Mid-Atlantic Technology, Research & Innovation Center
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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Multifunctional Carbon Nanomaterials

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MATRIC, Inc.
2/28/2011

CNST Center for Nanoscale Science & Technology

“Multifunctional”

- What is “multifunctional”?
- What does multifunctionality have to do with nanomaterials?

- What are the advantages of multifunctional design?
  - Weight Savings
  - Space Savings
  - Redundant Cost Savings

Approaches to Multifunctionality

Combined Functionality

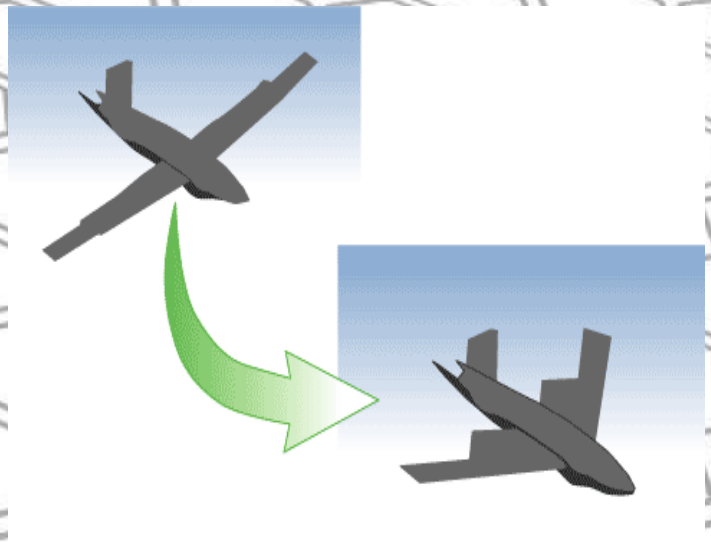
- Remove redundant components
- Reduce size/weight/cost of functional components

  ⇒ cram more functions into the same unit

Approaches to Multifunctionality

Adaptive Reconfiguration

- Changes properties dynamically
- Performs each function as needed (not all at once)

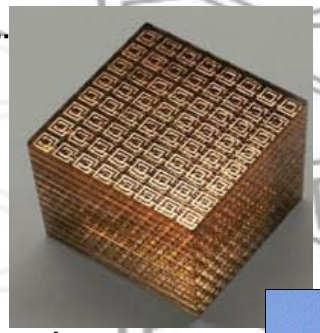


- Shape Change
- Conductivity Change
- Mechanical Properties Change

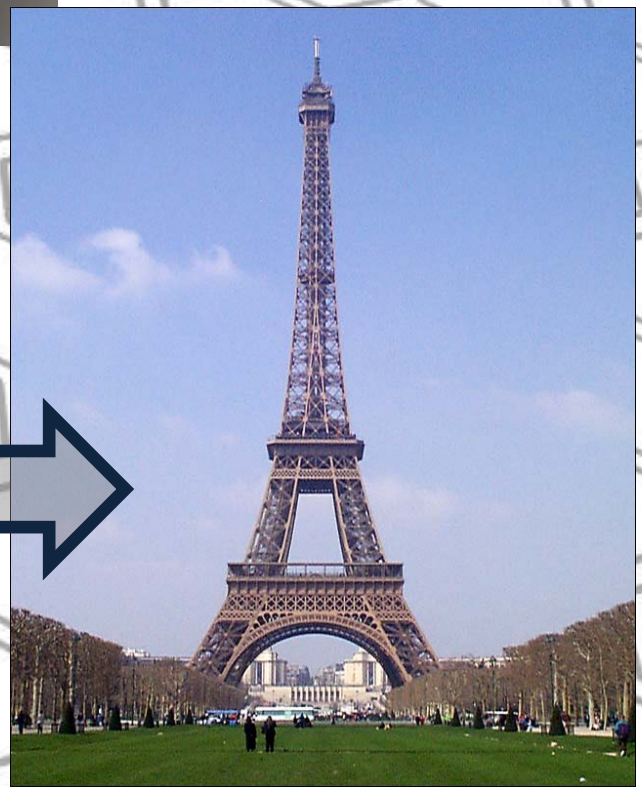
Approaches to Multifunctionality

"Metamaterials": Architecture Driven Properties

- Materials properties driven by geometric construction rather than bulk aggregation

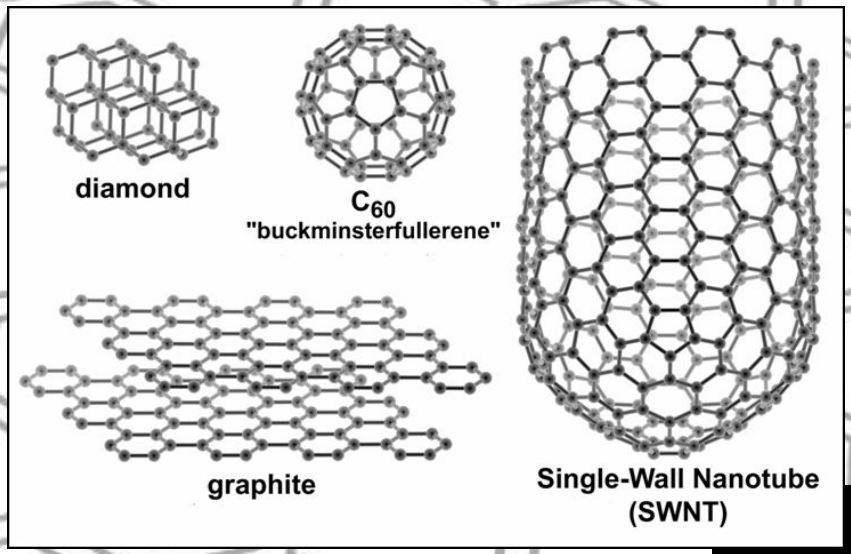


- Manipulate the topology of the relevant fields within the architecture
  - Optics – Electrodynamic Fields
  - Mechanical – Stress/Strain Fields

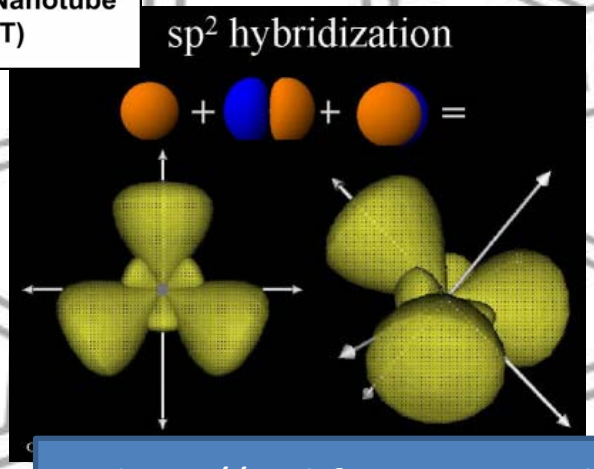


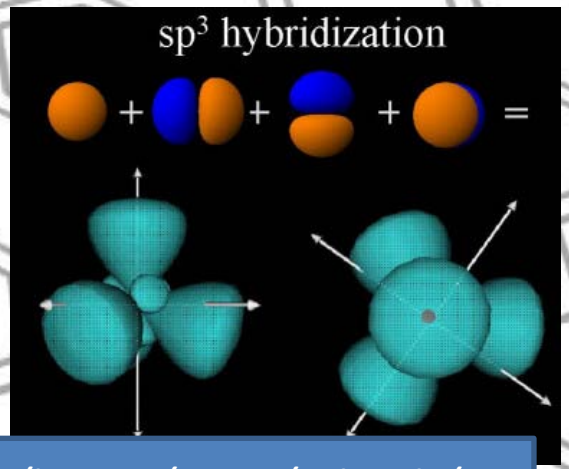
Carbon Nanomaterials

The Carbon Bond



- Diversity
  - sp, sp^2, sp^3
  - Delocalized π-bonding
- Size/Energy/Delocalization
- Electonegativity & covalence





