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INTRODUCTION TO NANOTECHNOLOGY 101

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Presentation at United Defense

Outline

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- Introduction to Nanotechnology
- Applications of Nanotechnology
- Nanotechnology Research at Clarkson
- Conclusions

Nanotechnology

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Nanotechnology is the manipulation of materials, devices and systems on the nanometer length scale.

One nanometer is a billionth of a meter (about 10 times the diameter of the hydrogen atom)

At the nanoscale different laws of physics come into play

Sizes

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	10^{-18}	electron
	10^{-15}	proton
	10^{-14}	atomic nucleus
(angstrom)	10^{-10}	water molecule
(nanometer, nm)	10^{-9}	
(10 nm)	10^{-8}	UV light, viruses
(100 nm)	10^{-7}	cell membrane
(micron, μm)	10^{-6}	bacteria
(10 μm)	10^{-5}	human cell
(100 μm)	10^{-4}	human hair
(millimeter, mm)	10^{-3}	sand grains
(centimeter, cm)	10^{-2}	human finger
(meter)	10^{0}	human

Nanotechnology

Aerosols Sizes

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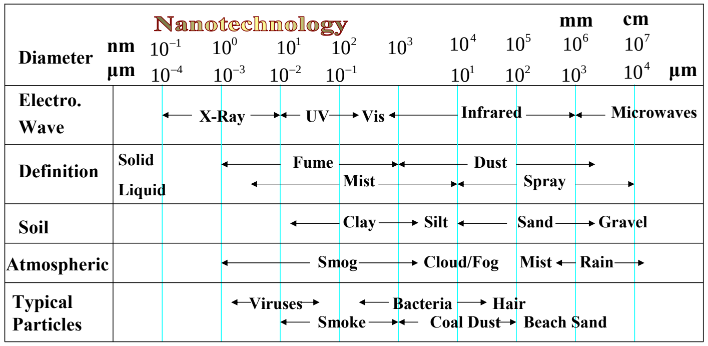

Nanotechnology Terminology

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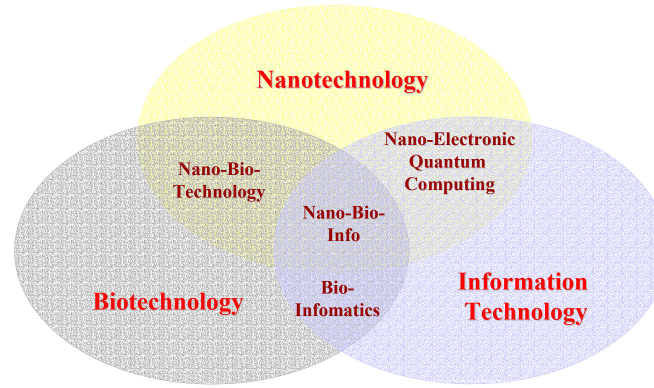

Nanotechnology

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- Nanoelectronic
- Nanomaterials
- Nanocomposites
- Nanodevices
- Nanostructure
- Nanosensors
- Nanobiotechnology
- Nanostructured Catalysts
- Molecular Mechanics

Nanotechnology Applications

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- Computers and Data Storage
- High Performance Materials
- Health and Medicine
- Energy and Environment
- Transportation
- Homeland Security

Health and Medicine

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- Targeted Drug Delivery
- Sensors for Disease Detection
- Artificial Tissues and Organs
- Nano-Robots for Protection Against Bacteria and Viruses

Energy and Environment

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- Energy Storage and Production
- Energy Efficiency
- Environmentally Friendly Manufacturing technologies
- Environmental Remediation Technologies
- Sensors for Environmental Monitoring

Homeland Security

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- Chemical, Biological, and Radiological Sensors
- High Strength, Light Weight Military Platforms
- Self Healing and Functional Materials
- Virtual Reality for Training

Carbon Nanotube

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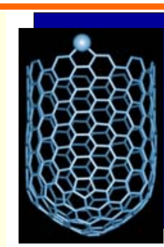
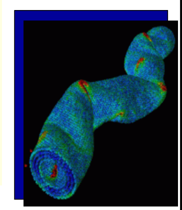
CNT is a tubular form of carbon with diameter of about 1 nm and a Length of a few nm to microns.

CNT exhibits extraordinary mechanical properties:

- Young's modulus > 1 Tera Pa
- Stiffness ~ diamond
- Tensile strength ~ 200 GPa
- Strain ~ 10%





Meyyappan, NASA

Carbon Nanotube

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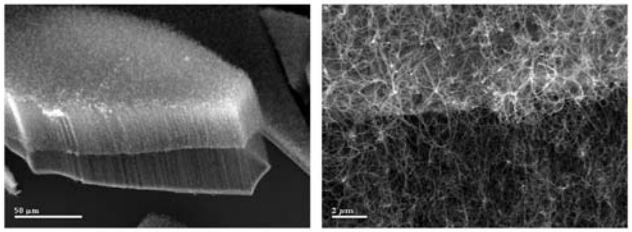
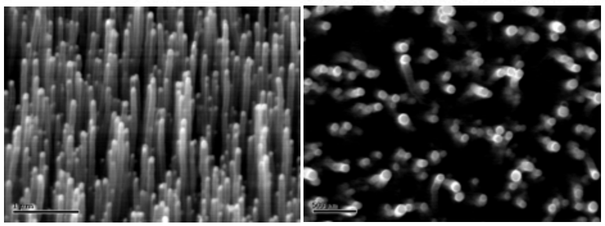


Meyyappan
NASA



Li et al.
(2002)

Carbon Nanotube

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Mechanical Applications

- High Strength Composites
- Body Armor
- Cables, Tethers, Beams

Challenges

- Fabrication of Composite with Controlled properties
- Characterization and Modeling
- Large Scale Production

Computational Nanotechnology

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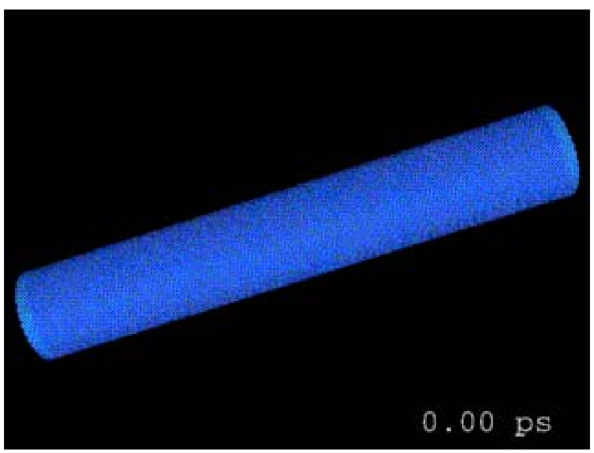

