Nanomaterials in Army RDT&E

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Army Research Laboratory

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

48th Navy and Marine Corps Public Health Conference, Emerging Chemicals Session
Hampton Roads Convention Center,
Hampton, VA
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"What would happen if we could arrange the atoms one by one the way we want them…?"

- Richard Feynman, "There's Plenty of Room at the Bottom", 1959

Taxonomy (ASTM)

- **nano, n**—(1) The SI definition, a prefix used to form decimal submultiples of the SI unit "meter", designating a factor of 10^{-9} denoted by the symbol "n". (2) Pertaining to things on a scale of approximately 1 to 100 nanometers (nm). (3) A prefix referring to an activity, material, process or device that pertains to a field of knowledge defined by nanotechnology and nanoscience.

- **nanoscale**, adj—having one or more dimensions from approximately 1 to 100 nanometers (nm).

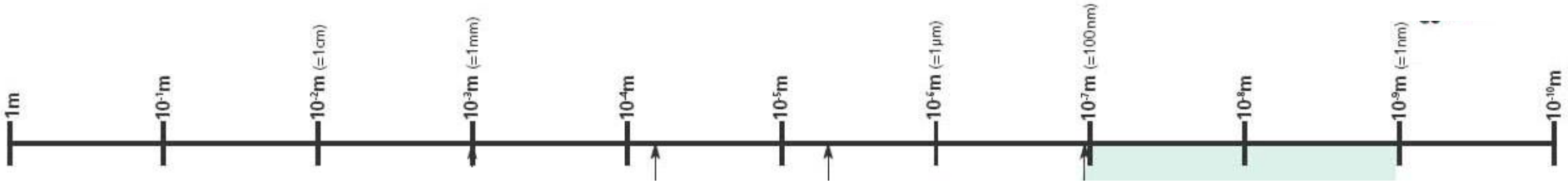
- **nanoparticle**, n—in nanotechnology, a sub-classification of ultrafine particle with lengths in two or three dimensions greater than 0.001 micrometer (1 nanometer) and smaller than about 0.1 micrometer (100 nanometers) and which may or may not exhibit a size-related intensive property.

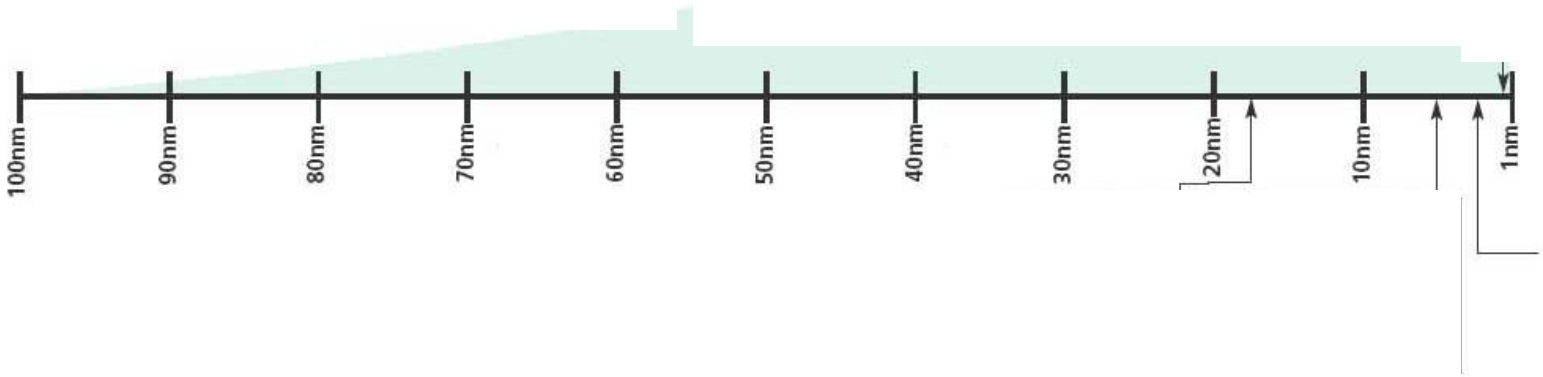
  DISCUSSION—This term is a subject of controversy regarding the size range and the presence of a size-related property. Current usage emphasizes size and not properties in the definition. The length scale may be a hydrodynamic diameter or a geometric length appropriate to the intended use of the nanoparticle.

- **nanostructured**, adj—containing physically or chemically distinguishable components, at least one of which is nanoscale in one or more dimensions.

  DISCUSSION—While many conventional nanomaterials are distinguished by physical or chemical characteristics, biological recognition may also be the basis for defining a nanostructure. Though this concept is formally contained by the word 'chemically' such a feature would lead to a distinctive type of nanostructured system.

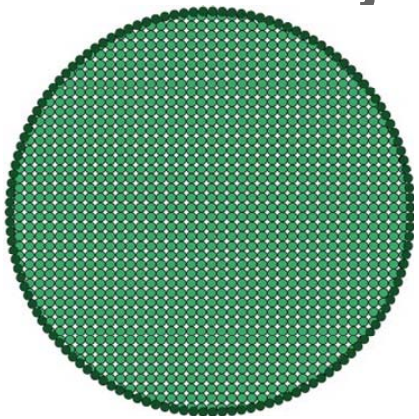
How Big is One Nanometer -- Length Scale?





Courtesy of The Royal Society & The Royal Academy of Engineering

Physical Properties Change: Melting Point of a Substance

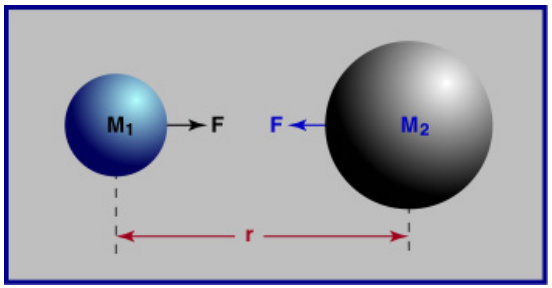
	At the macroscale	At the nanoscale
The majority of the atoms are…	…almost all on the inside of the object 	…split between the inside and the surface of the object 
Changing an object's size…	…has a very small effect on the percentage of atoms on the surface	…has a big effect on the percentage of atoms on the surface
The melting point…	…doesn't depend on size	… is lower for smaller particles

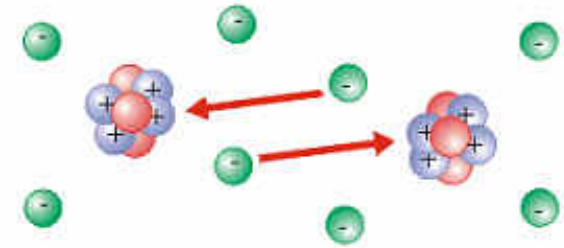
Why Do Properties Change?