http://webfac1.enmu.edu/longro/www/orbitals/

Multifunctionality from Carbon Nanomaterials

Carbon Properties
~Diamondoid/alkane : Graphene/Alkene: Alkyne

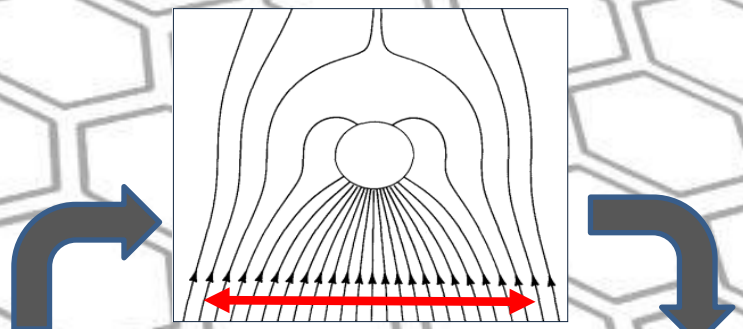
- Mechanical
- Thermal
- Electrical
- Chemical
- Nano/Microstructure Modification
  - Polymers (e.g. polyurethane)
  - Ceramics
  - Metals (e.g. aluminum)

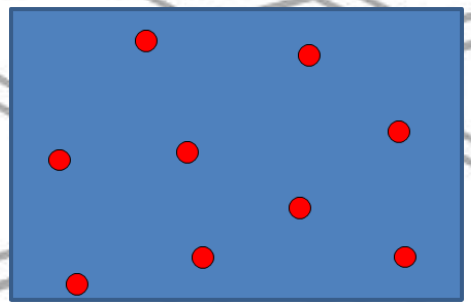
- High performance density⇒ Function miniaturization
- Diverse functionality from diverse allotrope structures
- Matrix phase structure modification

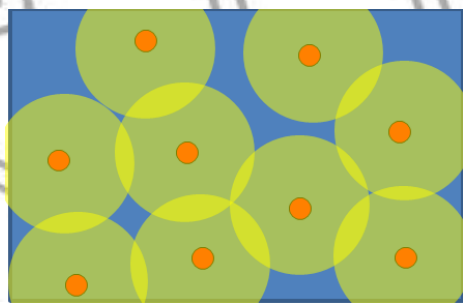
Nanocomposites: "Percent Contributions"

- **1% content ⇒ 99% effect**
  - conductive CNT networks
  - graphene gas barriers
  - resonance enhanced coupling

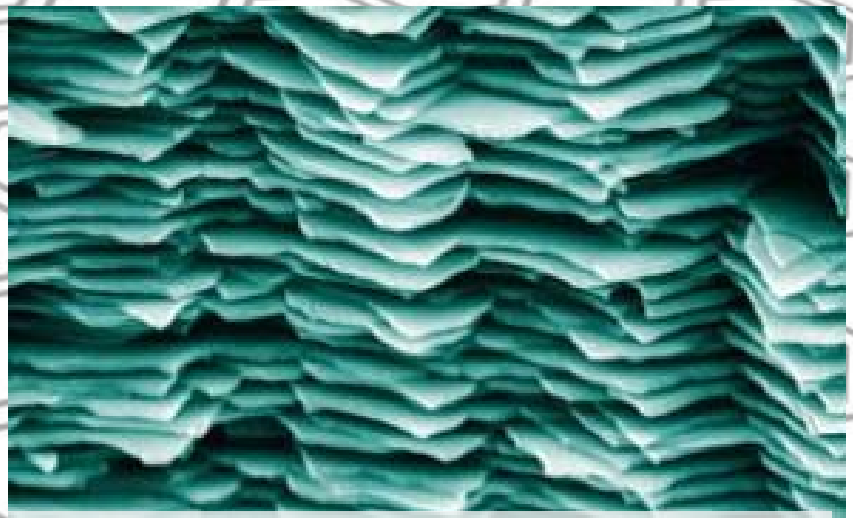
- Two origins
  - Geometric dimensionality (1D networks in 3D, 2D barriers, etc.)
  - Resonance, field modification, periodicity & coherent wave effects