Meyyappan
NASA

Computational Nanotechnology

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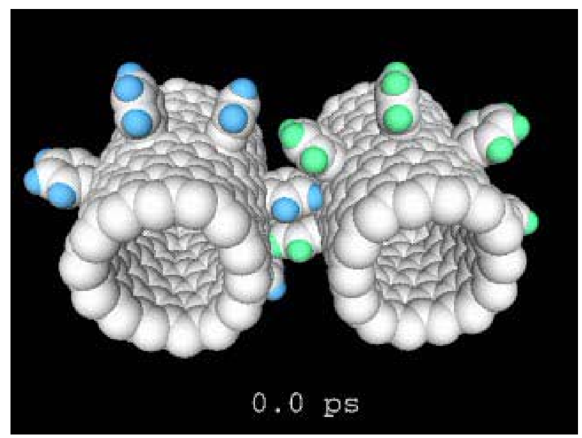

Meyyappan
NASA

Nanomaterials and Nanotechnology Research at Clarkson

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Nanomaterials, Self-Assembly: Zoo of Shapes

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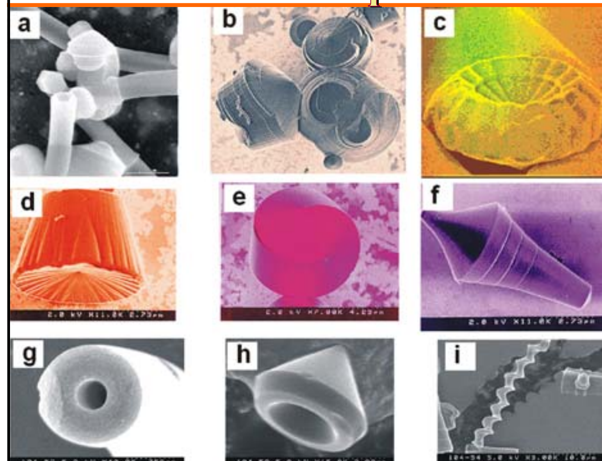

Nanoporous glass shapes sizes between 1 to 100 microns are self-assembled using biomemetic processes.

Sokolov

Color-coded Security Tags

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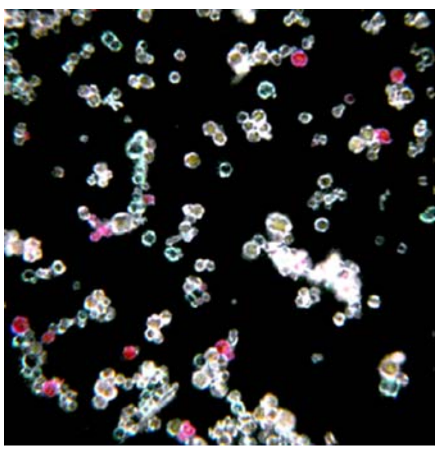

These glass particles can carry 100,000 Billions dye combinations. This makes them unbreakable security tags for labeling and tracing.

The tags can be used in medicine and biology for tagging various diseases.

Sokolov

Flow of Self Healing Agent into the Crack

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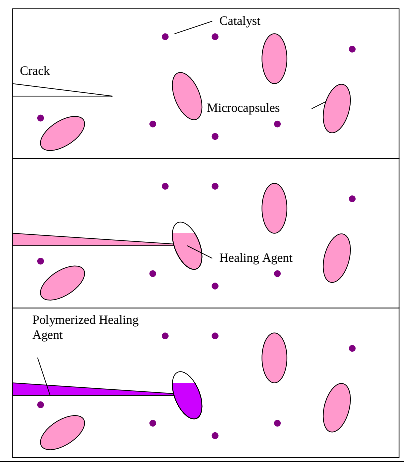

Self-healing Materials

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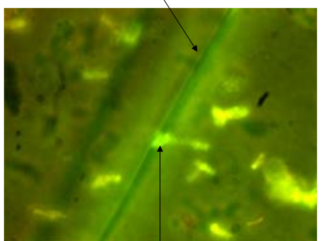
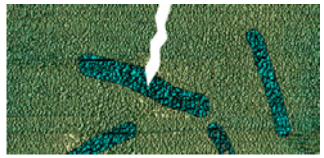
crack

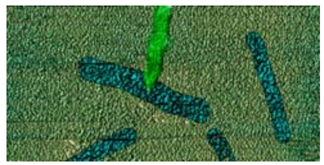


Release of healing component (fluorescent)

Crack



Healed crack



Sokolov

Liquid Flows Through a Fracture

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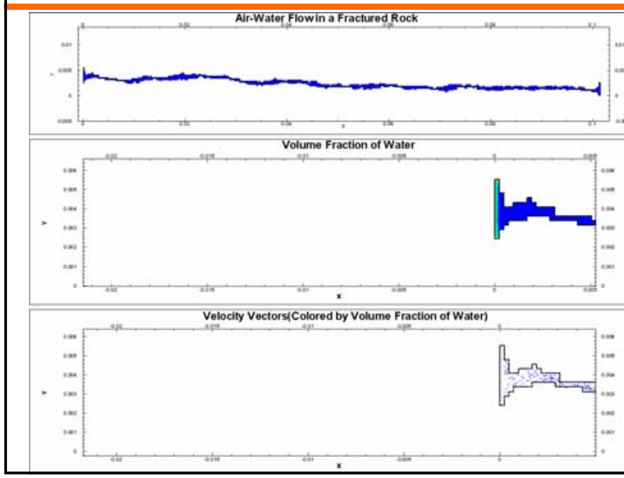

Ahmadi

Flows from the Capsule into the Crack

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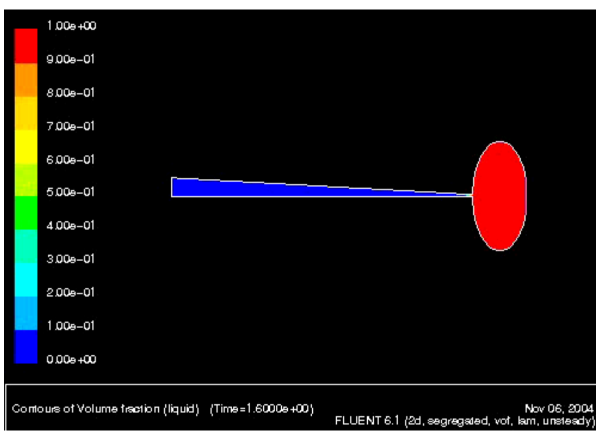

Ahmadi
McLaughin

Particle Technology for Military Use

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- Coating SiC nanoparticles for fillers in next-generation lighter but stronger body armor. (Natick)
- Preparation of metallic particle aerosols for obscuration of IR. (Aberdeen)
- Dispersing carbon black for use in lenses for eye protection from lasers. (TACOM)

Partch

Chemical Control of Particle Surfaces

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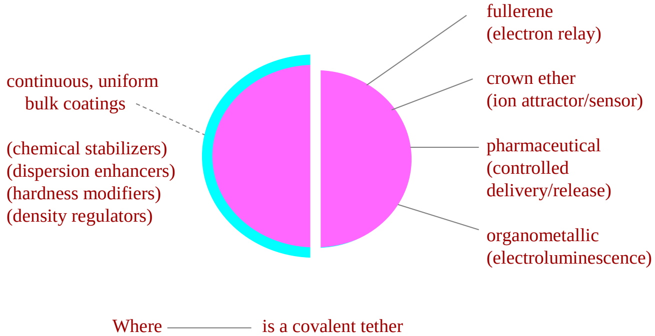

