Emerging Materials Technologies That Matter to Manufacturers

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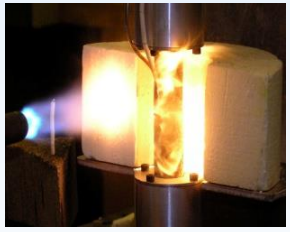
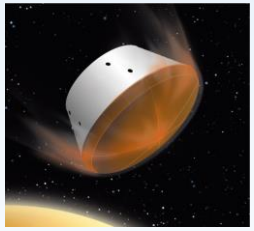
Presented at Manufacturing Matters Conference, Milwaukee, February 26, 2015

Materials Research Driven by Key Aerospace Challenges

Higher temperature and harsh environment for aerospace propulsion and planetary entry

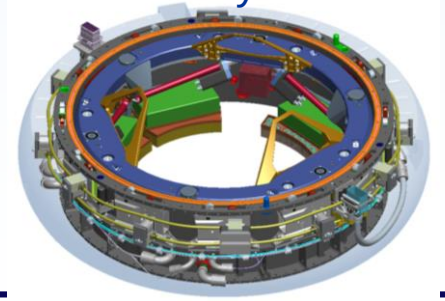


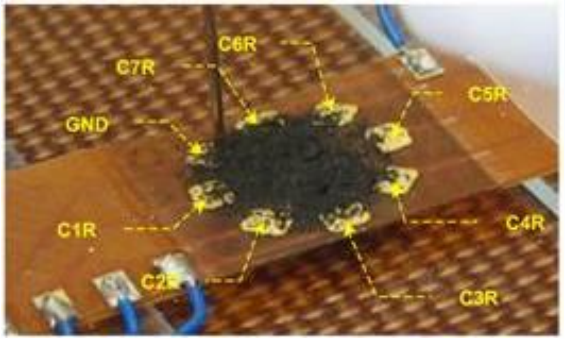


Lightweight requirements for large structures

