



Integrity ★ Service ★ Excellence

Low Density Materials

09 MAR 2012

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Program Manager
AFOSR/RSA**

Air Force Research Laboratory

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2012 AFOSR SPRING REVIEW



NAME: **Low Density Materials**

PORTFOLIO DESCRIPTION :

Transformative research targeting advanced materials that enable substantial reductions in system weight with enhancements in performance and function.

Research within the portfolio is focused on **INCREASING** the **SPECIFIC PERFORMANCE** of aerospace platforms.

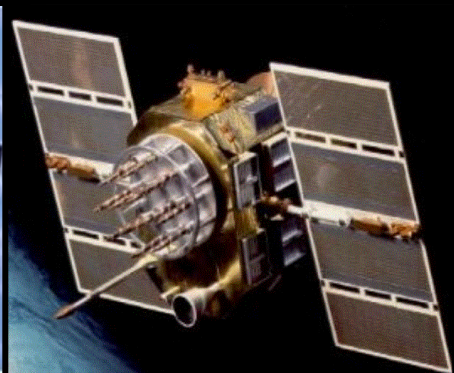
PORTFOLIO SUB-AREAS:

Structural Lightweighting →
Multifunctionality ↗
Hybrid Materials ↑

Increased emphasis on forging interdisciplinary teams to address broad-base challenges



Why Low Density Materials?



*If it has **structure** and **rises above the ground**,
material density is important!*



*Material density impacts: **payload capacity, range, cost, agility, survivability, environmental impact....***



Increasing Specific Performance in Aerospace Platforms



Specific Performance
Performance * ρ^{-1}

**HYBRID
MATERIALS**

MULTIFUNCTIONALITY

STRUCTURAL LIGHTWEIGHTING



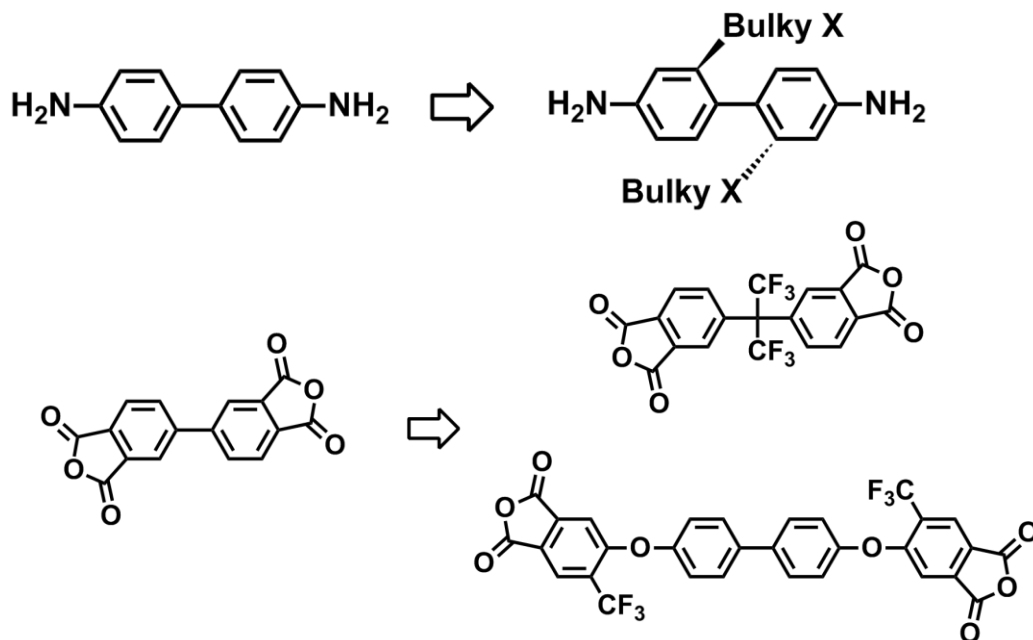
Polyimide Nanofiber Reinforced Structures



Novel Material Synthesis

Incorporating steric hindrances and reduced chain periodicity to achieve:

- Organo-solubility
- Structural rigidity and toughness
- High thermal stability



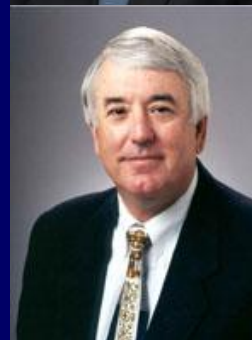
Dr. Yuris Dzenis
McBroom Professor



Dr. Stephen Cheng
NAE
Robert C. Musson
Trustees Professor



Dr. Frank W. Harris
Distinguished
Professor
Emeritus

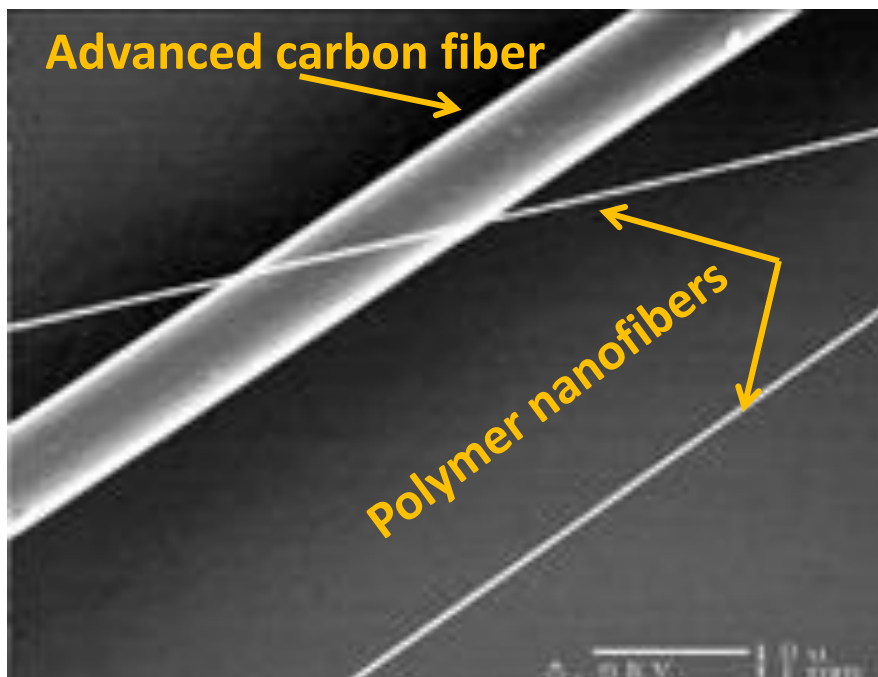




Nanofiber Reinforced Structures



High Strength, Tough Polyimide Nanofibers

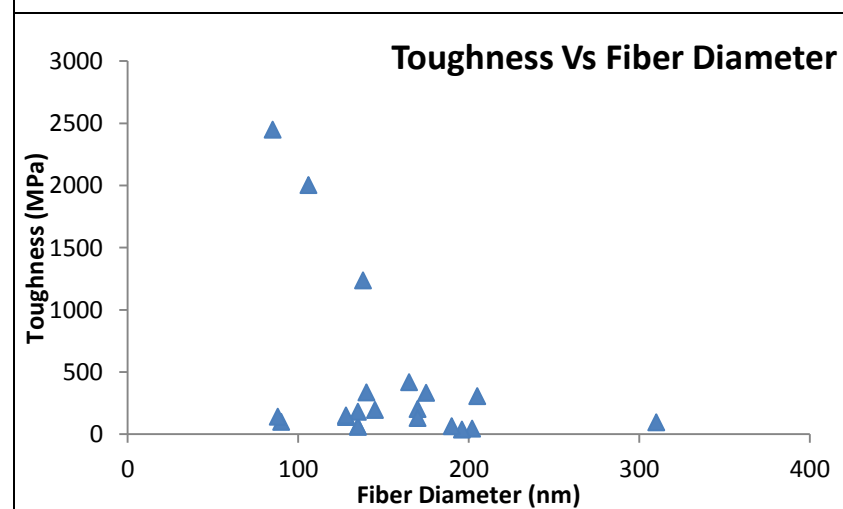
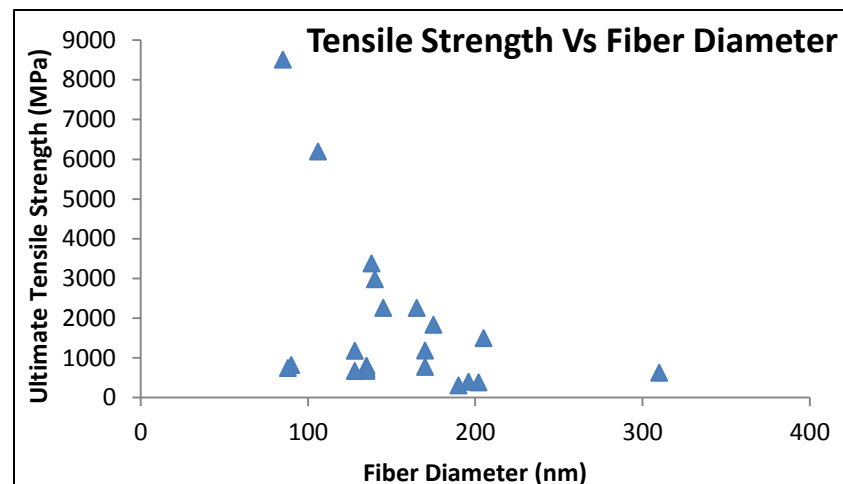


