

Evolution of manufacturing

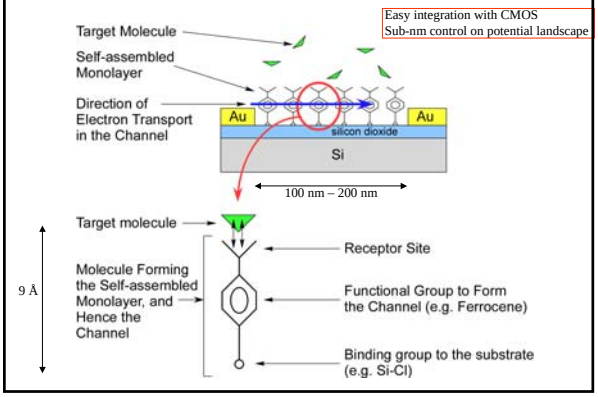


Basic dilemmas

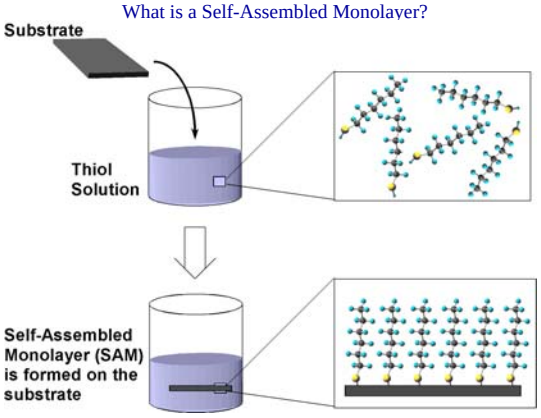
- How do we make the parts?
  - Chemical synthesis
  - Solid-state microfabrication
- How do we direct their self-assembly processes?
  - Specific covalent bonds
  - DNA programming
  - Genetically engineered polypeptides
  - Shape recognition
  - Directed surface tension forces



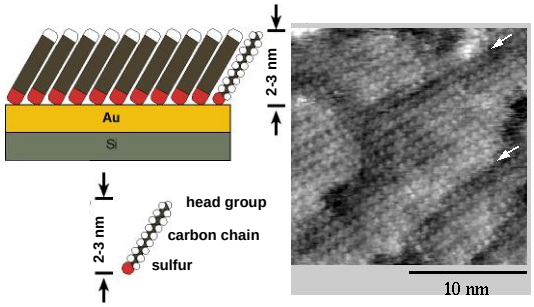
Hybrid silicon-organic systems



What is a Self-Assembled Monolayer?

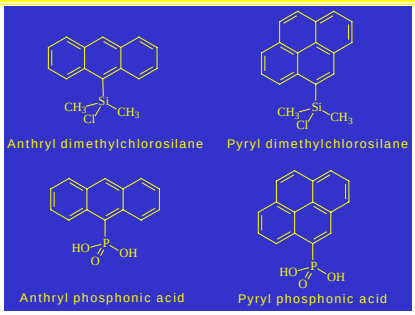


What is a Self-Assembled Monolayer (SAM)?



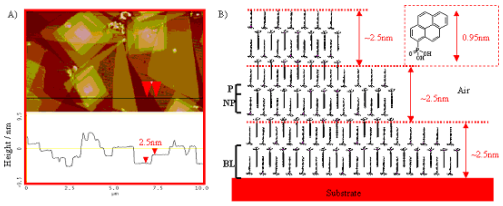
STM courtesy of IBM

Molecules Forming SAM on Silicon Dioxide Surface



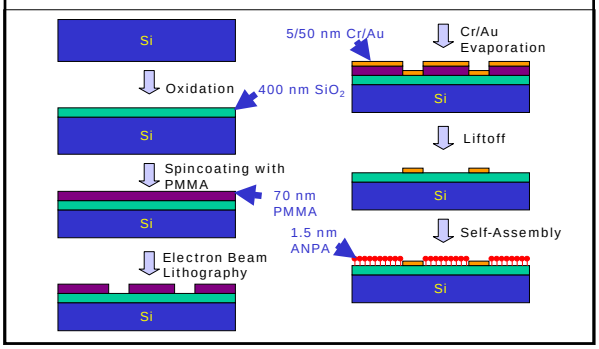
PYPA Self-Assembly

- Can form mono or multilayer structures
- Form interesting crystal structure (important for crystalline monolayer)
- Competition between π-π stacking, hydrogen bonding and solvent interactions