Low carbon and low emission aircraft

Lightweight and durable mechanical system/mechanisms



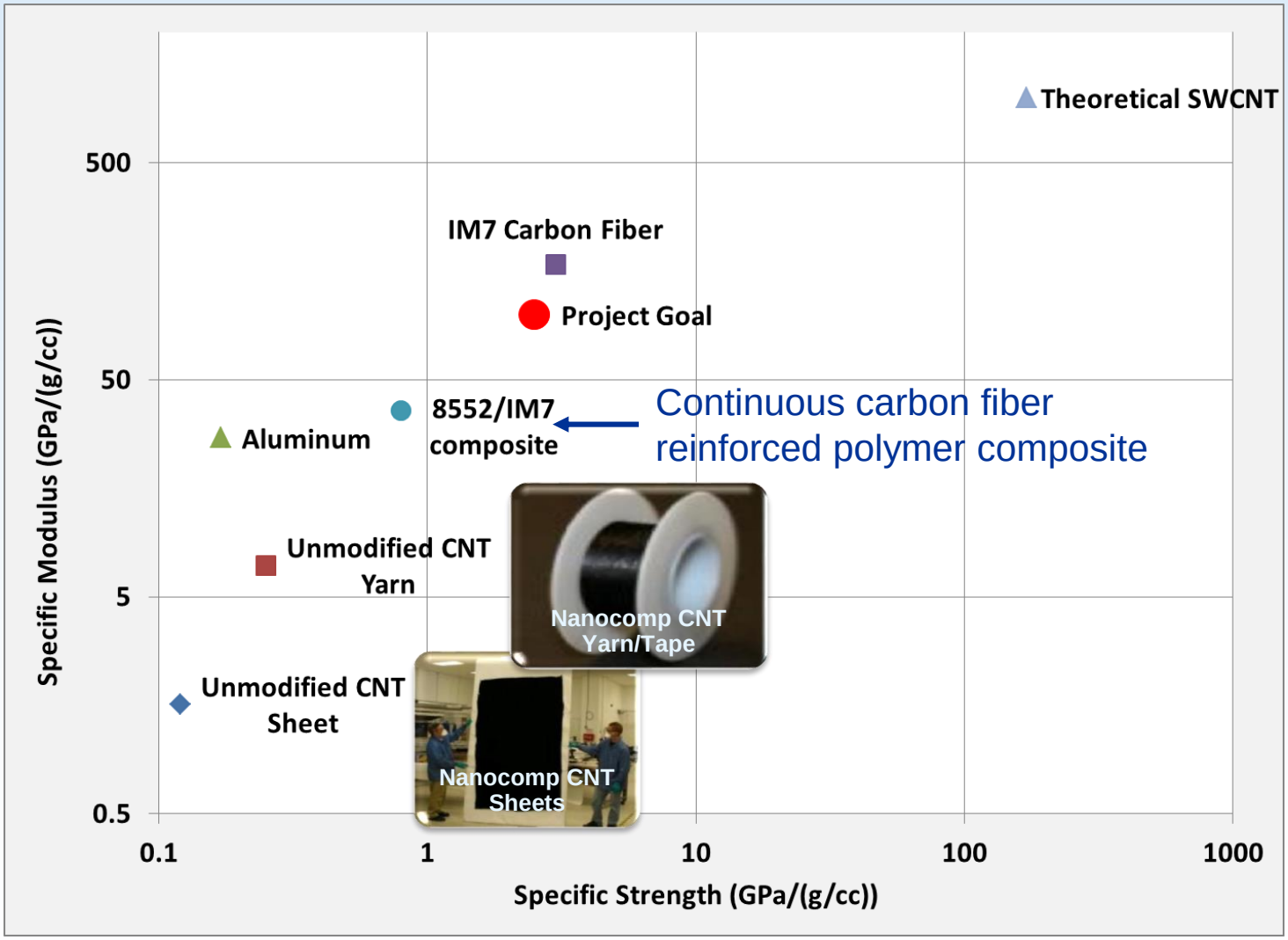


Structural health management

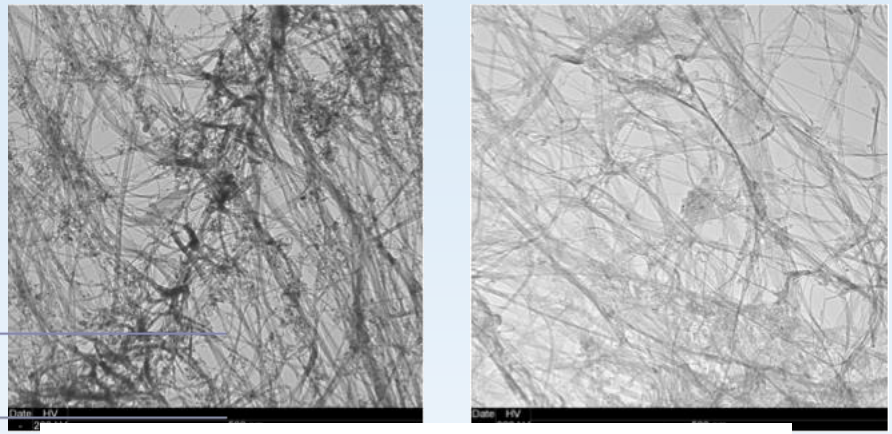
Outline

- **Nanomaterials**
- Smart materials
- Sensor materials
- Multifunctional and hybrid structures/materials
- Additive manufacturing of composite materials
- Material Informatics

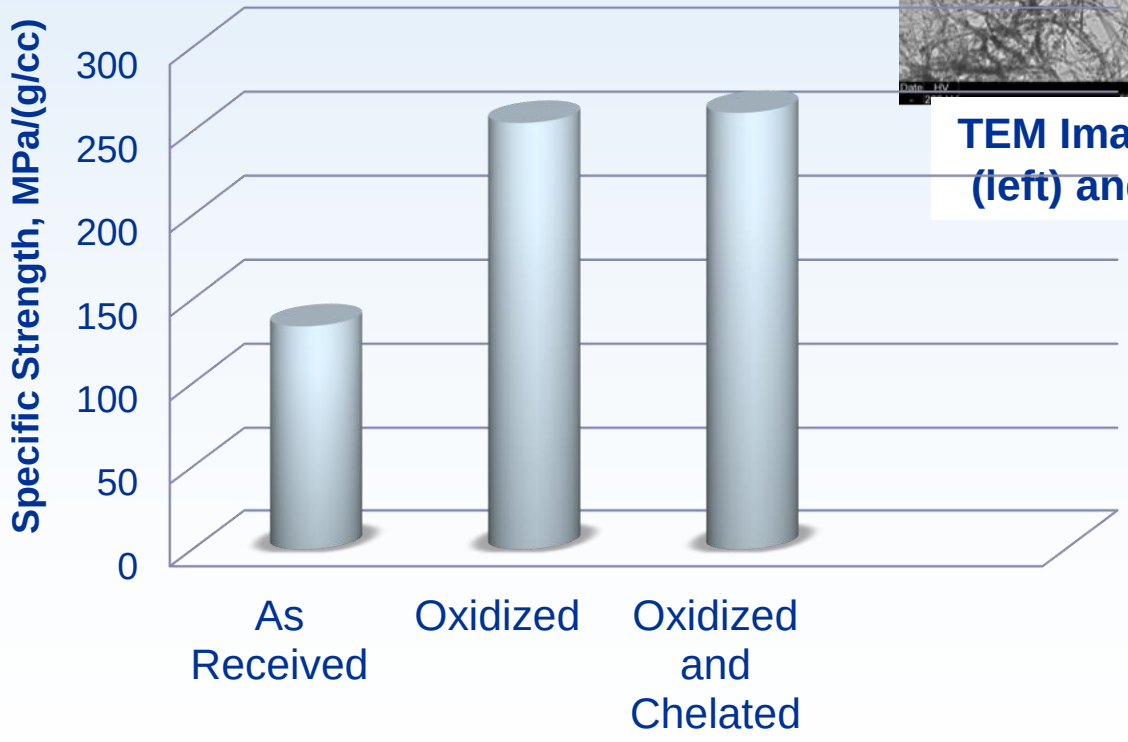
Replacing Carbon Fiber with Carbon Nanotube (CNT) in Polymer Composites Offer Significant Weight eduction



