Introduction to Nanotechnology and Nanoscience – Class#2

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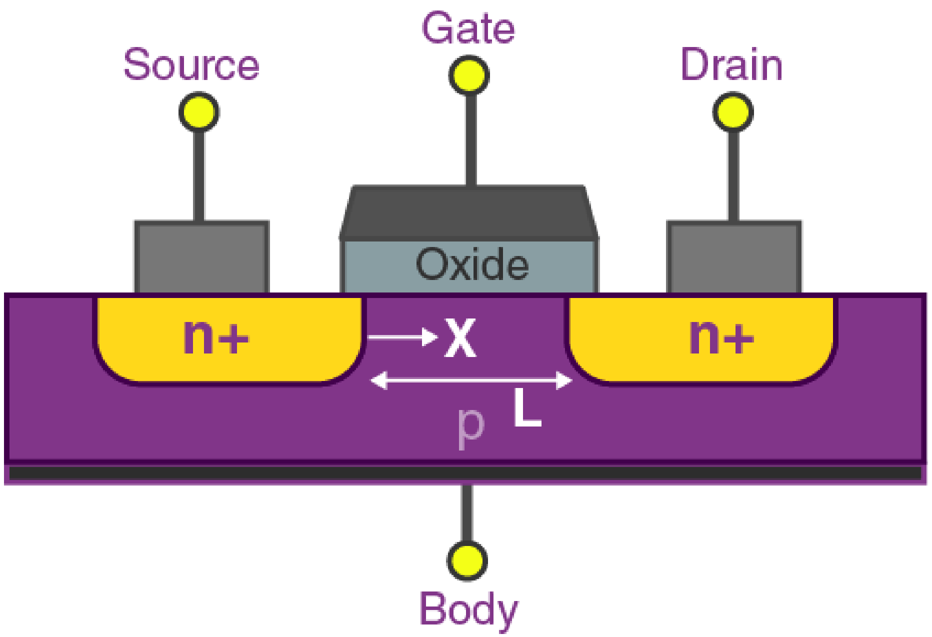
Outline

- Nanoscale Properties
- Nanofabrication: Top-down Technologies & Bottom-up Processes
- (some materials from Professor Lydia Sohn)

MOSFET History



MOSFET scaling (process nodes)

10 µm	1971
6 µm	1974
3 µm	1977
1.5 µm	1981
1 µm	1984
800 nm	1987
600 nm	1990
350 nm	1993
250 nm	1996
180 nm	1999
130 nm	2001
90 nm	2003
65 nm	2005
45 nm	2007
32 nm	2009
22 nm	2012
14 nm	2014
10 nm	2016
7 nm	2018
5 nm	2020
3 nm	2022
Future	
2 nm	~ 2024

Why Intel Stock Spiked, Then Crashed, Last Week After Its New CEO Addressed Investors

(Jan, 2023)

The market didn't appear to like new CEO Pat Gelsinger's "stay the course" strategy, but it's the right move long-term.

Why Gelsinger's comments may have disappointed some

Investors chasing Intel might have hoped its new CEO would announce more outsourcing of its manufacturing to **Taiwan Semiconductor Manufacturing** (NYSE:TSM). Such a move would probably improve Intel's competitiveness in the short-term, as Taiwan Semiconductor has already successfully begun producing 5nm chips. Meanwhile, Intel's struggles have put it well behind TSMC, and Intel now expects its 7nm chips (equivalent to TSMC's 5nm), out by the first half of 2023. Therefore, short-term investors were hoping Intel might quit trying to run its own fabs and become just a designer of chips, with outside foundries such as TSMC taking up the difficult manufacturing burden.

AFP

TSMC to launch chipmaking plant in Japan, but US plant to face delays

Amber WANG
Thu, January 18, 2024 at 3:57 AM PST · 3 min read

"In Japan, we are building a special technology fab(rication plant) in Kumamoto which will utilize 12- and 16-nanometre and 28- and 22- nanometer process technology … The volume production is on track for fourth quarter of 2024" said Liu.

"Fabrication facility in Arizona US is on track for N4 or 4 nanometer in the first-half of 2025 … have run into issues, which TSMC attributed to a shortage of skilled workers."

Nanotechnology Explosion

July 23, 2001

September, 2001

December 21, 2001

Some big numbers

Federal 2002 nanofunding	**$622 million**
Estimated nanosales volume in 2015	**$1.2 trillion**
States with active nanodevelopments	**24**

Why should I take this course?

"Nanoscience & ME"

What does a mechanical engineer do in nanoscience?

Materials scientist?

Chemical engineer?

Chemist, bioengineer, biologist, physicist, civil engineer?