**Continuous nanofibers electrospun
from novel, soluble polyimide**

8.7 GPa strength

47% failure strain

2,500 MPA toughness

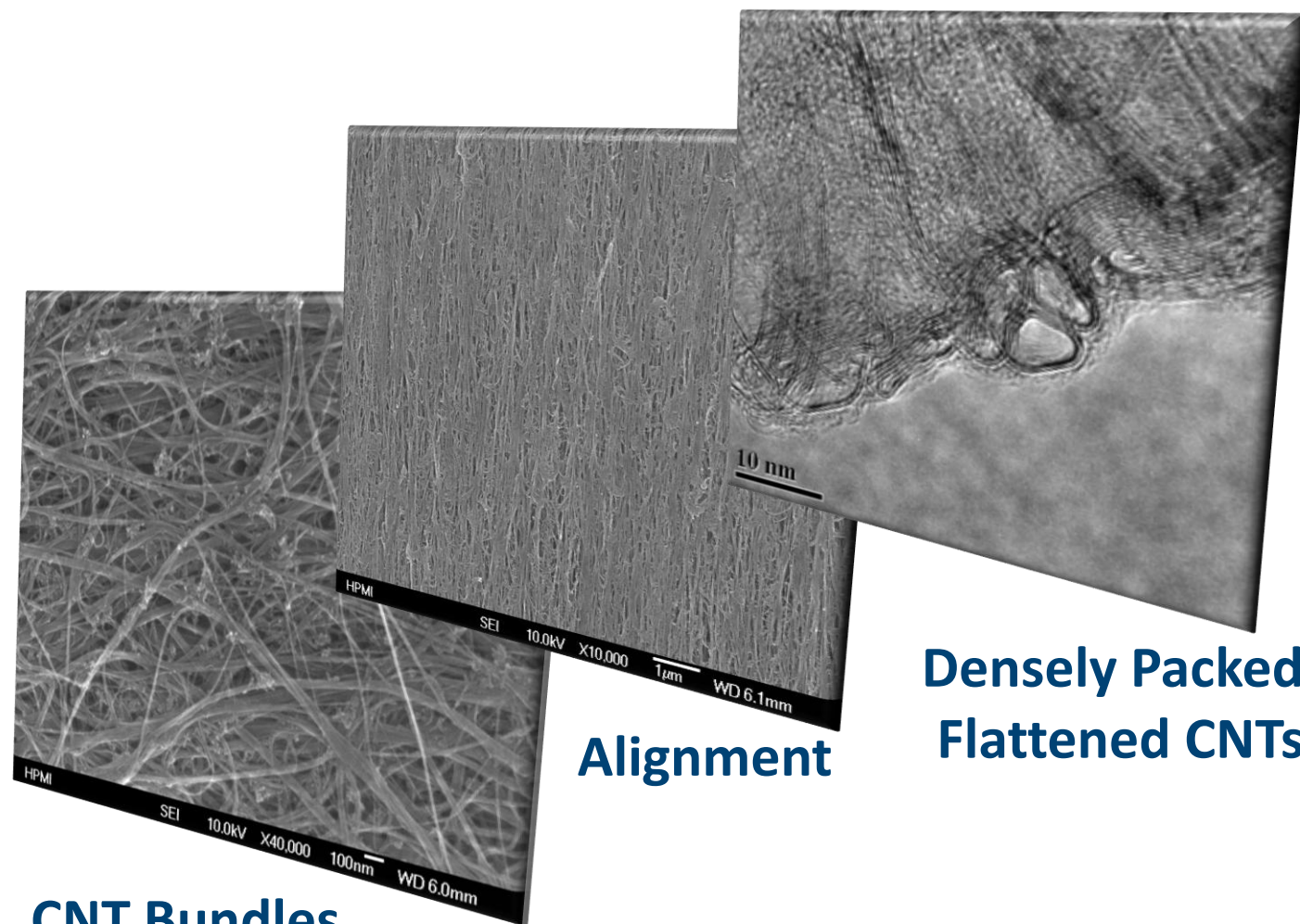




Translation of Nanoscale Properties to Macroscale Structures



Fundamental Challenge:
Improving CNT-CNT Load Transfer



Alignment

**Densely Packed,
Flattened CNTs**

CNT Bundles



Dr. Ben Wang
Fellow – IIE, SME, SAMPE



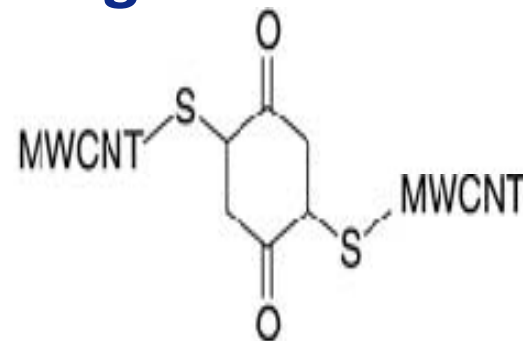
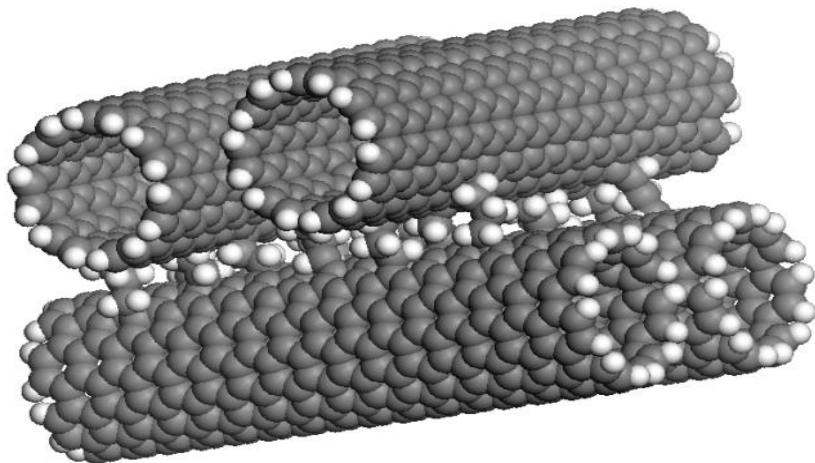
Dr. Richard Liang



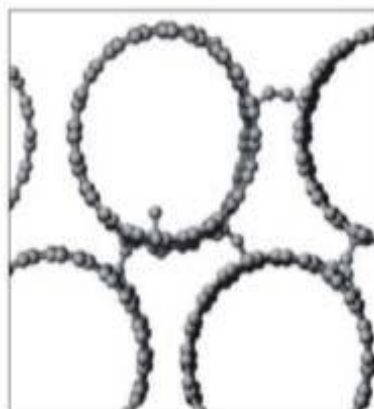
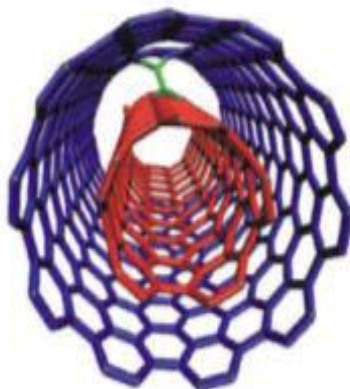
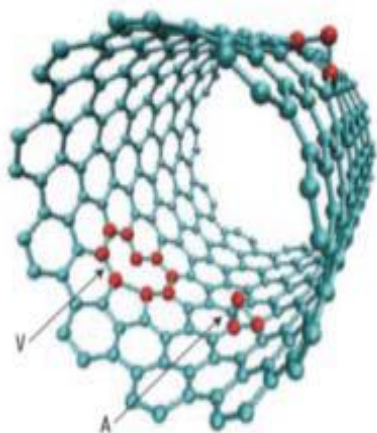
CNT-CNT Reaction Mechanisms



