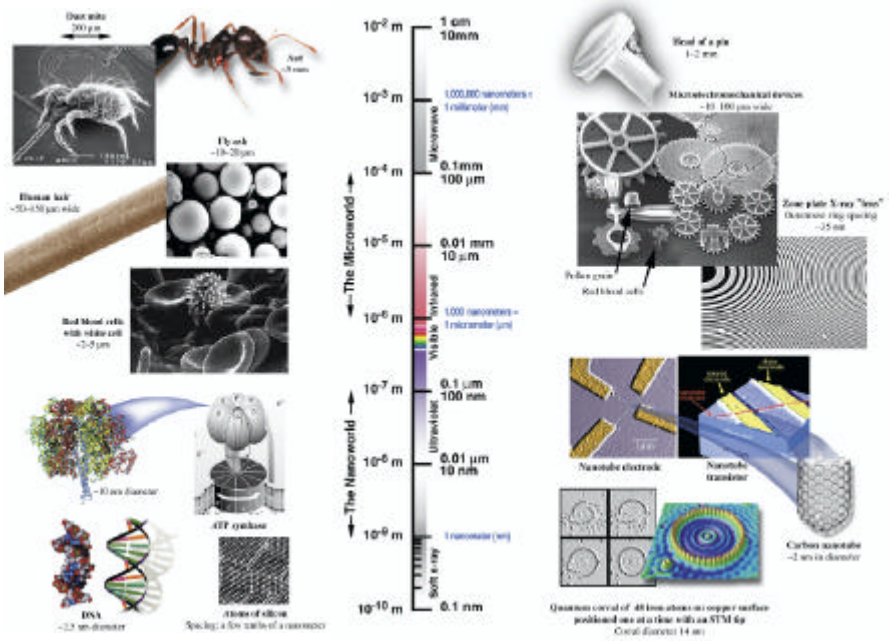
Assembling Nanomaterials

Richard W. Siegel

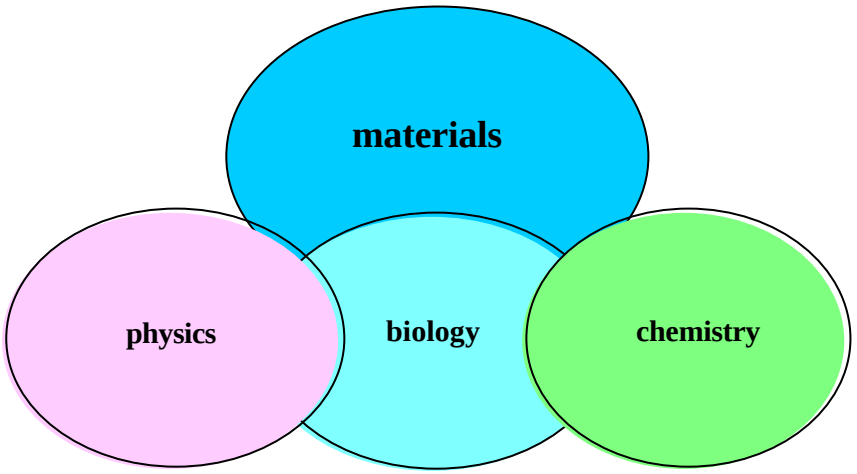
Rensselaer Nanotechnology Center
Rensselaer Polytechnic Institute