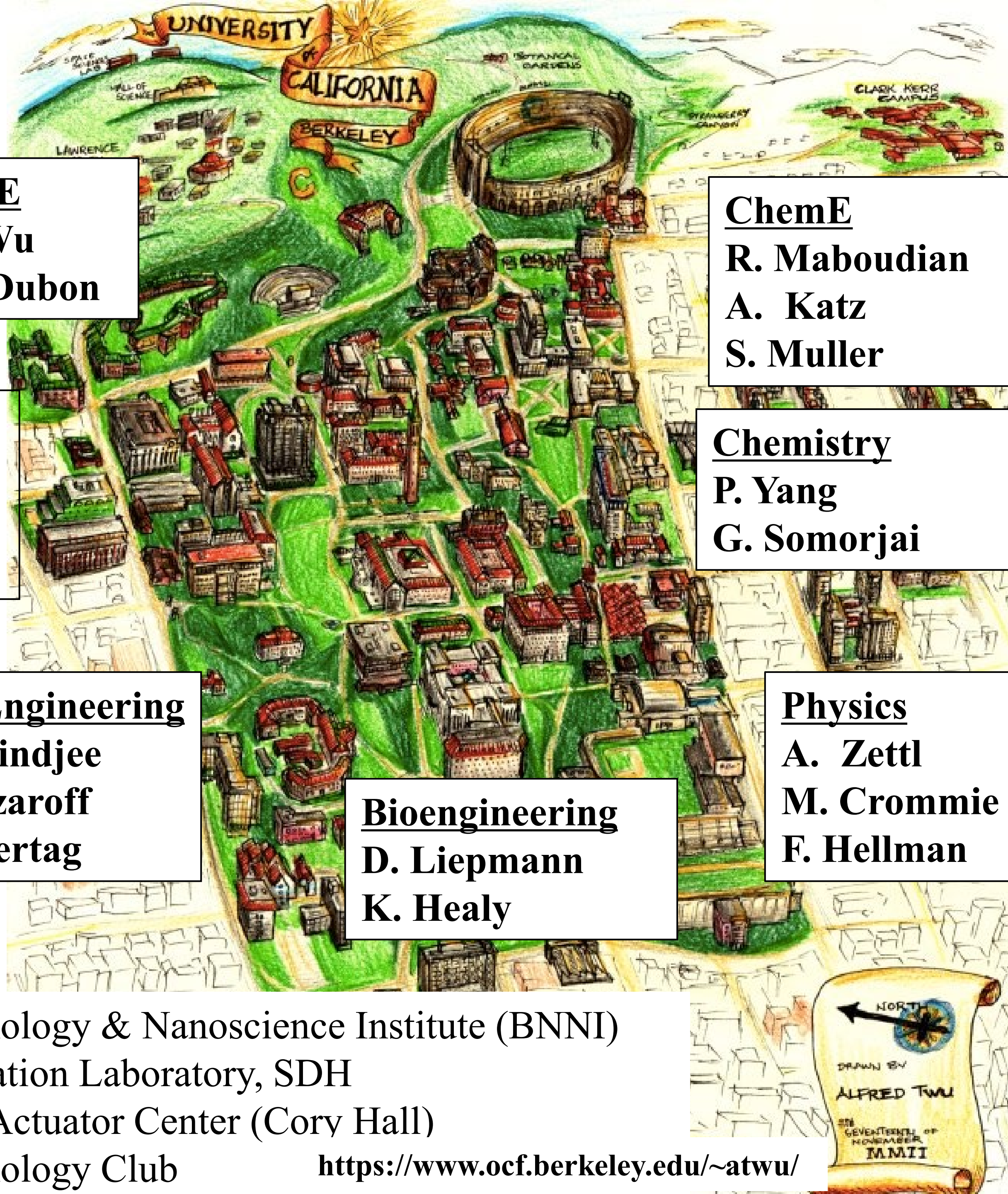
Research

- Nanoscience is **hot**!
- National labs, academia, industrial research organizations (IBM, PARC)

"Nano-Explosions"
Color-enhanced scanning electron micrograph of an overflowed electrodeposited magnetic nanowire array (CoFeB), where the template has been subsequently completely etched. It's a reminder that nanoscale research can have unpredicted consequences at a high level.

- Fanny Beron, École Polytechnique de Montréal, Montréal, Canada

http://www.mrs.org/science-as-art/



MSE
J. Wu
O. Dubon

ChemE
R. Maboudian
A. Katz
S. Muller

ME
L. Lin
L. Sohn
C. Grigoropoulos

Chemistry
P. Yang
G. Somorjai

Civil Engineering
S. Govindjee
W. Nazaroff
C. Ostertag

Bioengineering
D. Liepmann
K. Healy

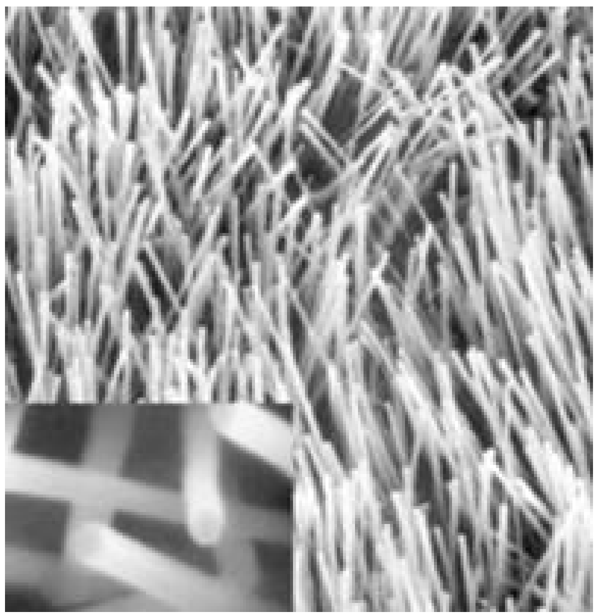
Physics
A. Zettl
M. Crommie
F. Hellman

Berkeley Nanotechnology & Nanoscience Institute (BNNI)
Marvell Nanofabrication Laboratory, SDH
Berkeley Sensor & Actuator Center (Cory Hall)
Berkeley Nanotechnology Club

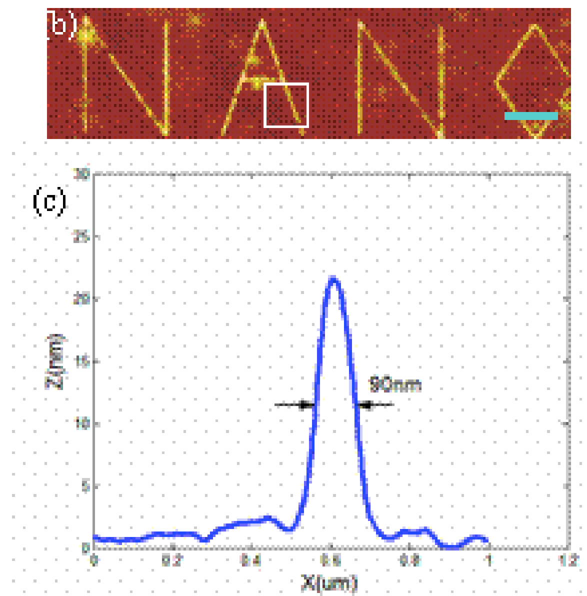
https://www.ocf.berkeley.edu/~atwu/

NanoScience in Mechanical Engineering

- Energy – energy storage, renewable energy
- Sensing – gas sensors, chemical sensors, etc.
- Optics



Cu_2O nanowires for photo-electrochemical water splitting (Lin Lab)