Fundamental Challenge: CNT-CNT Bonding



Crosslinking MWCNTs via Covalent Bonds



Irradiation-induced Crosslinking of CNTs

A. V. Krashenninnikov, K. Nordlund, "Ion and Electron Irradiation-Induced Effects in Nanostructured Materials," *J. Appl. Phys.* 107, 071301, 2010



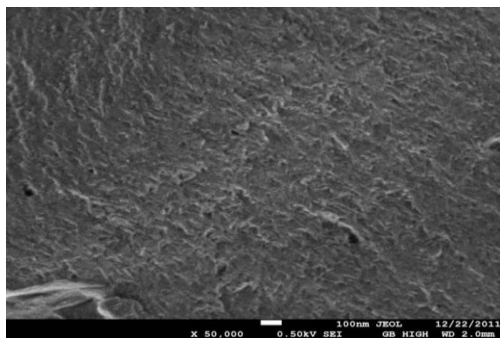
Training Tomorrow's Workforce



(AFOSR DURIP 11) Acquisition of a Thermal Field Emission Scanning Electron Microscope

Nanoparticle Reinforced Resins for Readily Processable, High Temperature, Low Density Composites and Energetic Materials

“The SEM will meet the increasingly stringent requirements of cutting-edge materials technology for fundamental research and the education and research training of students.”

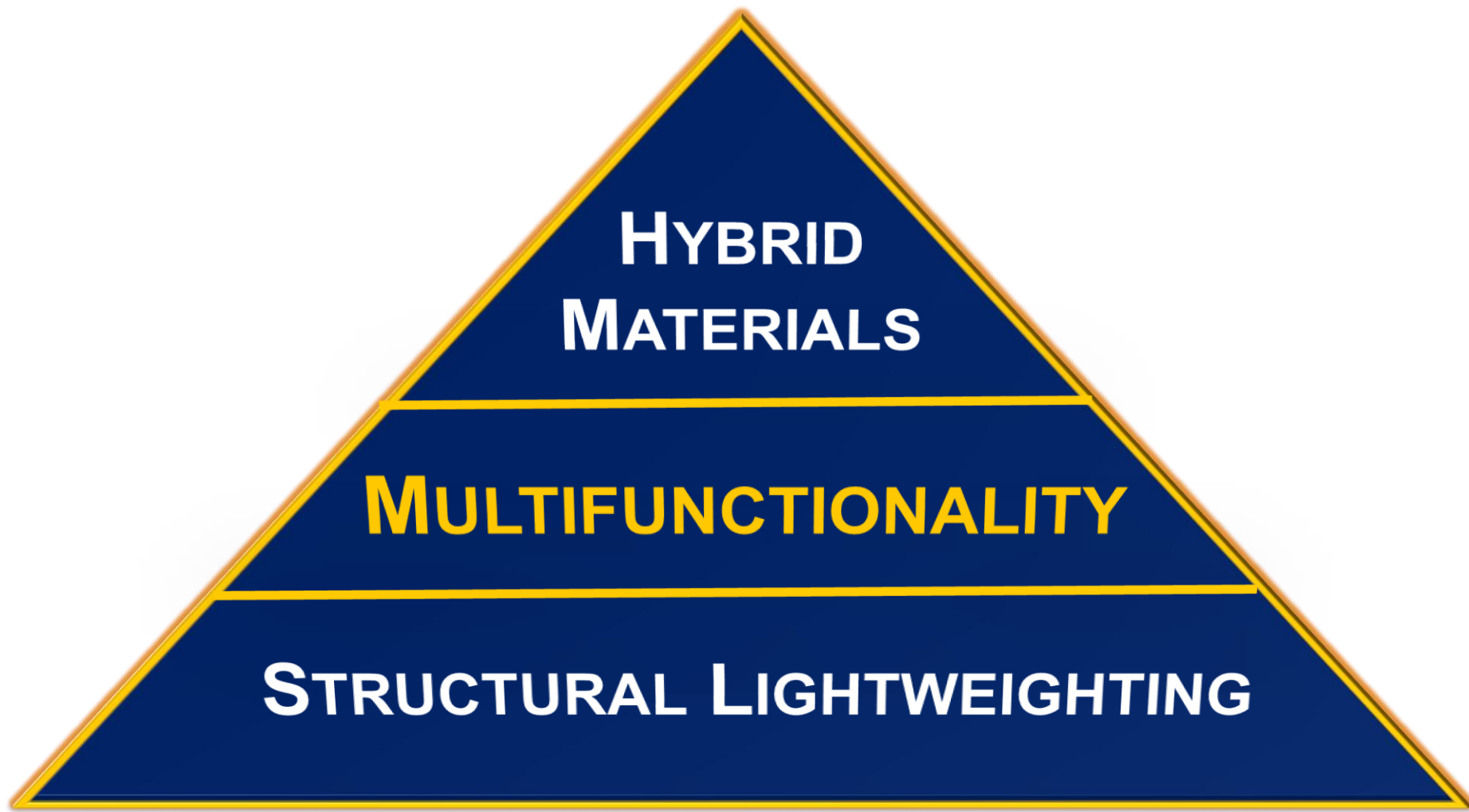


SEM of 0.3 wt% graphite/PETI-298, confirming the dispersed graphene



Dr. David Veazie
• 2010 AFRL Summer Faculty Fellow at AFRL/RW
• National Technical Achiever of the Year



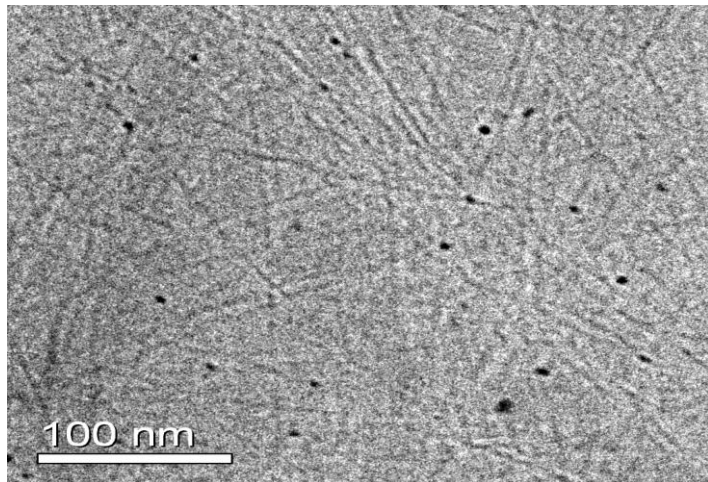




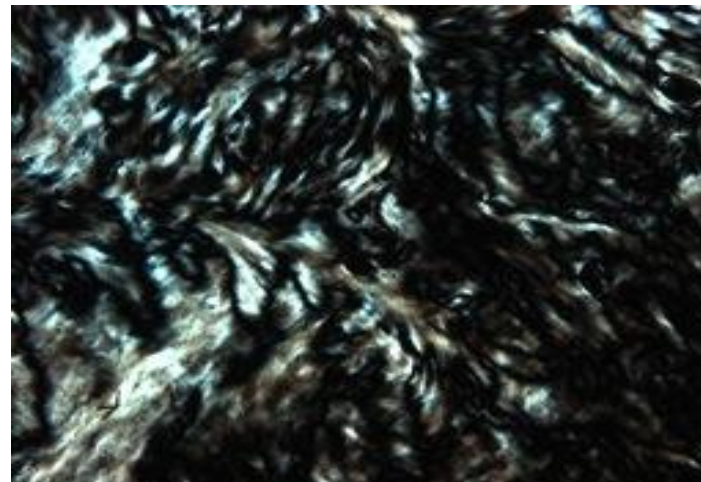
Multifunctionality: CNT Fibers



Liquid Phase Processing of CNTs



**Cryo-TEM CNT/
chlorosulfonic acid dispersion**



**Polarized light micrograph of 10 μm
CNT/chlorosulfonic acid dispersion**

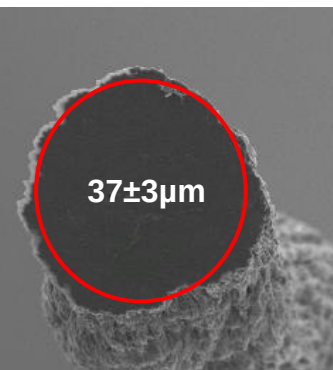
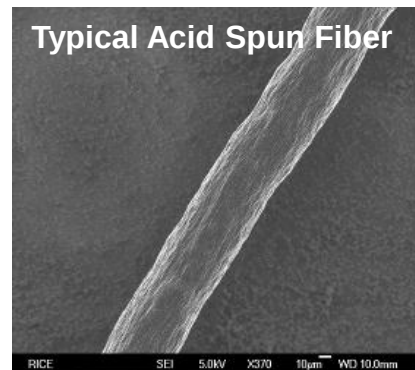