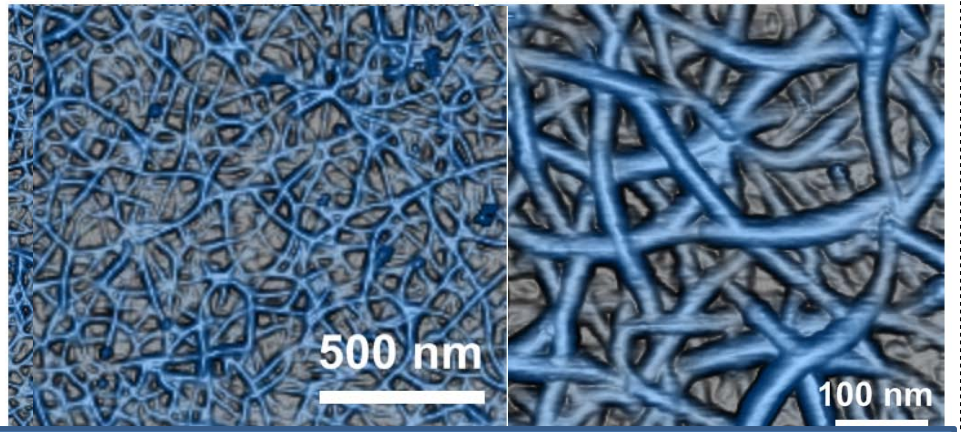




Nanoarchitectures: Percolated Networks & Stacked Platelets



http://www.physorg.com/news10408.html



http://parkafm.com/jp/AFM_image_gallery

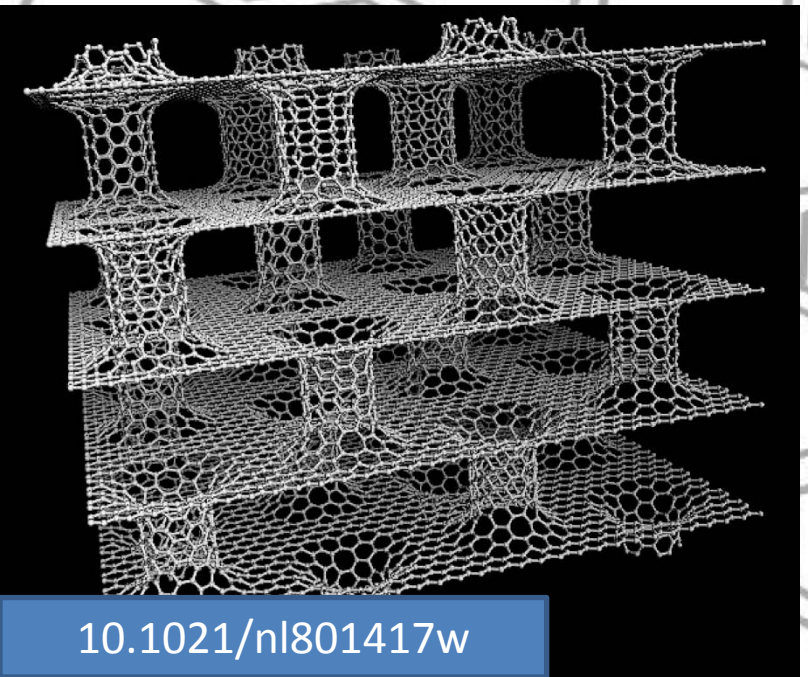
- Low degree of architectural order
- Distinctive properties dictated by average proximal connection between nano-objects

- Percolated networks:
  - Field transmission (electrical, thermal, mechanical stress)

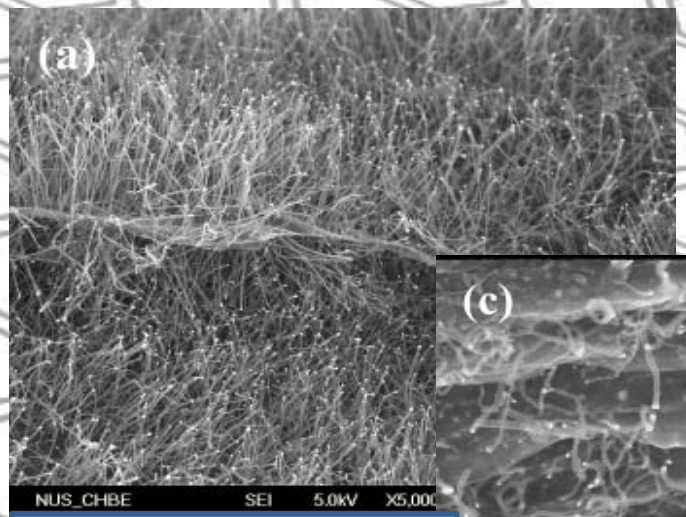
- Stacked platelets:
  - Tortuosity (molecular permeability, crack propagation,)
  - Overlap provides property propagation (e.g. Conductivity)

Nanoarchitectures: Pillars & Layers

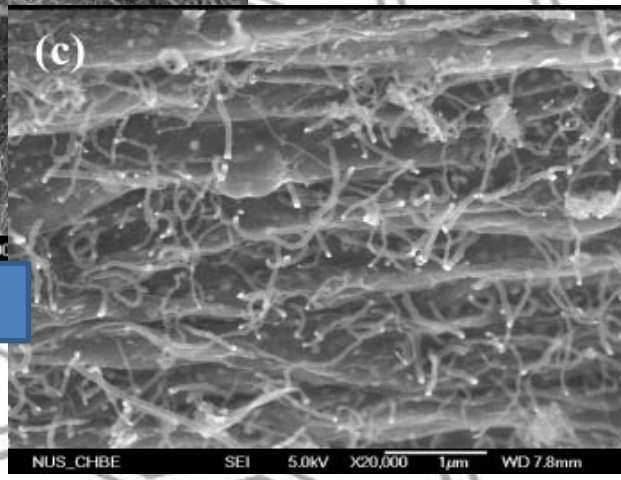
- **"Pillared graphene"**
  - High Strength
  - High Conductivity (electrical & thermal)
  - High surface area



10.1021/nl801417w



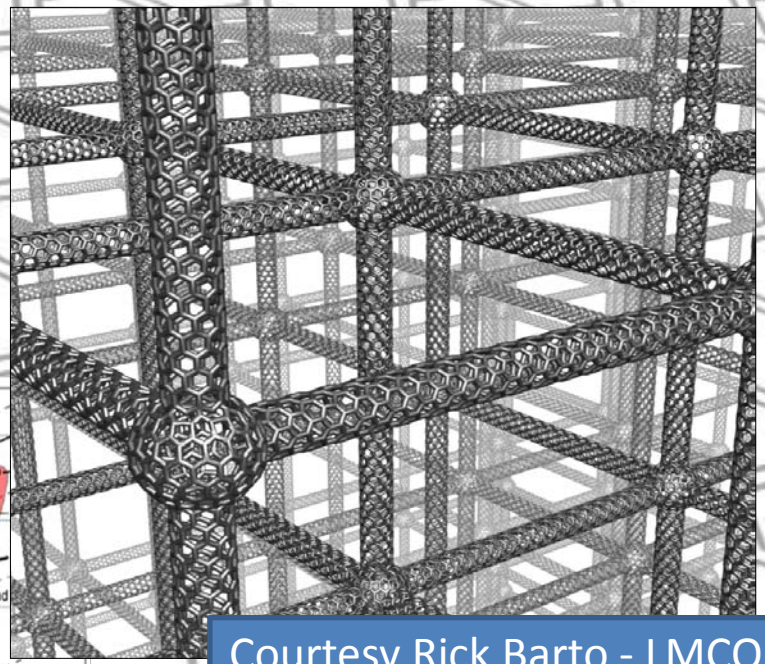
10.1021/nn102308r



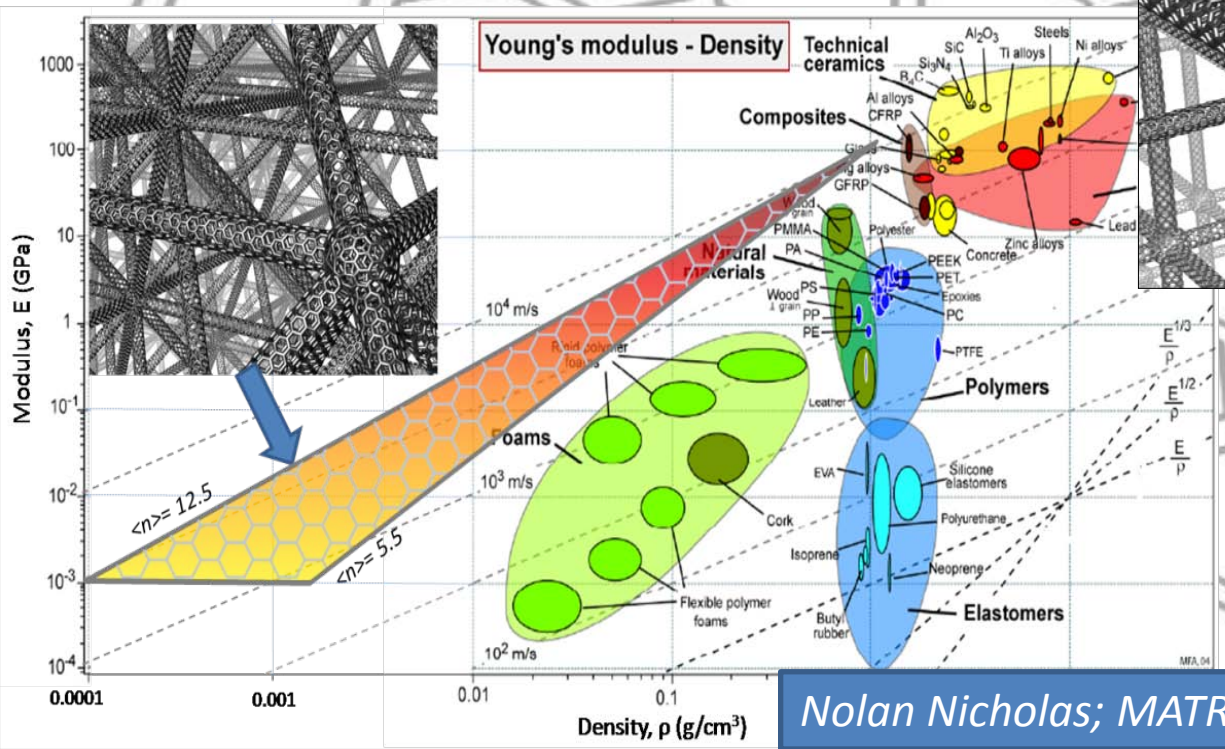
- Structural Energy Storages
  - Hydrogen Storage
  - Battery & Supercapacitor Electrodes