- Four important ways in which nanoscale materials may differ from macroscale materials
  - Gravitational forces become negligible and electromagnetic forces dominate
  - Quantum mechanics is the model used to describe motion and energy instead of the classical mechanics model
  - Greater surface to volume ratios
  - Random molecular motion becomes more important

Dominance of Electromagnetic Forces

- Because the mass of nanoscale objects is so small, gravity becomes negligible

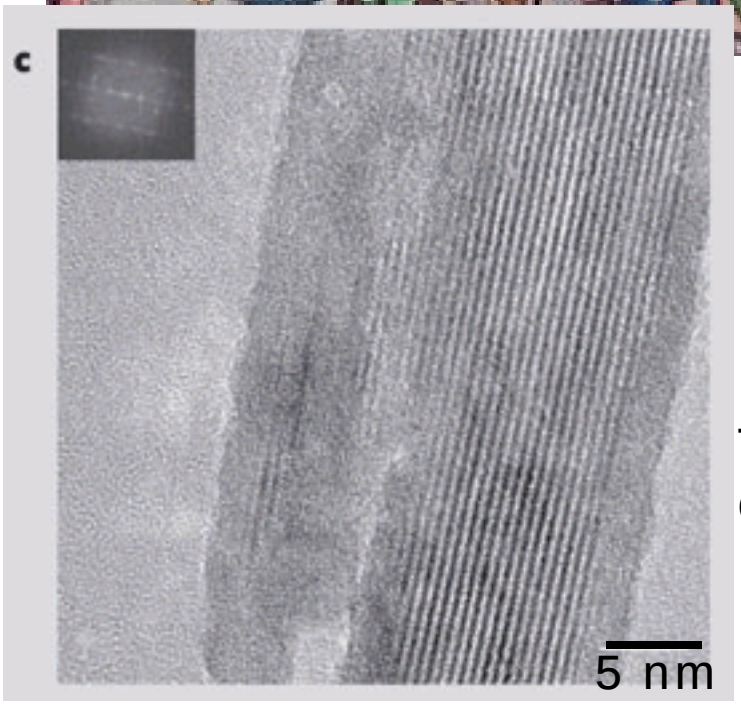




- Gravitational force is a function of **mass** and distance and is weak between (low-mass) nanosized particles
- Electromagnetic force is a function of **charge** and distance, is not affected by mass, so it can be very strong even when we have nanosized particles
- The electromagnetic force between two protons is 10^{36} times stronger than the gravitational force!

Are Nanomaterials really new?

During the middle ages, the people who fought crusaders with swords of Damascus steel had a high-tech edge - carbon nanotubes and nanowires in their sabres. Damascus sabres were forged from Indian steel called *wootz*. It is likely that the sophisticated process of forging and annealing the steel formed the nanotubes and the nanowires, and could explain the amazing mechanical properties of the swords



TEM image of cementite nanowires

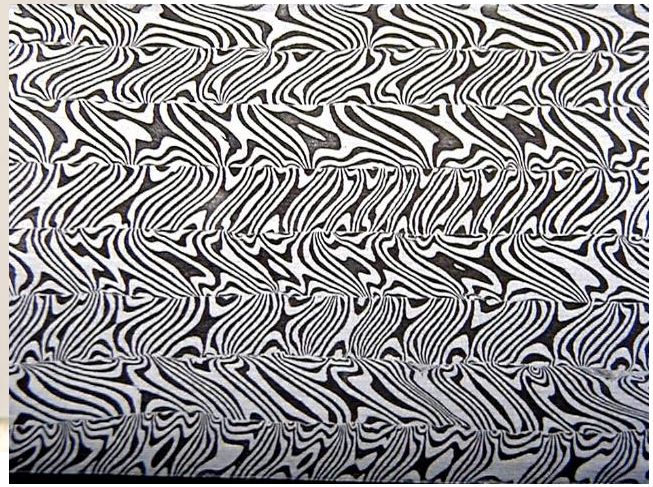
Nature, vol 444, p 286

Damascus Steel

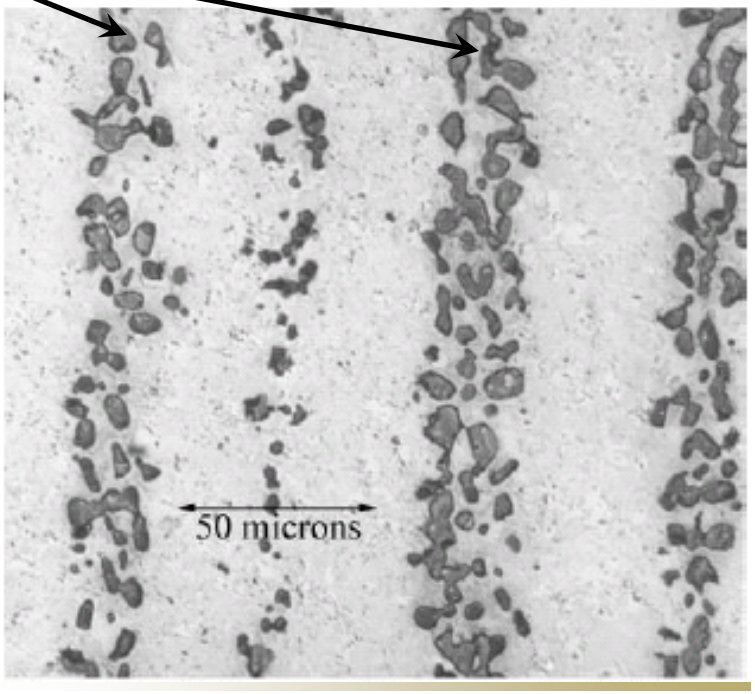
Wikipedia.org

Damascus blade showing the Damascene surface pattern containing a combined Mohammed ladder and rose pattern

http://www.tms.org/pubs/journals/JOM/9809/Verhoeven-9809.html



Cementite bands



Are Nanomaterials really new?

http://www.thebritishmuseum.ac.uk/science/lycuguscup/sn-lycugus-p1.html

- Lycurgus cup,4th century AD (now at the British Museum, London).

- Depicts King Lycurgus of Thrace being dragged to the underworld

- When illuminated from outside, it appears green. However, when illuminated from within the cup, it glows red.

http://www.physics.usyd.edu.au/pdfs/current/2005projects/LaurieField.pdf

Are Nanomaterials really new?

http://edoc.ub.uni-muenchen.de/2367/1/Soennichsen_Carsten.pdf

Lycurgus cup,4th century AD (now at the British Museum,London).The colors originates from metal nanoparticles embedded in the glass. At places, where light is transmitted through the glass it appears red, at places where light is scattered near the surface, the scattered light appears greenish.

http://edoc.ub.uni-muenchen.de/2367/1/Soennichsen_Carsten.pdf

Suspensions of spherical gold particles with various diameters (150, 100, 80, 60, 40, 20 nm from left to right) in water. The difference in colors is due to different scattering and absorption behaviour of small and large gold particles.