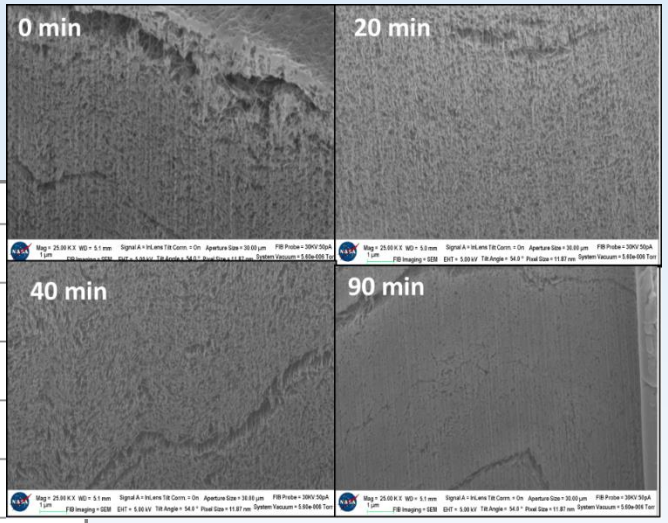
Benign Purification Method Developed for CNT Sheets

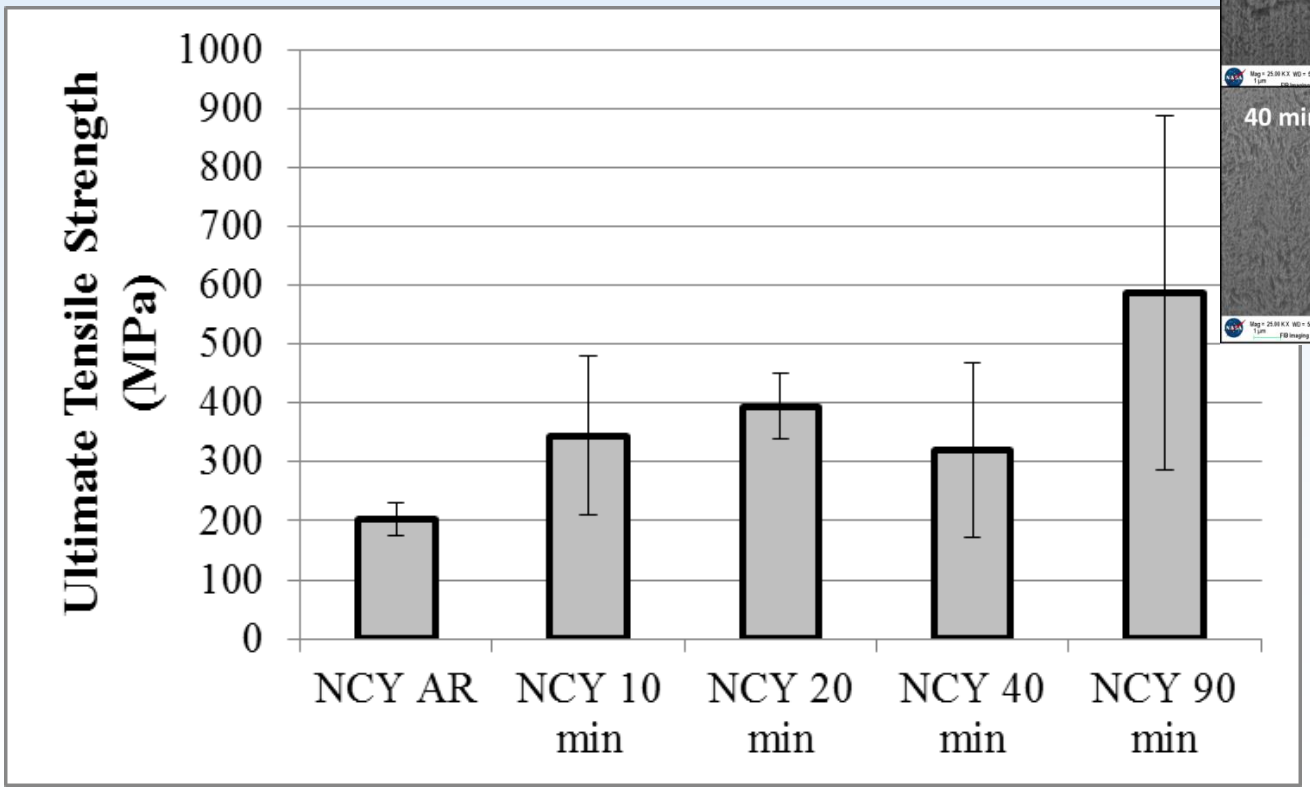


TEM Images of CNT Sheets Before (left) and After (right) Purification

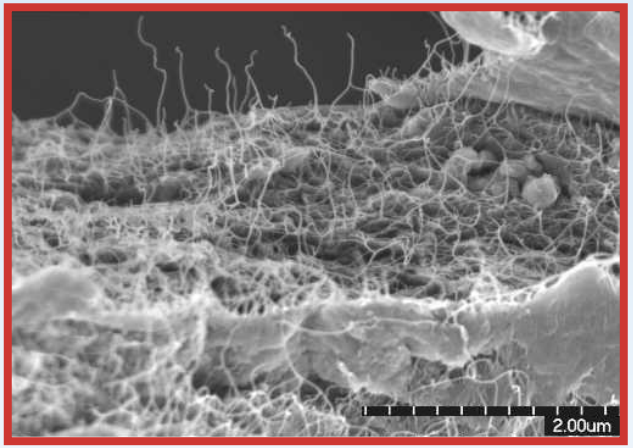


E-Beam Irradiation Improves CNT Yarn Properties

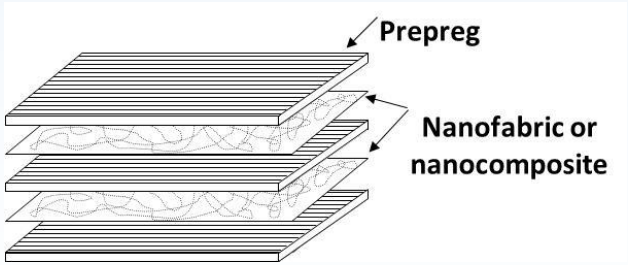




Engineered Properties of Fiber Reinforced Polymer Composites Through Incorporation of Nanotube and Nanofabric