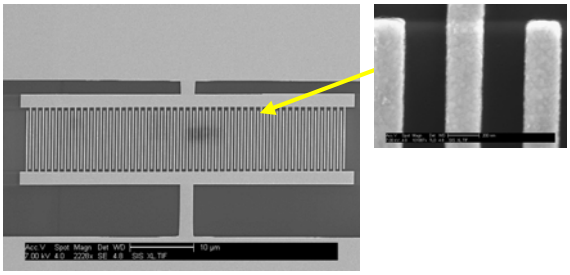


Hin-Lap Yip, Hong Ma, Alex K.-Y. Jen, Jianchun Dong, Babak A. Parviz, "Two-Dimensional Self-Assembly of 1-Pyrylphosphonic Acid: Transfer of Stacks on Structured Surface", submitted to the *Journal of American Chemical Society*

Fabrication Process of Electrodes

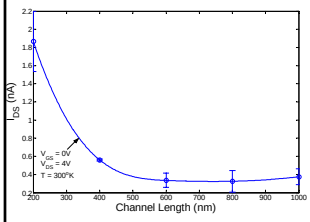


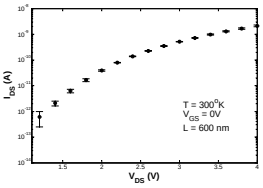
SEM Picture of the Fabricated Electrodes



Jianchun Dong, Babak A. Parviz, Hin L. Yip, Hong Ma, and Alex K-Y. Jen, "Construction and Electrical Characaterization of 0.9 nm Tall Channels Made via Pyryl Phosphonic Acid (PYPA) Self-assembly", Proceedings of *NSTI Nanotechnology Conference*, v3, pp. 188-191, Anaheim CA May 8-12 2005

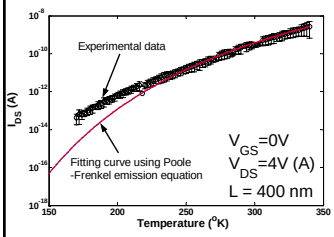
Channel length dependence of current for PYPA devices





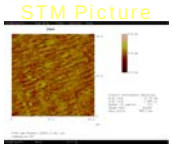
Parviz 2005

Temp. dependence of current for PYPA devices

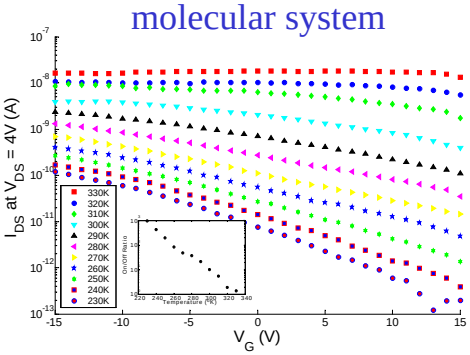


AFM Picture

STM Picture

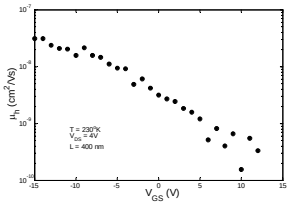


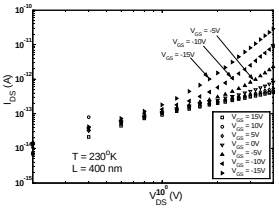
Gating the transport through the molecular system



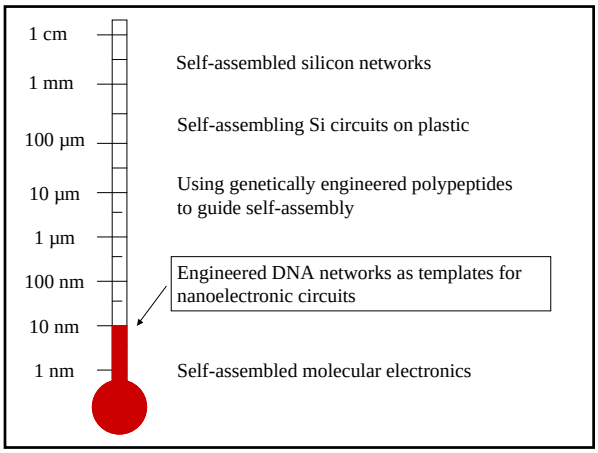
Jianchun Dong, Hin L. Yip, Hong Ma, Alex K.Y. Jen, Babak A. Parviz, "Gated lateral charge transport in a self-assembled pyryl phosphonic acid molecular multi-layer with defined 2.5 nm step heights", submitted to *Journal of Applied Physics*