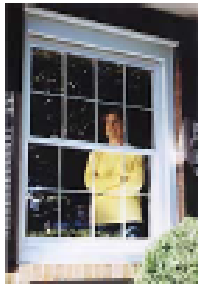
Nanomaterials Now

Display Screens
Motorola (NTs)

Cars - Humvee
GM (Nanocomposites)

Nano SilverSeal Refrigerator
Samsung (nanoparticle-coated)

Tennis Rackets
Wilson (C fibers)



PPG
SunClean self-cleaning windows
(Photocatalytic coating)

Nano-Care fabric

wrinkle-resistant, stain-repellent

(Eddie Bauer, Lee, Old Navy, Tiger Woods, Bass, Nike)

LAUFEN
bathrooms
Laufen Mylife floor-standing bidet with Wondergliss (Superhydrophobic coating)

Clay nanocomposite barrier coating

Superhydrophobic nanoscale coating applied to fabric

This slide is adapted from the presentation posted at www.toxicology.org/isot/rc/allegheny/Savage2006SOTRegional.ppt

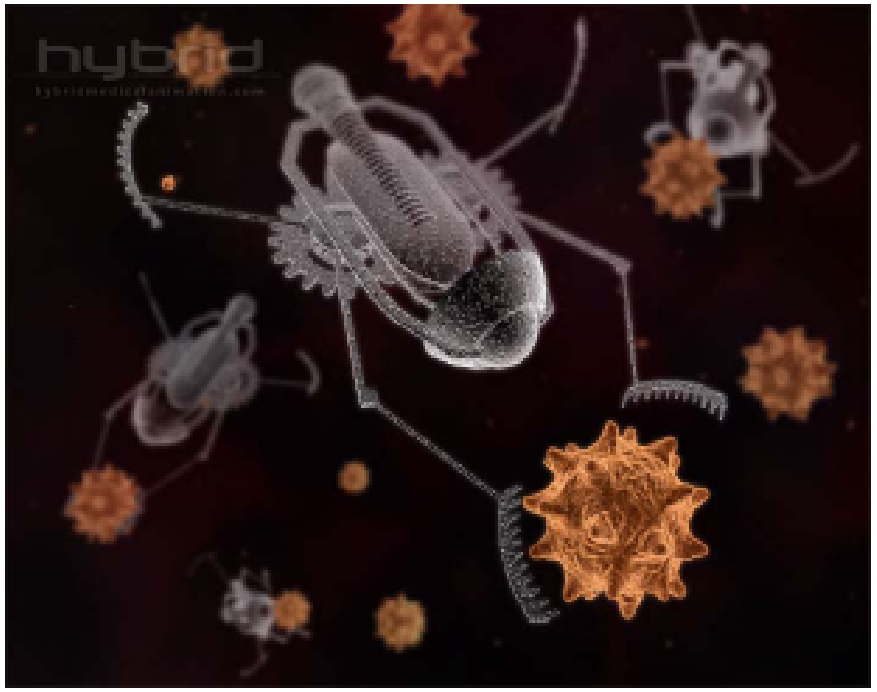
Nanotechnology in the Future?

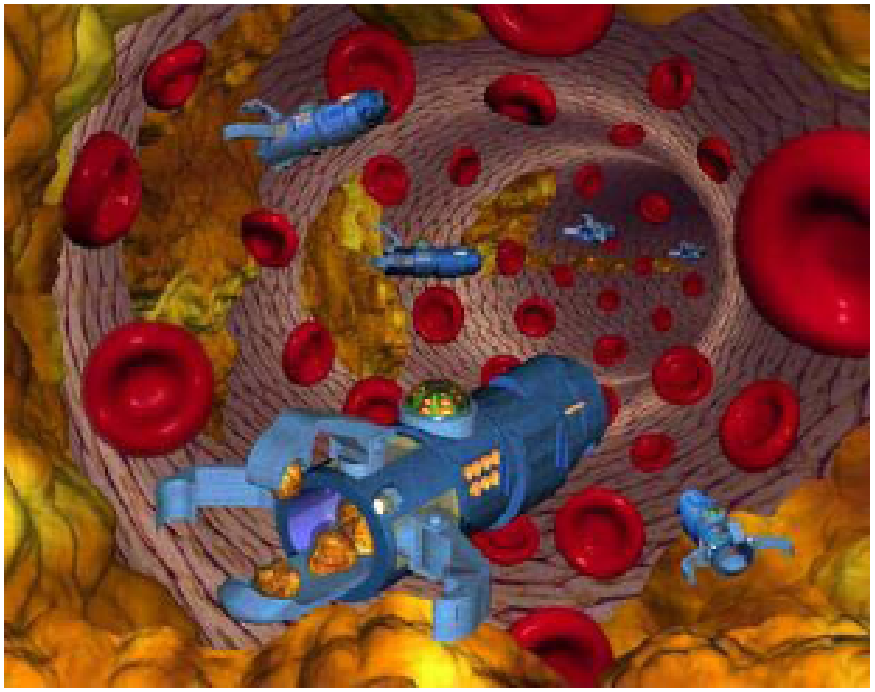
Tiny machines in your body curing cancer?

http://smalley.rice.edu/emplibrary/SA285-76.pdf

This slide is adapted from the lecture notes posted at http://www.physics.unc.edu/~falvo/Phys006D_Fall07/

Injectable Nanobots?





This slide is adapted from the lecture notes posted at http://www.nanohub.org/courses/nanomaterials

The Space Elevator?

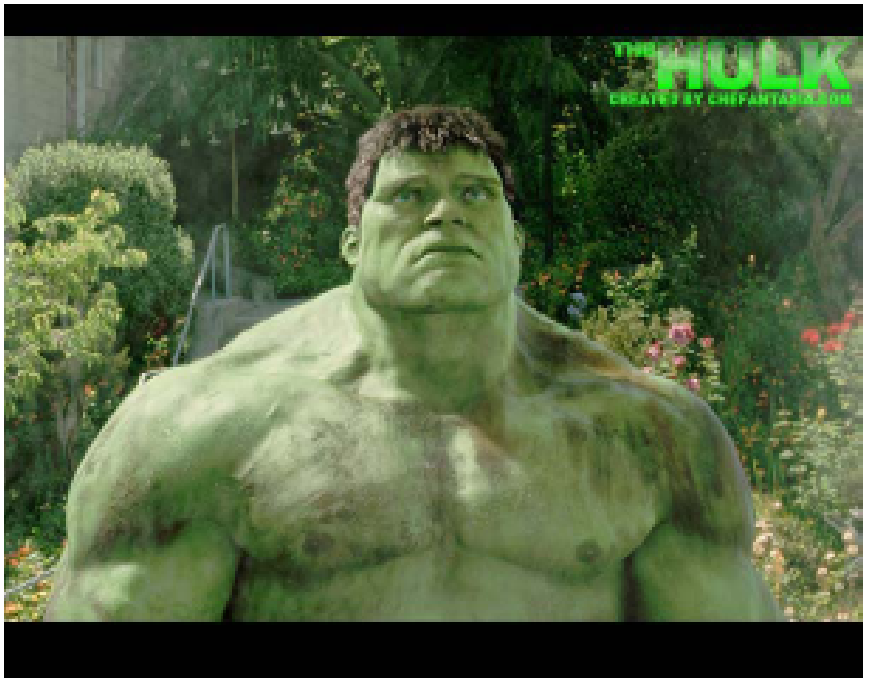
Ultra high strength materials allow tower to be built into space !(?)