Dr. Matteo Pasquali



**Technology
Transfer**

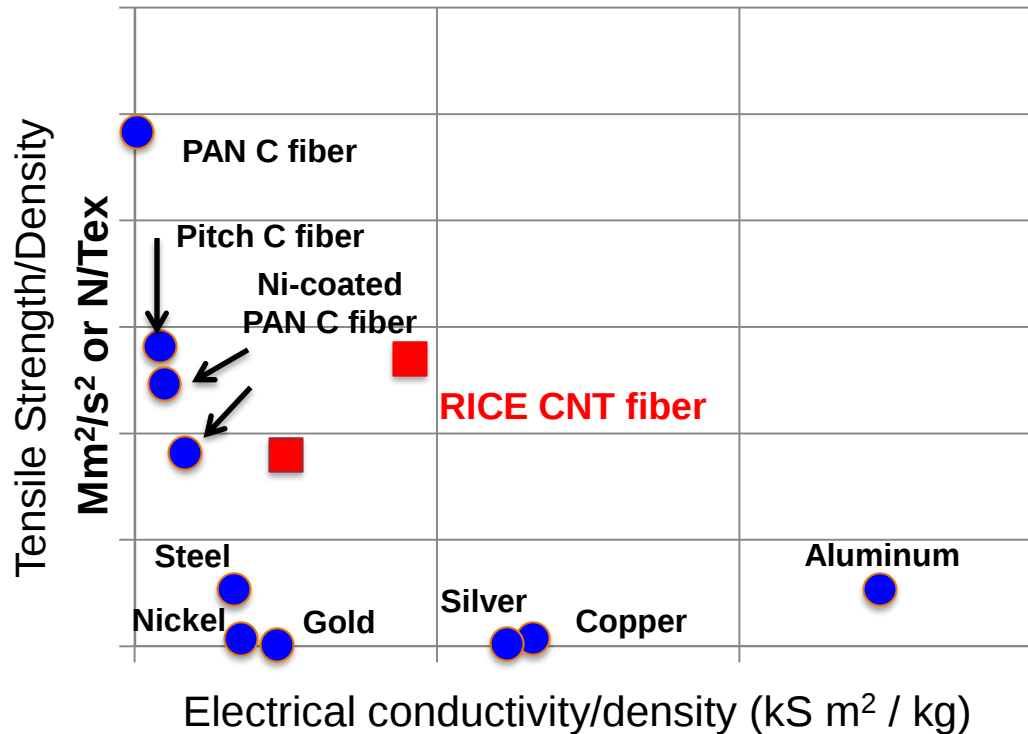
**Research in
collaboration
with Teijin Aramids**





Multifunctionality

Load-bearing + Electrical Conductivity



LED wired and held by
“invisible” CNT fibers



- Best electrical conductivity reported for neat CNT fibers
- Order of magnitude increase in electrical & thermal conductivity and strength

Research in collaboration of Teijin Aramids

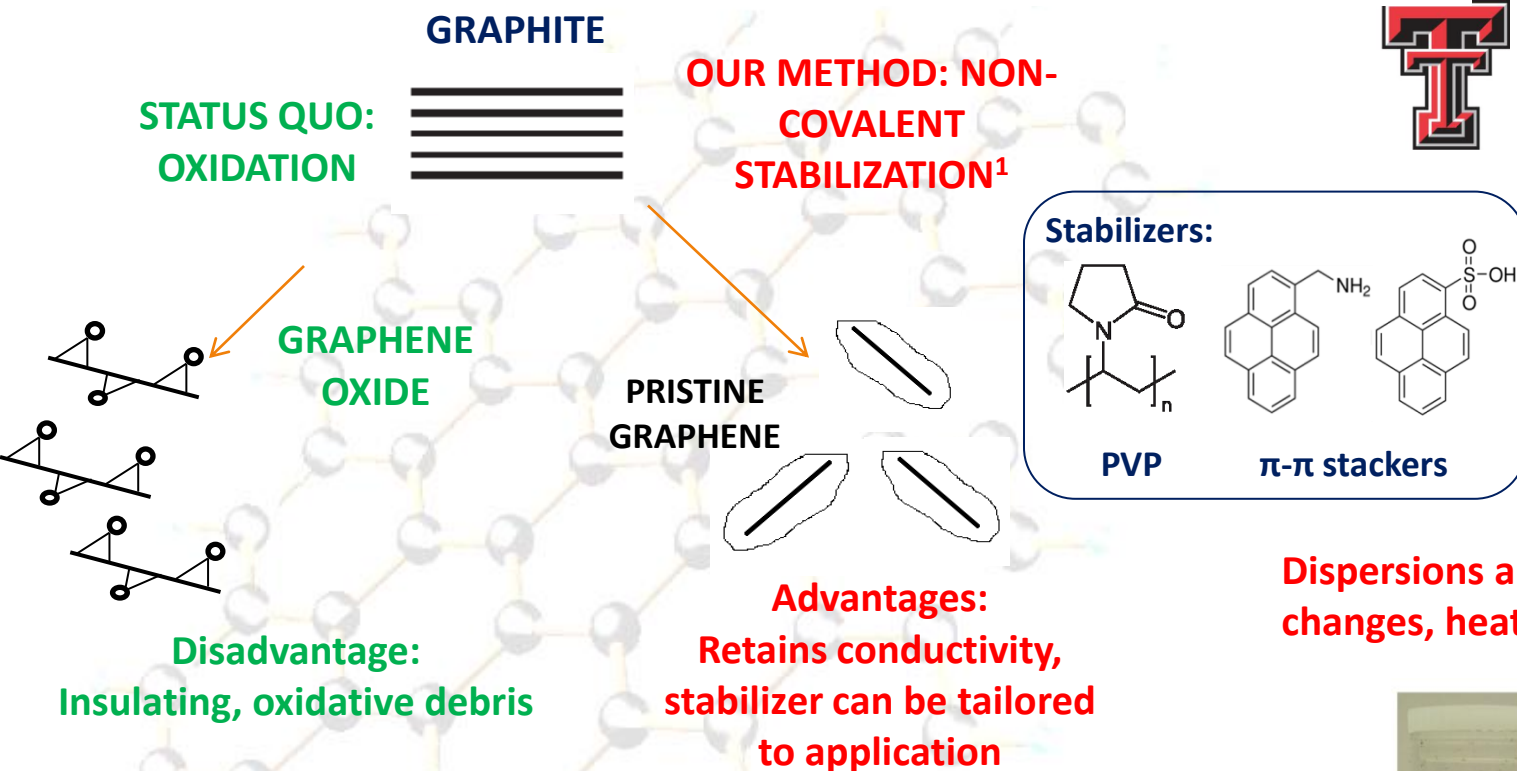
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Enabling Multifunctionality: Graphene Nanocomposites

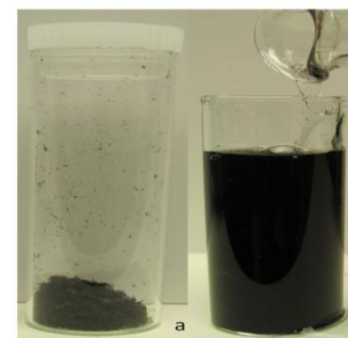


Non-covalent functionalization of graphene in solution



Dr. Micah Green
• 2010 AFOSR Young Investigator Award

Dispersions are stable against pH changes, heat, lyophilization

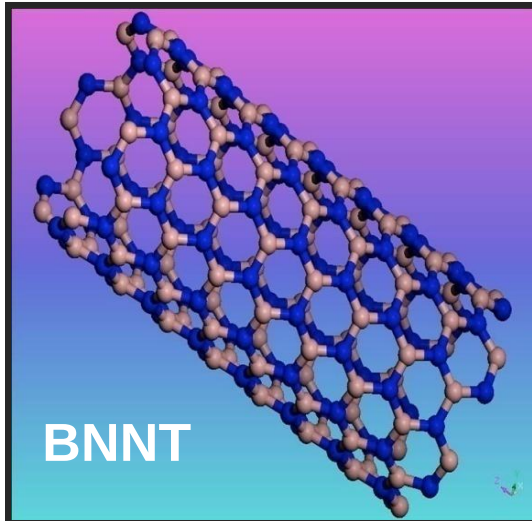


Physisorption of PVP on graphene surface guarantees excellent interfacial load transfer¹