Gate voltage dependence of mobility

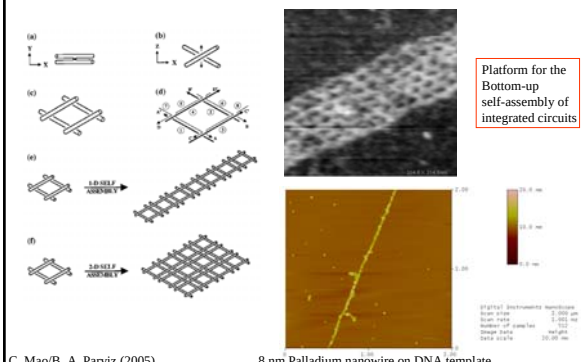




Parviz 2005



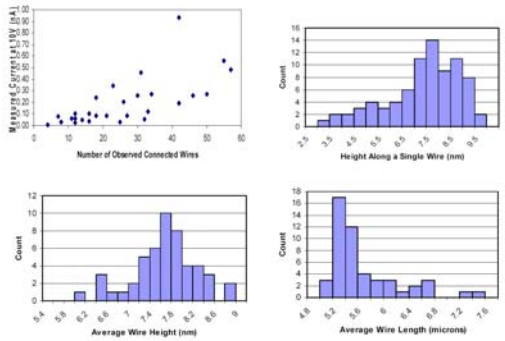
Self-assembling electronic components on DNA templates



C. Mao/B. A. Parviz (2005)

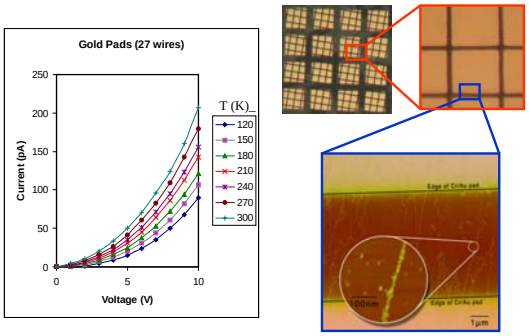
8 nm Palladium nanowire on DNA template

DNA Nanowire morphology study with AFM

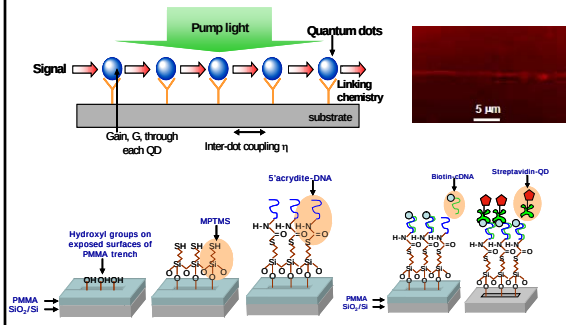


John Lund, Jianchun Dong, Zhaoxiang Deng, Chengde Mao, and Babak Parviz, "DNA Networks as Templates for Bottom-up Assembly of Metal Nanowires", *5th IEEE Conference on Nanotechnology*, Paper # TH-P2-5, Nagoya, Japan July 11-15, 2005

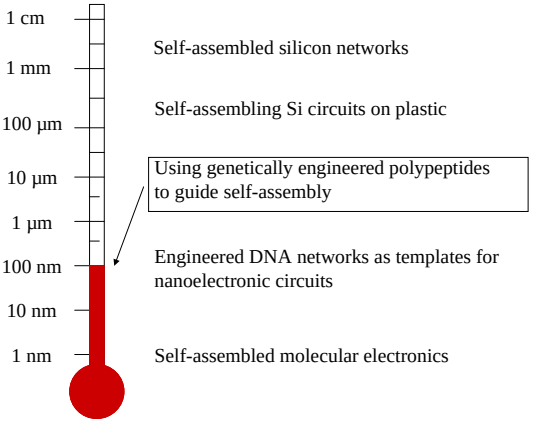
Electrical transport in DNA nanowires



DNA-directed self-assembly of nano photonic waveguides

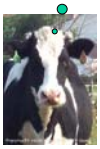


Chia-Jean Wang, Lih Y. Lin, and Babak A. Parviz, "Modeling and Simulation for a Nano-Photonic Quantum Dot Waveguide Fabricated by DNA-Directed Self-Assembly", *IEEE Journal on Selected Topics in Quantum Electronics*, v 11, n 2, March/April 2005, p 500-509



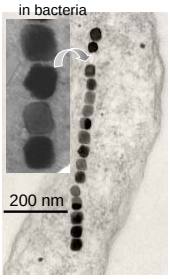
Organic tools – Inorganic goals

Why me?

