Fluidic Assembly and Interfacial Science of Nano-Microstructured Systems for Electronics and Medicine

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Three thrust areas

- Fluidic self assembly and nanomanufacturing:

- Self-assembled 3D microcontainer technology for biomedical applications

- Non-linear optical spectroscopy of OFET interfaces

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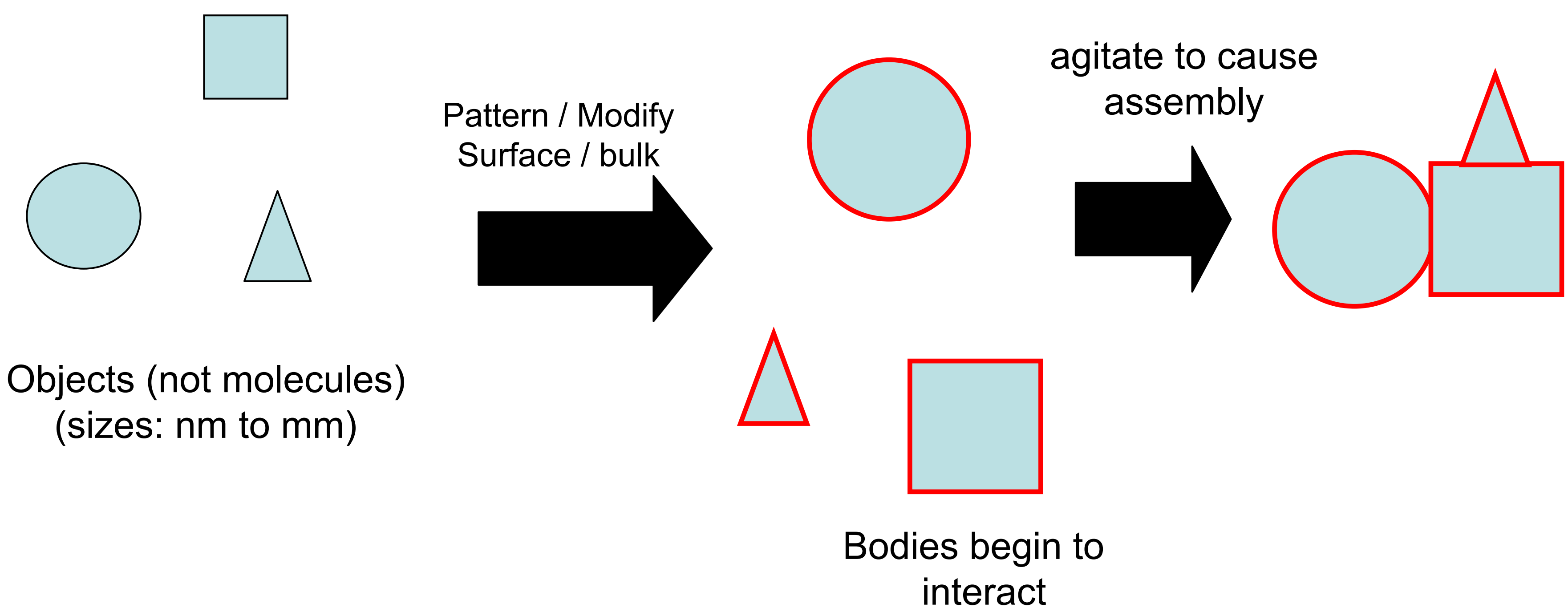
Bottom-Up Manufacturing



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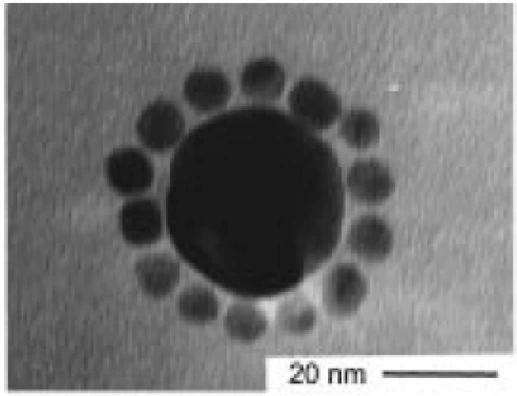
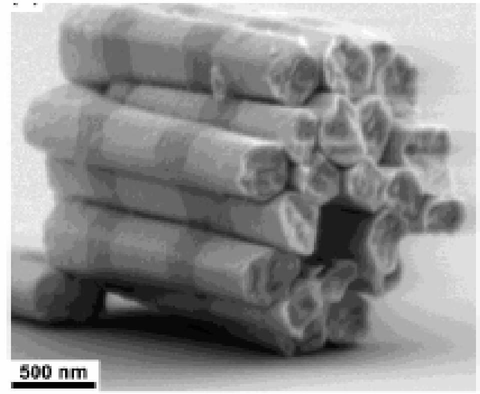
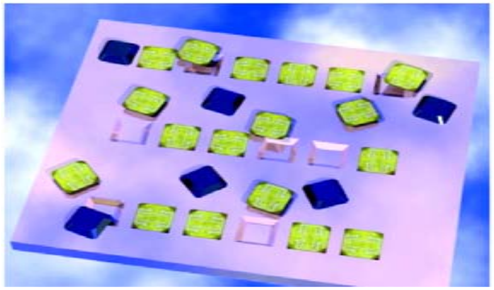
Some Limitations of several self-assembling strategies



Molecule based SA



Magnetic force based SA



Shape directed SA

- Objects on the 10-200 nm scale are rough
  - – molecular attachment does cannot result in large scale integration.
- Many assemblies are not permanent
  - – often break apart, cannot survive even mild sonication (magnetic, shape selective).
- Difficult to make robust electrical connections

Mucic, R. C. et al, *"DNA-Directed Synthesis of Binary Nanoparticle Network Materials," JACS.*, 1998, *120*, 12674-12675. Mirkin, C. A. et al. "*A DNA-based method for rationally assembling nanoparticles into macroscopic materials*", Nature (1996), 382(6592), 607-609. Love, J. C. *Three-Dimensional Self-Assembly of Metallic Rods with Submicron Diameters Using Magnetic Interactions" JACS* (2003), 125(42), 12696-12697.

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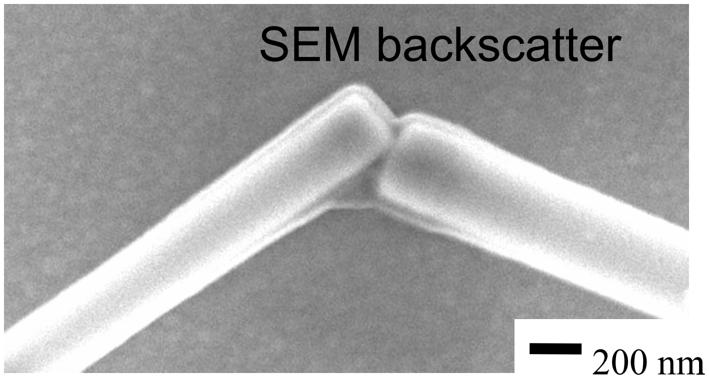
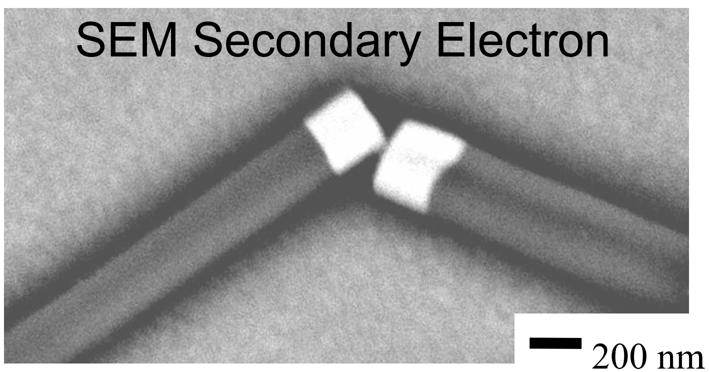
Permanent Bonding: Nano-Gluing of nanowires