Partch

Personal Body Armor

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Current vest ~ 38 lbs
2” x 2” tiles on Kevlar
Titles of aluminum oxide
micro-sized particles

Proposed vest < 18 lbs
Kevlar with embedded
silicon carbide
nano-sized partices

Completed coating 30 nm SiC particles with polycarbonate for Army Natick

Partch

Particle-Infrared Interactions

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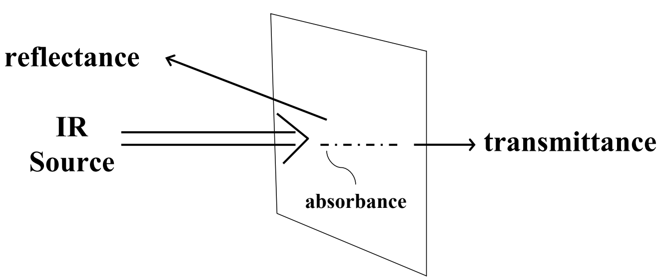

Partch

Aluminum Flake

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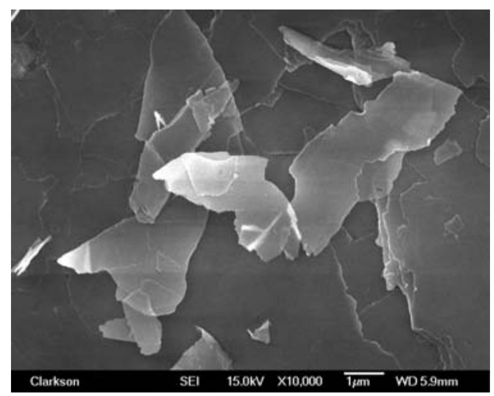

Flakes are 10-30 nm thick

Partch

Spectra of Particles in Nujol Suspension

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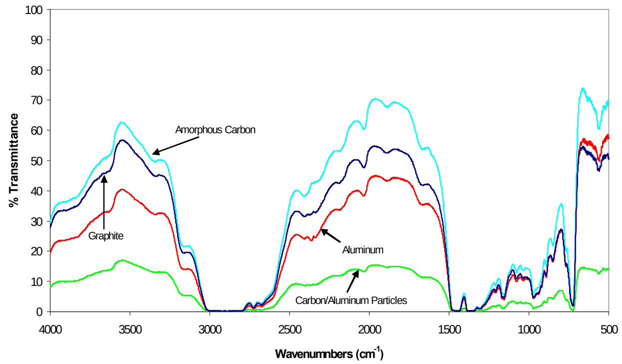

Partch

Laser Eye Damage

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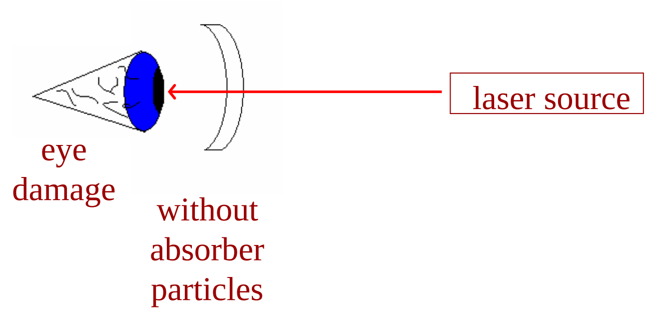

Partch

Eye Protection from Laser Damaged

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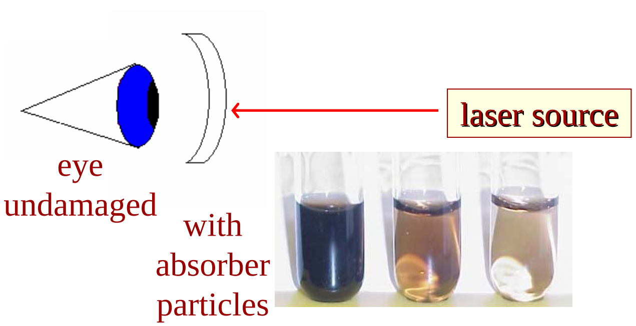

Work completed for Army-TACOM/Wright Patterson AFB

Partch

Nucleation and Growth

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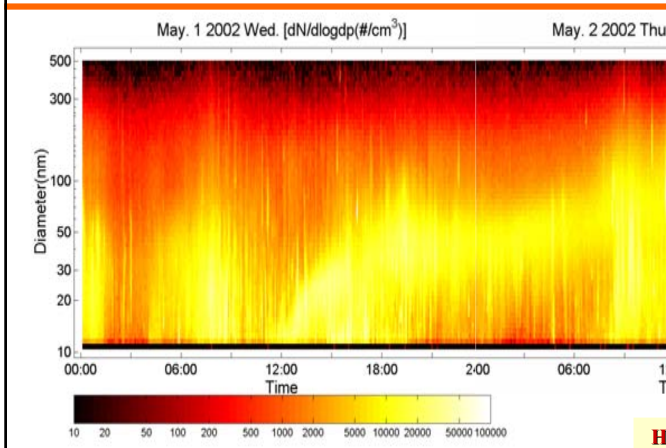

Hopke

Development of a New Condensation Particle Counter

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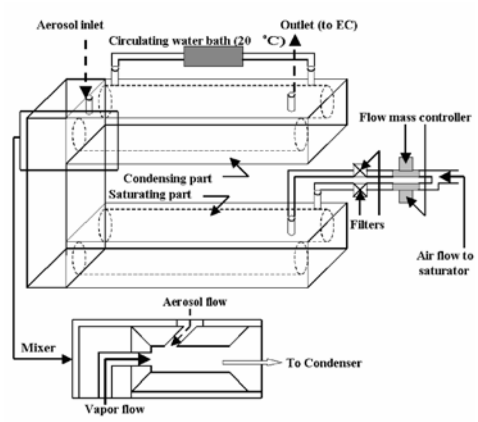

Hopke

Explore the Growth of Condensed Layers on Pre-exisiting Particles

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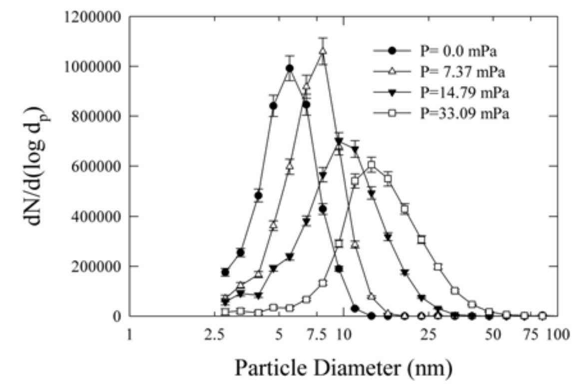

Hopke

Aerosol Time-of-Flight Mass Spectrometer

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Hopke

TSI ATOFMS provides particle size and composition on a particle-by-particle basis for particles > 50 nm.