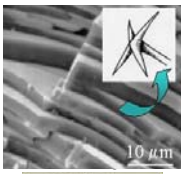


A Look at Biology …

Magnetic nanoparticles in bacteria

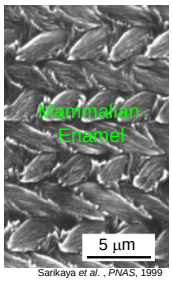


Sponge spicules: natural optical fibers



Weiner, et al., *Science* 2005

Hierarchically structured Dental tissues



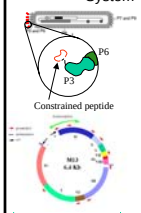
Sarikaya *et al.* , *PNAS*, 1999

Proteins control hard tissue formation through nucleation, growth, compartmentalization, …
… scaffolding, etc., leading to controlled architectures with hierarchical structures

Xiaorong Xiang, Mary Lidstrom, Babak A. Parviz, "Microorganisms as Microelectromechanical Systems", submitted to the *ASME/IEEE Journal of Microelectromechanical Systems*

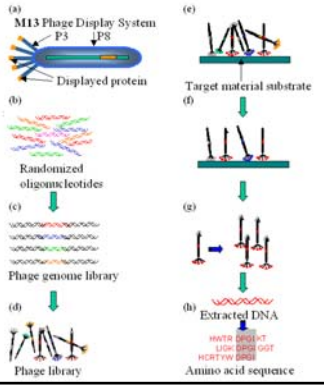
Phage display

M13
Phage-Display System



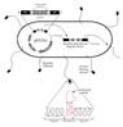
Principle: display at the N-terminus of phage M13 P3 protein

P3 copies per virion: 5
Random segment size: 7 or 12 aa
Primary clones: 1.9×10^9 (PhD12)
Sequence space: $20^7 = 1.28 \times 10^9$, $20^{12} = 4.1 \times 10^{15}$



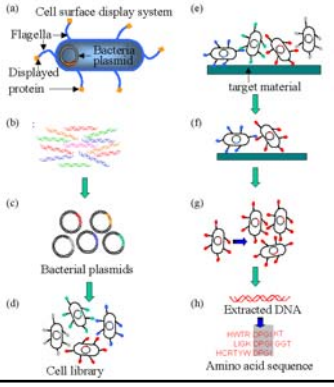
Cell surface display

FliTrx
Cell-Surface (Flagellar) Display System



Principle: cell surface display Within the active site loop of TrxA which is itself inserted within FliC

Flagella copies per cell: 10-15
Random segment size: 12 aa
Primary clones: 1.77×10^8
Sequence space: $20^{12} = 4.1 \times 10^{15}$



Quartz Binders: (80)

Au Binders:
GBP1:mhgktqatsgtiqs (14 AA)
GBP2:ALVPTAHRLDGNM(14 AA)
GBP3:LGQSGASLQGSEKLTNG(17 AA)
GBP4:SEKLVRGMEGASLHPA(16 AA)
GBP5:glndifeaqkiewh(14 AA)

Ag-Binders:
AgBP1:AYSSGAPPMPPF (16 AA)
AgBP2NPSSLFRYLPSD (16 AA)
AgBP3:SLATQPPRTPPV(16 AA)

Pt-Binders:
PtBP1:SVTQNKY(7 AA)
PtBP2:HKVTLHN(7 AA)
PtBP3:HGPDTRN(7 AA)

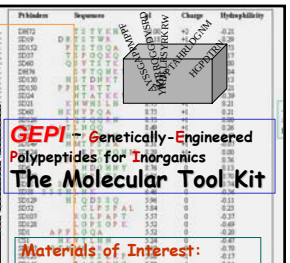
Pd-Binders:
PdBP1:SAGRLSA(7 AA)
PdBP2:TLPNHTV(7 AA)
PdBP3:INLSNRM(7 AA)

ZnO Binders:
CN122:LGSWGELLWQRQ(12 AA)
CN173:YRDLLRSYRKRW(12 AA)
CN177:HYANSIWALASQ(12 AA)

Cu_xO Binders:
CN225: RHTDGLRRIAAR(12 AA)
CN85: RTRRQGGDVSRD(12 AA)
CN44:NTVWRLNSSCGM(12 AA)

Table – I:

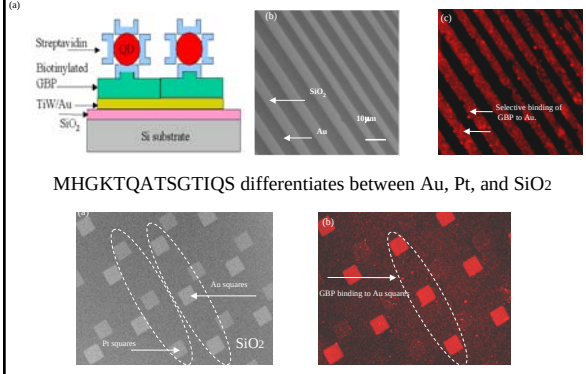
AU CSD
AG PD
Pt PD
pd PD
zno CSD
cu_xo CSD



GEPI – Genetically-Engineered Polypeptides for Inorganics
The Molecular Tool Kit

Materials of Interest:
- Biocompatible Materials
  Al_2O_3, Stainless Steel., Ti-Alloys, HA
- Semiconductors:
  ZnO/ZnS, CdO/CdS, Si/SiGe ..
- Functional Substrates:
  Silica, Mica, Graphite, Calcite
- Dielectrics/Ferroelectrics: ABO_3
- Magnetics: Metals, ferrites
- ….

Sarikaya et al., Ann. Rev. Mater. Res., **34**, 2004

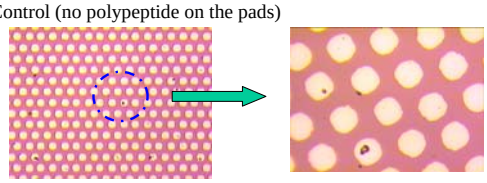


MHGKTQATSGTIQS differentiates between Au, Pt, and SiO_2

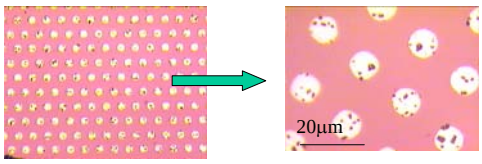
Xiaorong Xiong, Mustafa Gungormus Candan Tamerler, Mehmet Sarikaya, and Babak A. Parviz," Nanoscale Self-Assembly Mediated by Genetically Engineered Gold-Binding Polypeptide", *5th IEEE Conference on Nanotechnology*, paper # TU-PS8-3, Nagoya, Japan July 11-15, 2005

Peptide-mediated self-assembly of micron-scale particles

Control (no polypeptide on the pads)



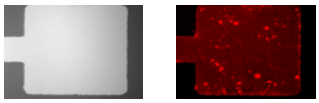
With gold-binding polypeptide on the pads



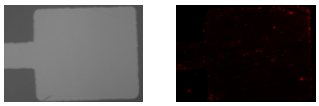
Mustafa Gungormus, Xiaorong Xiong, Candan Tamerler, Babak A. Parviz, and Mehmet Sarikaya, "Using genetically engineered gold binding polypeptide for micron-scale self-assembly", proceedings of the *Foundations of Nanoscience Conference (Self-assembled architectures and devices)*, pp. 85-88, Snowbird, Utah April 24-28, 2005

Electronic control of the polypeptide assembly

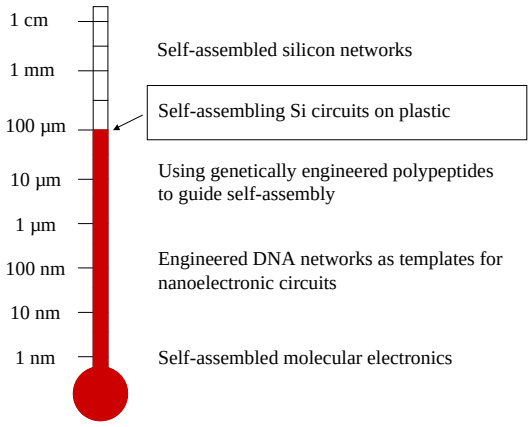
+ 0.5 V bias



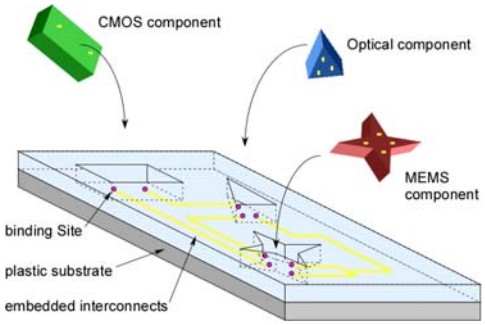
- 0.5 V bias



Xiaorong Xiong, Mustafa Gungormus, Candan Tamerler, Mehmet Sarikaya, and Babak Parviz, "Electronic Control of Binding of Genetically Engineered Polypeptides to Microfabricated Structures", to be presented at the *19th IEEE International Conference on MicroElectroMechanical Systems (MEMS)*, Istanbul, Turkey, January 22-26, 2006