Korea-U.S. NanoForum
Seoul, Korea

14 October 2003



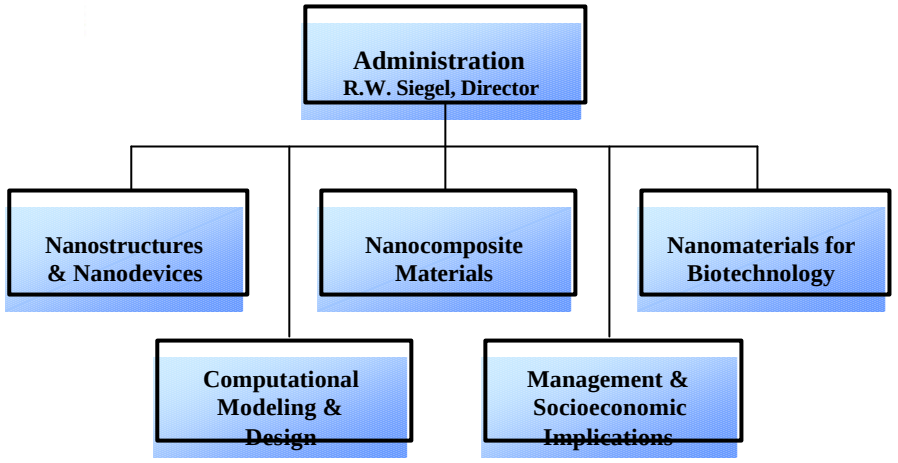
The Materials World



“Those who control materials control technology”

Eiji Kobayashi, Panasonic

Rensselaer Nanotechnology Center



Founded April 2001

Nanotechnology Sponsors at Rensselaer

ABB

ALBANY INTERNATIONAL

National Science Foundation

Eastman Kodak

Natick Soldier Center
U.S. Army

IBM

Philip Morris USA

Office of Naval Research

NYSTAR

State of New York

U.S. Department of Energy

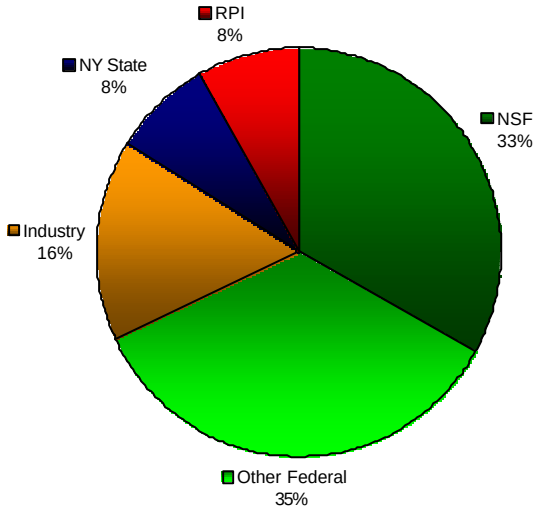
Defense Advanced Research Projects Agency

DARPA

NASA

Sources of Funding in the Rensselaer Nanotechnology Center

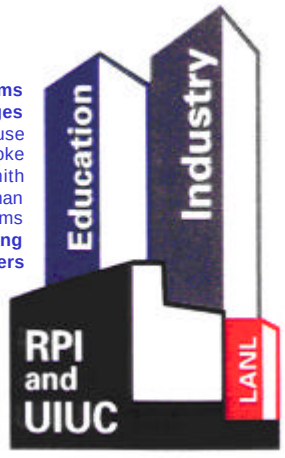
annual funding ca. $6 million



Nanoscale Science and Engineering Center for Directed Assembly of Nanostructures

www.rpi.edu/dept/nsec

K-12 Programs
Undergraduate Colleges
Morehouse
Mount Holyoke
Smith
Spelman
Williams
Distance-learning
Visiting Researchers



Industry Partners
ABB
Albany International
IBM
Eastman Kodak
Philip Morris
New York State