Nanoarchitectures: Spacefilling Frames

- **Spaceframe**
  - Architecturally driven properties
  - Decoupled variables
  - High surface area
  - Large free volume



Courtesy Rick Barto - LMCO



- Structural Energy storage
- Structural actuator materials
- Continuously graded materials (e.g. Stiff to soft)

Nolan Nicholas; MATRIC Research; unpublished

Decoupled Variables vs. Fortuitously Coupled Variables

- Fortuitously coupled variables: you get what you get – hopefully you like it
- The key issue is how to recognize when such couplings are present

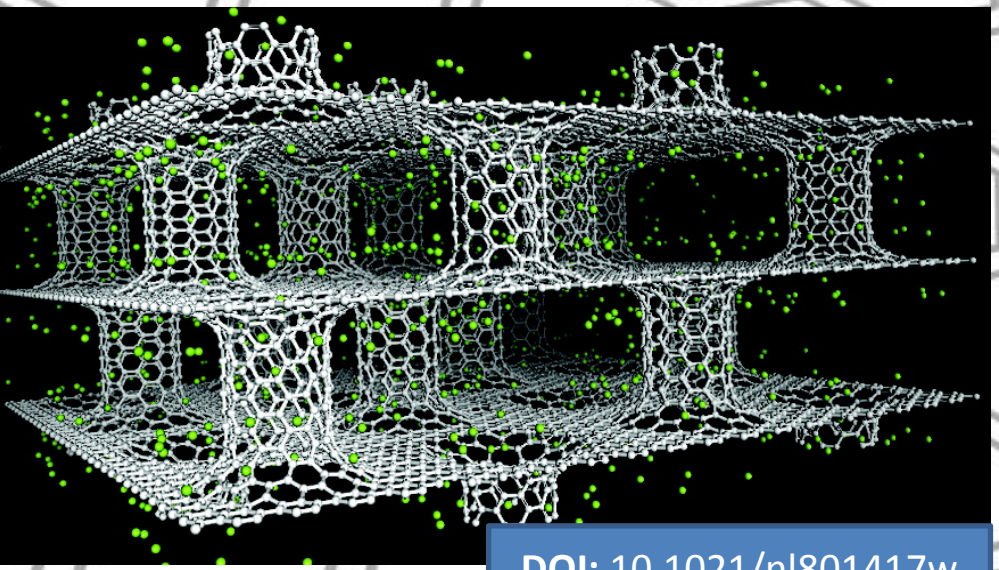
- Decoupled variables: menu item selection...
- The key is how to optimize a multidimensional parameter problem

Example Systems & Opportunities

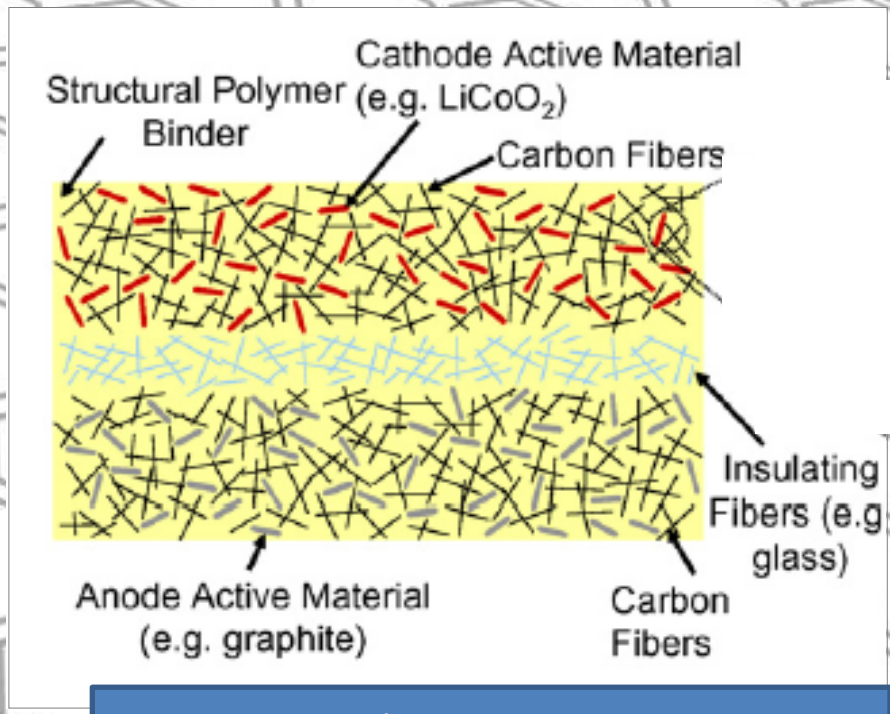
- "Mechanical Plus"
  - Electrical Conductivity (both highly conductive and static bleed)
  - Thermal Conductivity
  - Sensor
  - Energy Harvesting/Storage
  - Vibration Damping
  - Gas Barrier
- Actuation & "Smart" Materials
- Environmentally Responsive & "Smart" Materials
- BioMedical Materials
- Epoxy Curing & Adhesive Interfaces
- Graded Materials
- Damage Protection (thermal, chemical, UV, etc.)