Polymer nanocomposite for structural and thermal management



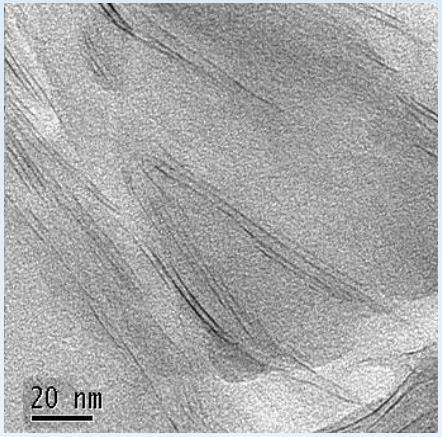
Incorporation of nanofabric in composite

Toughening of composites

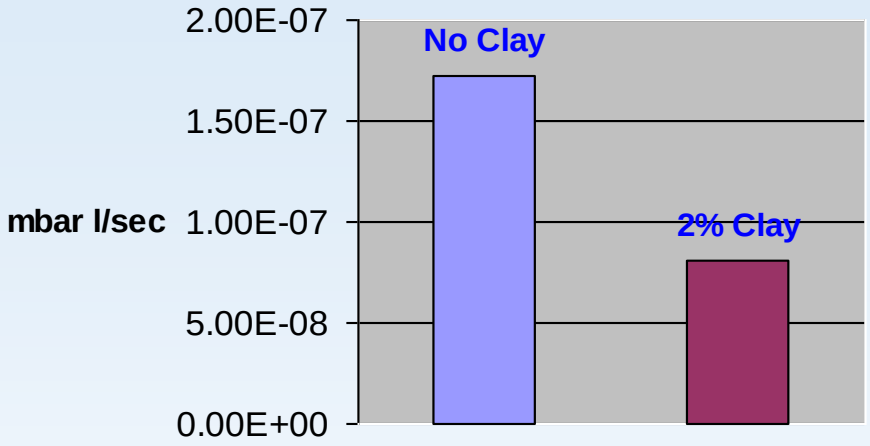
Normal PMC

Nanotoughened PMC

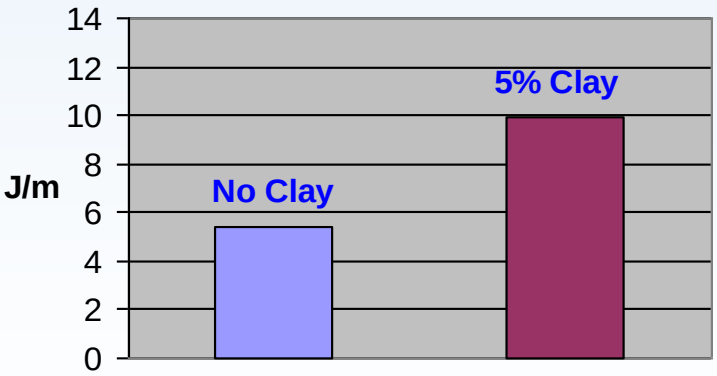
Nanoclay Polymer Composite



TEM of Thermoplastic Polyimide/Clay Nanocomposite



60% Reduction in H_2 Permeability



2X Increase in Notched Izod Toughness

Five-fold lower leak rate in propellant storage tank

Application of Nanoclay Composites in Food Packaging Industry

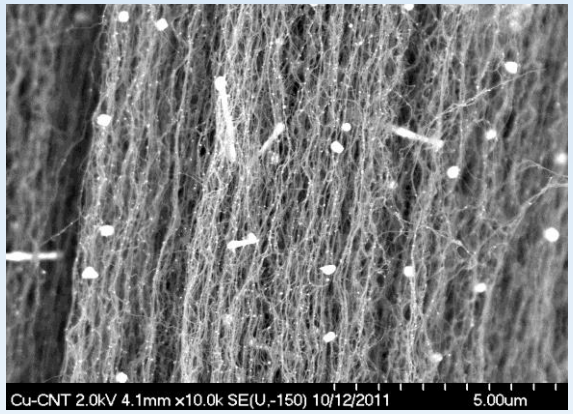
Oxygen sensitive products

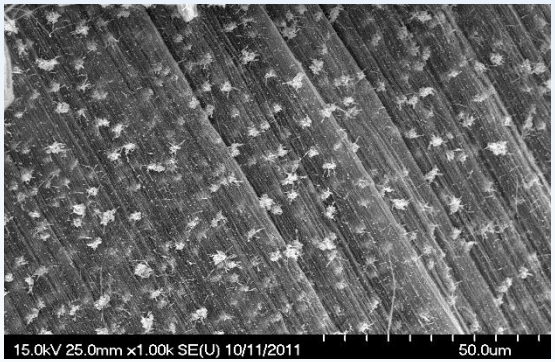
Carbon dioxide sensitive products

Source: Nanocor presentation

Carbon Nanotube Reinforced Copper Composite

- Powder Metallurgy
  - Ball mill MWCNT and Cu alloy powder
  - Consolidate by Field Assisted Sintering Technology (FAST) or extrusion
- Vapor Infiltration
  - Start with highly oriented MWCNT nanoforests
  - CVD or otherwise infiltrate with carbide forming element to form carbide monolayer
  - Infiltrate with copper by CVD or cast with molten copper