Expertise in Nucleation

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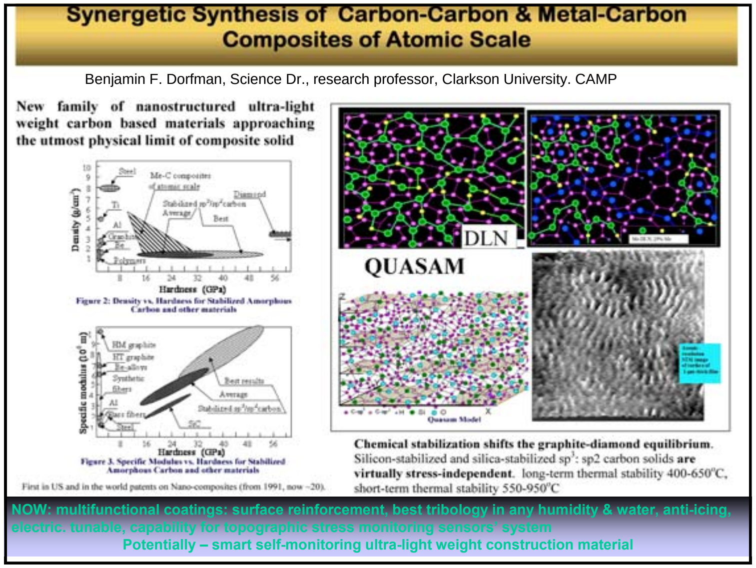
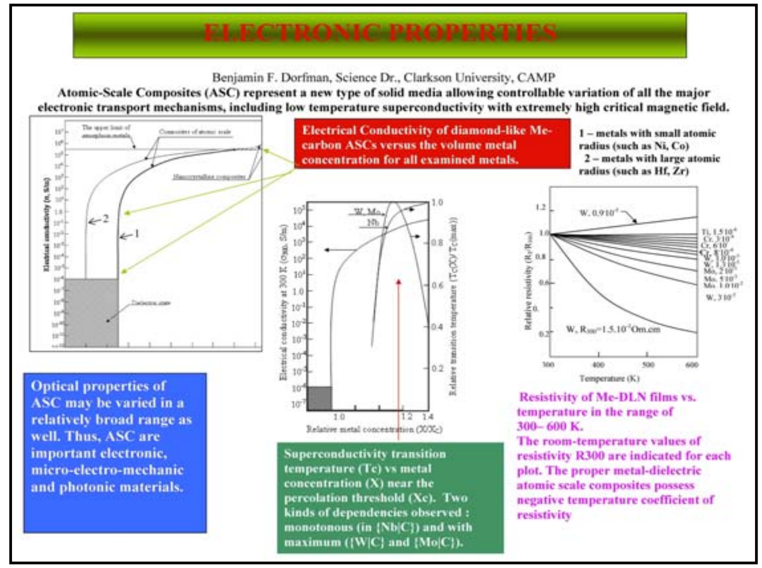
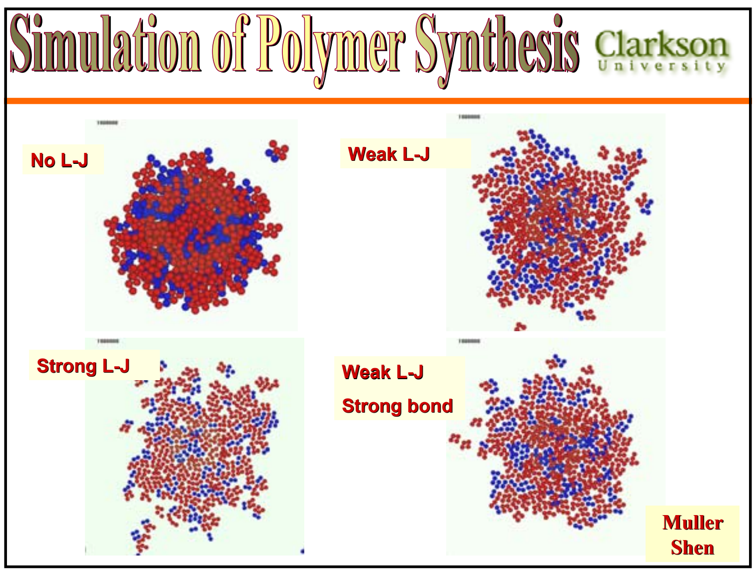
Expertise in the experimental study of vapor-liquid nucleation including homogeneous, heterogeneous, and ion-induced.

Tools to study nucleation and to characterize airborne particles in sizes ranging from 3 nm and up.

Hopke


Synergetic Synthesis of Carbon-Carbon & Metal-Carbon Composites of Atomic Scale
Benjamin F. Dorfman, Science Dr., research professor, Clarkson University. CAMP
New family of nanostructured ultra-light weight carbon based materials approaching the utmost physical limit of composite solid
Figure 2: Density vs. Hardness for Stabilized Amorphous Carbon and other materials
Figure 3. Specific Modulus vs. Hardness for Stabilized Amorphous Carbon and other materials
First in US and in the world patents on Nano-composites (from 1991, now ~20).
DLN
QUASAM
Quasam Model
Chemical stabilization shifts the graphite-diamond equilibrium.
Silicon-stabilized and silica-stabilized sp3: sp2 carbon solids are virtually stress-independent. long-term thermal stability 400-650°C, short-term thermal stability 550-950°C
NOW: multifunctional coatings: surface reinforcement, best tribology in any humidity & water, anti-icing, electric. tunable, capability for topographic stress monitoring sensors' system
Potentially – smart self-monitoring ultra-light weight construction material


ELECTRONIC PROPERTIES
Benjamin F. Dorfman, Science Dr., Clarkson University, CAMP
Atomic-Scale Composites (ASC) represent a new type of solid media allowing controllable variation of all the major electronic transport mechanisms, including low temperature superconductivity with extremely high critical magnetic field.
Electrical Conductivity of diamond-like Me-carbon ASCs versus the volume metal concentration for all examined metals.
1 – metals with small atomic radius (such as Ni, Co)
2 – metals with large atomic radius (such as Hf, Zr)
Optical properties of ASC may be varied in a relatively broad range as well. Thus, ASC are important electronic, micro-electro-mechanic and photonic materials.
Superconductivity transition temperature (Tc) vs metal concentration (X) near the percolation threshold (Xc). Two kinds of dependences observed : monotonous (in {Nb|C}) and with maximum ({W|C} and {Mo|C}).
Resistivity of Me-DLN films vs. temperature in the range of 300– 600 K.
The room-temperature values of resistivity R300 are indicated for each plot. The proper metal-dielectric atomic scale composites possess negative temperature coefficient of resistivity
Temperature (K)


Simulation of Polymer Synthesis
Clarkson University
No L-J
Weak L-J
Strong L-J
Weak L-J
Strong bond
Muller
Shen