Two nanowires
glued to each other

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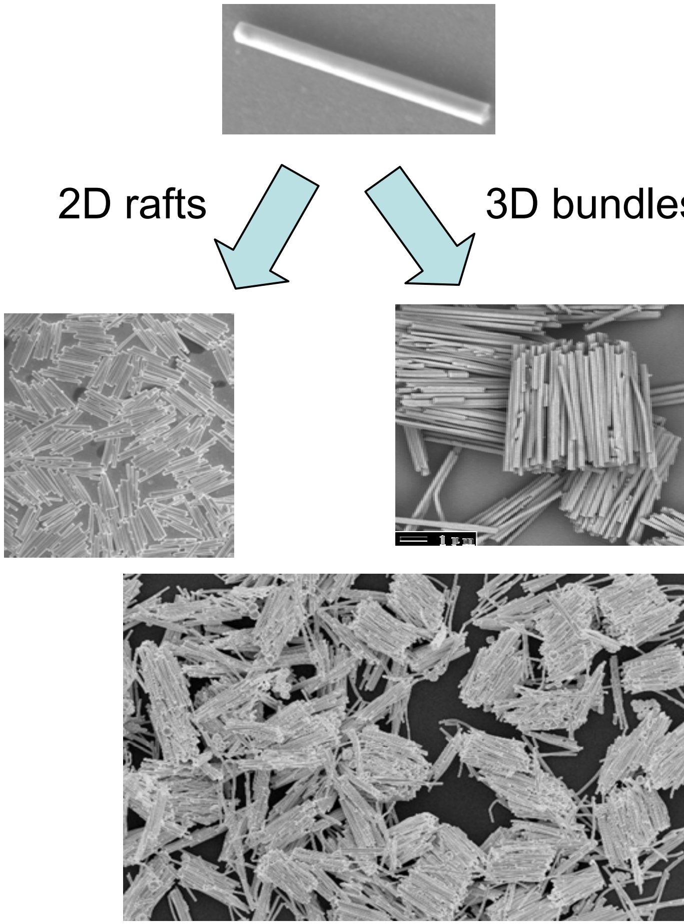
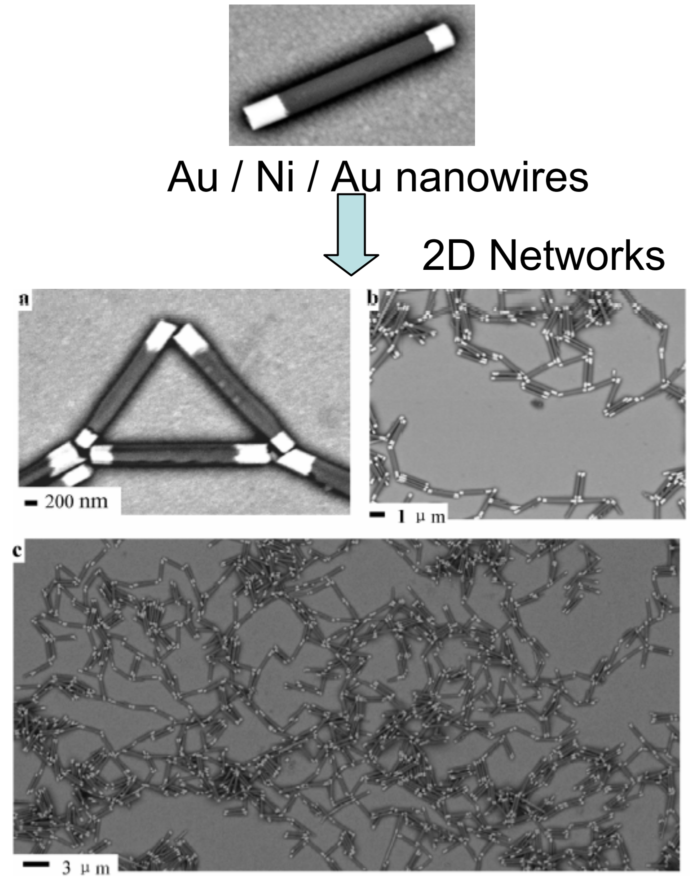
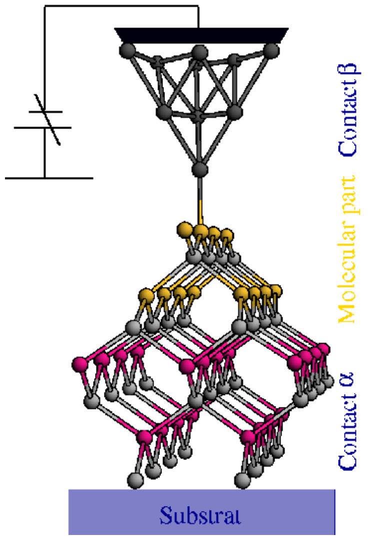
Nano-Gluing of bundles and networks



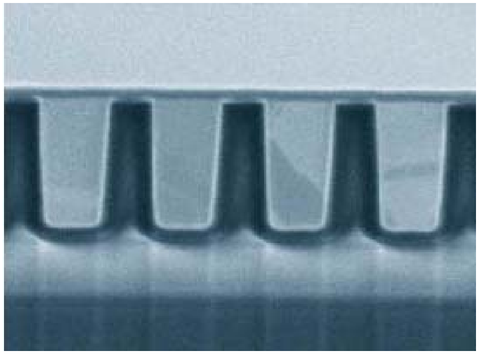


Z. Gu, Y. Chen and D. H. Gracias, *"Surface Tension Driven Self-Assembly of Bundles and Networks of 200 nm Diameter Rods Using a Polymerizable Adhesive"*, Langmuir (2004), 20(26),11308-11311.

Nanoscale Electrical Contacts using Solder

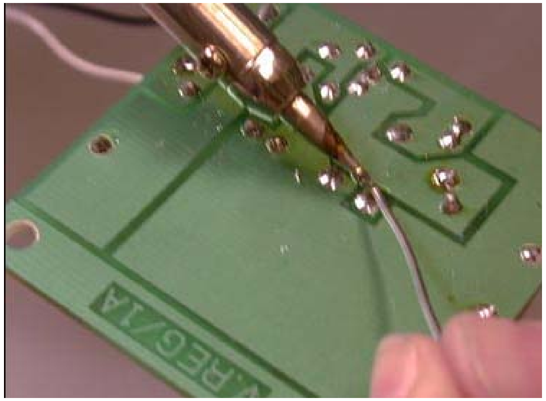


Molecular contacts
High resistance,
no temperature stability



Damascene Integration
expensive, difficult to align
to many nanoparticles

Mere physical contact
(high resistance)



Soldering is used extensively on the mm-micron scale.
Will it work on the nanoscale ?