¹Wajid *et al*, *Carbon*, 2012



BNNT Multifunctionality



	Carbon nanotubes	Boron nitride nanotubes
Mechanical Properties	1.33 TPa	1.18 TPa
Electrical Properties	Metallic or semiconducting	Semiconducting (~ 5.5 eV band gap)
Polarity	No net dipole	Permanent dipole Piezoelectric (0.25-0.4 C/m²)
Neutron Scattering cross-section	C = 0.0035	B = 767 (B¹⁰ ~3800) N = 1.9
Thermal Oxidative Stability	Stable to 300 – 400 C in air	Stable to 800 C in air



Single Tube Nanomechanics

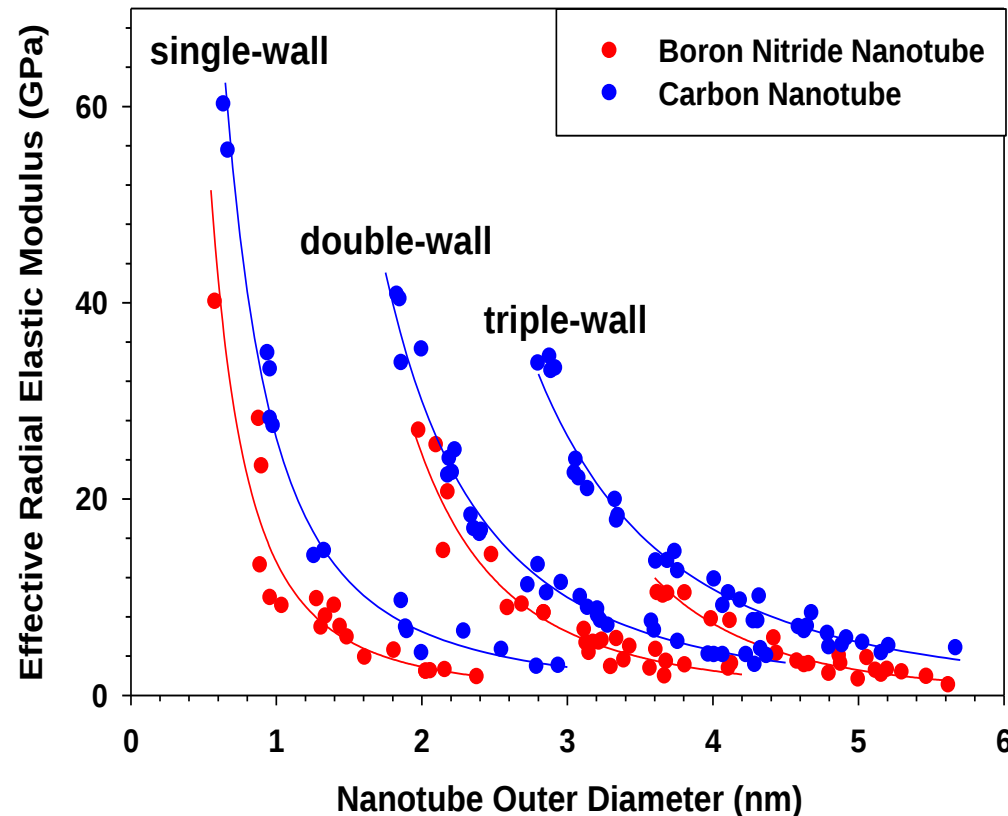


Tensile Test

Single tube pull-out test

Peel Test

1st report of radial deformability of BNNT



Dr. Changhong Ke
2010 AFOSR
Young
Investigator
Award

BINGHAMTON
UNIVERSITY
STATE UNIVERSITY OF NEW YORK

BNNTs have 40-60% lower effective radial elastic modulus than comparable CNTs



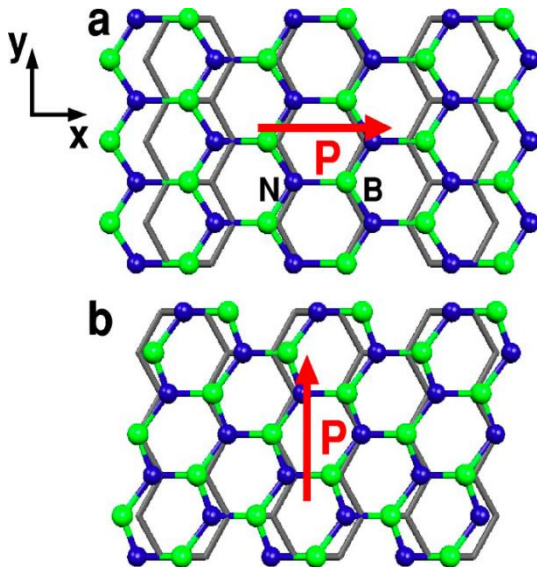
Multifunctionality

Load-bearing + Actuation



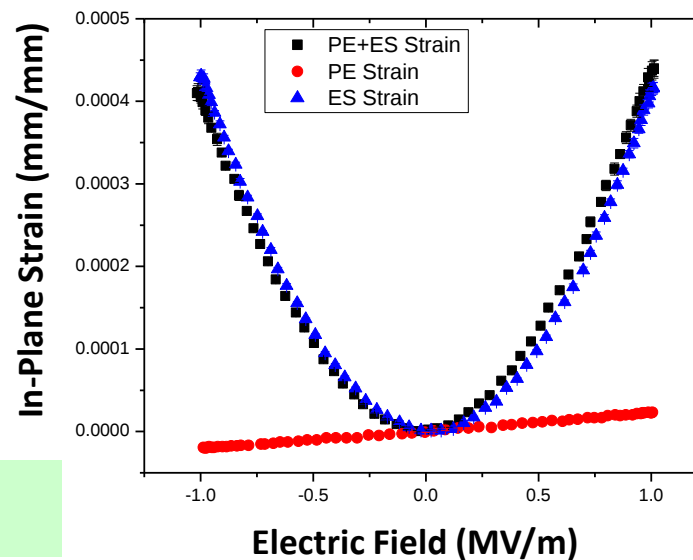
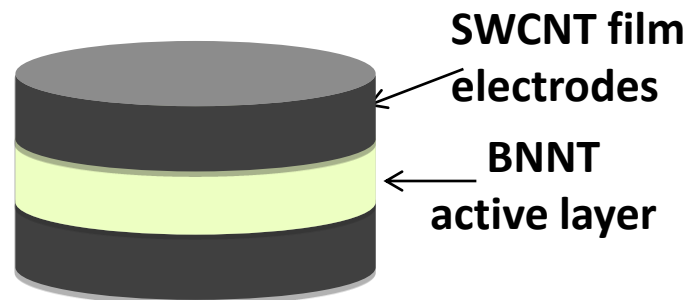
1st experimental observation of
electrostrictive strain in BNNT