Check out www.liftport.com and http://www.spaceelevator.com/docs/General.SE.presentation.ppt

This slide is adapted from the lecture notes posted at http://www.physics.unc.edu/~falvo/Phys006D_Fall07/

Nanotechnology according to Hollywood

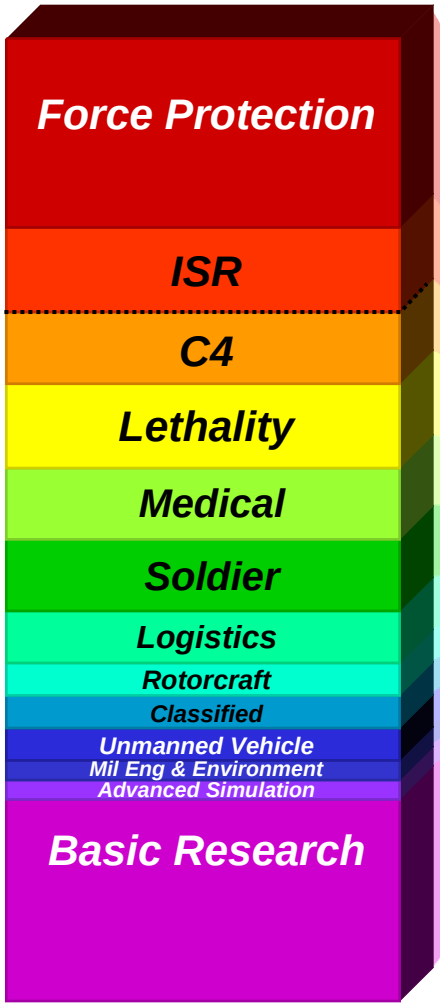
Nanotechnology Scientist:
Willem Dafoe in Spiderman



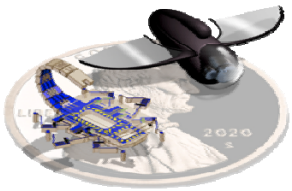
Created by Nanotechnology:
The Hulk

This slide is adapted from the lecture notes posted at
http://www.nanohub.org/courses/nanomaterials

Nanotechnology will have profound impact on the future of the Army



Protection



Robotics

Nanomaterials

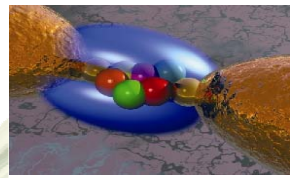
Bio-inspired

Multi-functional

Self Assembly

Characterization

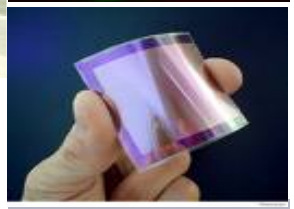
Energetics



Electronics

Adaptive

Photonics



Power

Lethality

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

U.S. Army Research Laboratory

Mission

Provide innovative science, technology, and analyses to enable full spectrum operations.

Vision

America's Laboratory for the Army: Many Minds, Many Capabilities, Single Focus on the Soldier

Acknowledged Scientific, Technical and Analytical Excellence

Recognized bridge between the Nation's Scientific and Technical Communities and the Army

Leader in providing innovative solutions for the current and future Army

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Army S&T Performing Organizations

Personnel

G-1

Medical

Medical Command
MEDCOM

Materiel

Army Materiel Command
AMC

Infrastructure/ Environmental

U.S. Army Corps of Engineers
USACE

Strategic Defense

Strategic Missile Defense Command
SMDC

Research, Development and Engineering Command
RDECOM

- Army Materiel Systems Analysis Agency — AMSAA
- Aviation and Missile RDEC — AMRDEC
- Armament RDEC — ARDEC
- Communications and Electronics RDEC — CERDEC
- Edgewood Chem-Bio Center — ECBC
- Natick Soldier Center — NSC
- Simulation & Training Technology Center — STTC
- Tank-Automotive RDEC — TARDEC

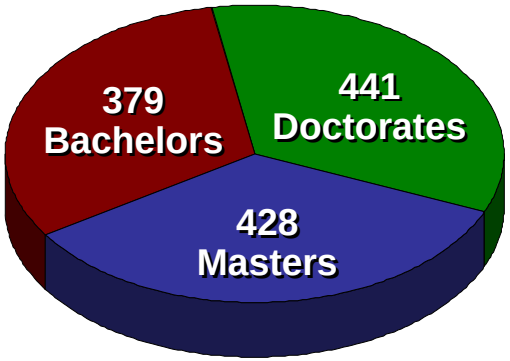
ARL provides underpinning Science, Technology, and Analysis to the Army

Army Research Office

- Vehicle Technology
- Human Research & Engineering
- Survivability/ Lethality Analysis
- Computational & Information Sciences
- Sensors & Electron Devices
- Weapons & Materials Research
- Mathematical & Information Sciences
- Physical Sciences
- Engineering Sciences

Civilian Personnel Profile

1248 S&E Workforce



1480 Technical Staff

277	Electrical/Electronics Engineers
200	Physicists/Physical Scientists
171	Mechanical Engineers
90	General/Industrial Engineers
43	Aerospace Engineers
72	Materials Engrs./Metallurgists
61	Engineering Psychologists
77	Chemical Engineers/Chemists
6	Biologists
52	Operations Research Analysts
126	Computer Scientists/Engineer
35	Mathematicians/Statisticians
20	Meteorologists
5	Ceramic Engineers
13	Other E&S
232	E&S Technicians

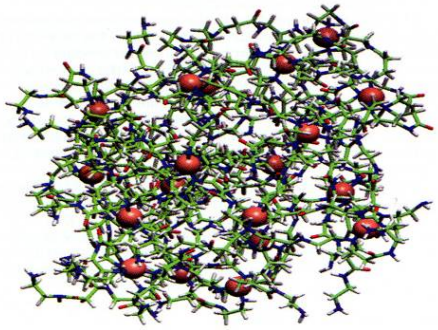
As of 9/30/2007

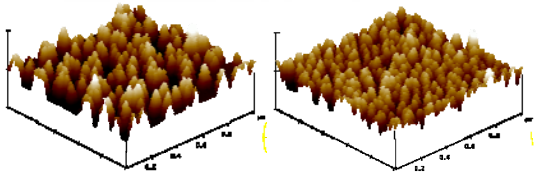
What's the Army S&T Community Doing?