- Corrosion, Oxidation, Intermetallic Diffusion

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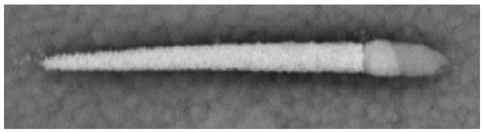
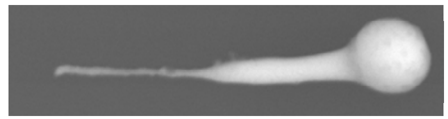
Nanoscale reflow of solder

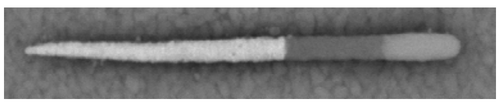


Reflow

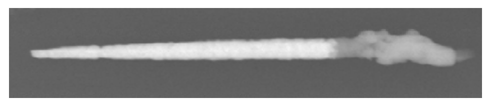


Au-Sn NW (d=50nm)

Add a diffusion barrier layer – Nickel (Ni)

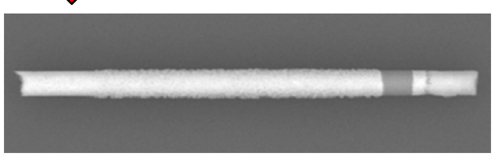


Reflow

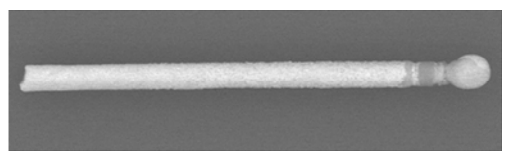


Au-Ni-solder (d=50nm)

And a wetting layer – thin Au segment



Reflow



Model NW system:
Au-Ni-Au-solder

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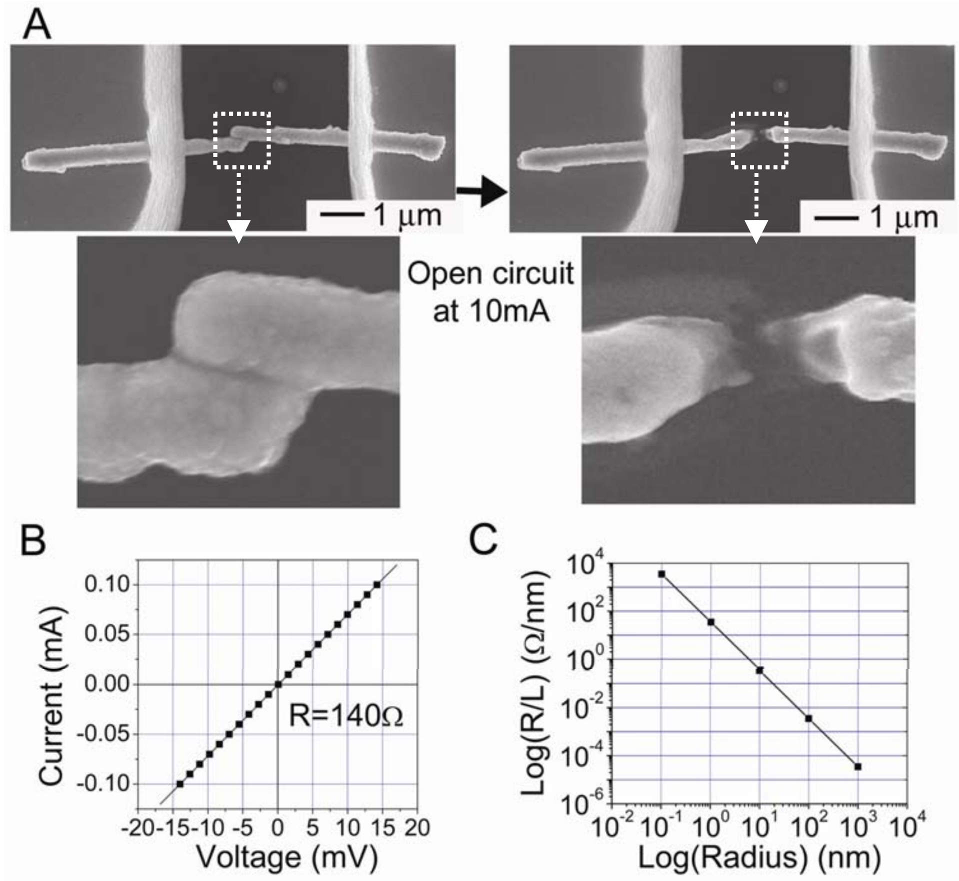
Soldering Nanowires Together



•Z. Gu, H. Ye, D. Smirnova, D. Small and D. H. Gracias, *"Reflow and Electrical Characteristics of Nanoscale Solder"*, Small (2006), 2, 2, 225-229.

•H. Ye, Z. Gu, T.Yu and D. H. Gracias, *"Integrating nanowires with substrates using directed assembly and nanoscale soldering"* IEEE Transactions on Nanotechnology (2006) 5,1, 62-66.

•S. J. Papadakis, Z. Gu and D. H. Gracias, *"Dielectrophoretic assembly of reversible and irreversible metal nanowire networks and verticaly aligned arrays"*, Applied Physics Letters (2006).

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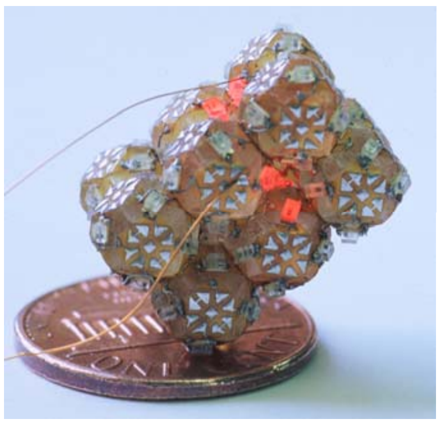
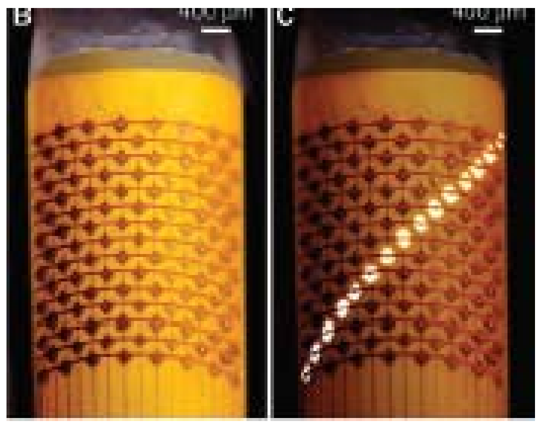
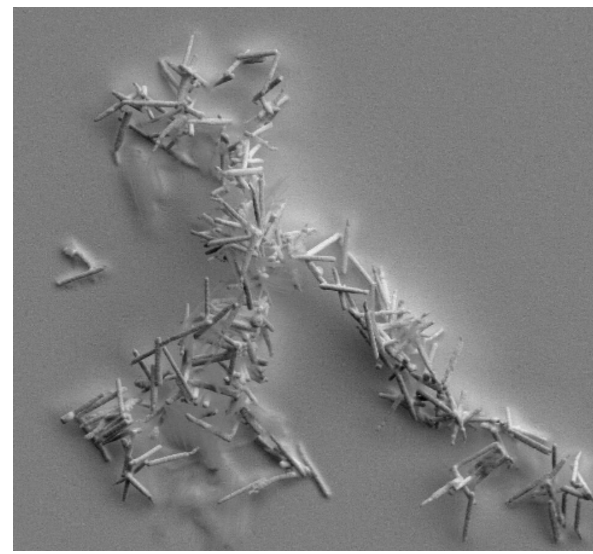
Solder based Self-Assembly to form 3D electronic Structures







mm Scale

100 Micron Scale

100 nm scale

Gracias et al, <u>Science</u> 289 (2000) 1170-1172; Jacobs et al, <u>Science</u> 296 (2002) 323-325.