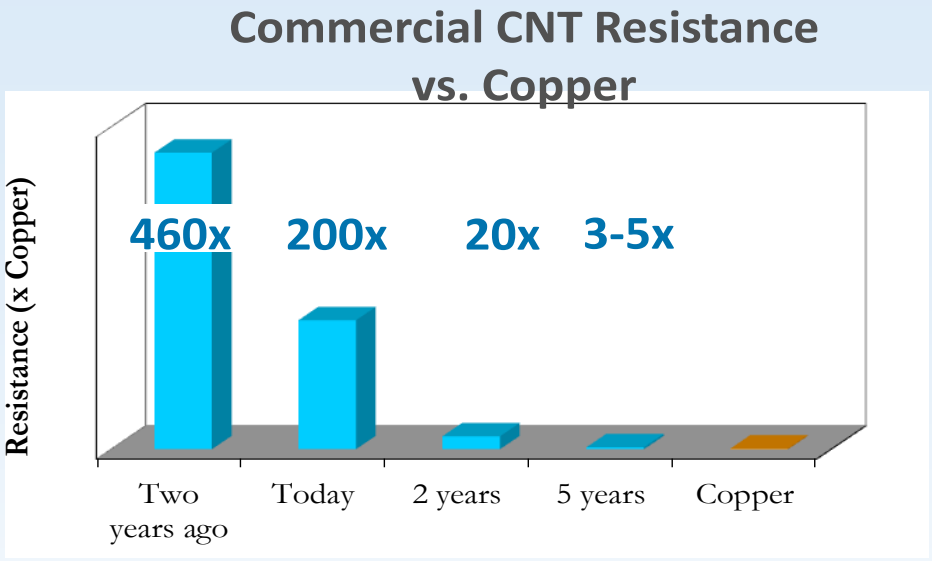


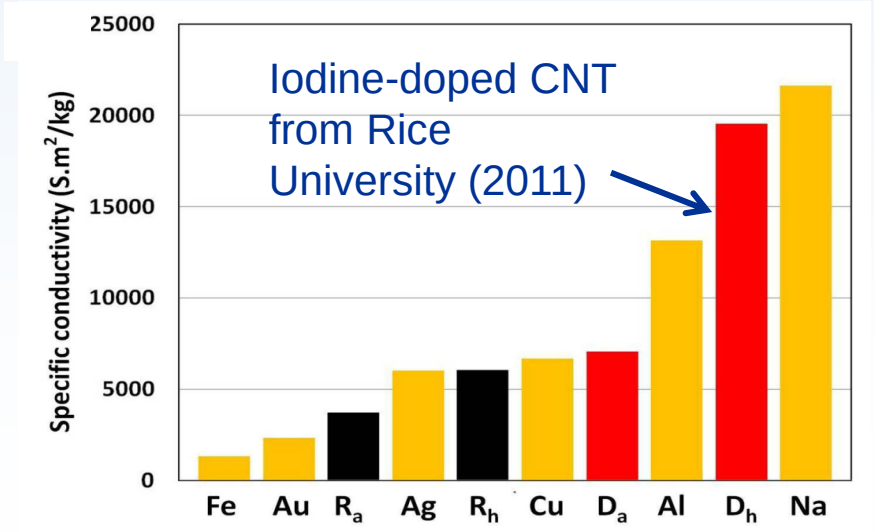


5 v/o multiwalled carbon nanotube (MWCNT)/Cu Nanoforest Composite

CNT reinforced Cu holds promise for increasing thermal conductivity of Cu, but significant manufacturing challenges remain

Electrically Conductive CNT Yarns/Fibers Offer Potential for Significant Current Carrying Capability Than Cu