Theoretical Prediction of
Net Polarization



Field induced strain (e_{33})

$$e_{33} = d_{33} \cdot E + M_{33} \cdot E^2 + \dots$$



Dr. Cheol Park



Prof. Alex Zettl
Fellow - APS

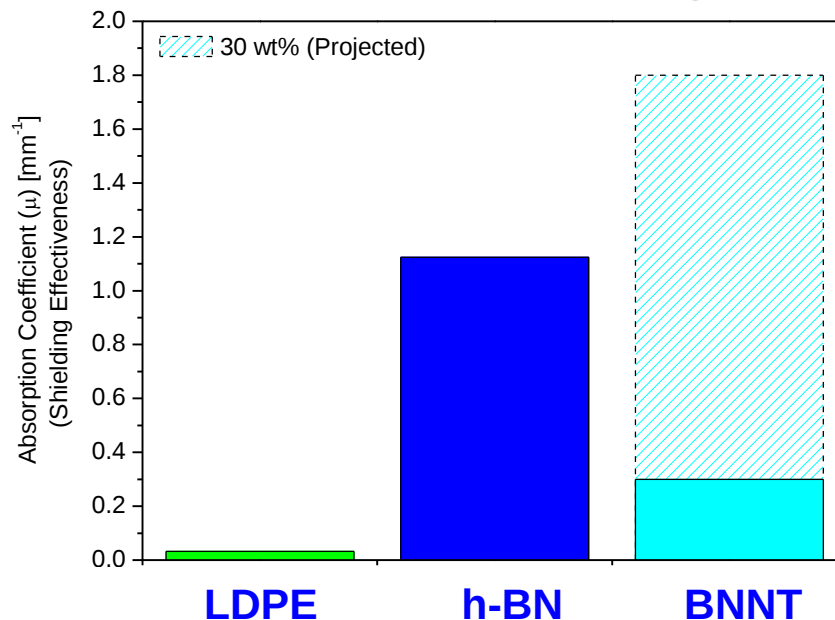


Multifunctionality

Load-bearing + Radiation Shielding

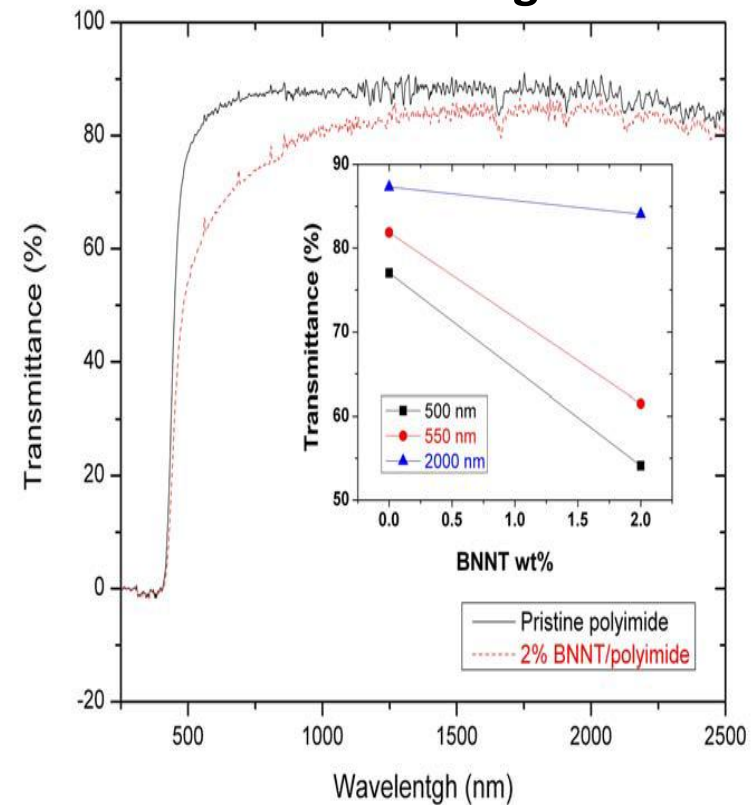


Neutron Shielding



$$\ln\left(\frac{I_s}{I_0}\right) = -\mu x, \Rightarrow \mu = \ln\left(\frac{I_0}{I_s}\right) \cdot \frac{1}{x}$$

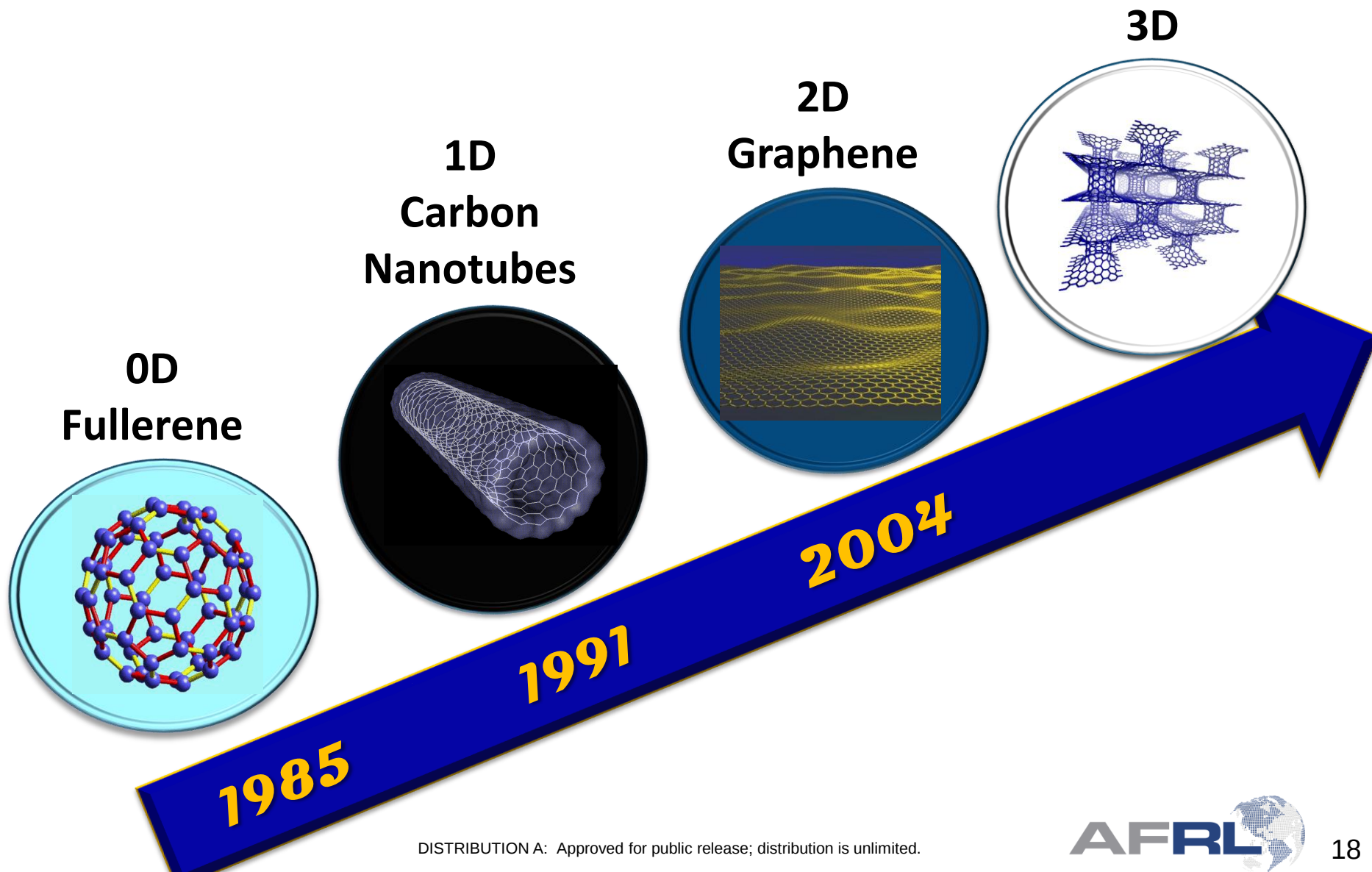
UV Shielding



Shielding Effectiveness of BNNT exceeds h-BN on weight basis



Nanostructured Carbon



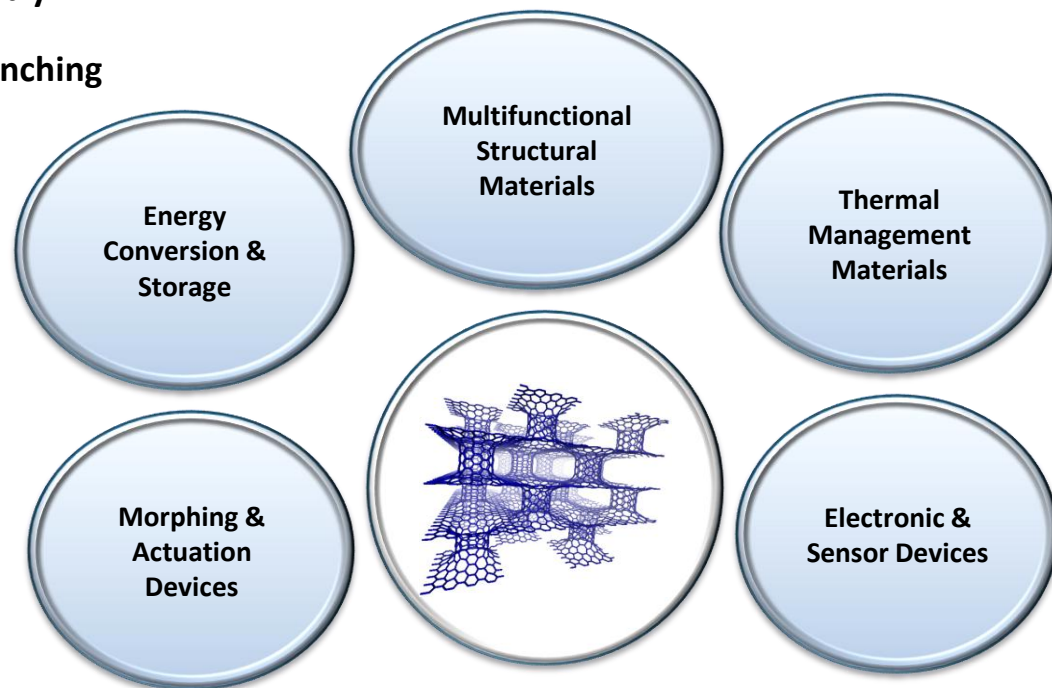


MURI 11 Topic: Nanofabrication of 3D Nanotube Architectures



Objective: Controlled assembly and atomic-scale bonding of nanoscale elements (e.g. carbon nanotubes and graphene), leading to network structures with exceptional 3D thermo-electro-mechanical properties