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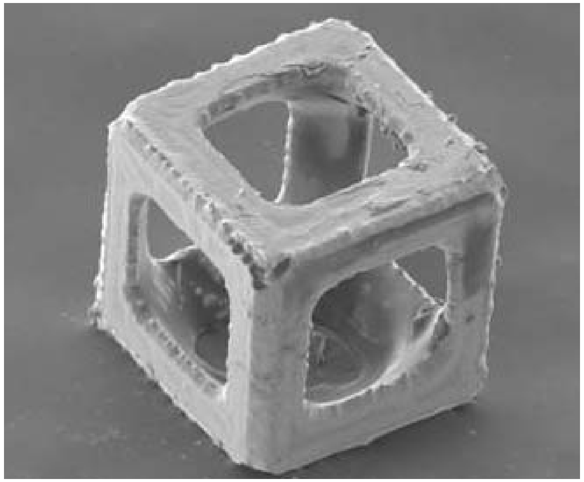
3D Self-Assembled Micropatterned Containers

- 3D
- MEMS/CMOS-compatible fabrication process
- Multiple sizes
- Arbitrary shapes
- Controlled porosity
- Easily detectable
- Remote release
- Modifiable surfaces
- Volume: Pico-nanoliter



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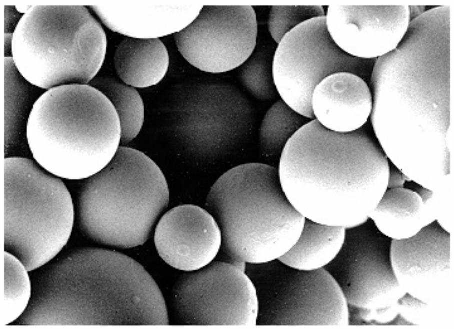
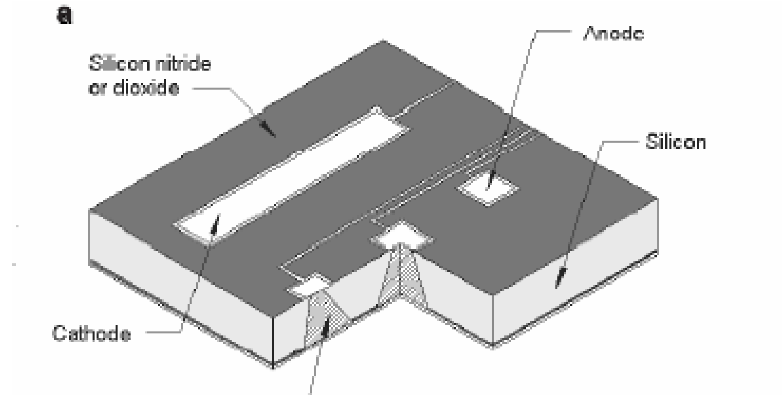
Present day encapsulants



Advantages
- Degrade easily: Biodegradable
- Good for controlled release
- Biocompatible

Disadvantages
- Degrade easily: Not chemically and mechanically stable
- Difficult to get monodisperse sizes and porosity
- Difficult to control, image and communicate to



Advantages
- Mechanically and chemically stable
- Precise size and pore size
- Can be integrated with electronics

Disadvantages
- Inherently 2D
- Large
- Serial fabrication processes

Peyratout, C. S. et al, Tailor-made polyelectrolyte microcapsules: From multilayers to smart containers. Angewandte Chemie, International Edition (2004), 43(29), 3762-3783; Bramwell, V. W. et al Particulate delivery systems for biodefense subunit vaccines, Advanced Drug Delivery Reviews (2005), 57(9), 1247-1265. Santini, John T., Jr.; Cima, M. J. et al A controlled - release microchip. Nature (1999), 397(6717), 335-338. Desai et al, Biotechnology and Bioengineering, 57, 1, 1998

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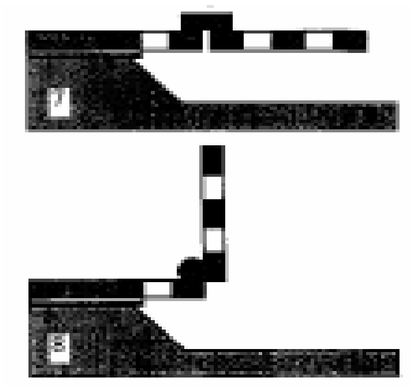
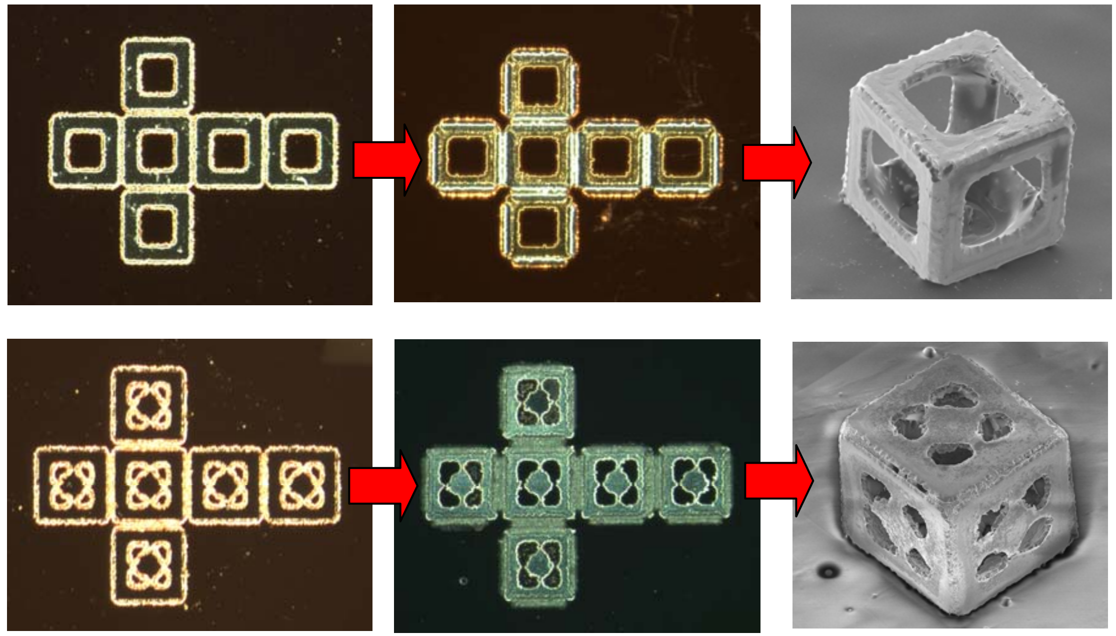
3D container fabrication





Arbitrary Porosity

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Containers can be made in large numbers

Highly parallel process

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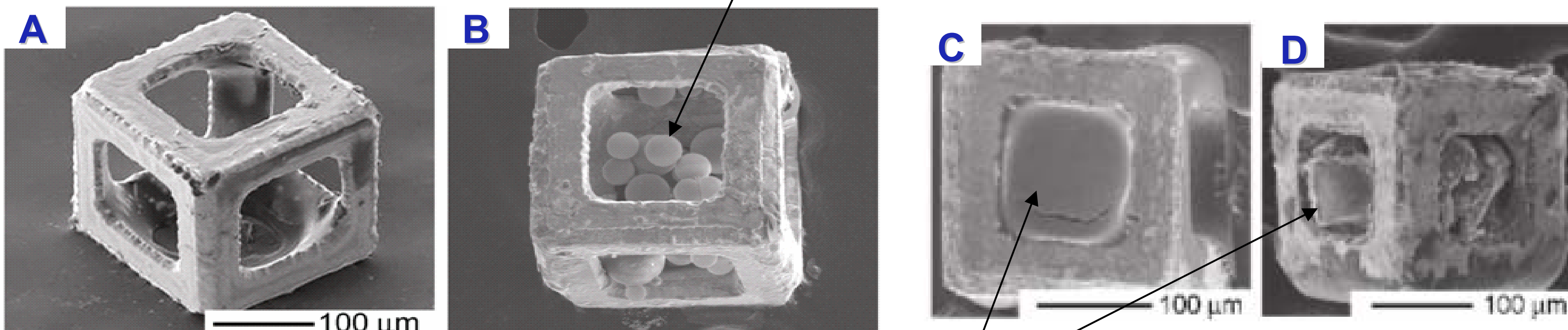
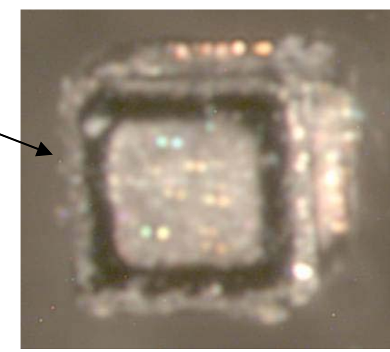
Containers can be loaded by microinjection