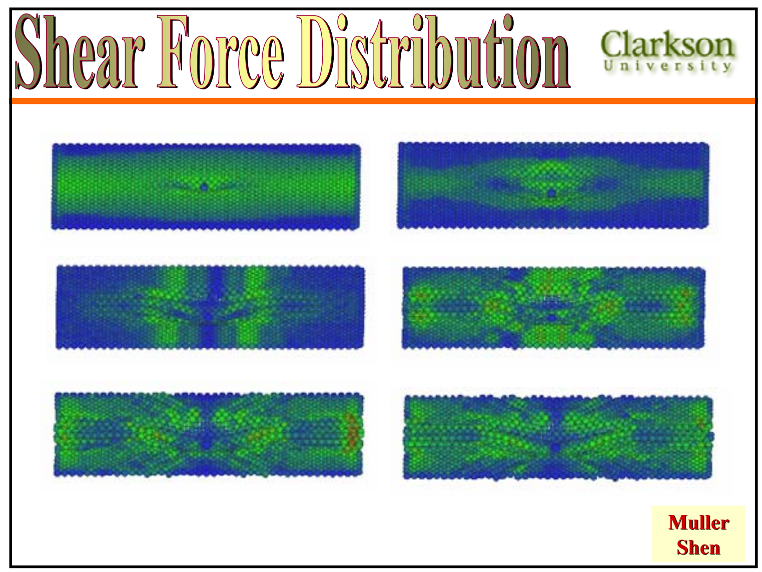
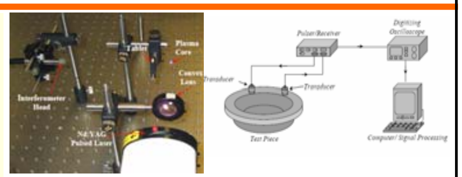

Shear Force Distribution
Clarkson University
Muller
Shen

Photo-Acoustics Research Group
Clarkson University

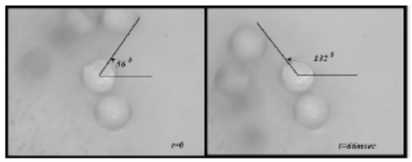
Acoustic Monitoring of Industrial Processes

- Non-contact, non-destructive techniques
- Online quality control



Motion and Adhesion of Nano/Micro-Particles

- Adhesion of nano/micro-scale objects
- Motion of micro-particles on dry surfaces

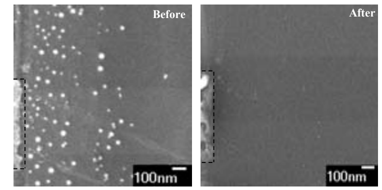


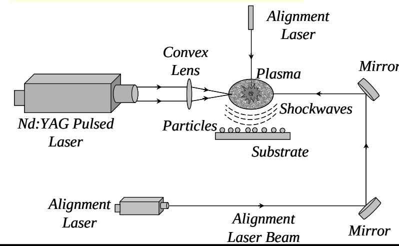
Cetinkaya

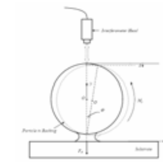
Photo-Acoustics Research Group
Clarkson University

Nanoparticle Removal with Pulsed Lasers

- Challenge: Removal of sub-100nm particles
- Pulsed laser induced plasma methods







Cetinkaya

Cryogenic Surface Cleaning
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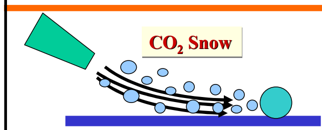
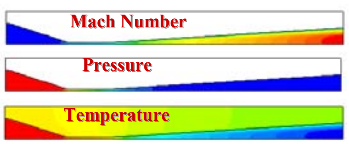
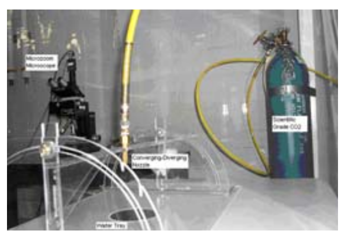
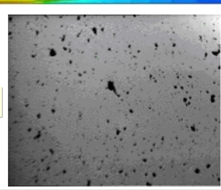


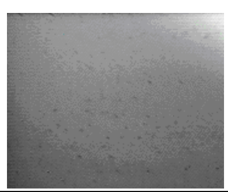




Before



After



Ahmadi

Ceramic Nanocomposites for Lightweight Armor
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- Carbon Nanotube (CNT) reinforced ceramic composites to enhance fracture toughness without compromising ballistic impact performance.
- CNTs can absorb energy through their highly flexible elastic behavior during deformation.
- Potential to improve performance of armor systems significantly compared to the current state-of-the-art.

Jha

Ceramic Nanocomposites for Lightweight Armor

Clarkson University

Research Needs:

- Understand the underlying science issues
- Investigate and optimize manufacturing methods
- Formulate physics-based multi-scale predictive models
- Perform material characterization through extensive testing
- Develop design procedures for CNT reinforced ceramic matrix composite structures

Jha

NANOSTRUCTURED POLYMER MATERIALS

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- DIRECTED SELF-ASSEBLY OF NANOPARTICLES REGULATED WITH POLYMERS
- PHASE SEGREGATION IN POLYMER SYSTEMS DRIVEN BY OUTSIDE CONDITIONS
- TEMPLATING POLYMERS WITH POLYMERS

Minko

Applications

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- SMART COATINGS/THIN FILMS:

-Self-repairing, self-healing systems (with external signal, stimuli);

-responsive surfaces (change mechanical behavior, size, surface energy, wettability, adhesion, etc with external stimuli)

-adaptive surfaces (response to environmental changes);

FOR PROTECTIVE COATINGS, TEXTILES, SMART CLOTHES, SELF-HEALING COMPOSITES

Minko

Applications

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- SENSORS

- miniaturized sensors to detect small amount of chemicals
- transform the interaction between chemicals and polymer materials into electrical or optical signals;
- rapid analysis and high selectivity due to the high permeability of ultra-thin films

FOR ANALYSIS of toxins, chemical weapons, food quality

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Applications

- NEW MATERIALS WITH UNIQUE PHYSICAL PROPERTIES (MECHANICAL, ELECTRO-CONDUCTIVE, THERMOCONDUCTIVE, OPTICAL)

-Nanoscopic metal clusters separated by nonmetal materials, quantum dots, supraparamagnetic particles, nanowires

For electromagnetic screens, miniaturized optical and electronic devices, information storage

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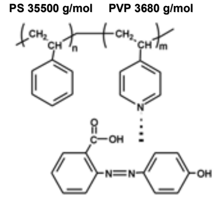
Fabrication of Polymeric Membranes (Templates) Fabrication of Ordered Arrays of Metal Clusters

Supramolecular assembly (SMA)

PS 35500 g/mol PVP 3680 g/mol



2-(4-Hydroxyphenylazo)benzoic acid (HABA)

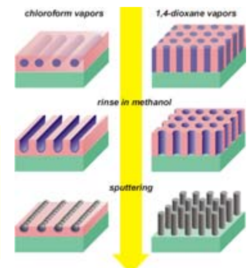
Functions of low-molar mass additive (HABA)

- determines copolymer symmetry: S→C morphology
- affects interfacial interactions
- serves as extractable agent
- provides desired functionality/physical properties

Fabrication of a well-ordered film

1. Stoichiometric ratio solution preparation
2. Dip- or spin coating
3. Vapor annealing
4. HABA extraction

Fast and simple route!