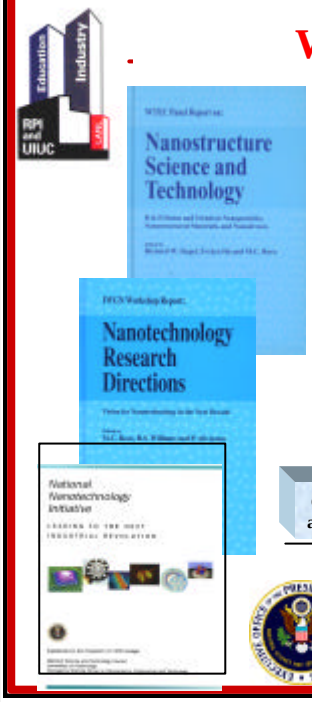
Rensselaer Polytechnic Institute

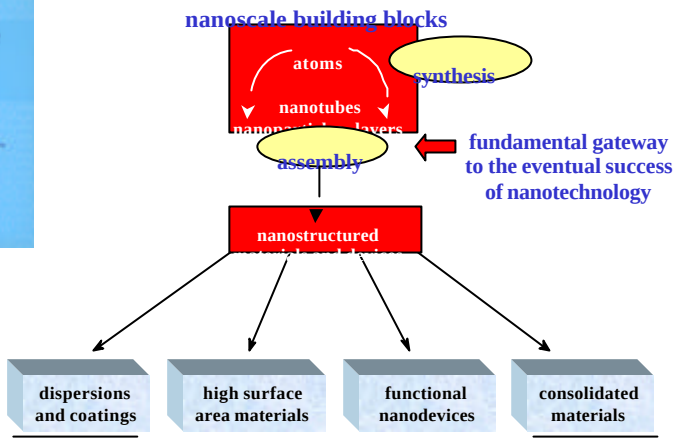
University of Illinois at Urbana-Champaign

Los Alamos NATIONAL LABORATORY

Founded September 2001

Why Directed Assembly?





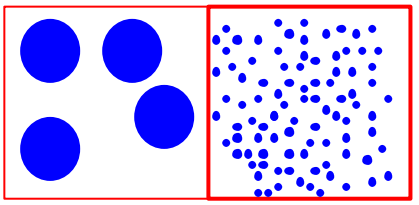
applications in our macroscopic world

http://www.nano.gov/

What is special about nanoscale building blocks?

- Size confinement

- High surface area
- Many interfaces



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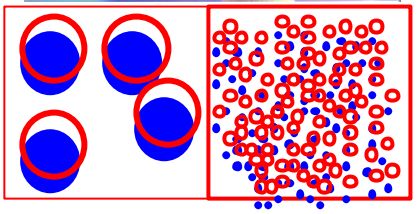
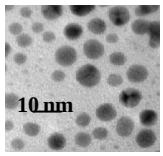
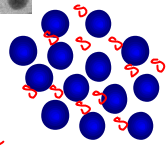


NSEC research thrust 1 projects

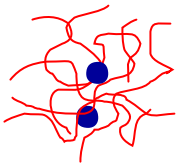
Nanoparticle Synthesis
(Benicewicz , Braun, Moore, Siegel)
- organic and inorganic particles
- chemically heterogeneous surfaces



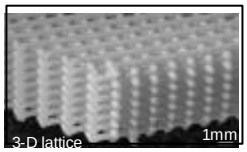
Phase Behavior of Nanoparticle-Polymer Mixtures
(Schweizer, Zukoski)
- study scattering and rheological properties
- provide comparison to modeling efforts
- provide understanding for novel assembly



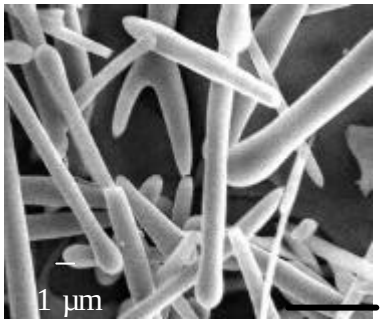
Polymer Nanocomposites
(Lookman, Schadler, Siegel)
- explore effects of novel nanoparticle fillers (isolated particles, strings, clusters)
- tailor interface between filler and polymer matrix
- assemble multifunctional nanocomposites



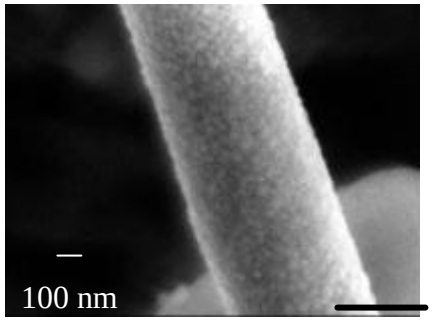
Directed Assembly of Nanostructured Materials
(Lewis, Schadler, Zukoski)
- design concentrated nanoparticle gels for direct-writing
- fabricate polymer nanocomposites with hierarchical features