Container loaded with beads



Container loaded with hydrogels



Open faced containers were used for ease of visualization

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Applications

- Cell encapsulation and release
- Cell therapy
- Remote controlled release

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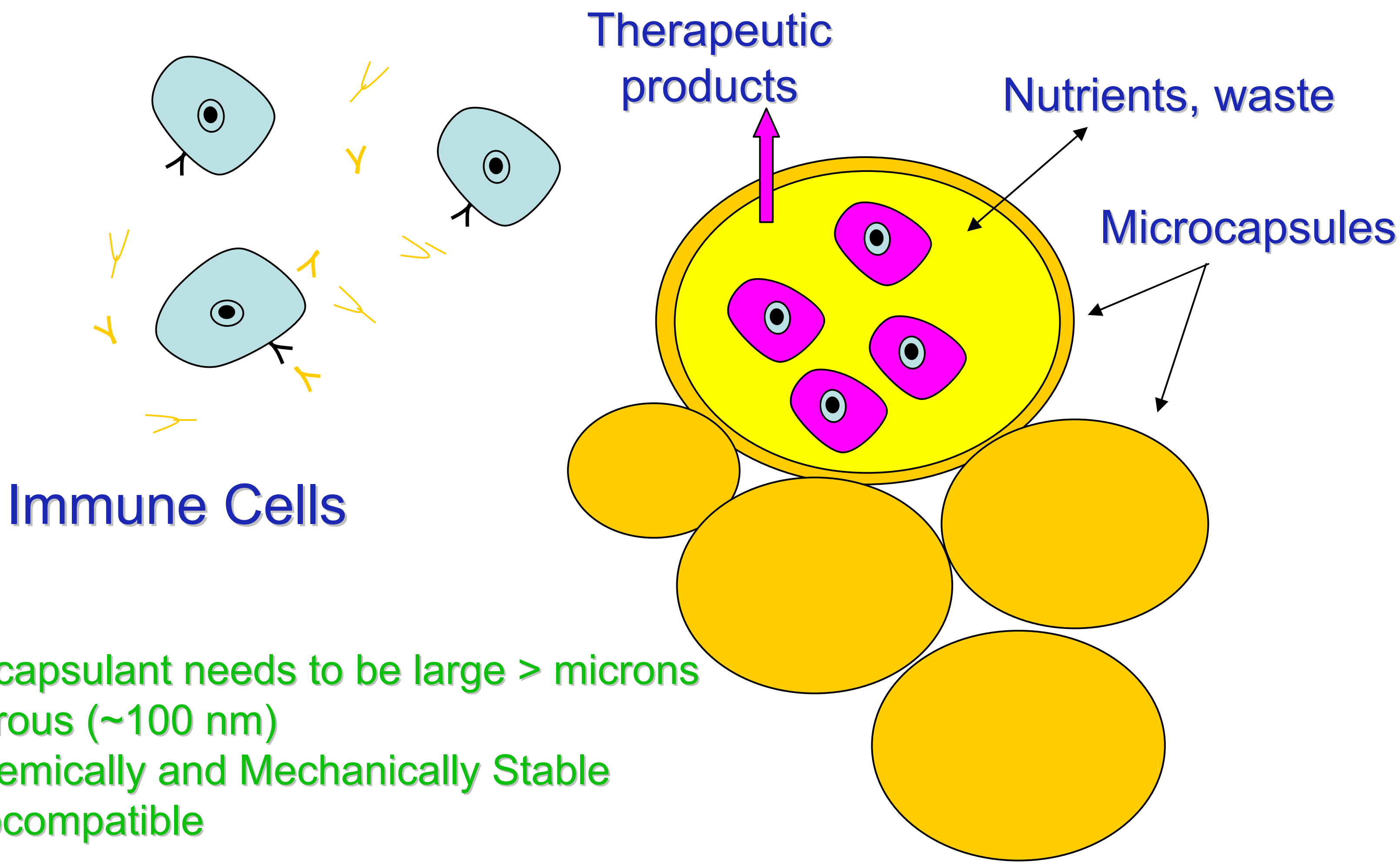
Cell Therapy (CET) without Immunosuppresion



- Encapsulant needs to be large > microns
- Porous (~100 nm)
- Chemically and Mechanically Stable
- Biocompatible

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Applications of Cell therapy is widespread

Solution to abnormal release pattern: Transplant Islet Cells

1st reported in mid-1970's (W.L. Chick, Joslin Res. Lab., Boston) glucose homeostasis achieved in rats

Since then transplanted cells have been used to
- **secrete hormones**
- **neurotransmitters**
- **growth / inhibition factors**
- **gene therapy.**

These include the use of a variety of cells

Hepatocytes for the treatment of liver failure
- **Chromaffin cells for chronic pain,**
- **Cells that produce clotting factors for hemophilia,**
- **Human growth factor for dwarfism,**
- **Nerve growth factor for amyotrophic lateral sclerosis (ALS)**
- **Treatment of Parkinson's and Alzheimer's disease.**

T . M. S. Chang, Nature Reviews Drug Discovery (2005), 4(3), 221-235.

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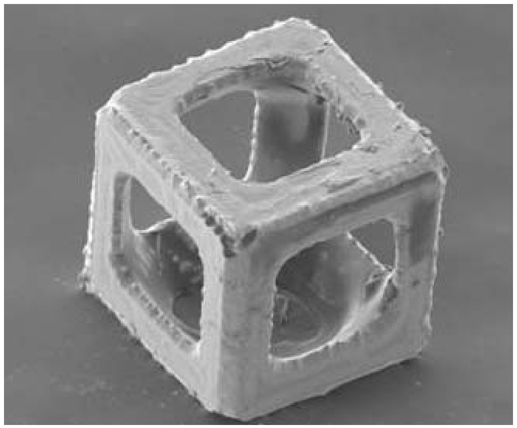
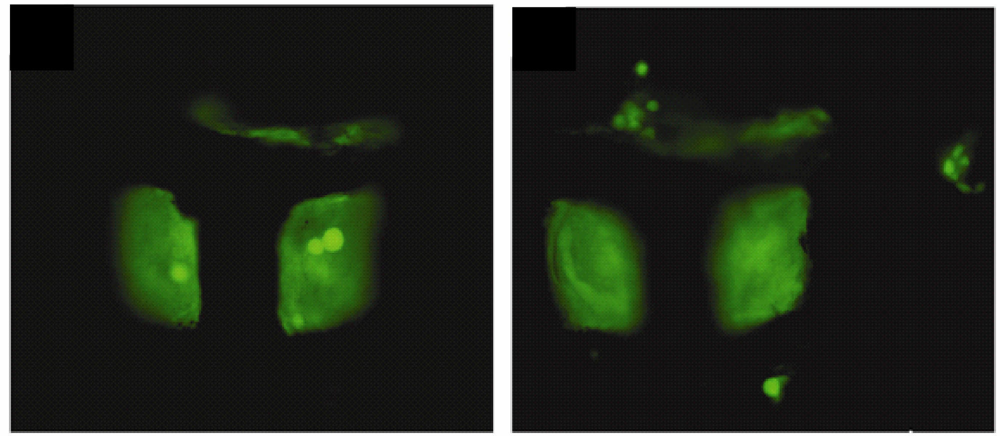
3D Micro Containers for cellular encapsulation and release