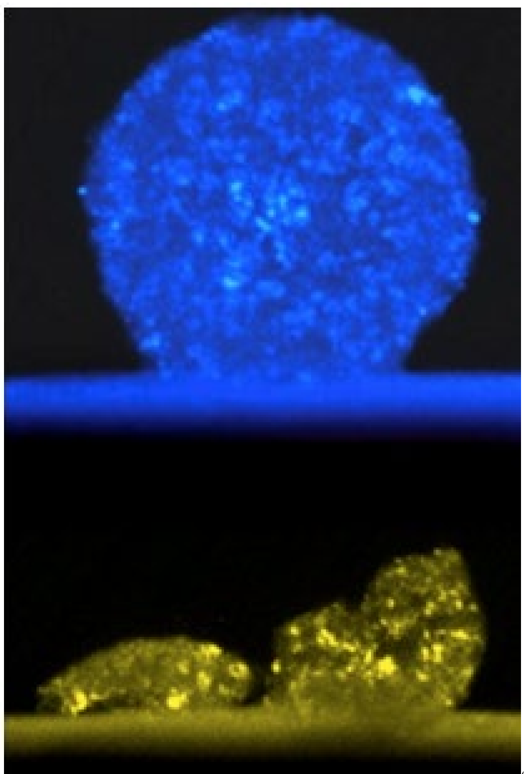


"Superlens" (Zhang Lab)

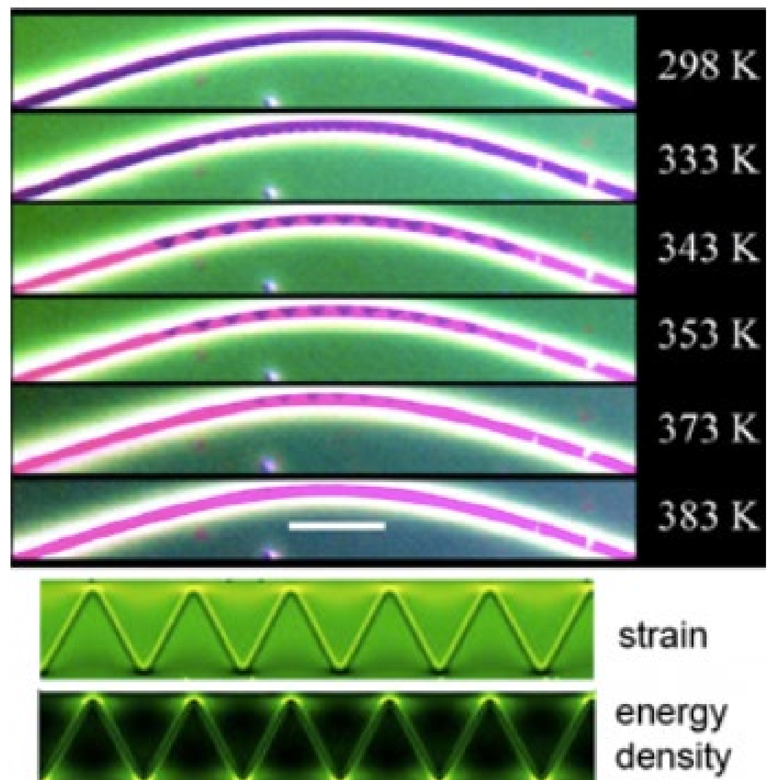
NanoScience in Materials Science

- Nanomaterial synthesis, material properties, and characterization

In-situ TEM nanomechanics (Andrew Minor Lab)



Strain engineering of VO_2 nanobeams (Junqiao Wu Lab)

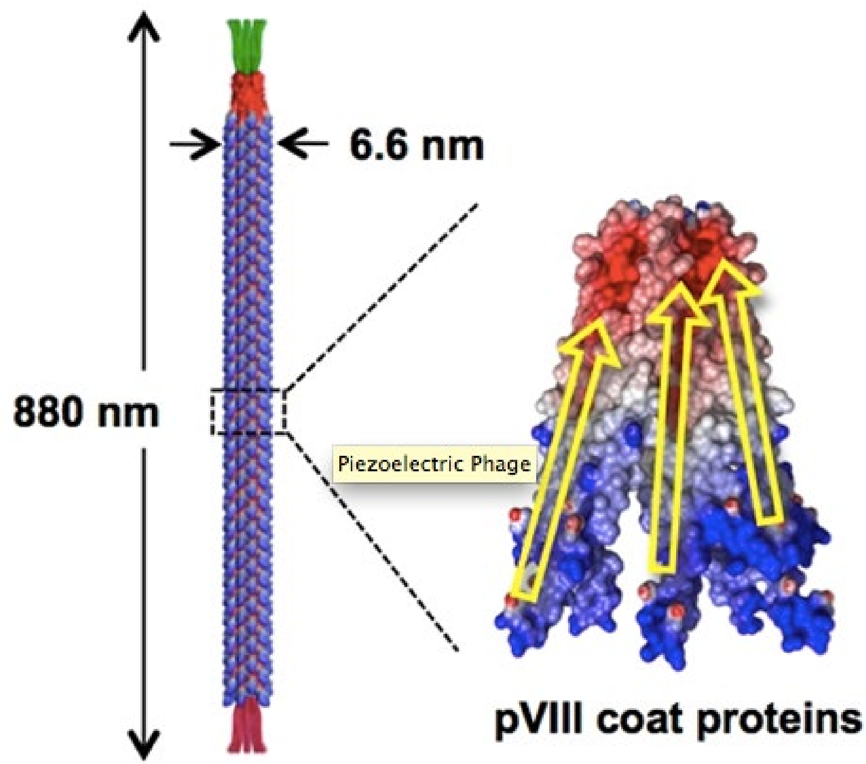


NanoScience in Bioengineering

- Virus-based piezoelectric energy generation
- Super-resolution imaging
- Drug delivery

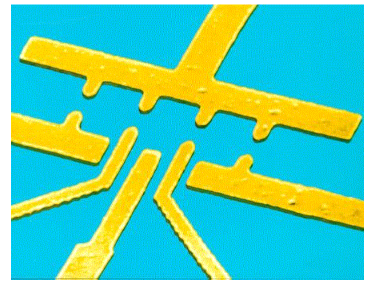
Seung-Wuk Lee Lab:

M13 bacteriophage piezoelectric generator
6 nA, 400 mV
Operates a liquid crystal display

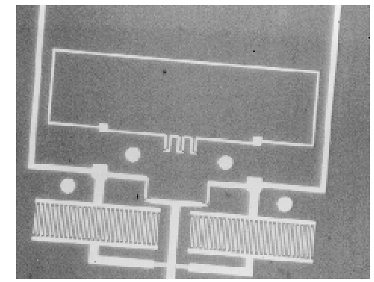


NanoScience in Physics & Chemistry

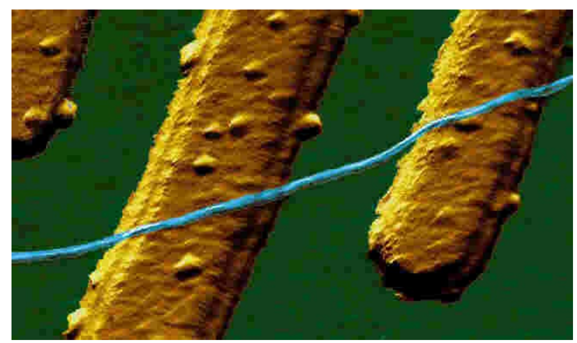
- Physics
  - Nanomechanics
  - quantum computation
  - quantum teleportation
  - artificial atoms
- Chemistry
  - carbon nanotubes
  - Nanowires
  - self-assembly
  - structures based on DNA
  - supermolecular chemistry



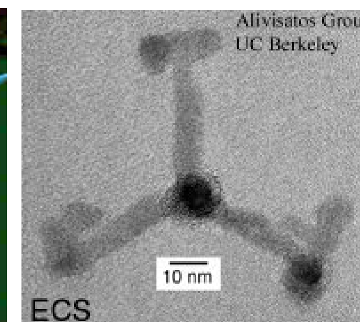
Lateral Quantum Dot
Leo Kouwenhoven



Superconducting QuBit
John Clarke



Carbon Nanotube
Cees Dekker



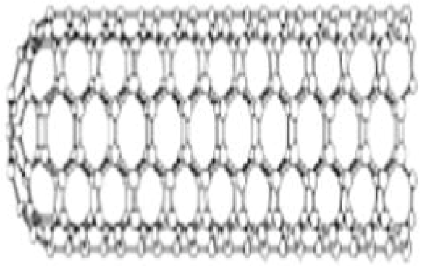
Tetrapod
Paul Alivisatos

NanoScience in Civil Engineering

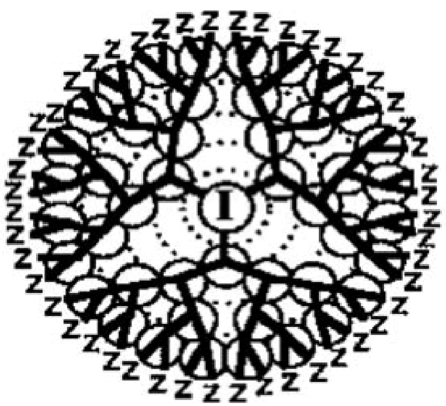
- Materials – nano-reinforced materials
- Environmental chemistry
- Water treatment

Nanomaterials for water purification:
Journal of Nanoparticle Research (2005) 7: 331–342