Nanoparticle-assembled TiO_2 microtubes



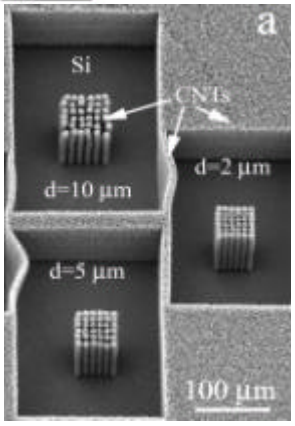
6 µm



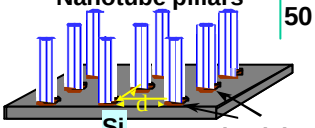
350 nm

Ma, Siegel, Schadler (2003)

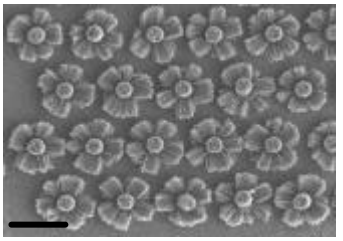
Controlled assembly of nanotube arrays



Nanotube pillars



Vertical and Horizontal



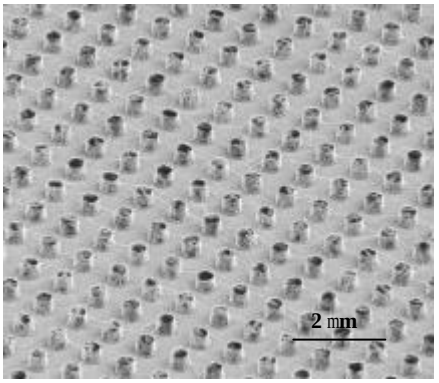
50 mm

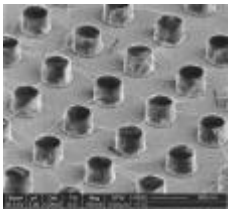
Wei, Vajtai, Jung, Ward, Zhang, Ramanath, Ajayan (2002)

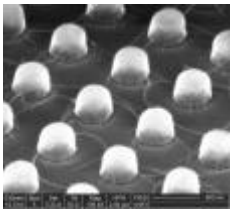
Funded by ONR and the MARCO Interconnect Focus Center *(Collaboration with Motorola)*

Carbon nanotube interconnects

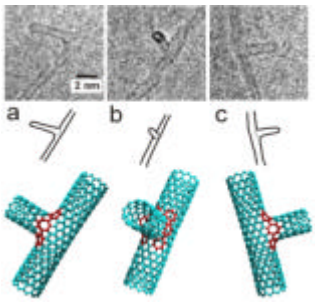
Ajayan, Wei, et al. (2003)