	Estimated FY07%
* **NANOELECTRONICS/NANOPHOTONICS/NANOMAGNETICS-**	
Network Centric Warfare	
Information Dominance and Quantum Computing	**~37%**
Sensors and detection technology	
Displays	
Nanotechnology for power and energy	
Digital signal processing and communications	
Bioelectronics	
* **NANOMATERIALS BY DESIGN**	**~38%**
Structural Nanomaterials	
Polymer Nanomaterials	
Ballistic Nanomaterials	
Nano-energetic Materials	
NanoMaterials Processing and Assembly	
Stimuli Responsive Nano Materials	
Nanoengineered Functional Materials	
Bio-inspired nanomaterials	
* **BIONANOTECHNOLOGY**	**~25%**

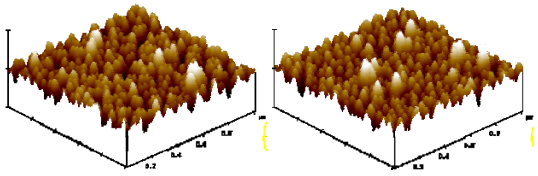
Sampling of Army Research on NanoEngineered Materials

- The Institute for Soldier Nanotechnologies
- Organic and Polymeric Nanomaterials
  - ✓ Directed Assembly
  - ✓ Coatings
  - ✓ Resins for Composites
  - ✓ Nanoscale modification of fibers and fiber-matrix interphase
  - ✓ Transparent nanocomposites for armor applications
- Inorganic Nanomaterials
  - ✓ Nanostructured ceramics
  - ✓ Trimodal aluminum alloys
  - ✓ Nanograined W for penetrators
  - ✓ BAM composites for penetrators

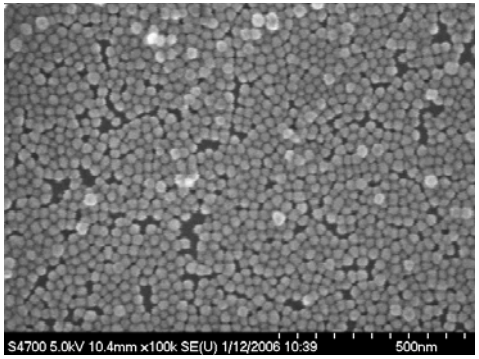




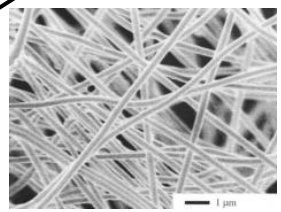
(a) (b)



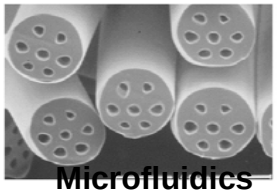
(c) (d)



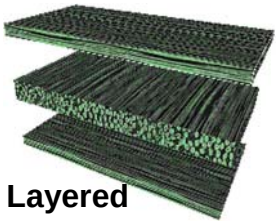
Multifunctional Adaptive-Active Nanostructured Fibers and Materials



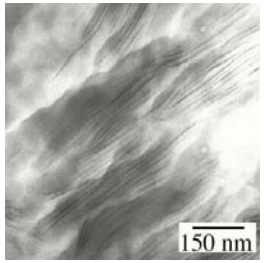
Nanofibers



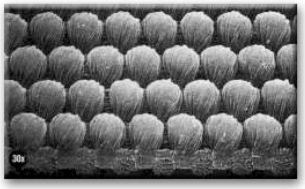
Microfluidics



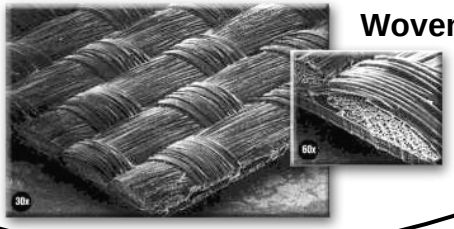
Layered Nanostructures



Nanocomposites



Nanostructures



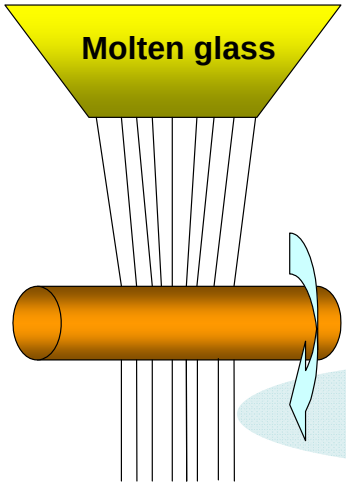
Woven-Materials

Layers of Multifunctional Nanomaterials

Increased Functionality with Decreased Weight & Volume

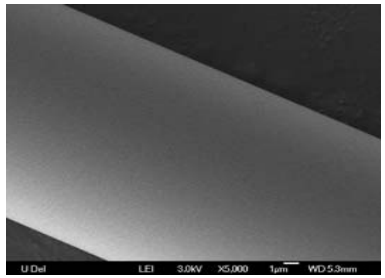
Nanoscale Design for Damage Tolerant Composites

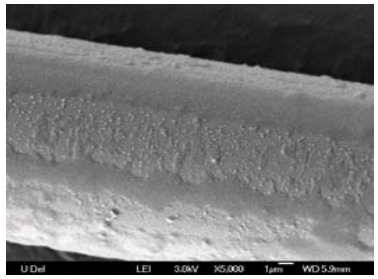
Particles incorporated into sizing package and applied during manufacture