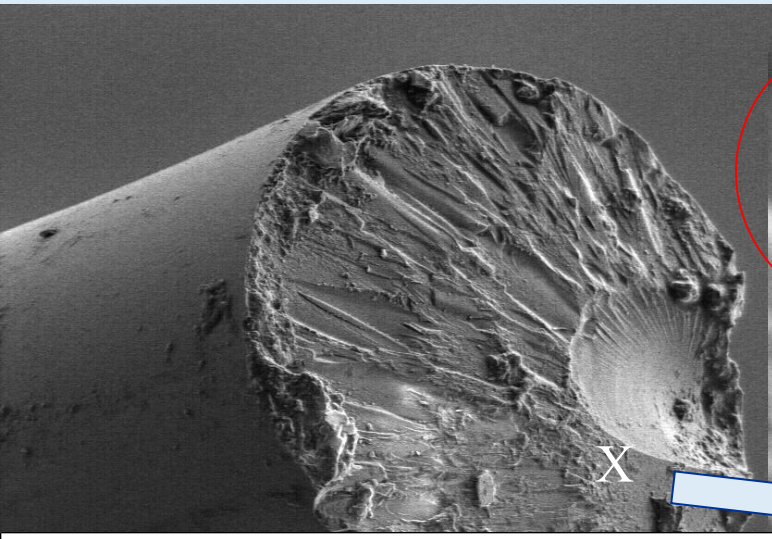


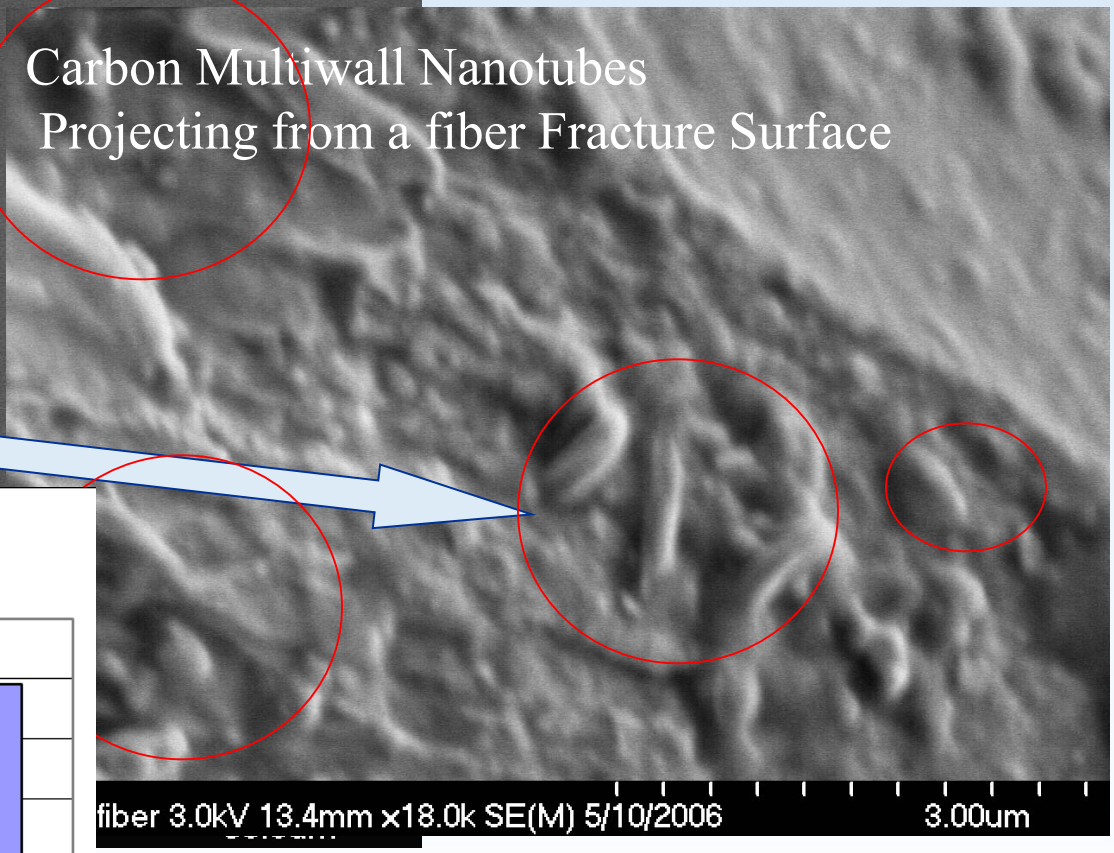


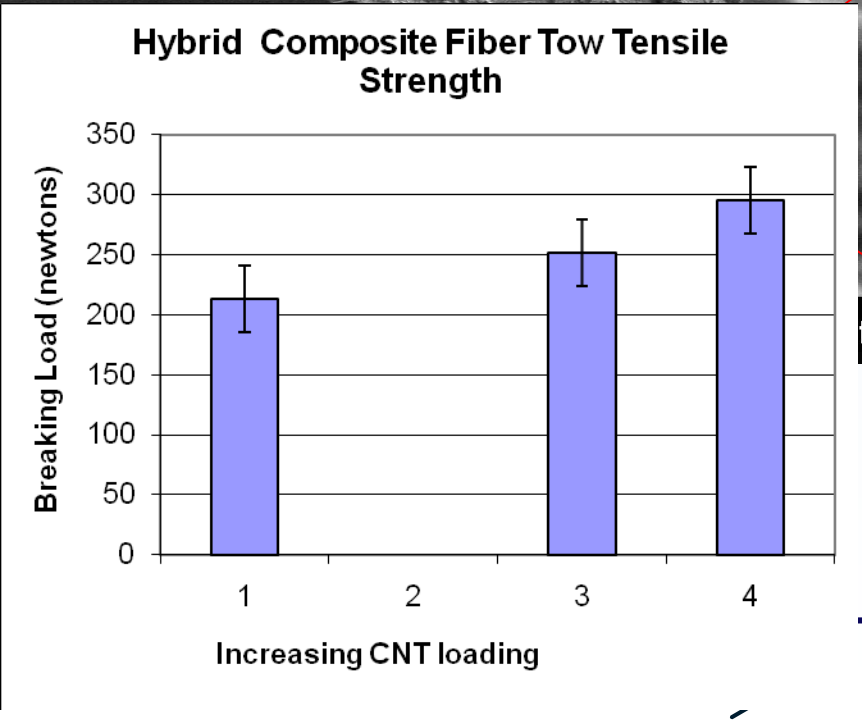
Experimental CNT fibers can carry more current than Cu on a mass basis