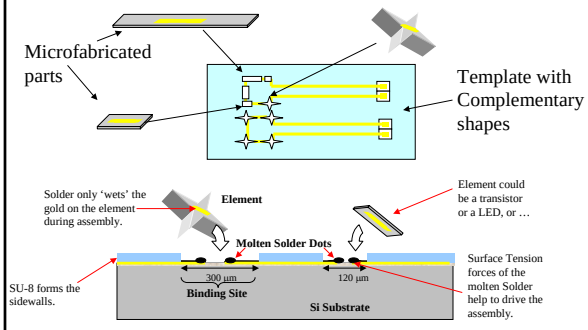
Shape recognition for self-assembly



Putting CMOS on plastic, easily re-configurable circuits

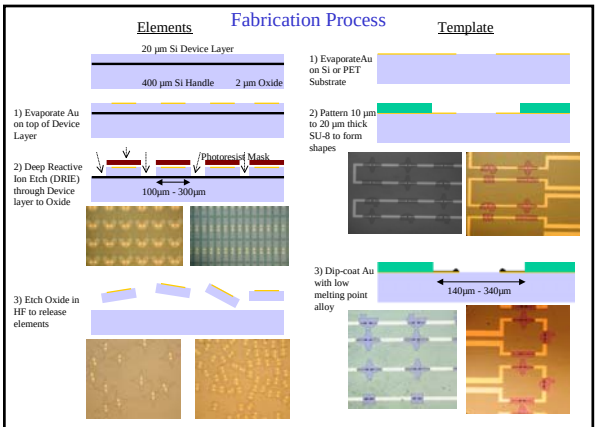
Cheap, "device" integration, macroelectronics