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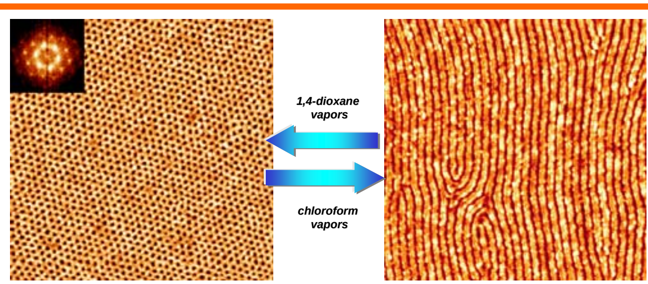
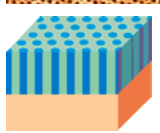
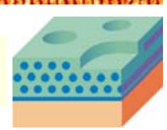
Re-orientation of Cylinders by Solvent Vapor Annealing





Switching is reversible and fast (minutes) and does not depend on chemical nature of substrate!



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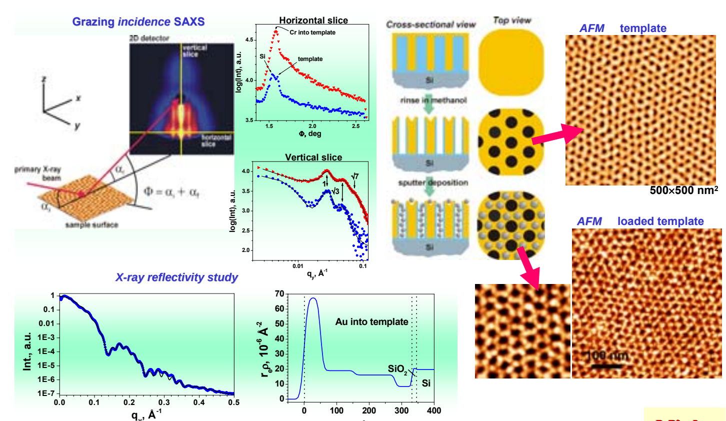
Loading of Block Copolymer Template with Metal Clusters



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Two-Scale Hierarchic Pattern from Ni Dots

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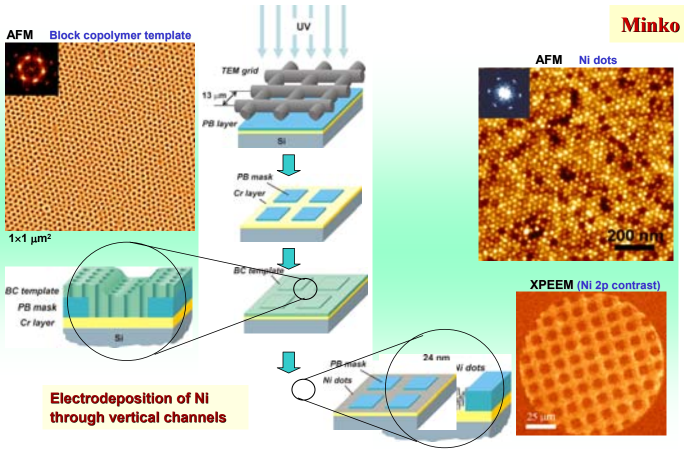

Electrodeposition of Ni through vertical channels

Templating Single PE Molecules

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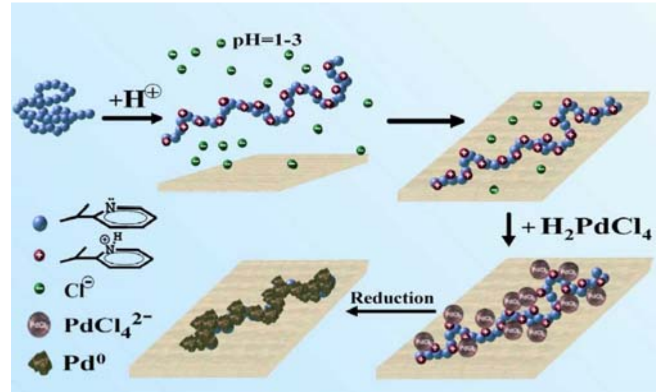
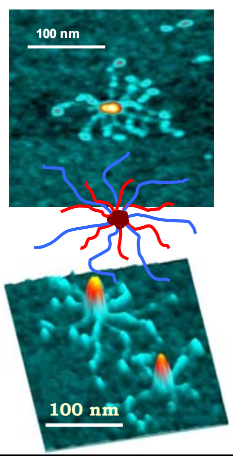


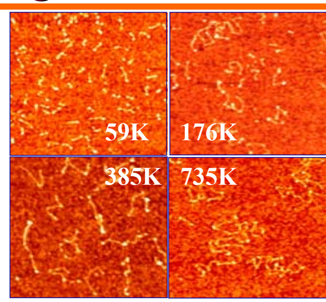
JACS 2002, 124, 10192-10197, *Nano Letters*, 2002, 2, 881-885

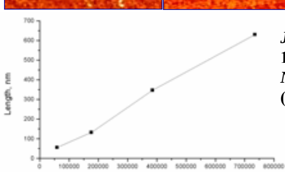
Minko

Fabrication of Nanowires via Metallization of Single Molecules

Clarkson University





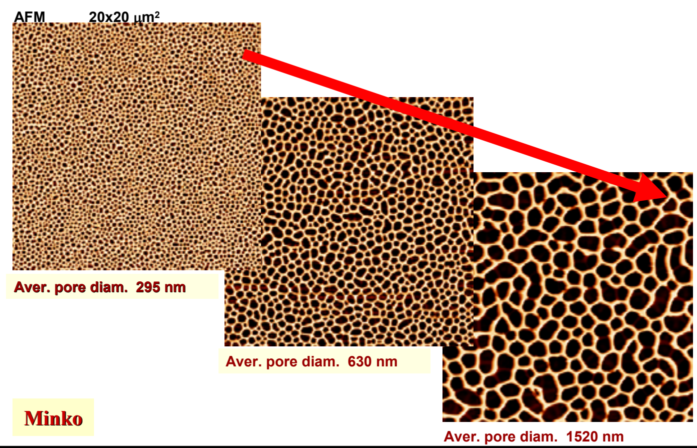


JACS. 2002, 124, 10192-10197
NanoLetters 2003; 3 (3); 365-368.