MDA-MB-231 cells in ECM, 5% agarose gel stained with viability stain Calcein-AM

Released via immersion/agitation in warm cell culture medium

200 mm size chosen based on Thomlinson & Gray (1955): hypoxic environment >150-200 mm from blood vessel

Remote tracking, guiding and controlled release

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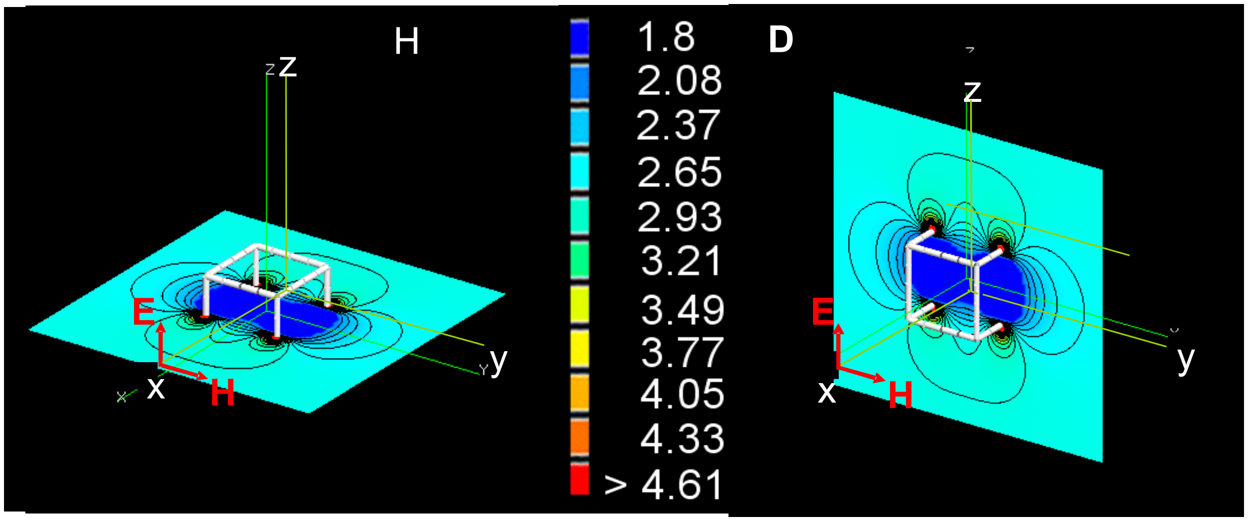
Metallic Micro Containers behave as Faraday Cages



Finite element EM simulation of the near Magnetic Field
Linear polarized plane wave excitation source of 1V/m

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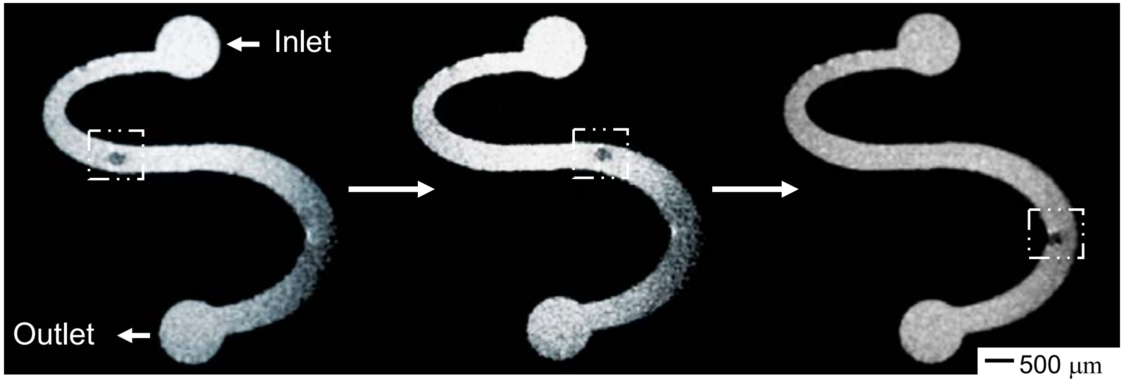
Easily detected and tracked



MR snapshots of the container moving in a 500 micron S shaped channel under pressure driven flow

B. Gimi, T. Leong, Z. Gu, M.Yang, D. Artemov, Z. M. Bhujwalla and D. H. Gracias, *"Self-assembled three dimensional radio frequency (RF) shielded containers for cell encapsulation"*, Biomedical Microdevices (2005), 7 (4), 341-345.

Remote controlled chemical release

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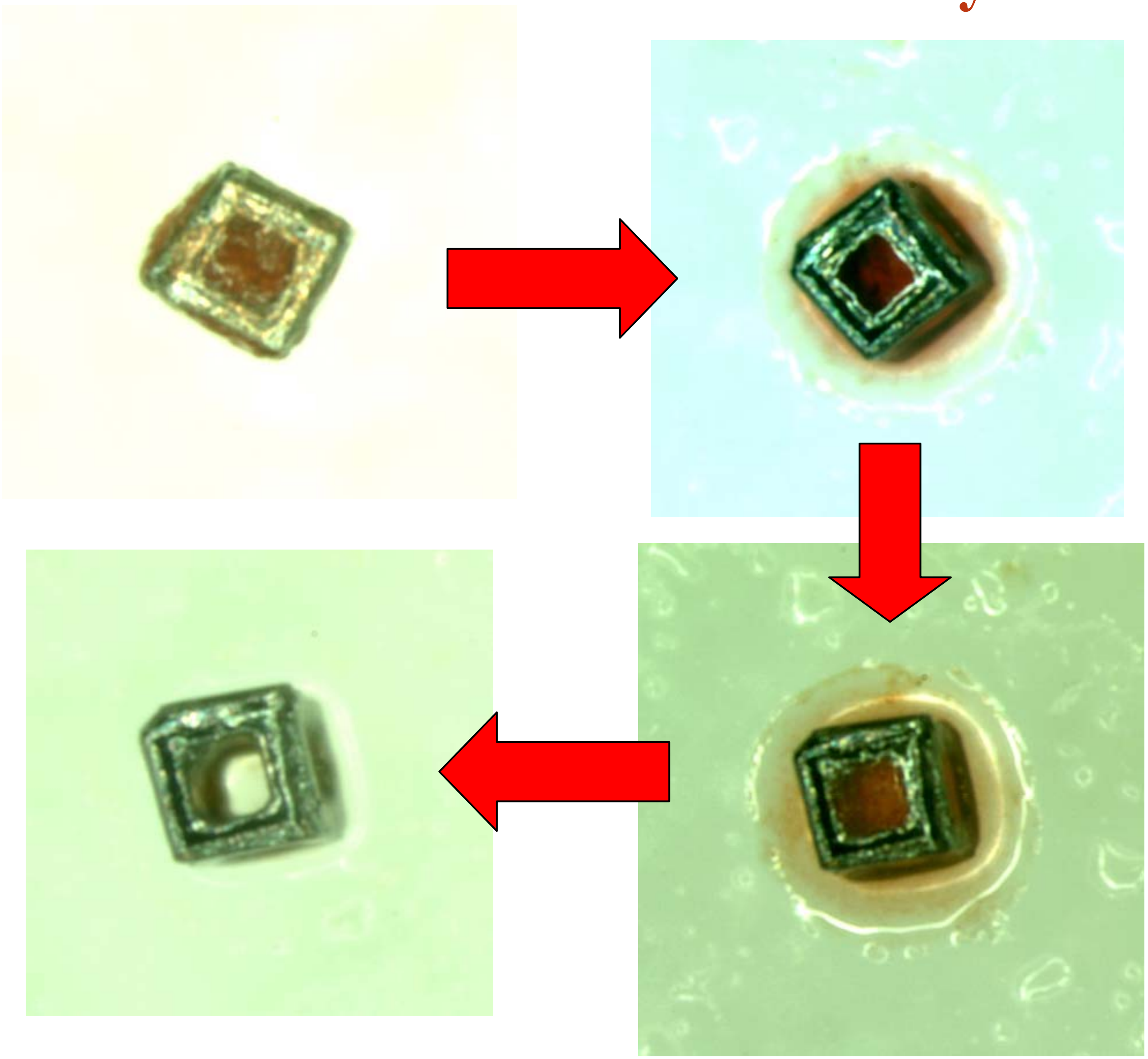
Remote controlled release of a dye