Shape Recognition for part to template Self-Assembly

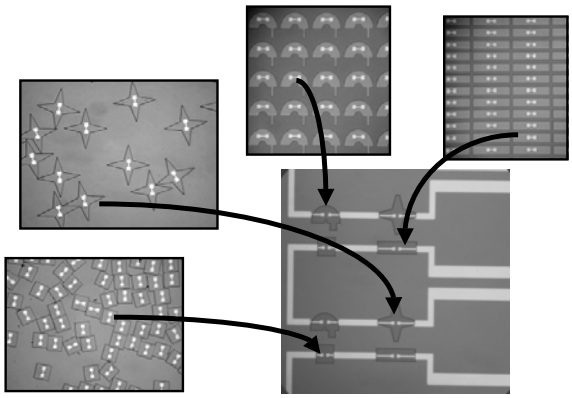


SA is performed with submerged parts and template

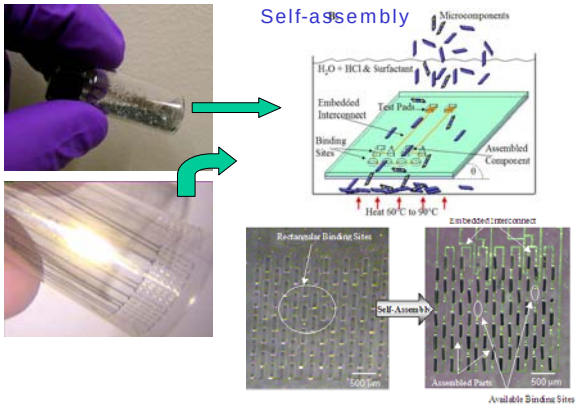
Fabrication Process



Shape recognition for self-assembly

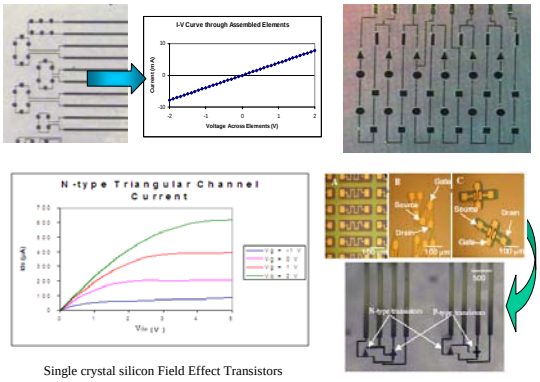


Self-assembly



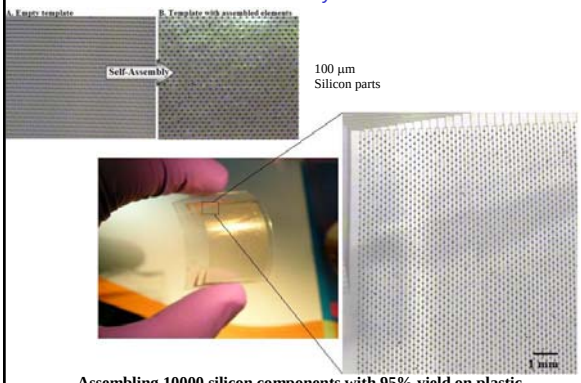
Sean A. Stauth, and Babak A. Parviz," Self-assembled silicon networks on plastic", *proceedings of the 13th International Conference on Solid-State Sensors, Actuators, and Microsystems (Transducers' 2005)* pp. 964-967, Seoul, Korea June 5-9, 2005

Active and passive self-assembly results

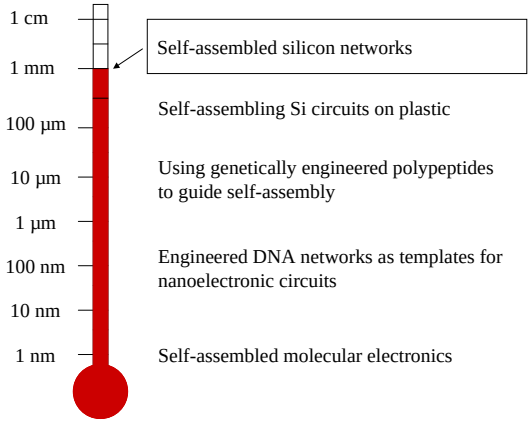


Single crystal silicon Field Effect Transistors

Self-assembly results

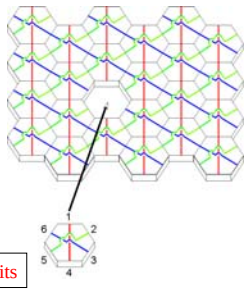


Assembling 10000 silicon components with 95% yield on plastic



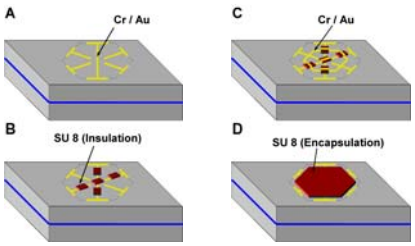
Self-Assembling Silicon Networks

- Goal: to make micron-sized silicon elements that can self-assemble into an electrical network (electronic powder)
- Making a 2-D network structure that can be expanded to 3-D
- Incompatible process integration
- First cut: CMOS compatible
- Driving force: low T_{melt} alloy
- 100 micron size scale
- Use available solid-state Fabrication technologies



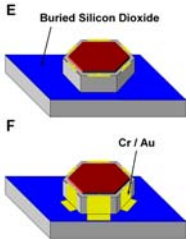
Towards 3-D self-assembled Si circuits

Fabrication Process



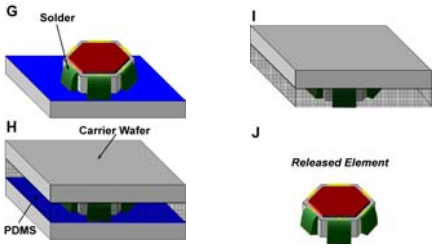
Fabrication Process

Elements on the surface of the wafer

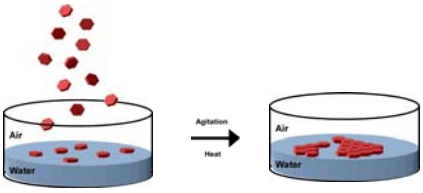


Jianchun Dong, Babak A. Parviz, Hong Ma, Alex Jen, "Using self-assembly for the construction of nano-scale lateral transport molecular electronic devices and micro-scale silicon-based networks", Invited paper, *Proceeding of Optics East (Nanosensing: Materials and Devices)*, pp. 112-122, Philadelphia, October 25th – 28th 2004