Minko

Responsive Membranes which Change Pore Size with External Stimuli

Clarkson University



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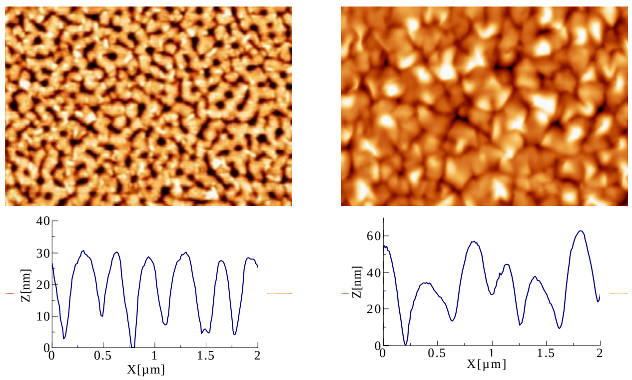
Pores Are Open at pH 5 and Closed at pH 2

Clarkson University



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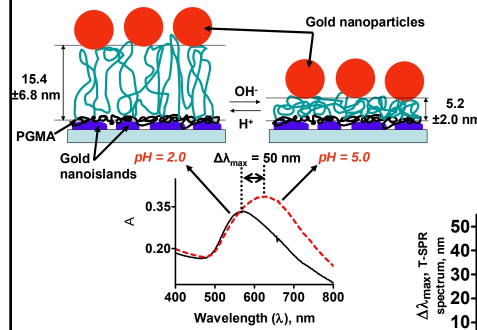
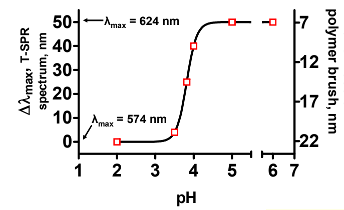
Nanosensors

Clarkson University



JACS, Nov. 2004



Schematics of the reversible pH change induced swelling of gold nanoparticle coated polyelectrolyte polymer brushes.

Bottom: T-SPR spectra of gold nanoislands at pH 2.0 and pH 5.0.

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Adaptive Surfaces from Mixed Brushes

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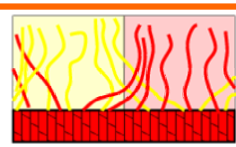
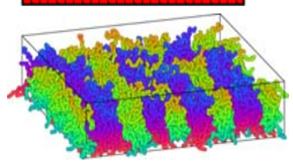
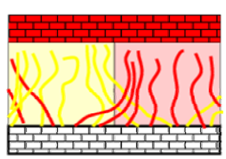
brush of two incompatible polymers in a common solvent



chains avoid energetically unfavorable contacts but grafting prevents macrophase separation



interaction with confining wall switches morphology



Phys. Rev. Lett. **2002, 88, 3, 035502**

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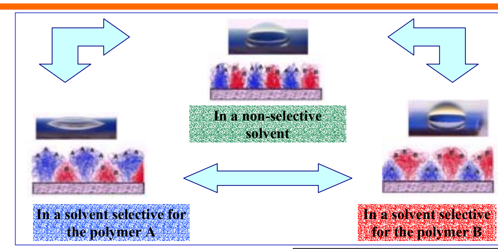
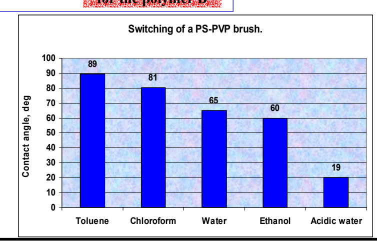


***Langmuir*, 2002, 18, 289-296**

***Macromol. Rapid. Commun.*, 2001, 22, 206-211**



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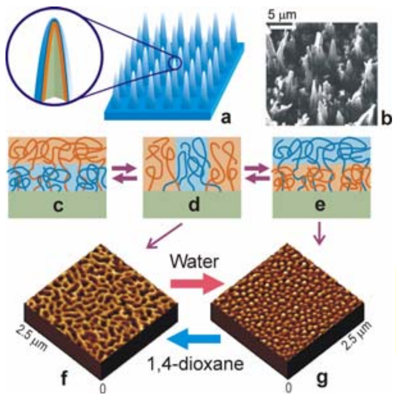
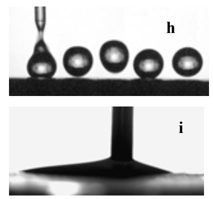
Ultrahydrophobic - Hydrophilic Switching



Pin -like PTFE substrate with grafted PS-P2VP mixed brush.



Rolling of water drop on PTFE with the grafted PS-P2VP binary brush after exposure to toluene (h) and wetting after exposure to water (i).

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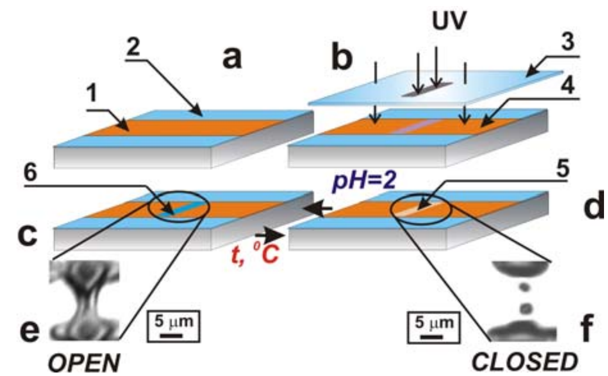
JACS, 2003, 125 (13); 3896-3900

Microfluidic Application – Switchable Channels



JACS, 2003, 125, 8302-8306.

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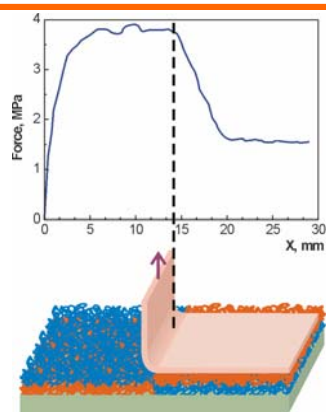
REGULATION OF ADHESION



JACS, 2003, 125 (13); 3896-3900

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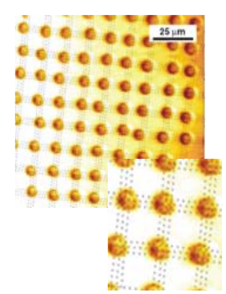
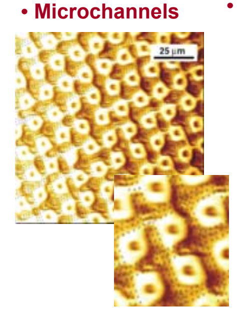
Local tuning of adsorption, wetting, adhesion

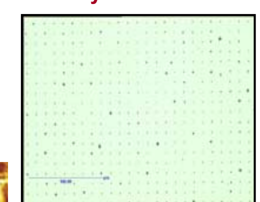
- Microreactors



- Microchannels



- 2D array of colloids



Polymer Preprints 2003, **44**(1), 478-479

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JACS, 2003, 125, 8302-8306.