Materials Enabling Future Aerospace Needs



Multi-Path Synthesis and Assembly

- doping-induced branching
- metal nanoparticle-induced branching
- atomic nanotube welders

Multiscale Characterization

- atomic scale structure
- node integrity
- mechanical properties
- electron & phonon transport

Multiscale-Multiphysics Design

- density function theory
- molecular dynamics (MD)
- mesoscale/continuum models
- finite element



Synthesis and Characterization of 3D Carbon Nanotube Solid Networks, Rice U. MURI Team



Pulickel M. Ajayan, PI
Synthesis, characterization,
mechanical, electrochemical,
thermal properties



James Tour
Synthesis, chemistry,
devices, electrical properties



Matteo Pasquali
Solvent processing, rheology,
fibers, mechanical properties



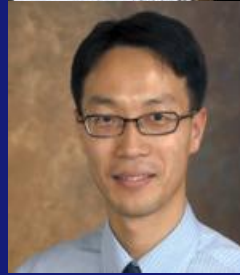
Boris Yakobson
Ab-initio modeling, simul
structure-property correl;
thermo-mechanical properties



Ray Baughman
Synthesis, fiber spinning,
mechanical, thermo-mechanical,
electro-mechanical properties



Mauricio Terrones
Synthesis, chemical processing,
atomic scale characterization,
structure modeling



Jonghwan Suhr
Synthesis, modeling,
thermo-mechanical behavior,
viscoelastic properties,
composites

Multidisciplinary, Collaborative Team





Nanofabrication of 3D Nanotube Architectures

Case Western Reserve U., MURI Team



Tim Fisher
(Purdue)

“thermal transport & management, nanotechnology”



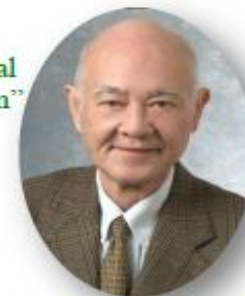
Zhonglin Wang
(GaTech)

“nanoscale structure & device characterization & novel hybrids”



Zhenhai Xia
(NTU)

“mechanical/electrical multi-scale simulation”



Chung Chiu Liu
(CWRU)

“electrochemistry, sensors & energy devices”



Liming Dai
(CWRU)

“C-nanomaterials syntheses & devices”



Quan Li
(KSU)

“liquid crystal materials, chemistry, self-assembly”



Vikas Prakash
(CWRU)

“multi-scale structure-property characterization; thermal management”



Xiulin Ruan
(Purdue)

“thermal modeling of e - p & p - p coupling”

THE MURI TEAM



**HYBRID
MATERIALS**

MULTIFUNCTIONALITY

STRUCTURAL LIGHTWEIGHTING



Hybrid Materials Design



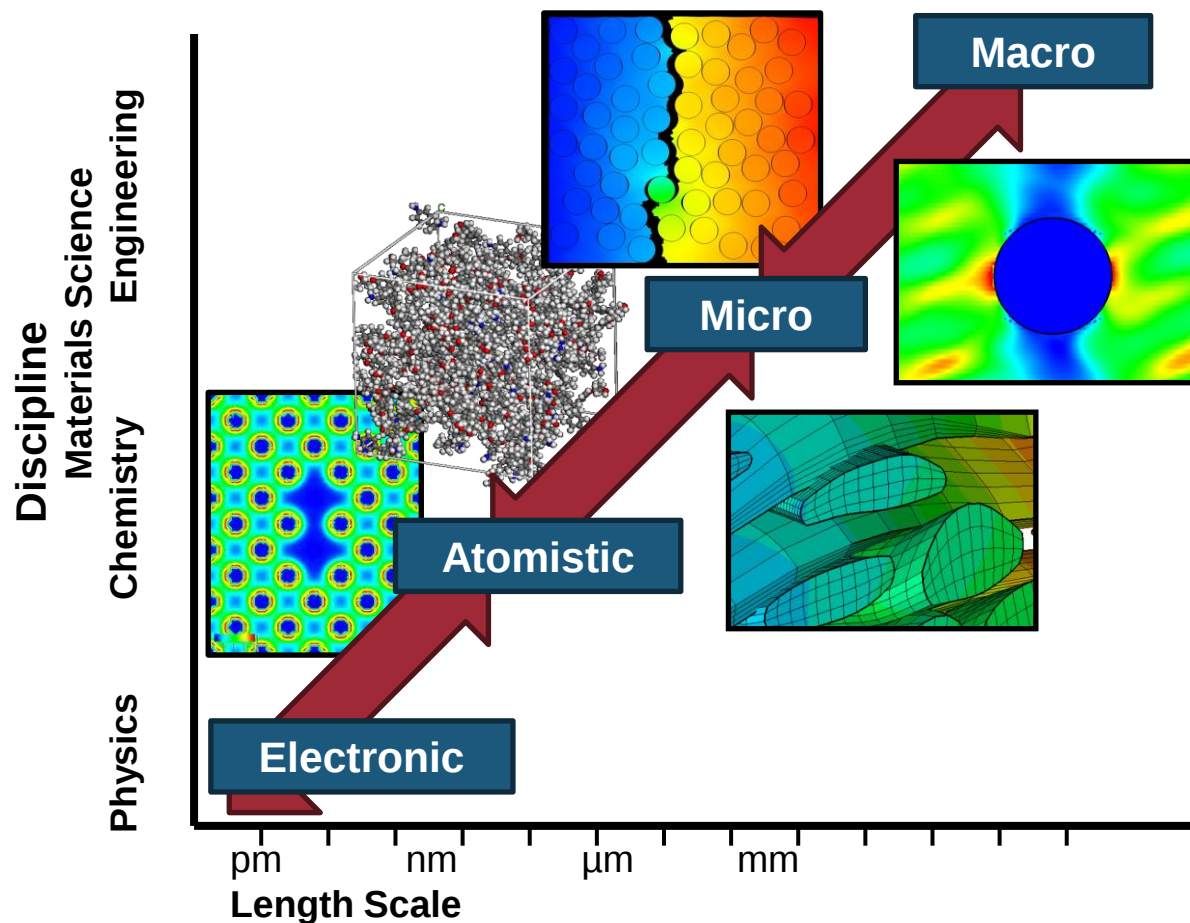
**Design the structure
based on limitations of
the material**