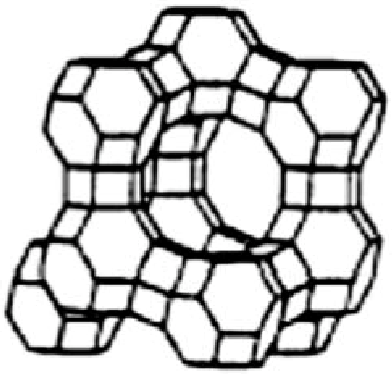
Carbon Nanotubes



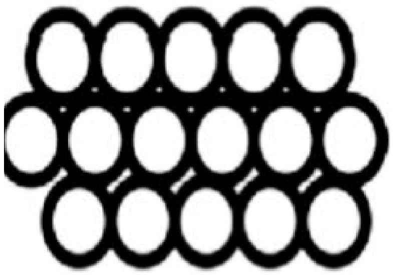
Dendrimers



Zeolites

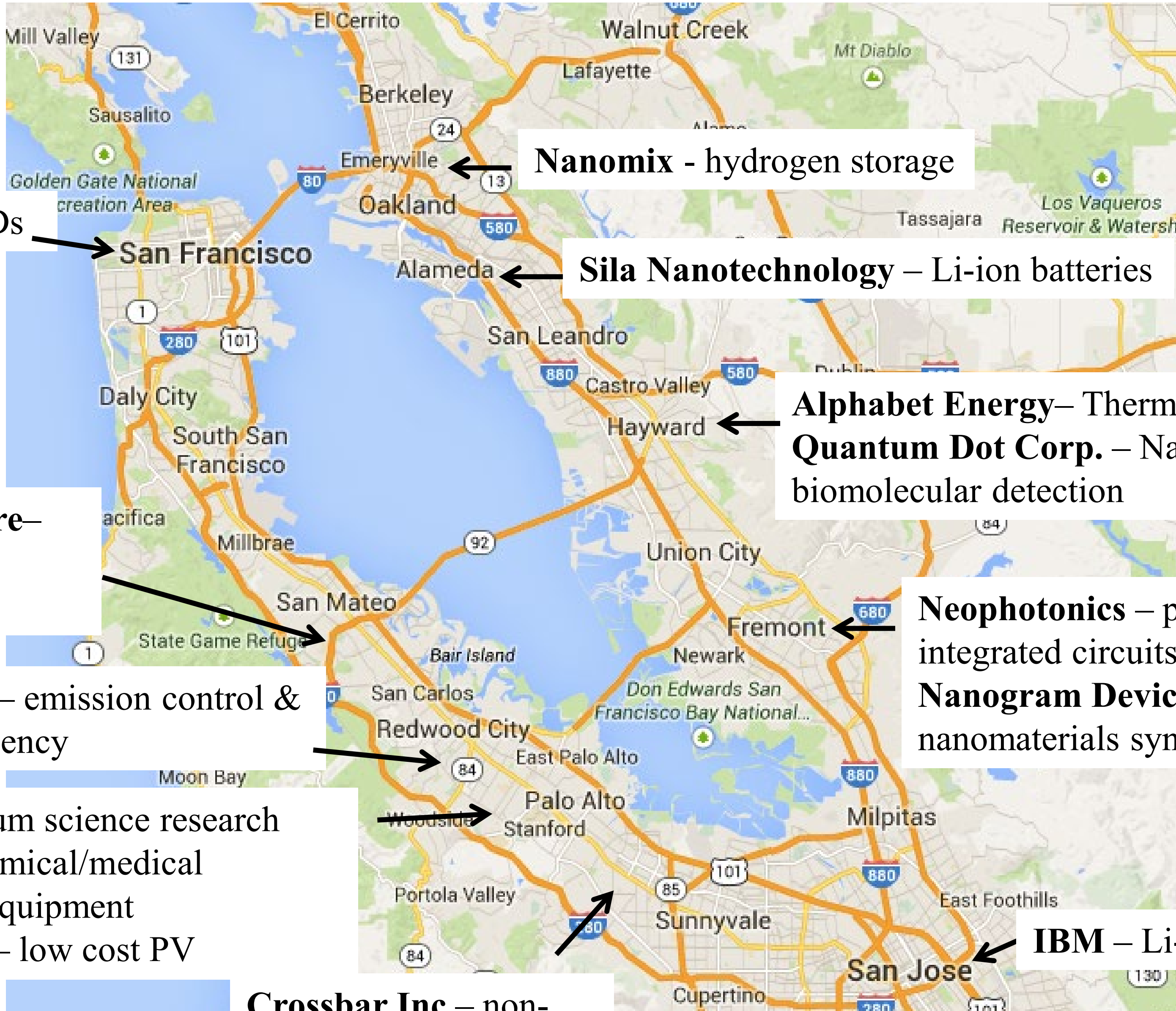


Metal-Oxide Nanoparticles



Nanotech in the Bay Area

Microsystems Laboratory
UC-Berkeley, ME Dept.



Nanomix - hydrogen storage

Optiva– LEDs

Sila Nanotechnology – Li-ion batteries

Alphabet Energy– Thermoelectrics
Quantum Dot Corp. – Nanocrystals for biomolecular detection

Lumiphore– biological detection

Neophotonics – photonic integrated circuits
Nanogram Devices- nanomaterials synthesis

Nanostellar– emission control & energy efficiency

HP – quantum science research
Agilent-chemical/medical diagnostic equipment
Nanosolar – low cost PV

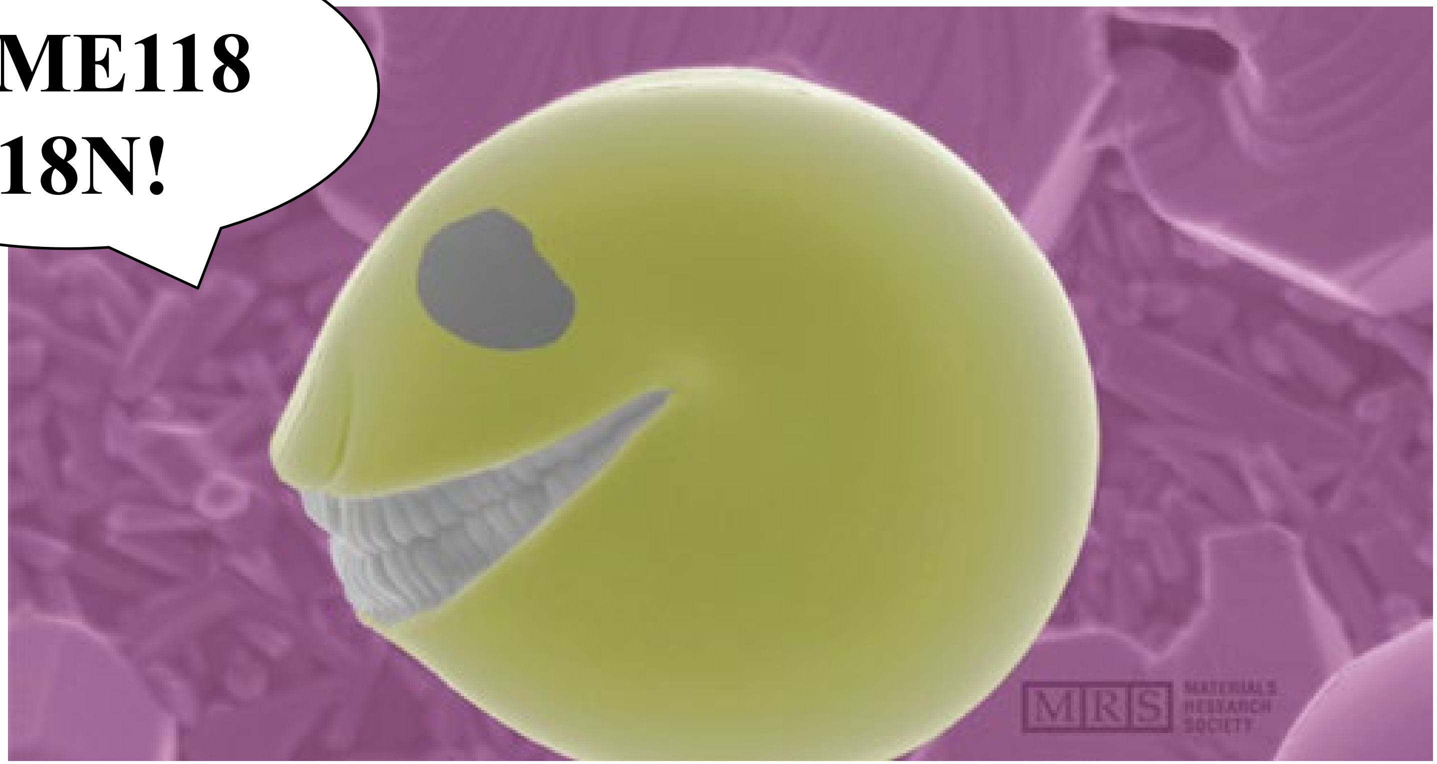
IBM – Li-air batteries

Crossbar Inc – non-volatile memory

http://www.nanotech-now.com/business-by-location.htm

"Nano PacMan"

**Take ME118
ME 218N!**



Scanning electron microscope image of a copper oxide cluster, 3.5 microns in diameter, prepared by evaporation and condensation over an alumina substrate. The smiley nose and eye are present in the original SEM image, which has only been color-enhanced.
- Elisabetta Comini, University of Brescia, Italy

http://www.mrs.org/s10-science-as-art-winners/

Why Nanostructures?