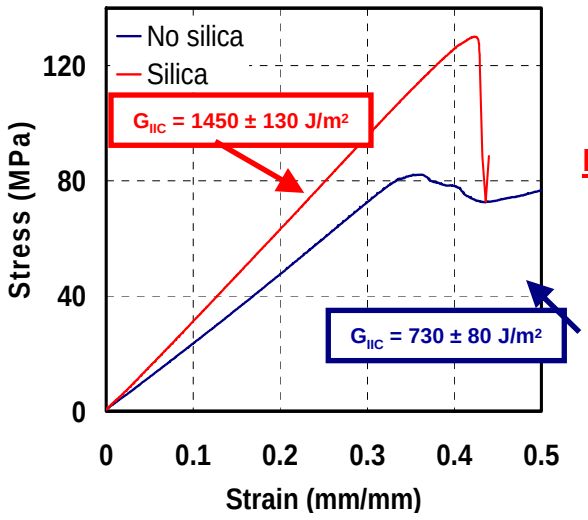


Fabrics used in rate-responsive composite materials with enhanced toughness

Sizings in Pilot-Scale Fiber Manufacturing

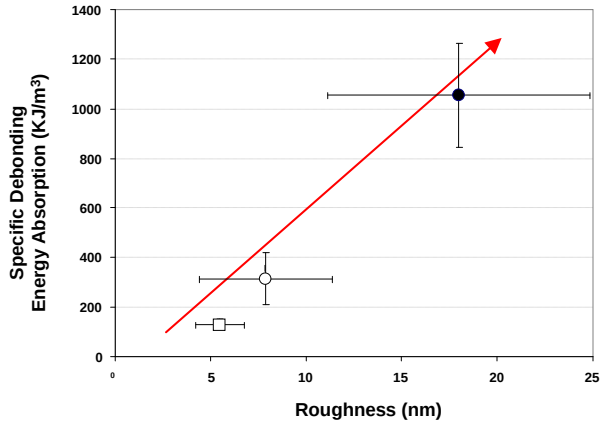




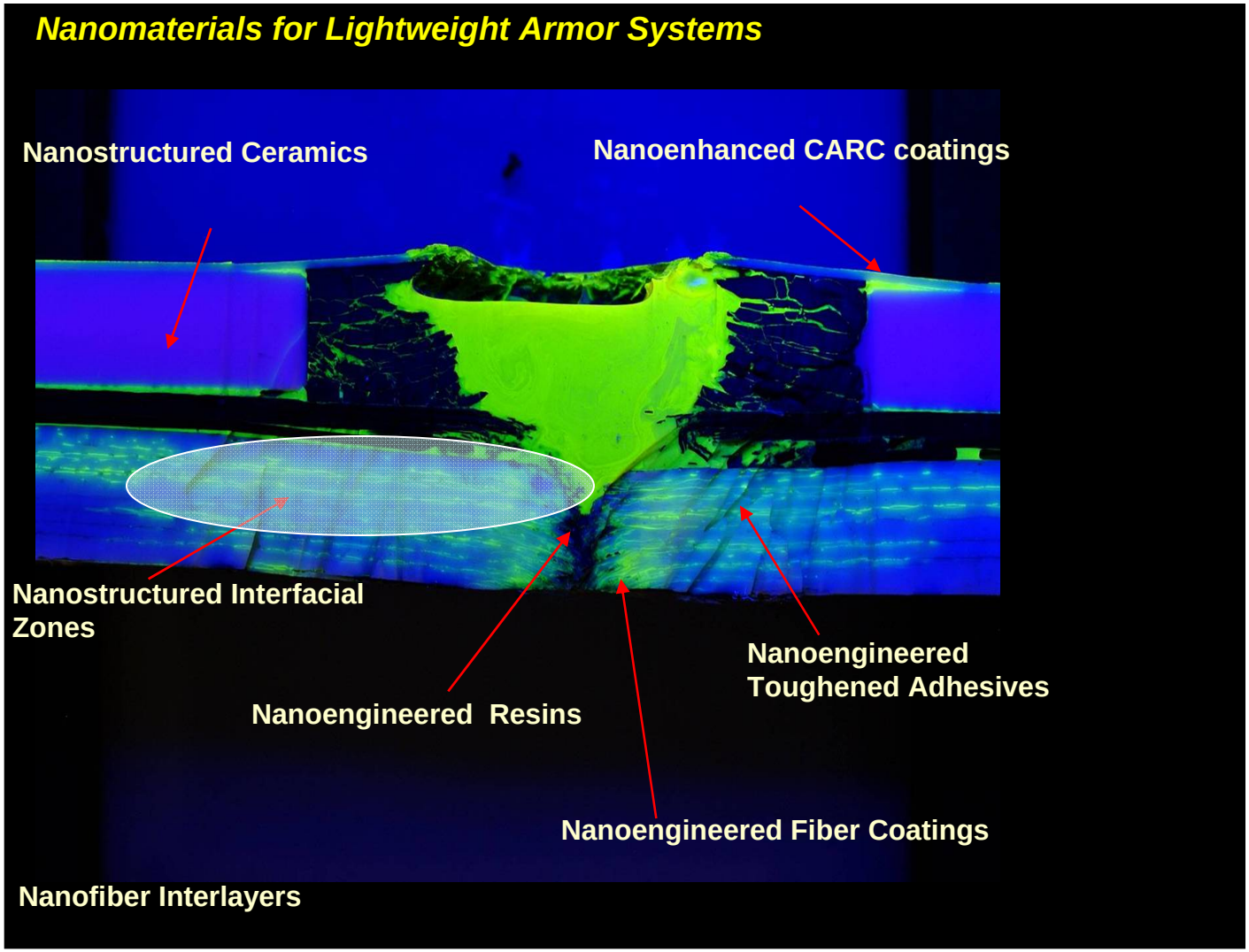


Macro-scale Performance Enhancement

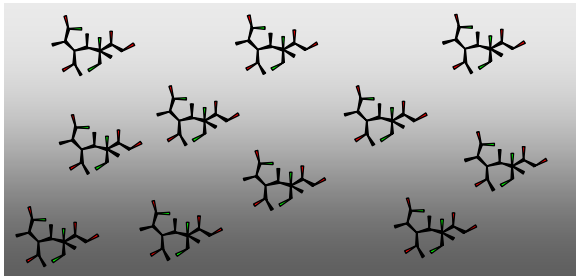
- Improved toughness
- Improved energy absorption
- Minimal impact on cost
- Minimal impact of base fiber



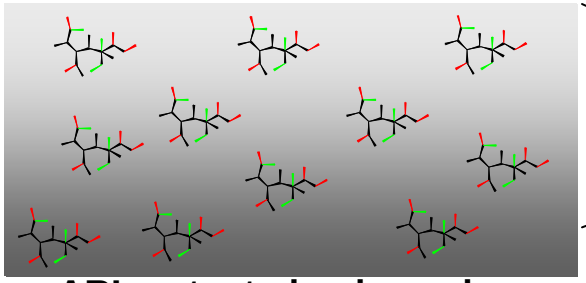
Nanomaterials for Armor Systems



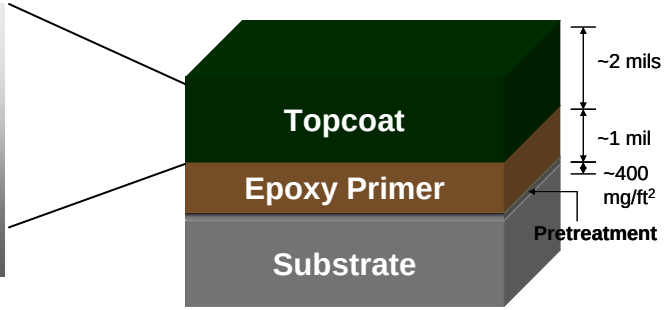
Nano-Engineered Additives for Self Detoxifying Surfaces

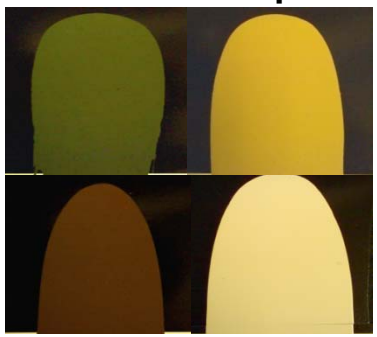


Typical additives

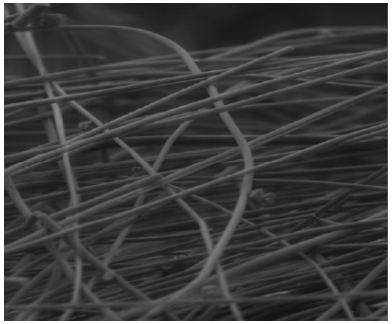


ARL patented universal transport vehicle





Self detoxifying CARC



Activated fibers

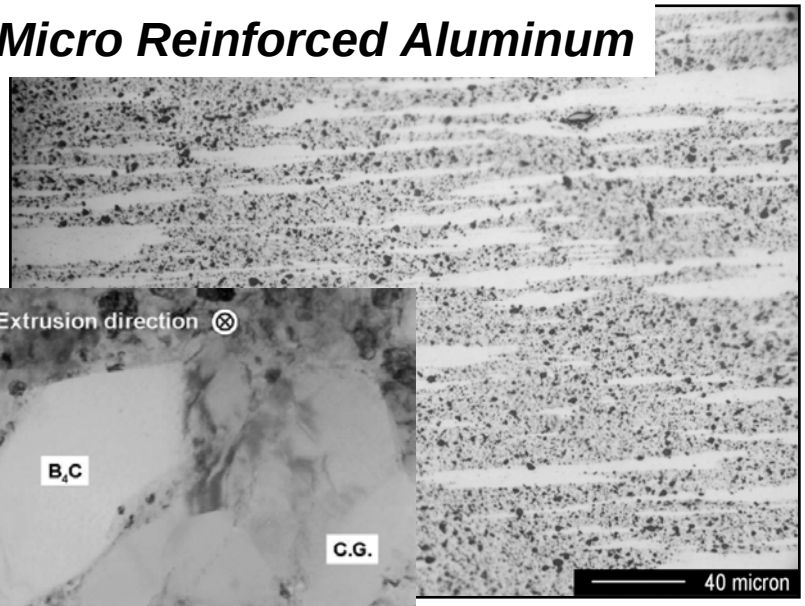
Self-segregating materials address several issues