Droplet Motion with Surface Tension Gradient

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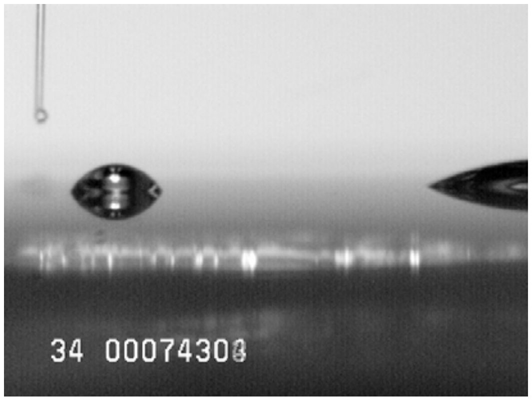
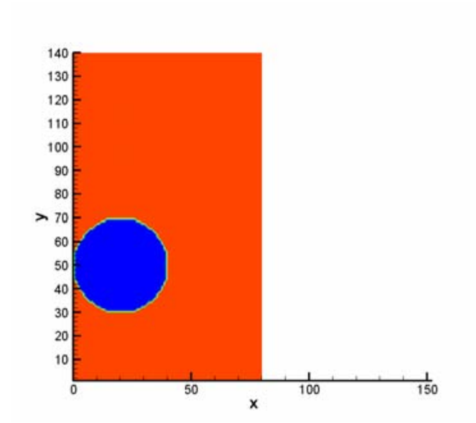


McLaughlin

Droplet Motion with Surface Tension Gradient

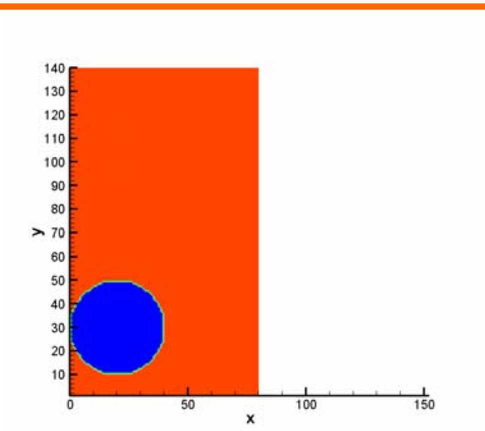
Clarkson University



McLaughlin

Droplet Motion with Surface Tension Gradient

Clarkson University



McLaughlin

Simulation Using Lattice Boltzmann Method

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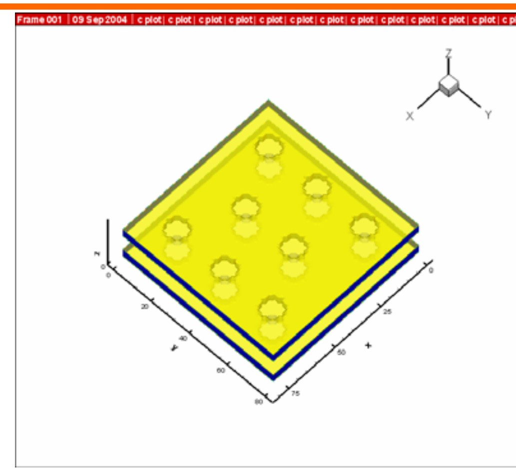
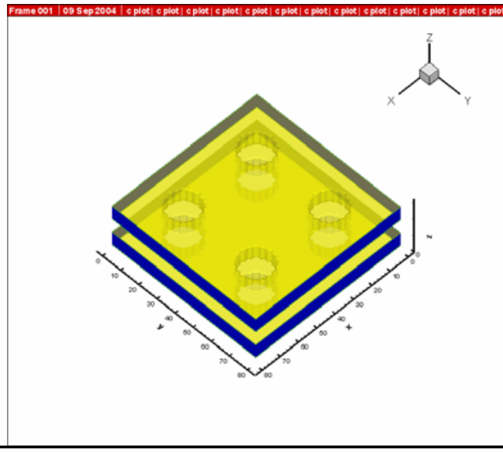


McLaughlin

Simulation Using Lattice Boltzmann Method

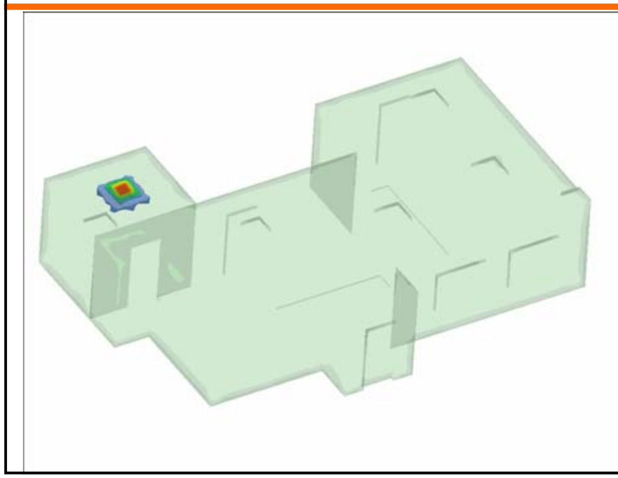
Clarkson University



McLaughlin

Simulation of Pollutant Dispersion

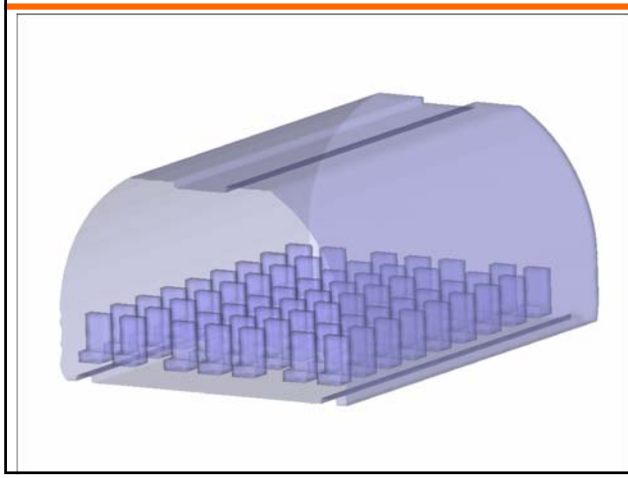
Clarkson University



Ahmadi

Simulation of Pollutant Dispersion

Clarkson University



Ahmadi

Undergraduate Curriculum

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Basic Science Courses

Past
- Physics
- Chemistry
- Mathematics

Future
- Physics
- Chemistry
- Mathematics
- Biology
- Nanotechnology

Undergraduate Curriculum

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Elective Courses on Nanotechnology

- Bulk and nano properties
- Introduction to synthesis of nano-materials
- Characterization of nanosystems
- Examples of nanomaterials:
  - tubes, wires, particles
- Surface phenomena
- Quantum phenomena
- Emerging applications

Suni Rasmussen

Summary

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- Nanotechnology is critical to the future development of micro- electronics, computing, high performance materials, manufacturing, energy, transportation, etc.
- Challenges include:
  - Synthesis techniques
  - Characterization of nanoscale properties
  - Large scale production of materials
  - Applications
- Industry-university collaboration and integration of fundamentals of nanotechnology into engineering and science curriculum is important for the future development

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Thank You!

Questions?