**Design the material
based on structural
requirements**



Hybrid Materials Design

Materials Modeling Hierarchy



*Slide created by Dr. Tim Brietzman, ARFL/RXBC

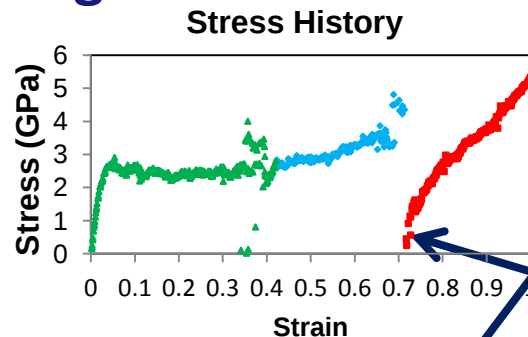
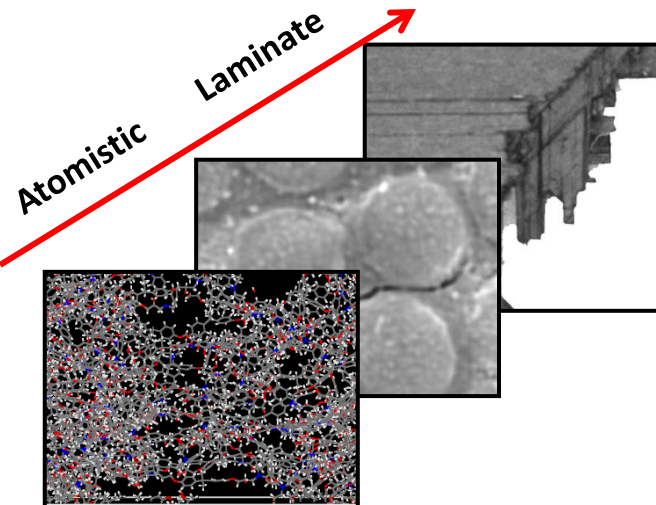
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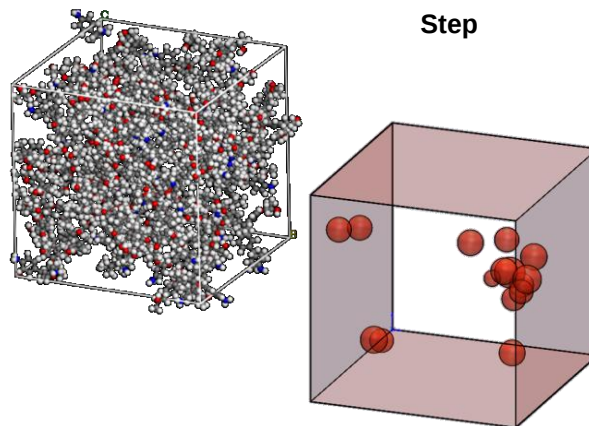
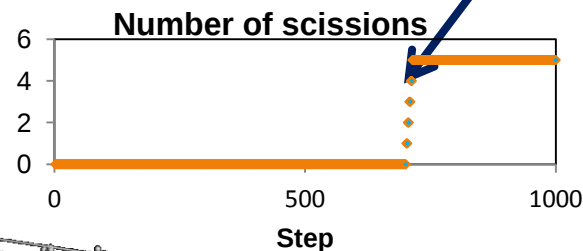
Hybrid Materials Design



Connecting Atomistic & Microscale Behaviors -- Essential for Materials Design



Polymer network breakdown



Molecular representation of epoxy resin and mapping of nanoscale voids due to bond scission



Dr. Tim Breitman
AFRL/RXBC



Dr. Rajiv Berry
AFRL/RXBN

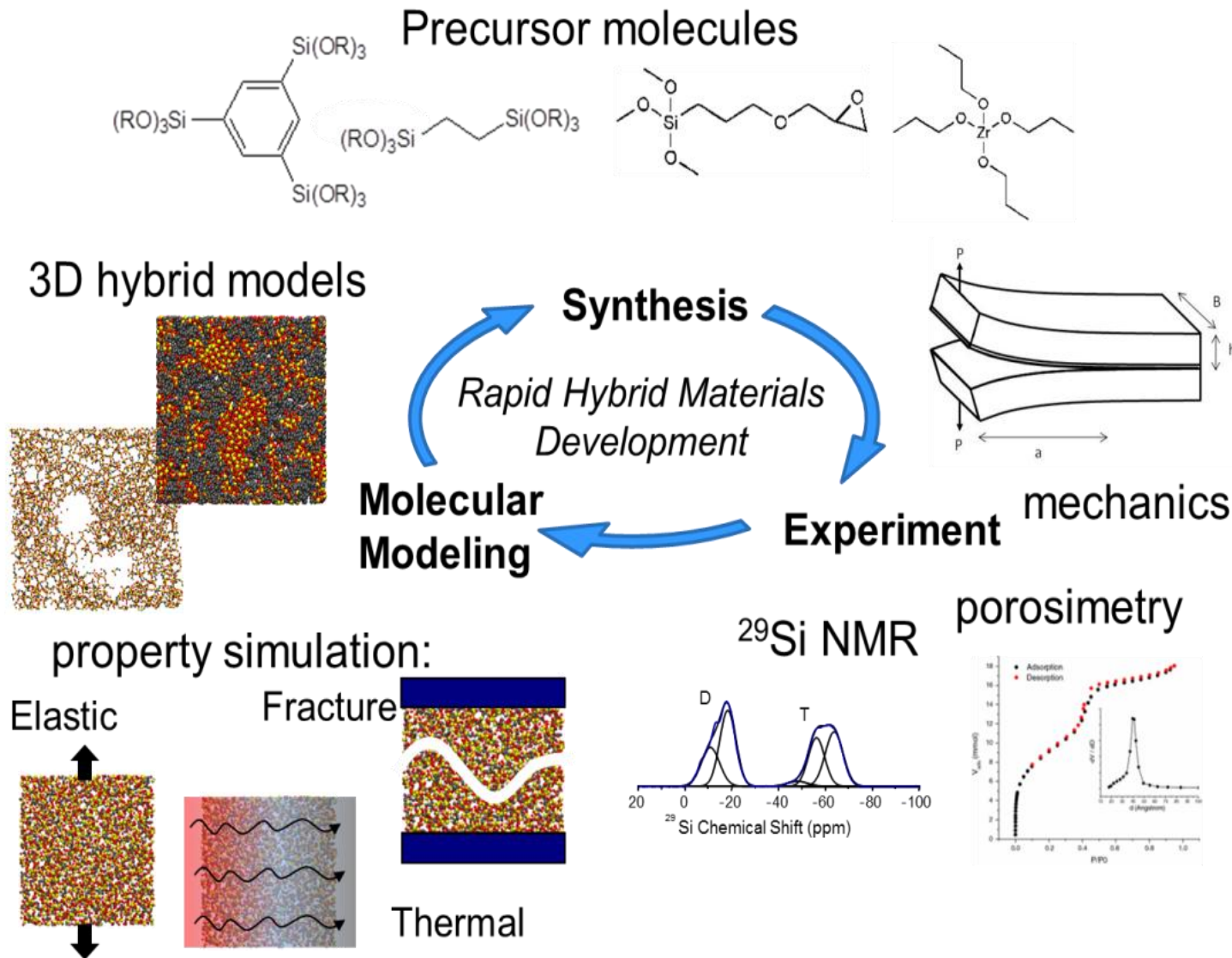


Dr. Jim Moller





ICMSE Hybrid Materials Design



Prof. Reinhold Dauskardt
Fellow – ACerS, ASM





2011 Basic Research Initiative



AFOSR/NSF Joint Research Solicitation

ODISSEI: Origami Design for Integration of Self-assembling Systems for Engineering Innovation



**Advance understanding of folding and unfolding of materials
structures across scales for design of engineered systems**

- **Packaging/Deploying Control Surfaces**
 - Satellites
 - Solar sails
 - Precision air drop
 - Tube launched systems
- **Mechanisms**
 - Compliant mechanisms
 - Actuators
- **Materials**
 - Hierarchical materials design
 - Atomistic assembly
 - Active/tunable materials



Research Community Leadership



AFOSR Low Density Materials

AFRL

DIRECTORATES

RX, RV, RW
LRIRs, STTRs,
MURIs,
Workshops,
Reviews, Visits

INTERNATIONAL

US-India Tunable
Materials Forum

US-AFRICA
Initiative

DOD COMMUNITY

Reliance 21 Board
Materials and
Processing COI

OTHER AGENCIES



Lightweight
Structures



Nanostructured
Materials



Origami
Engineering



Acknowledgements



Dr. Marilyn Minus



Dr. Greg Odegard



Dr. Kishore Pochiaju



Dr. Samit Roy



Dr. Ajit Roy
AFRL/RX



Dr. Brandon Arritt
AFRL/RV



Dr. Ashlie Martini



Dr. Robert Moon



Dr. Satish Kumar



Dr. James Seferis
GloCal Network Corp.



Dr. Rajesh Naik
AFRL/RX



Dr. Ryan Justice
AFRL/RX



Dr. Jeff Youngblood



Dr. Olesya Zhupanska
2011 DARPA Young Faculty



Dr. Henry Sodano



Dr. Chris Muratore
AFRL/RX



Dr. Benji Marayama
AFRL/RX



Dr. Markus J. Buehler



Dr. Sharmila Mukhopadhyay



Dr. Mesfin Tsige



Dr. Soumya Patnaik
AFRL/RX