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OFET Interfaces

- Organic active element
- Solution processing
- Flexible substrates

Disadvantages

- Mobility is low
- Not very stable

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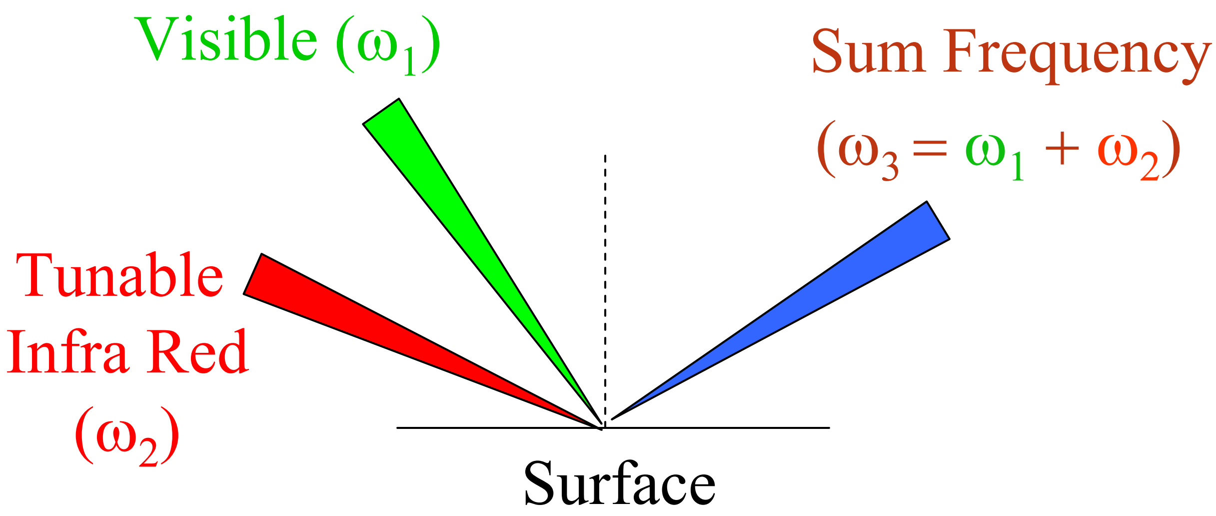
IR + Visible Sum Frequency Spectroscopy



$$I_{SF} \sim \chi^{(2)} \sim N <\alpha^{(2)}>$$

In a centrosymmetric bulk $<\alpha^{(2)}> = 0 \Rightarrow$ No Signal
At an surface $< a^{(2)} > \neq 0 \Rightarrow$ SFG Signal

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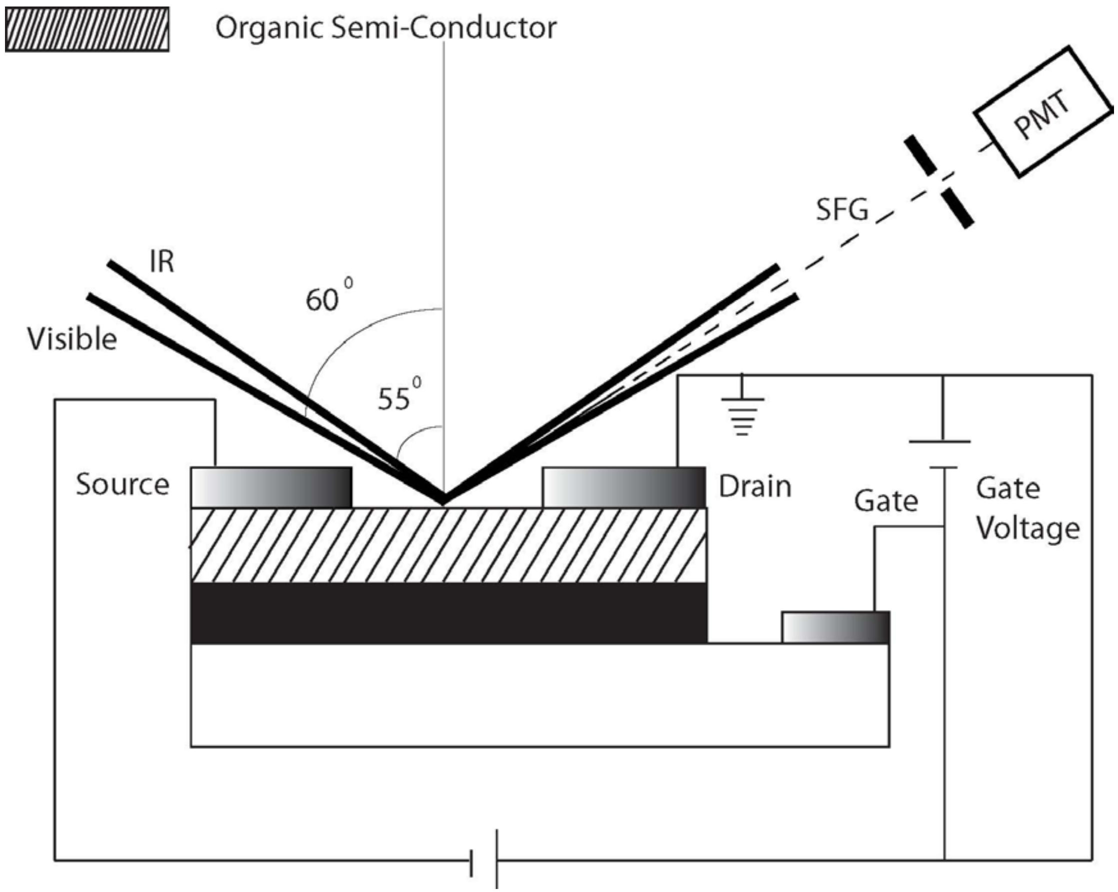
Conduction in OFETs: Integrated SFG system with 4 point probe station