Initial application of CNT in data cables, with future application in power cables with improvement in electrical conductivity

CNT/Glass Fiber Composite

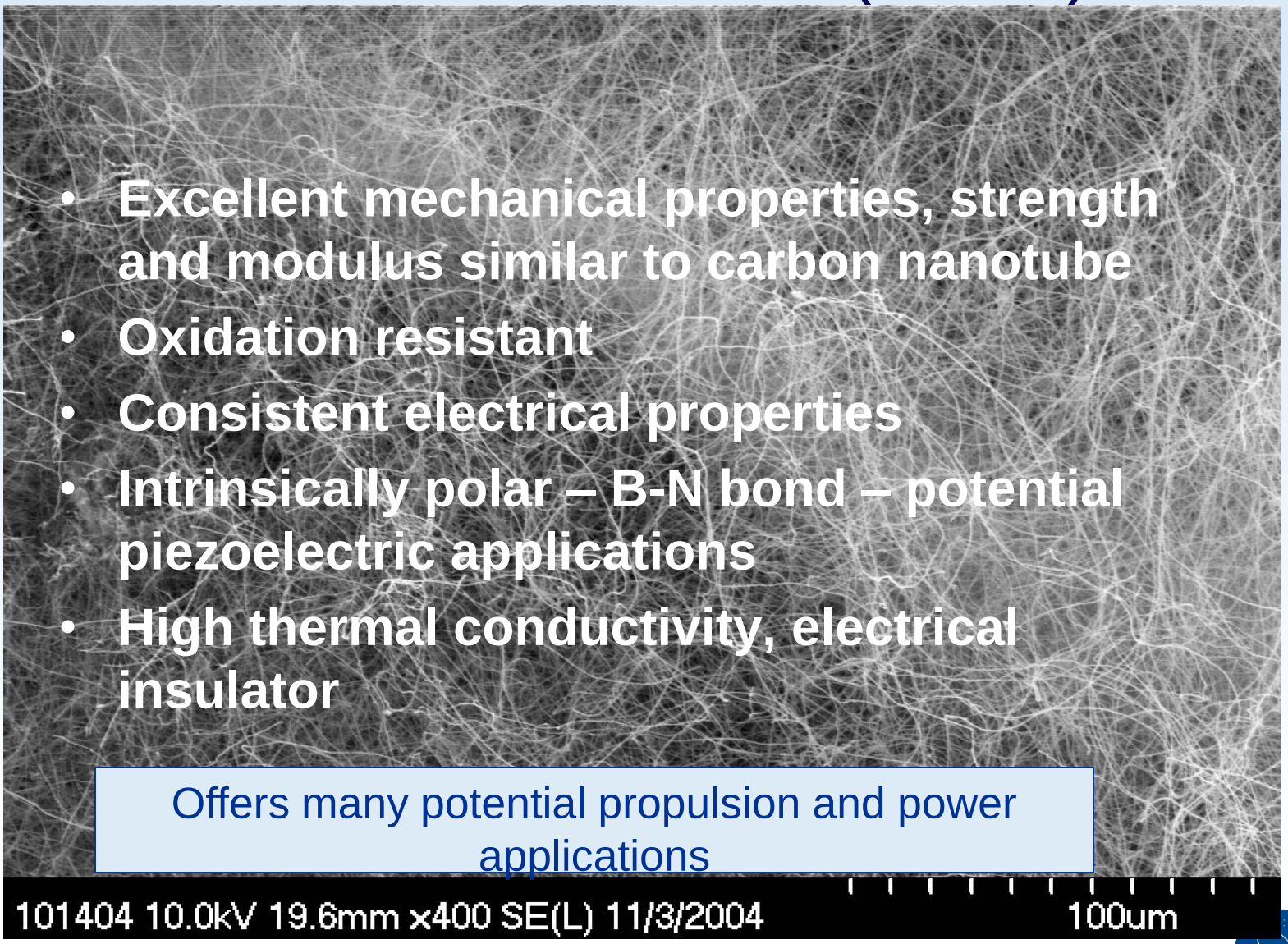






CNT/glass fiber composite offers potential for economical fiber with same strength as carbon fiber