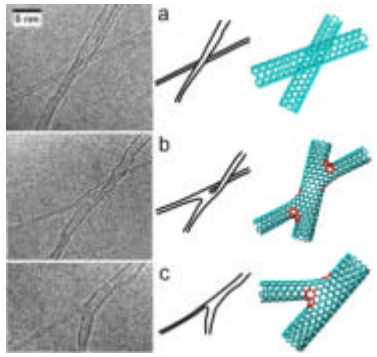


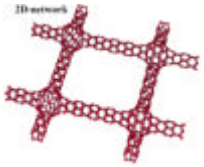


Creating single-wall nanotube junctions



e-beam welding





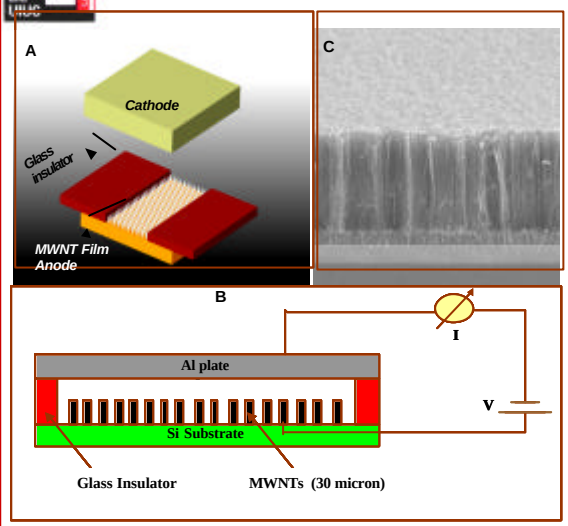
Future

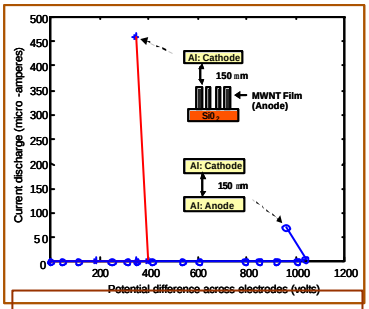
Terrones, Banhart, Ajayan et al. (2002)

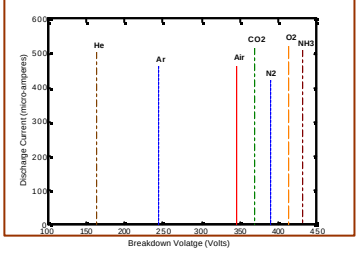
Funded by the MARCO Interconnect Focus Center

Carbon nanotube gas breakdown sensor

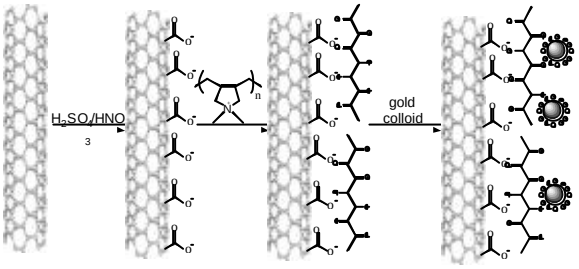
Koratkar, Ajayan et al., Nature (10 July 2003)



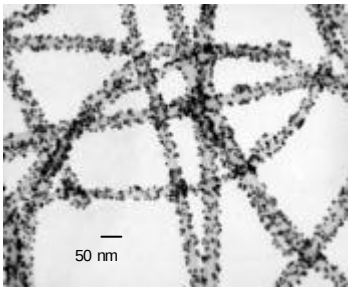




Attachment of Au nanoparticles to N-doped CNTs



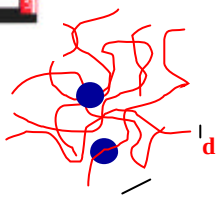
Functional groups are attached along the lengths and ends of N-doped carbon nanotubes (CNT). These become the sites for selective Au nanoparticle attachment.



Jiang, Eitan, Schadler, Ajayan, Siegel, et al. (2003)

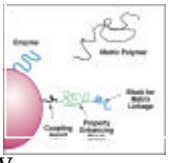
Funded by US Army Natick Soldier Center

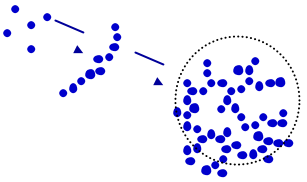
Polymer nanocomposites



$R_g > R > d \lesssim 1$ nm

- **Control Filler Properties**
  - particle size
  - shape (spheres, nanotubes…)
  - interface chemistry/functionality
  - connectivity
    - * isolated species
    - * chains
    - * aggregates
  - filler volume fraction



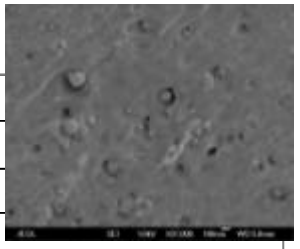


Goal: Design composites with tailored properties
- Mechanical
- Optical
- Electrical...