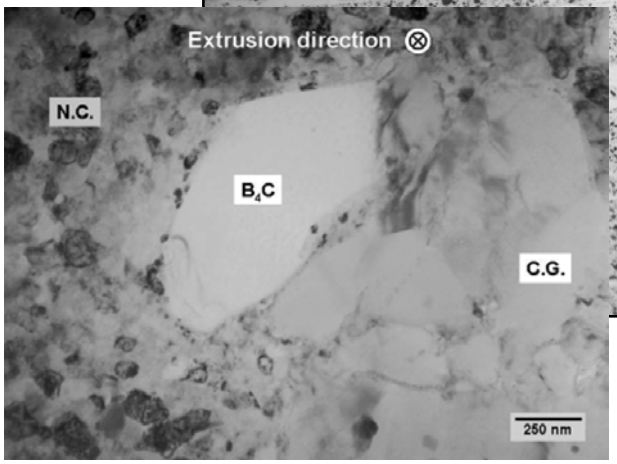
- Decreased additive requirement
- Minimizes mass transport issues
- Minimal impact on base coating

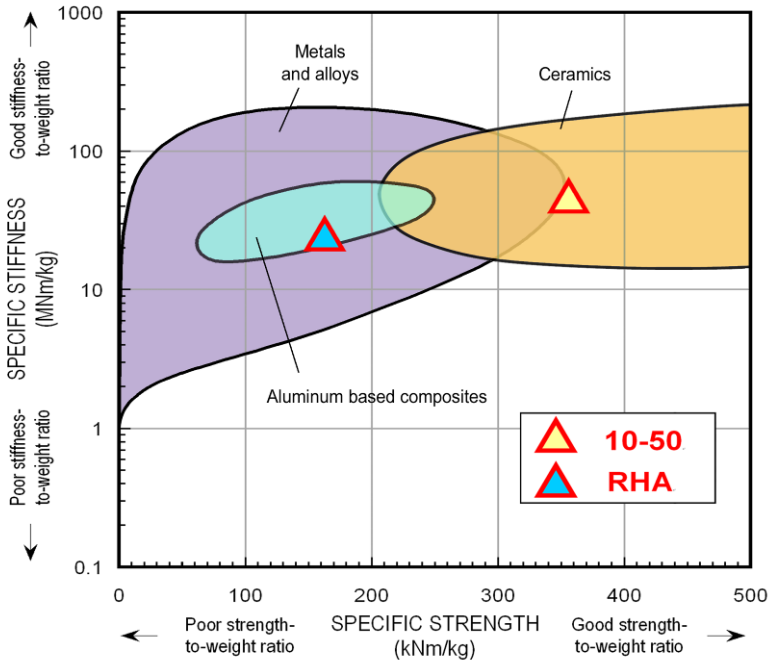
- 99.9999 % reduction of pathogens such as *C. albicans* and MRSA with 1 wt % of additive
- Platform technology – can deliver many reactive moieties to coating surface
- Compatible with many existing coating and fiber systems

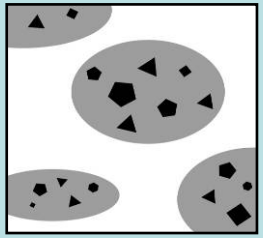
Tri-Modal Aluminum Alloys

Nano-Micro Reinforced Aluminum









- B_4C
- Nanocrystalline Al 5083
- Coarse-Grained Al 5083

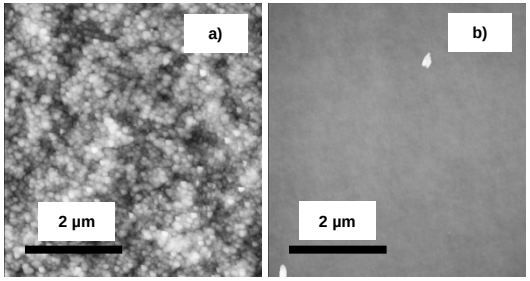
High strength at high strain rates

Nearly the Strength of RHA at One-Third the Weight!

OPTICALLY TRANSPARENT NANOPOROUS GLASS-POLYMER COMPOSITES

	Glass (Starphire)	Vycor-PMMA	PMMA	Vycor
Density (g/cm^3)	2.50	1.81	1.2	1.45
Young's modulus (GPa)	73.1	30	2.5	17
Modulus of Rupture (MPa)	39	57	62	21
Acoustic Impedance (kg/(m^2-s))	14.6	7.8	3.2	4.85

AFM scans suggest more tortuous crack path in filled/unfilled Vycor compared to conventional glass

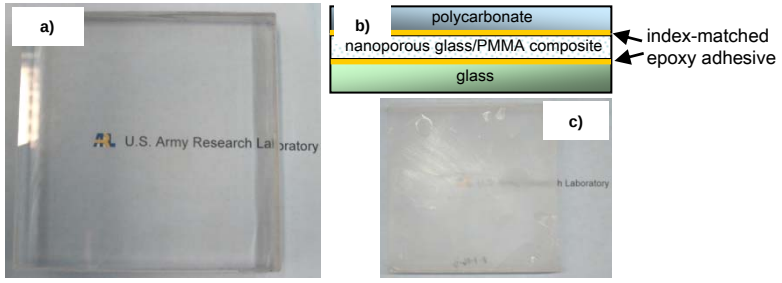


AFM topology scans of filled Vycor (a) and Starphire glass (b) cleaved surfaces. The height contrast scale in both images is 200 nm.