- IC & MEMS > 100 nm
  - Batch manufacturing – low cost
  - Multi-domain Integration (Electrical, mechanical, fluidic, optical …)
- Nanotechnology < 100 nm
  - Quantum effects in nanostructures (quantum dots, wires, tubes …)
  - High surface area to volume ratio – high sensitivity

Size-Dependent Properties

At the nanometer scale, properties become size dependent!

For example,

- Thermal properties
- Mechanical properties
- Optical properties
- Electrical properties
- Magnetic properties

New properties enable new applications

Surface Area to Volume Ratio

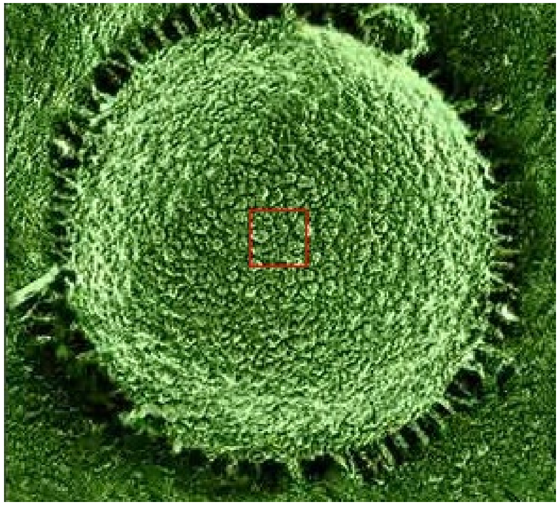
(a)

(b)

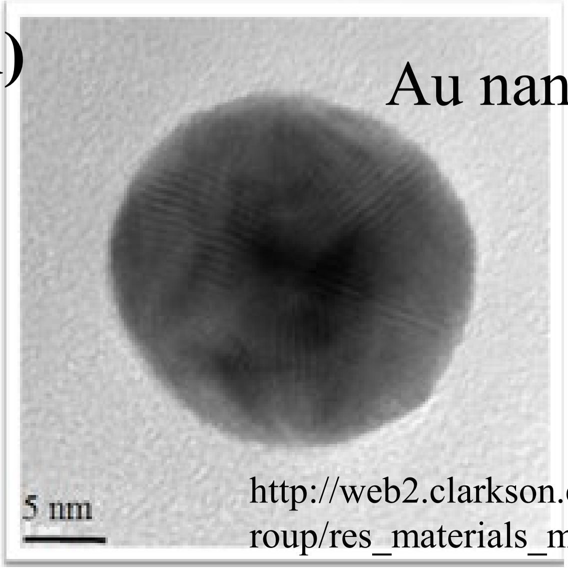
Tomato seed

(c)

Cell



(d)