Issues:
- Dispersion/miscibility
- Interface mechanics
- Polymer properties change due to filler

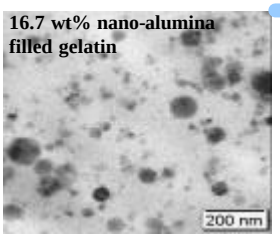
Mechanical behavior of filled and neat PMMA

Comparison between micron-size and nanoscale alumina fillers in PMMA

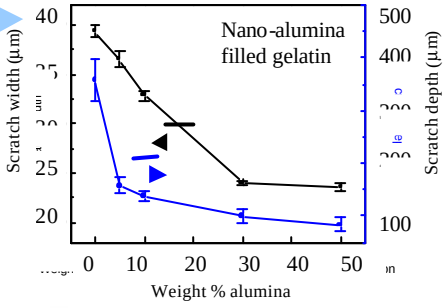


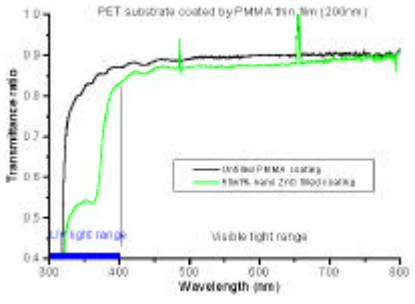
Ash, Schadler, Siegel (2002)

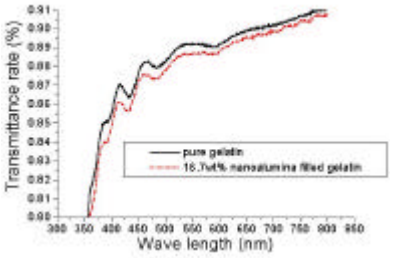
Polymer nanocomposites – assembly and properties



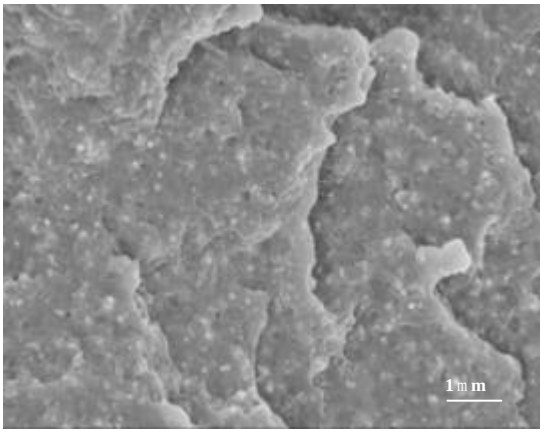
Chen, Schadler, Siegel, Irvin (2002)







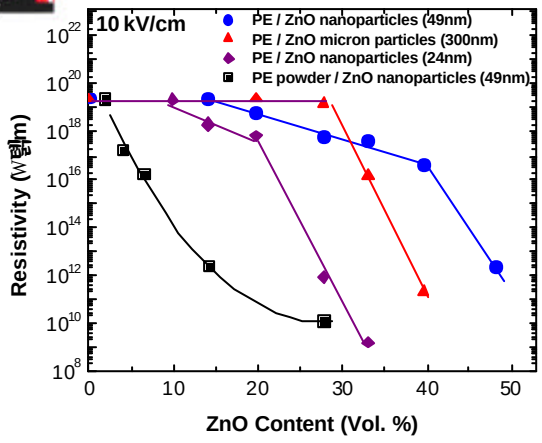
LDPE / ZnO nanocomposite



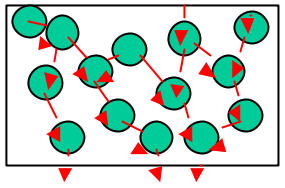
SEM of 50 wt% ZnO in LDPE

Hong, Schadler, Siegel, Mårtensson (2002)

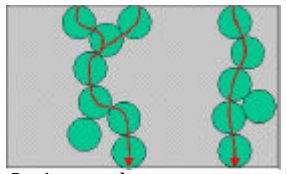
Resistivity of ZnO/LDPE nanocomposites



Conduction mechanisms:



Tunneling



Continuous paths

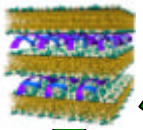
Hong, Schadler, Siegel, Mårtensson (2002)

NSEC research thrust 2 projects

Preparation/Synthesis
(Ajayan, Crivello)

Characterization
(Ramanath, Ajayan)