Structural Energy Storage

- Aircraft fuel fractions around 30% are typical of modern jet aircraft
- 19.7% of weight "around town" Nissan Leaf electric car is in its power system



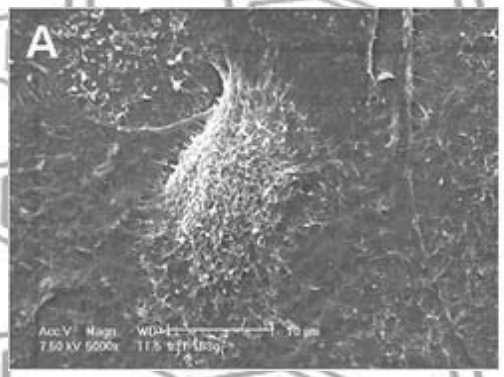
DOI: 10.1021/nl801417w

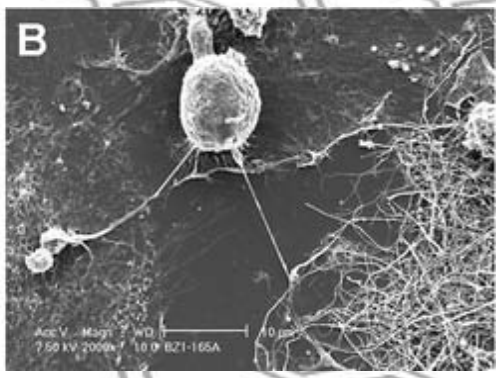


doi:10.1016/j.jpowsour.2008.09.082

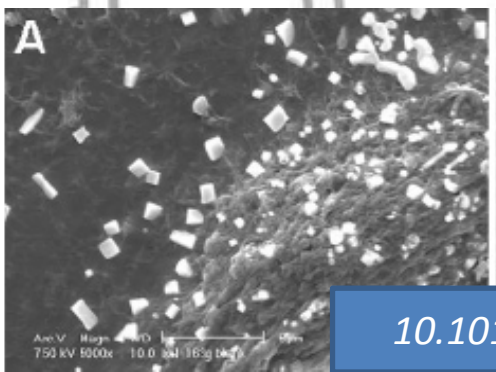
BioMedical Materials

- **High Strength**
- **Enhanced Biocompatibility**
- **Therapeutic Delivery**





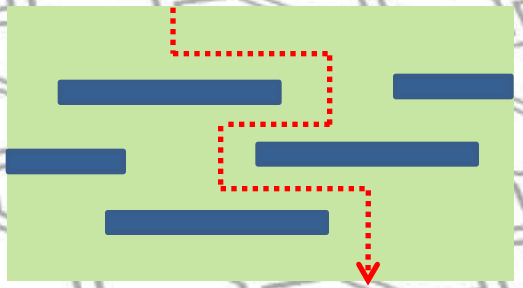
- Drug Release Materials
  - graphene oxide
  - nanodiamond
- Biocompatible implants & scaffolds

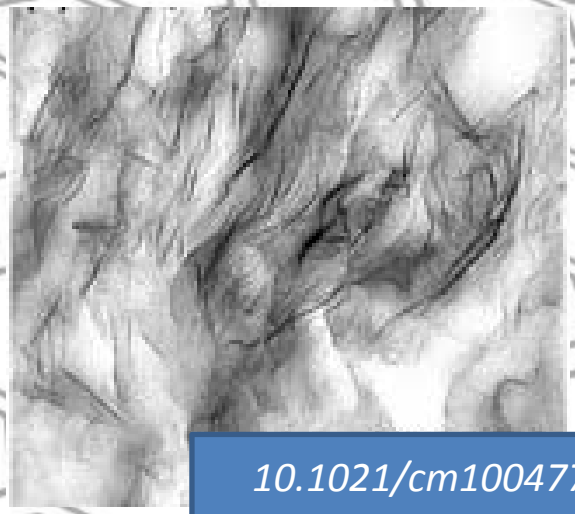


10.1016/j.ijbiomac.2010.01.006

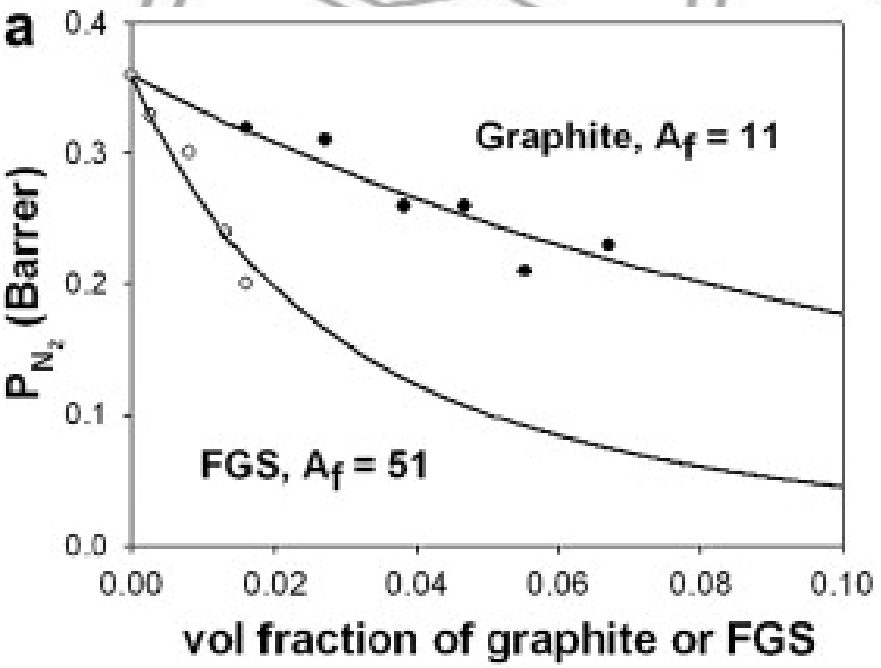
Gas Barrier

Graphene Nanocomposite Gas Barrier
- •Graphene impermeability
- •Nanoplatelet tortuosity
- •Material Stress Field & Gas Solubility