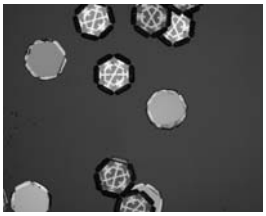
Fabrication Process

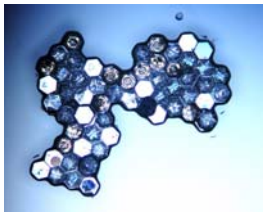


The Assembly Process



The Assembled Network





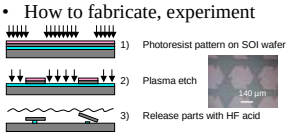
Elements before assembly

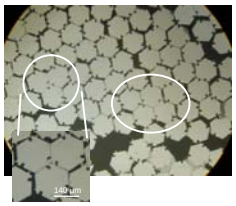
Elements after assembly

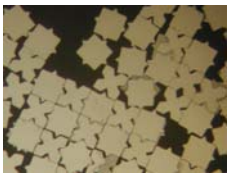
Towards 3D silicon circuits

Programming the self-assembly process at an interface

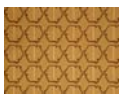
- How to fabricate, experiment





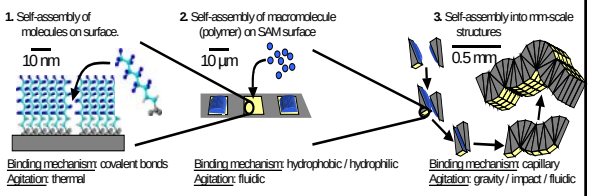


Investigating the use of magnetic (Ni) strips on parts to aid in agitation



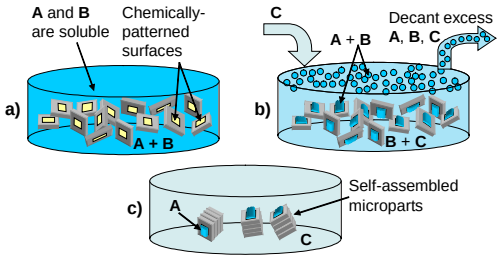
Towards 3D Self-assembly

Hierarchical self-assembly scheme across the size-scale



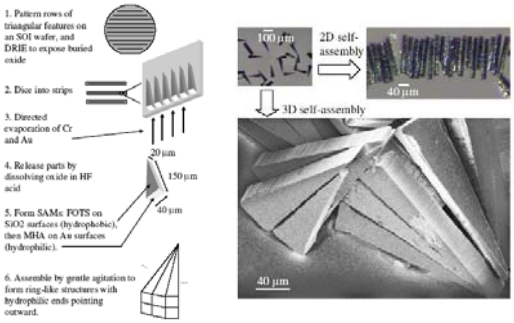
Christopher J. Morris, Sean A. Stauth, and Babak A. Parviz, "Using Capillary Forces for Self-Assembly of Functional Microstructures", proceedings of the *Foundations of Nanoscience Conference (Self-assembled architectures and devices)*, pp. 52-56, Snowbird, Utah April 24-28, 2005

Towards 3D Self-assembly



Christopher J. Morris, Harvey Ho, and Babak A. Parviz, "Insoluble Liquid Energy Minimization for Polymer Deposition on Free-Standing Microfabricated Parts", submitted to the *ASME/IEEE Journal of Microelectromechanical Systems*

Self-assembly in Solution



Christopher J. Morris, Harvey Ho, and Babak A. Parviz, "Using Insolubility Wave-front for Polymer Deposition on Self-Assembling Microfabricated Parts", Proceedings of *The 2005 International Conference on MEMS, Nano, and Smart Systems*, pp. 223-227, Banff, Alberta, Canada July 24-29, 2005

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  - Walt Wyman

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Mehmet Sarikaya (Mat. Sci)
Mary Lidstrom (Microbiology)
Lih Lin (Electrical Eng.)
Chengde Mao (Chem, Purdue)
Deirdre Meldrum (Electrical Eng.)

Washington Technology Center
Center for Nanotechnology at the University of Washington
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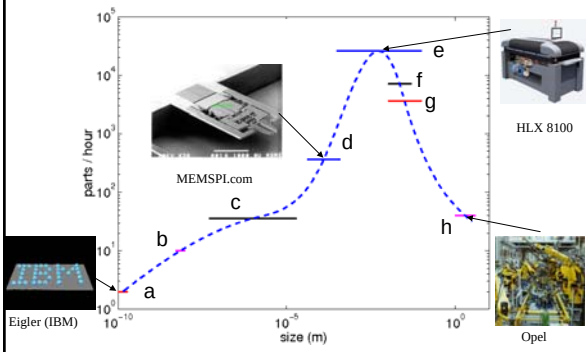
Questions?

Serial assembly?



Christopher J. Morris, Sean S. Stauth, and Babak A. Parviz, "Self-assembly for micro and nano scale packaging: steps towards self-packaging", to appear in the November 2005 issues of *IEEE Transactions on Advanced Packaging*