Molecular Modeling
(Garde, Redondo)



Protein-Nanoparticle
Composites
(Dordick, Schadler, Ajayan)

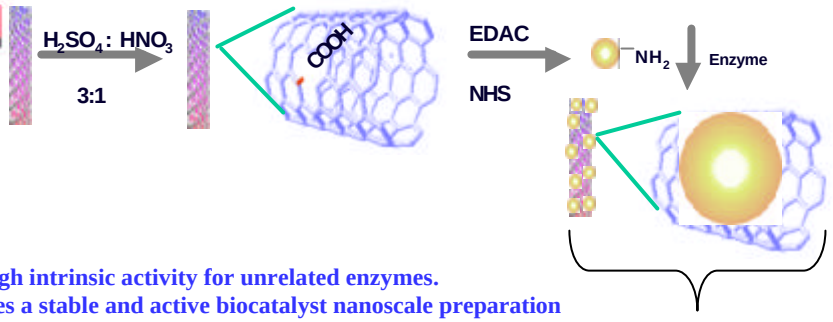
Biorecognition-Driven
Self-Assembly
(Wong, Lu, Dordick, Siegel)

Tissue Engineering/Biosensing
(Bizios, Siegel, Dordick)

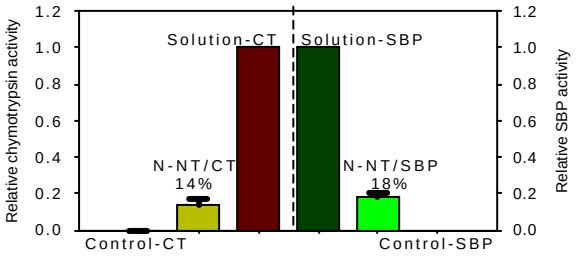
Potential applications of biocatalytic nanocomposites

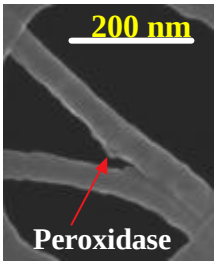
- Catalysts
- Chromatographic packings
- Biocatalytic membranes
- Non-fouling coatings and paints
  - Protein, lipid, polysaccharide resistant
  - Microbial resistant
  - Sessile invertebrate resistant
- Non-clogging drain pipes
- Implantable medical devices
- Microelectronics and microfabrication

Biofunctionalizing carbon nanotubes



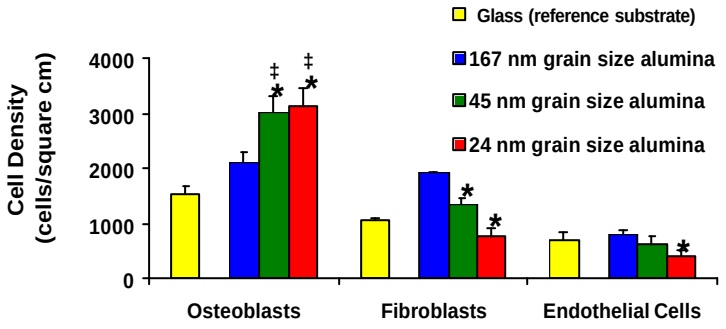
Very high intrinsic activity for unrelated enzymes.
Indicates a stable and active biocatalyst nanoscale preparation





Cellular compatability

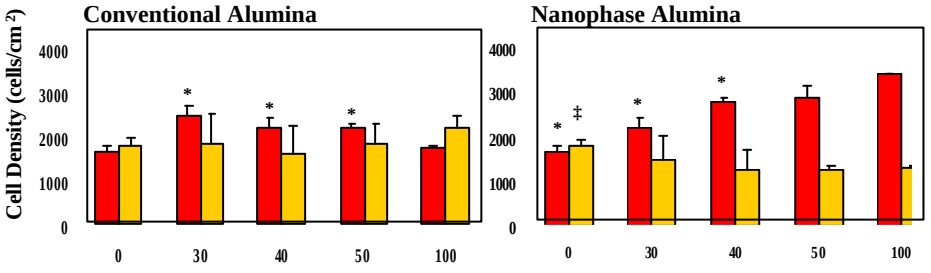
Data for alumina nanoceramic; similar behavior found for other nanoceramics and ceramic/polymer nanocomposites