10.1021/cm100477v

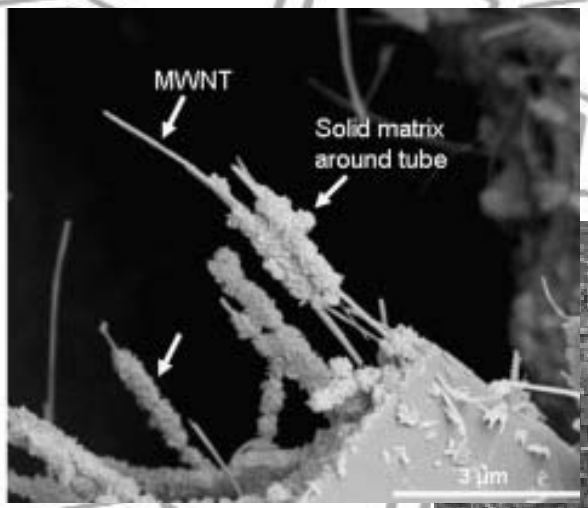


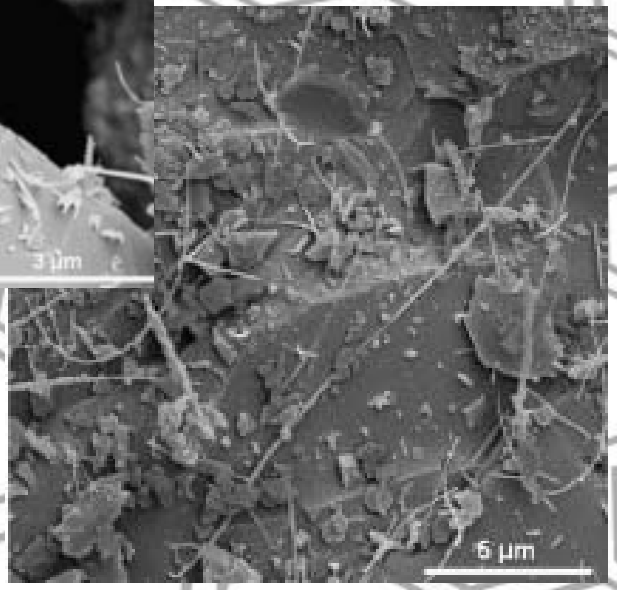
10.1016/j.polymer.2009.05.038

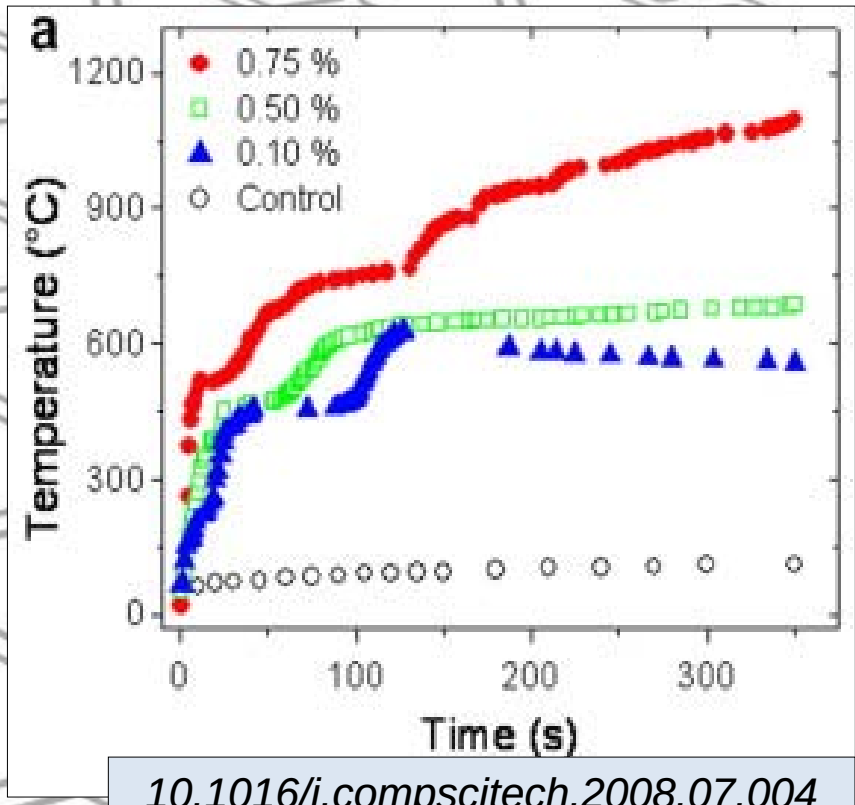
Simultaneous enhancements in
- •Mechanical Strength
- •Electrical & Thermal Conductivity
- •In-Situ Sensing

Epoxy Curing

Improved strength
Enhanced curing





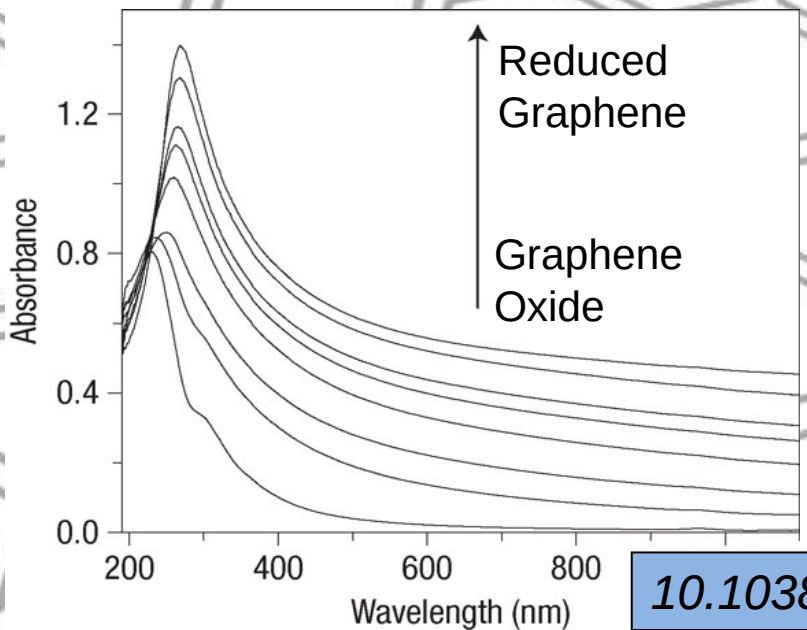


10.1016/j.compscitech.2008.07.004

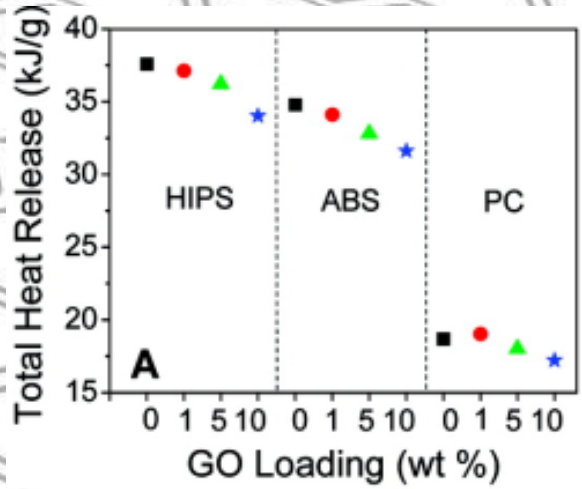
Nanocomposite Protection

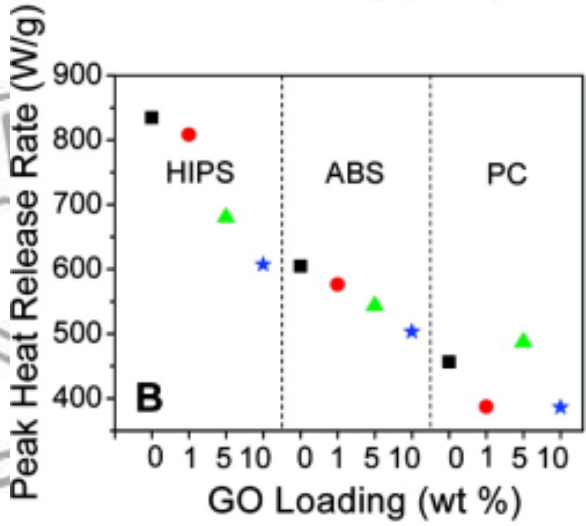
Chemical & physical properties of graphenic carbon engender protective properties to a polymer matrix while also providing mechanical enhancements