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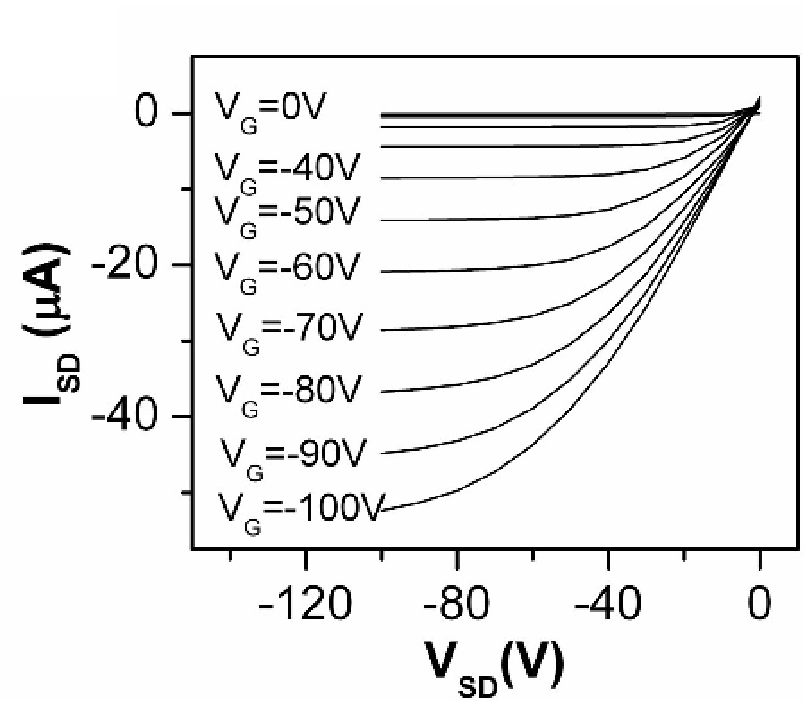
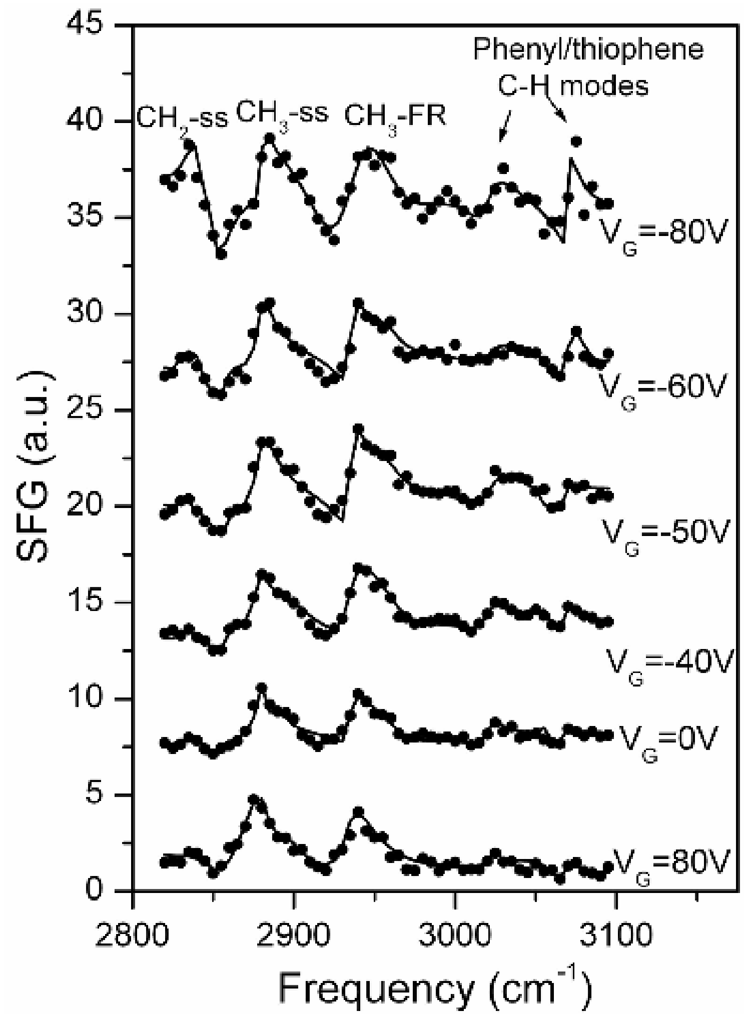
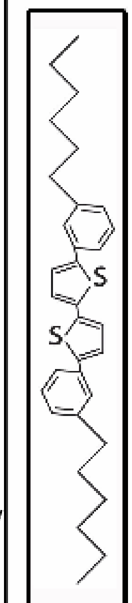
Simultaneous electrical and spectroscopic measurements







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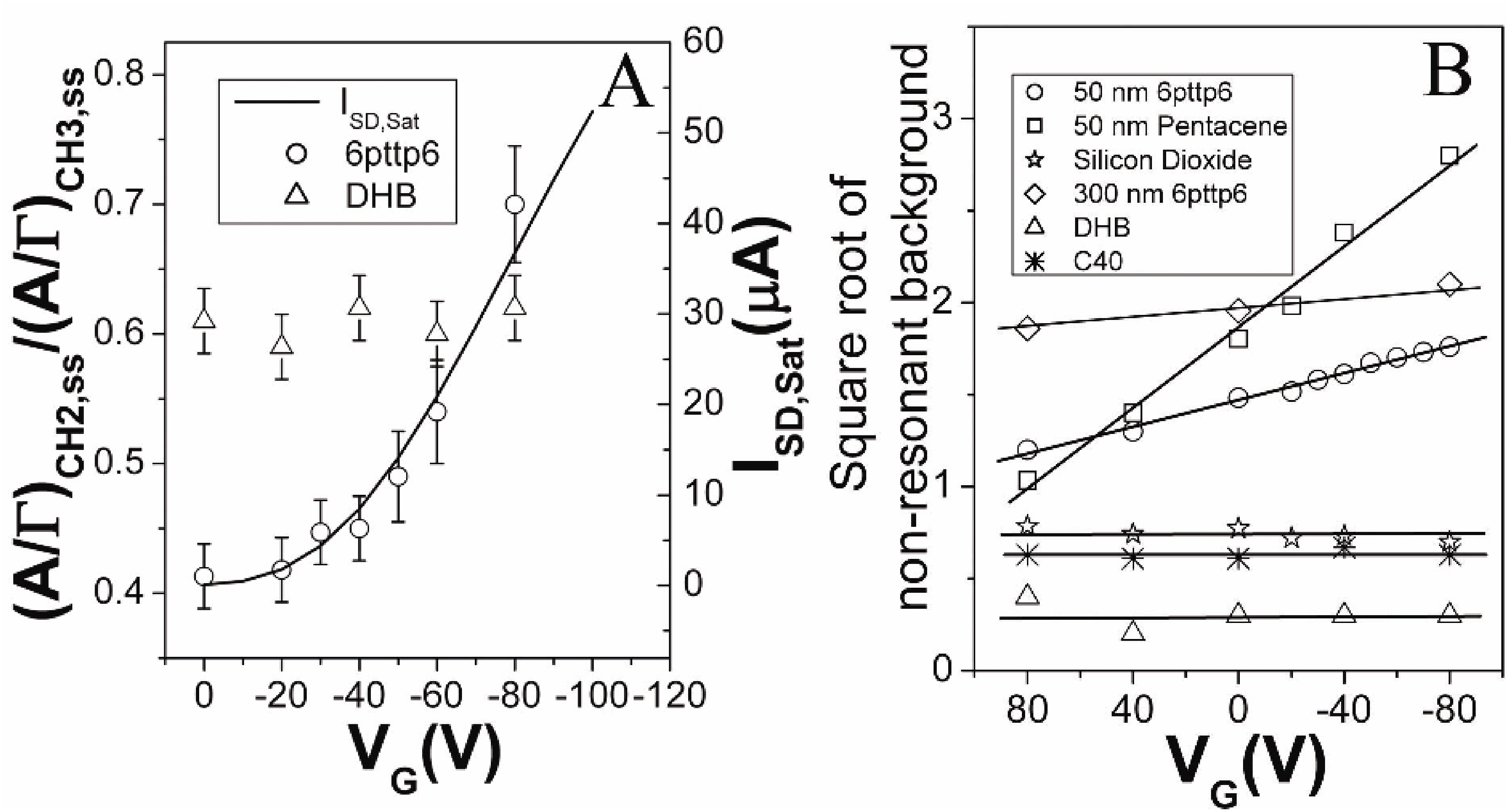
Strong correlations seen between surface structure and electrical characteristics of OFETs



H. Ye, A. Abu-Akeel, J. Huang, H. E. Katz and David H. Gracias, *"Probing Organic Field Effect Transistors In-Situ During Operation Using SFG",* submitted (2006)

Thank you

http://www.jhu.edu/chbe/gracias/

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