Webster, Siegel, Bizios (2001)

Osteoblast and fibroblast adhesion

on conventional and nanophase alumina / PLA composites



Substrates (% alumina loading)

Values are mean ± SEM; n=3;

***p<0.05 (compared to osteoblast adhesion on the respective 100%alumina; Student's t-test);**

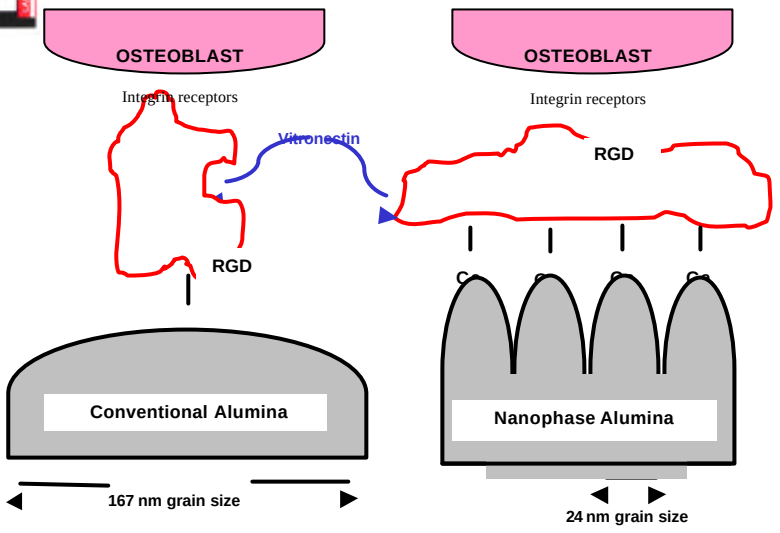
‡ p<0.05 (compared to fibroblast adhesion on 100% alumina; Student's t-test).

Osteoblasts **Fibroblasts**

McManus, Siegel, Bizios (2001)

Osteoblast adhesion

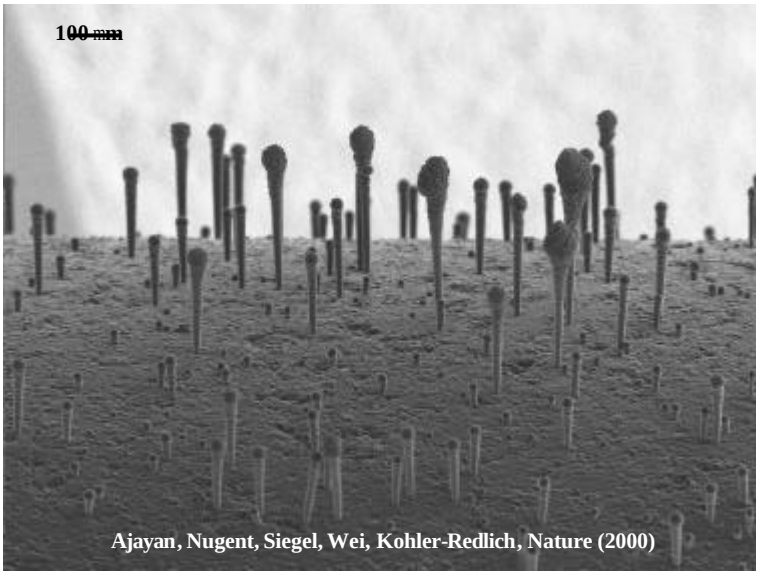
driven by surface topography



Conclusions:

- We are now able to create a wide variety of nanoscale building blocks
- We are learning how to assemble them into useful nanostructured materials
- Hierarchical systems at the micro-scale and beyond are beginning to be created
- Society is beginning to benefit from nanoscience and its applications
- There is much more to come….!

Thank you



Ajayan, Nugent, Siegel, Wei, Kohler-Redlich, Nature (2000)