- Fire Retardancy
- UV Absorbance
- Chemical Attack Resistance



10.1038/nnano.2007.451





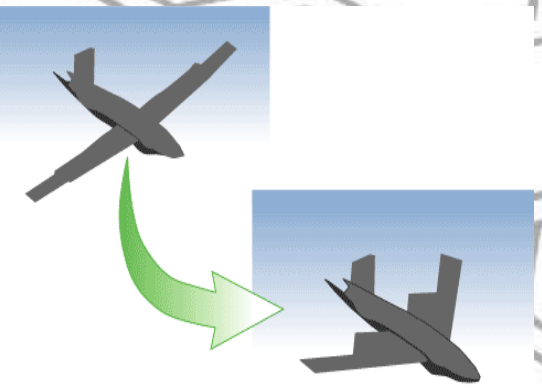
10.1021/am900419m

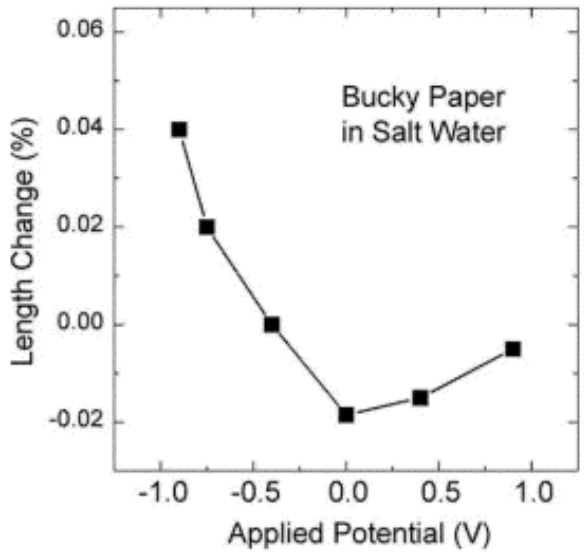
Actuators & Smart Materials

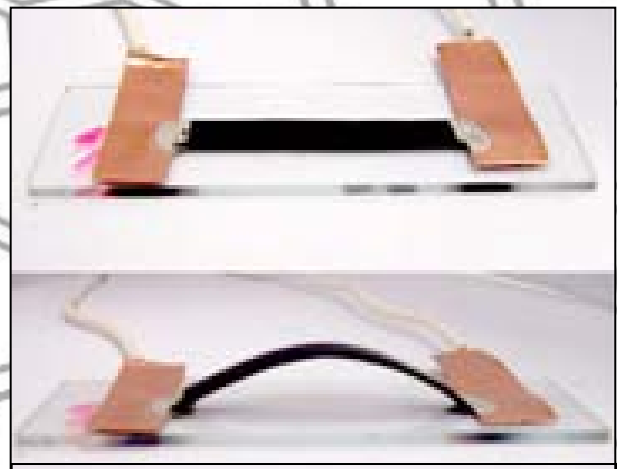
- Smart/adaptive materials provide adaptive multifunctionality

- CNTs have been observed to have extraordinarily high electro-actuation properties

- Adaptive thermal-conductivity nanomaterials could provide passive optimization of clothing & device insulation







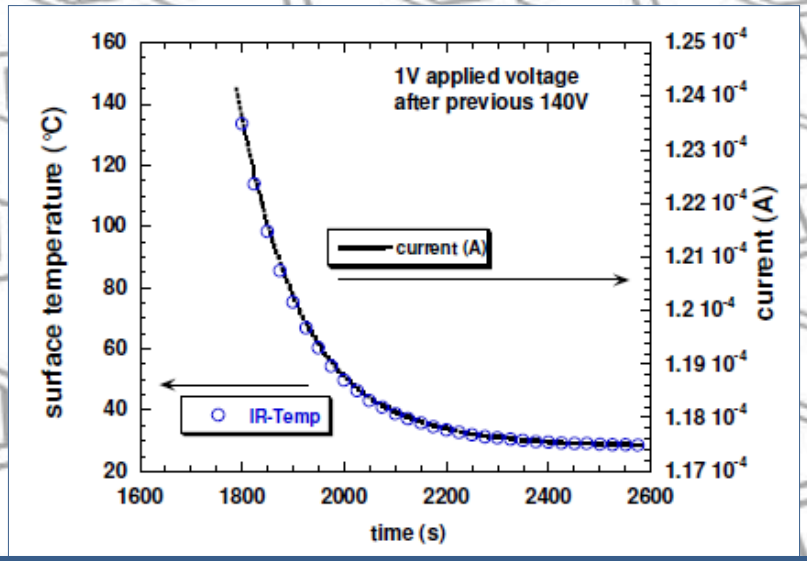
Chen, et al., Appl. Phys. Lett. ***92****, 263104*

In-Situ Sensors

Mechanical Enchancement

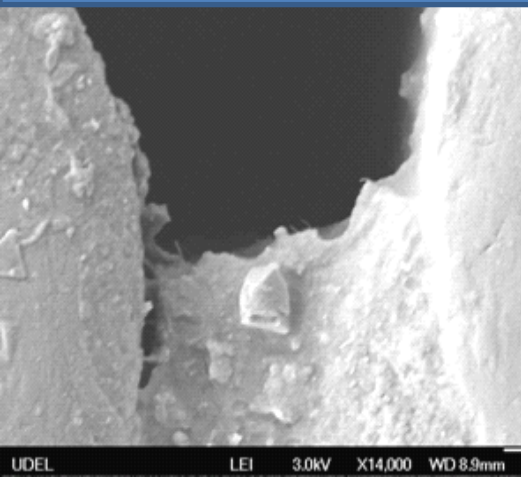
In-Situ Sensors

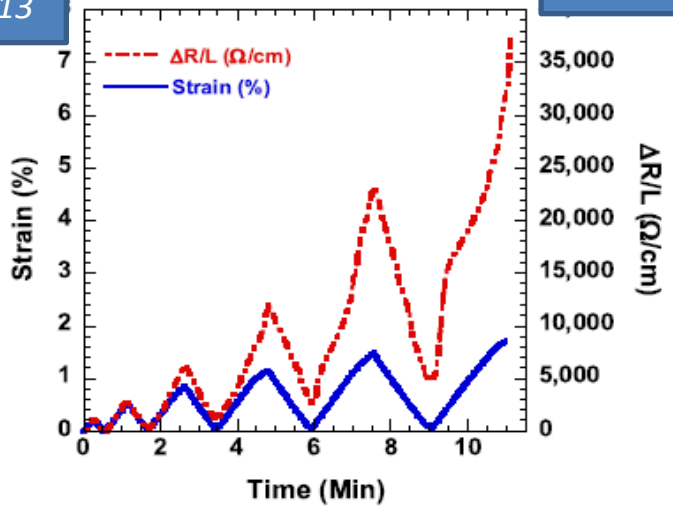
- CNT composite conductivity is often sensitive to operating conditions
  - Strain
  - Temperature