Filled Vycor with optical polish 95% transmittance, 0.3% haze, 100% clarity

Filled Vycor plate with optical polish in center region exhibits excellent optical properties

Transparent laminate constructed with polycarbonate and glass with nanocomposite interlayer; 86% transmittance, 4% haze, 94% clarity



(a) Transparent laminate with filled Vycor interlayer (b) schematic of laminate (c) rough-ground filled Vycor before incorporating into laminate with index-matched epoxy

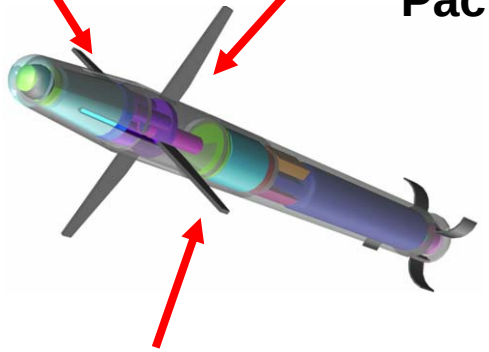
- **Transparent glass-polymer nanocomposite is possible through infiltration and careful polymerization of low viscosity monomer (MMA) in nanoporous glass.**
- **Polished material is highly transparent with high clarity and low haze**
- **Filling pores with polymer increases failure strength of Vycor by greater than 250%**
- **Manufacturing process has been scaled to accommodate 16"x16" sheets**

Notional Applications for Munitions

Nanotechnology For Power & Energy

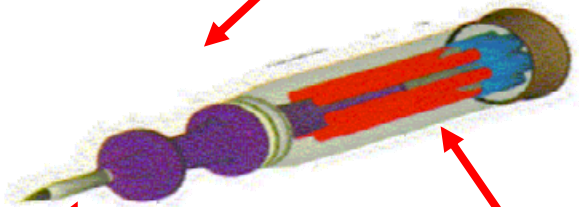
-On-board Nanoelectronics for GNC

-Shock resistant Packaging materials

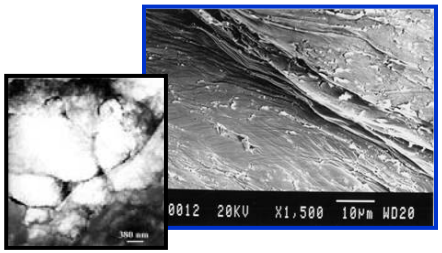


Nanomaterials for Actuators

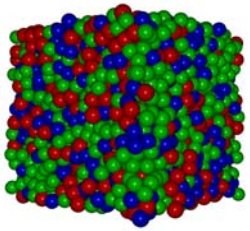
Lightweight Nanocomposites For Packaging Components



Metallic Nanomaterials For Penetrators

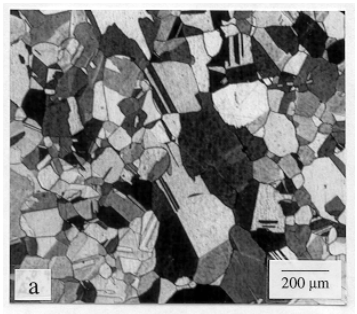


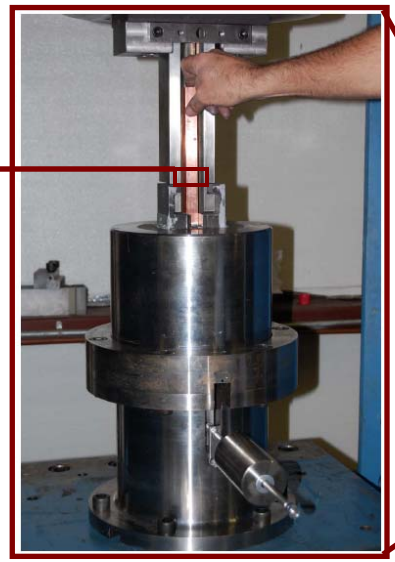
Nanoenergetics

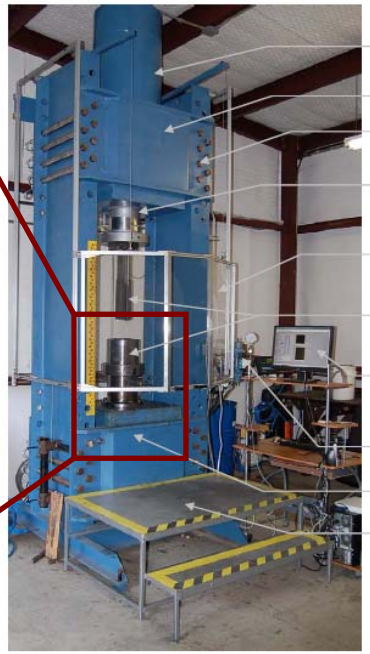


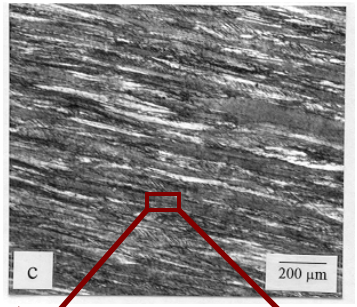
Nanostructured Metals by Equal Channel Angular Extrusion

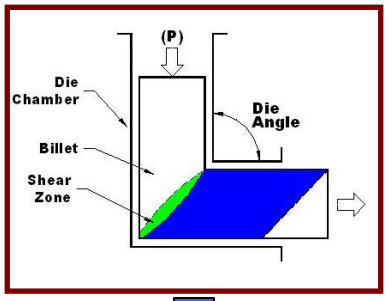
Equal Channel Angular Extrusion (ECAE) is a deformation processing method which yields nanostructured metals in bulk quantities. The resulting nanostructured metals demonstrate concurrently high strength and ductility

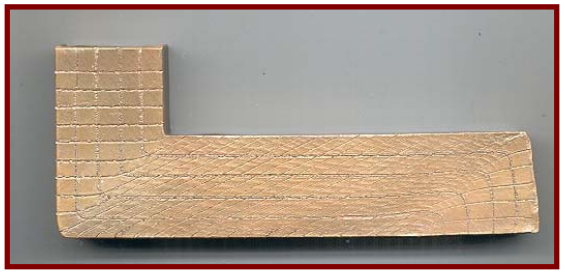


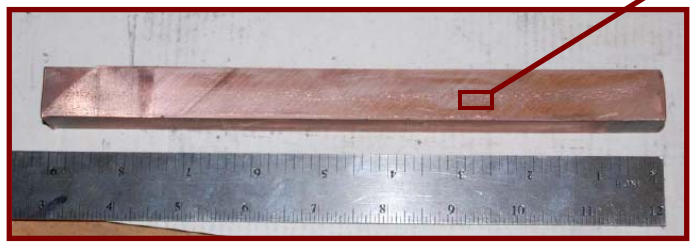


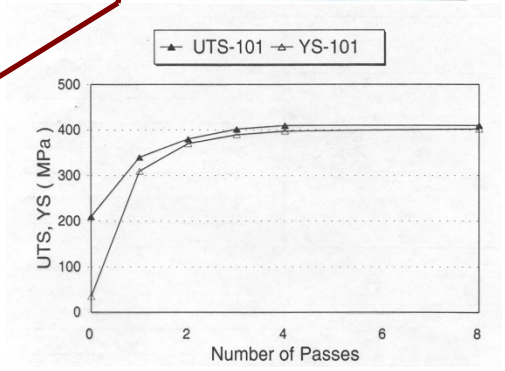












TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Summary

- Nanomaterials with unique properties have long been in existence, are currently used, and will be extensively used in the future
- These unique properties of nanomaterials are being exploited by ARL to provide:
  - **Higher performance materials**
  - **Lighter, stronger structures**
  - **Ultradurability/ultrareliability**
  - **Unprecedented situational awareness**
  - **Affordable precision munitions**