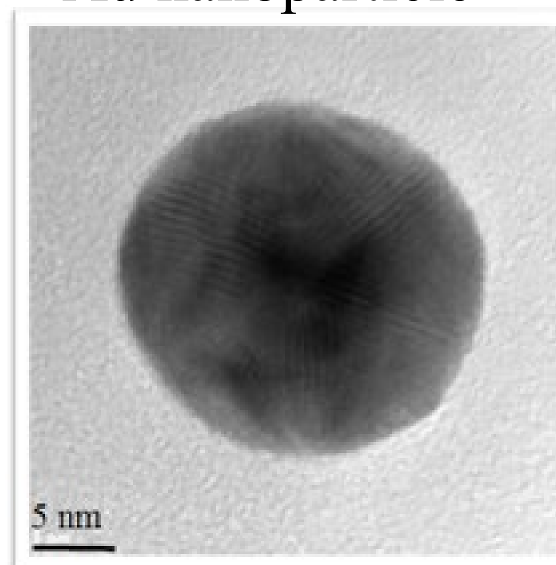
Au nanoparticle

http://web2.clarkson.edu/programs/goia_group/res_materials_modif_au.php

Chemical reactivity

vs

Au nanoparticle



Catalyst

Inert

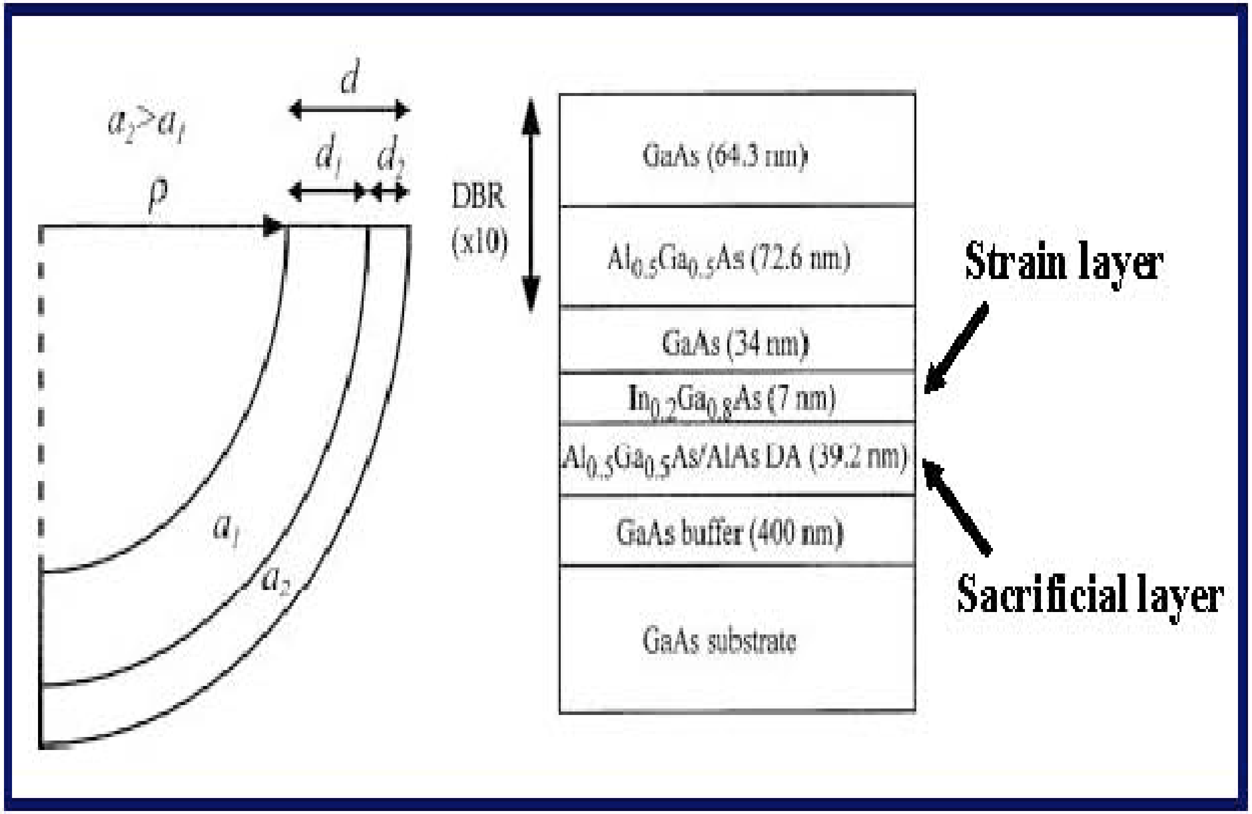
Mechanical Properties

- At the nanoscale, surface and interface forces become dominant.
- For example,

  Adhesion forces

  Capillary forces

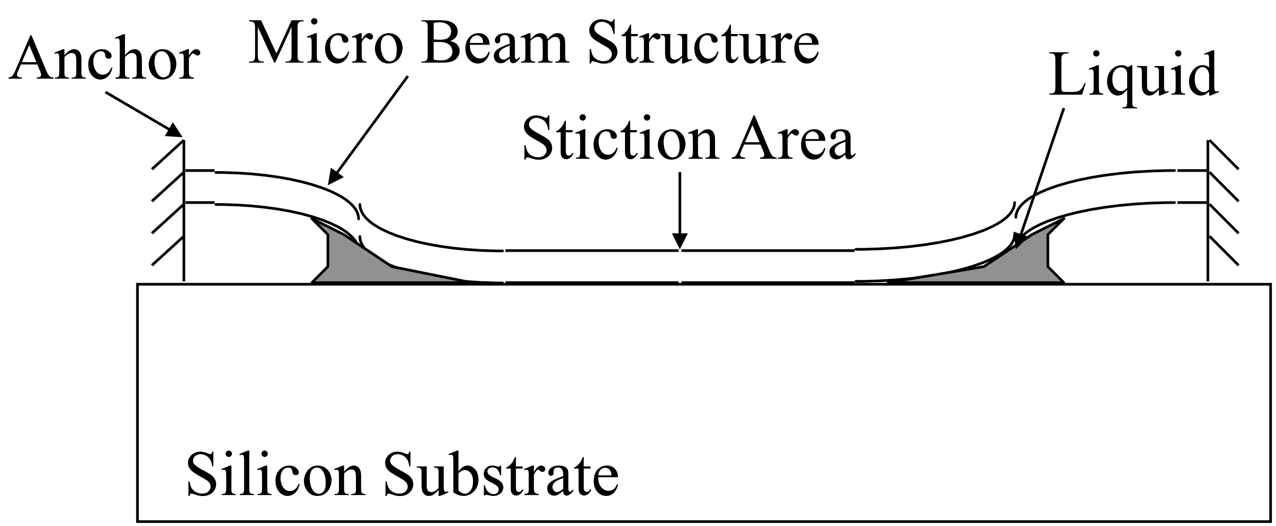
  Strain forces



Surface coatings are extremely important to prevent sticking in nanoscale electro-mechanical systems (NEMS)