ICCE-17 Proc.; Neitzert, et al. 20733.pdf

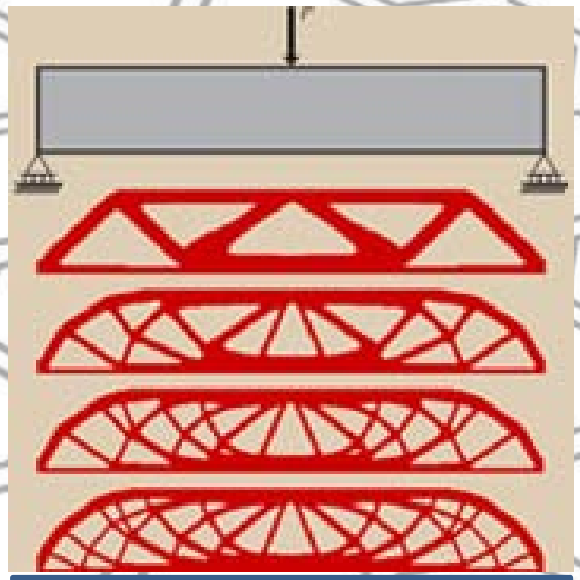
10.1088/0957-4484/19/21/215713



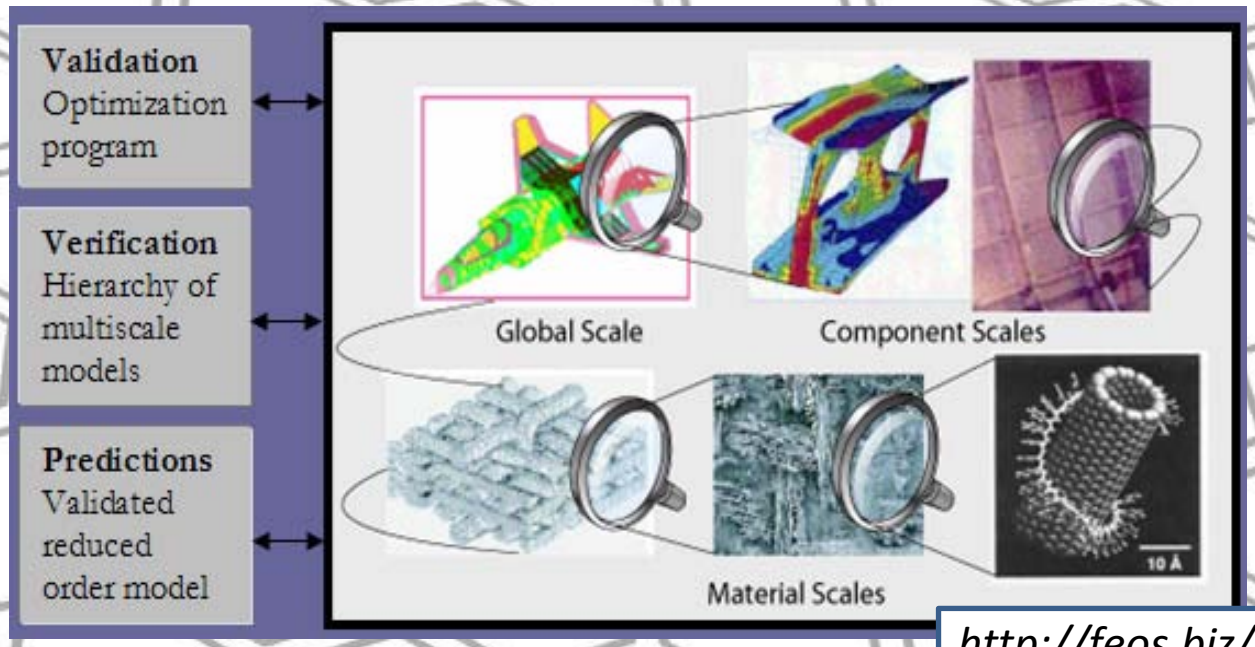


Achieving Multifunctionality:
Multi-Property Optimization

- Topological optimization
- Integrated system optimization
- Weighted optimization problem in multidimensional space



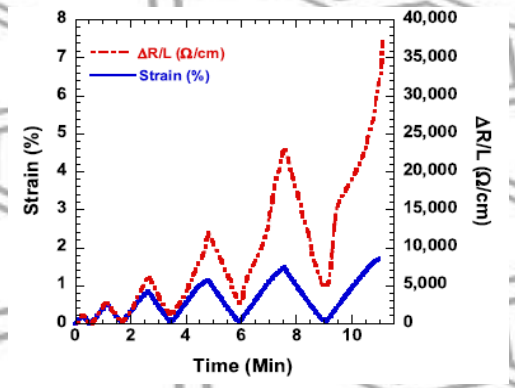
http://www.civil.jhu.edu/research-highlights

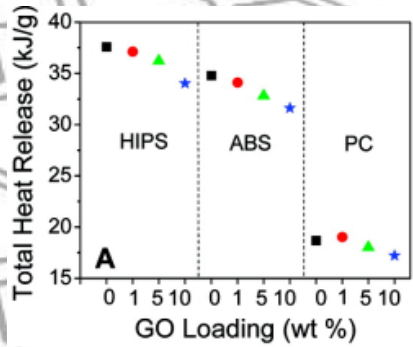


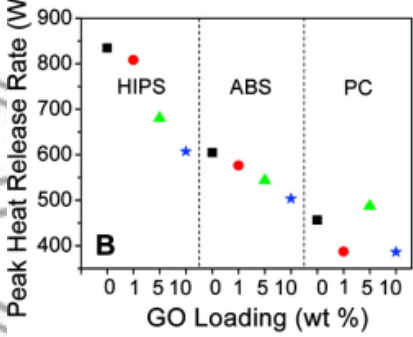
http://feos.biz/

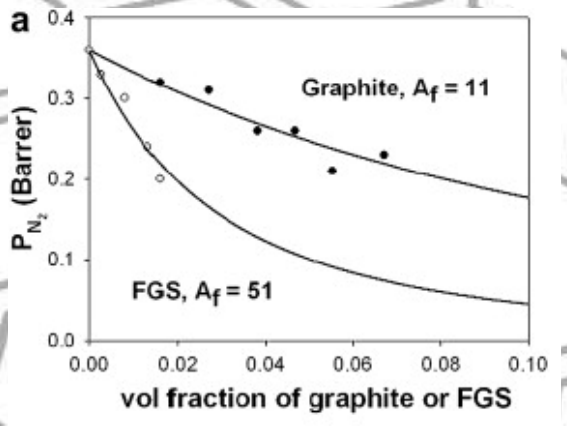
Achieving Multifunctionality: Multiparameter Measurement

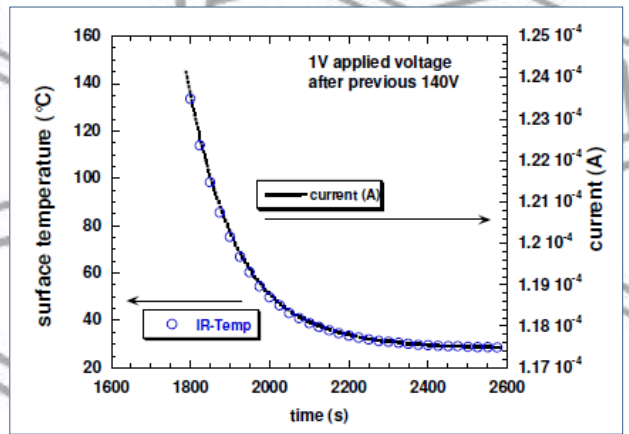
- Materials systems & properties are measured as independent, uncorrelated data points
- Integral correlation & regularization of multi-parameter testing is needed











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- –Expertise in R&D commercialization from ideation through production
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- •Fossil fuels & products
- •Environmental technologies
- •Polymer synthesis & processing
- •Nanomaterials
- •Separations technologies
- •Catalysis
- •Agricultural Sciences
- •Biomedical Device Development
- •Cellular & Immunological Research
- •Aerospace Software & Systems Engineering