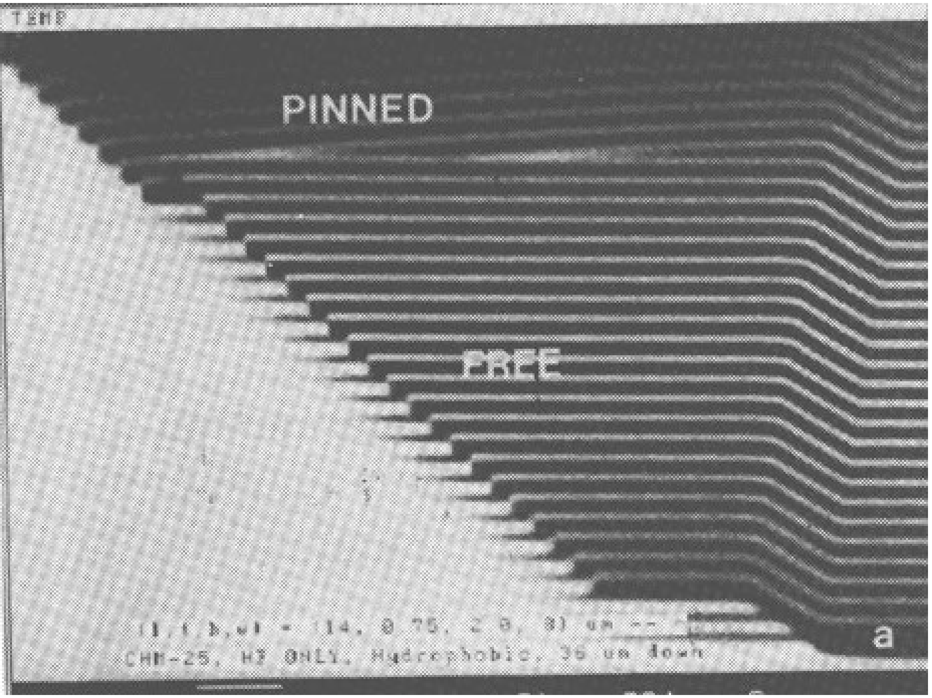
Stiction in Micro/Nano Structures

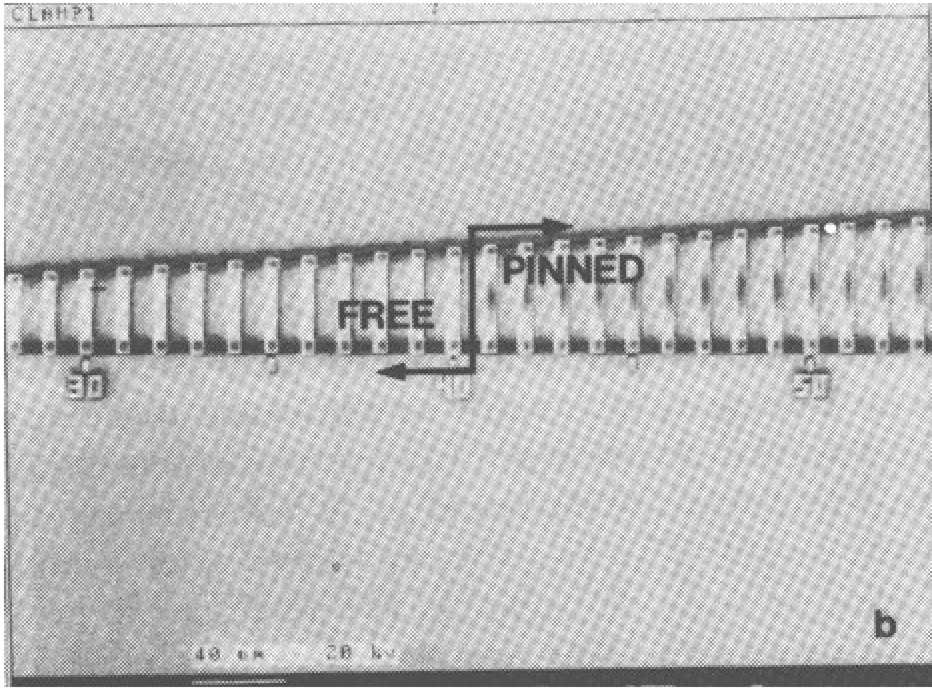
- Strong capillary forces during the releasing process and pin down the free-standing microstructure



Microstructure Stiction Examples

- Shorter beams may survive stiction problems*

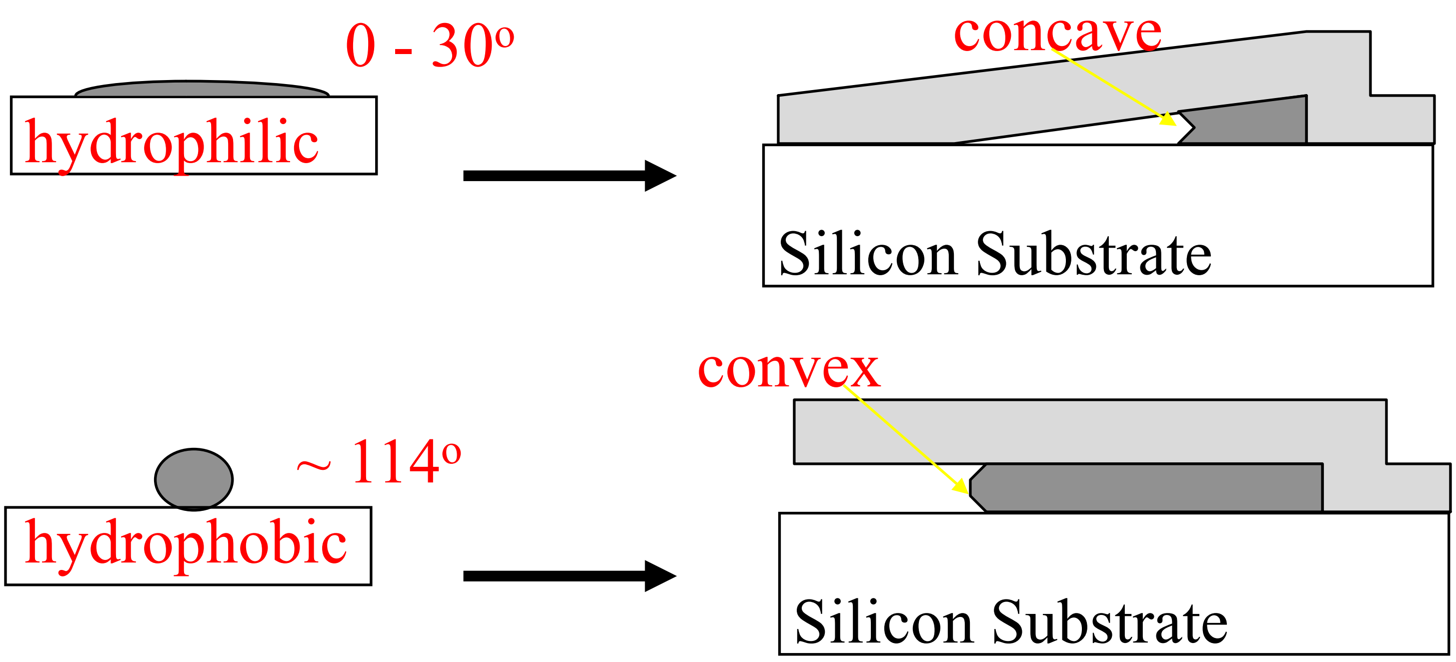




***Carlos Mastrangelo, Univ. of Michigan**

Anti-Stiction Coating

- Self-assembled monolayer (SAM) coating by using OTS (octadecyltrichlorosilane) - $C_{18}H_{37}SiCl_3$



Melting Temperature

Nanocrystal size decreases

↓

Surface energy increases

↓

Melting point decreases

3 nm CdSe nanocrystal melts at 700 K compared to Bulk CdSe at 1678K