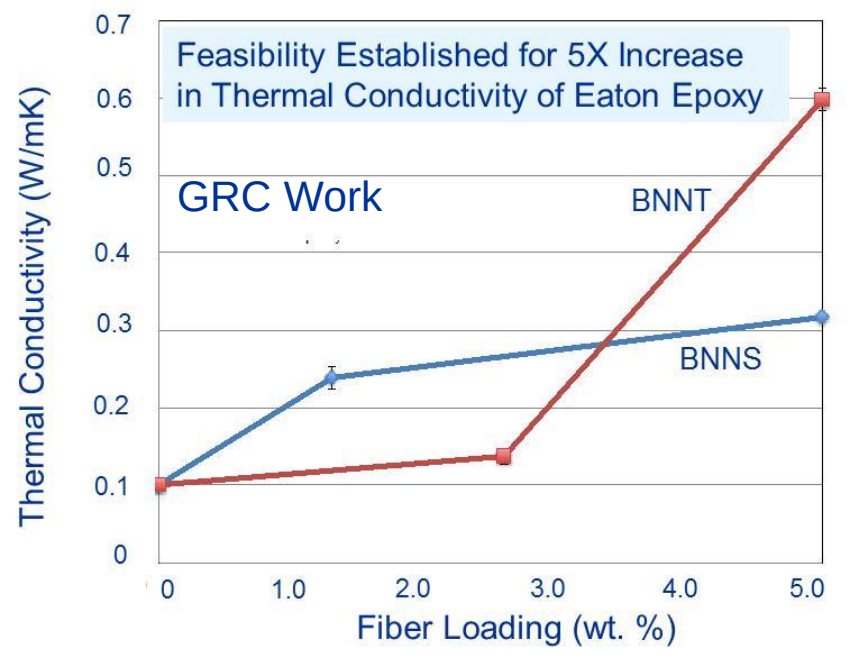
Boron Nitride Nanotube (BNNT)

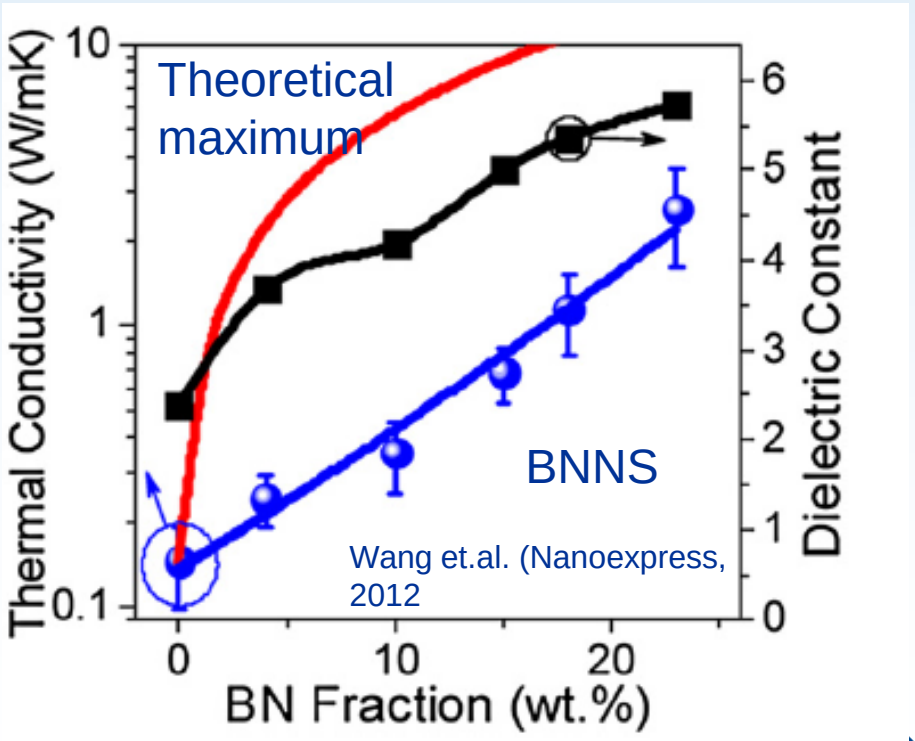


- **Excellent mechanical properties, strength and modulus similar to carbon nanotube**
- **Oxidation resistant**
- **Consistent electrical properties**
- **Intrinsically polar – B-N bond – potential piezoelectric applications**
- **High thermal conductivity, electrical insulator**

Offers many potential propulsion and power applications

Thermal Conductivity Enhancement of Polymer Composites with BNNT and BNNS Additions

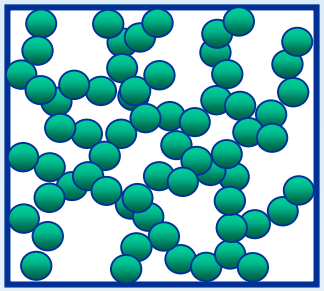




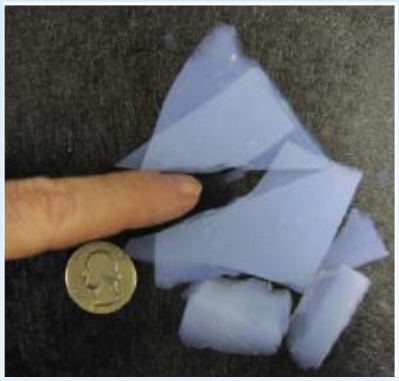
Polymers with electrical insulation and high thermal conductivity required for

- Packaging materials in high speed electronics
- Electrical machines

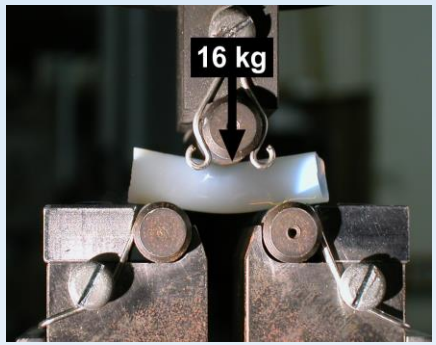
Mechanically Strong Aerogel Thermal Insulation



Highly porous solid, 10-40 nm pore size



…but are extremely fragile and moisture sensitive

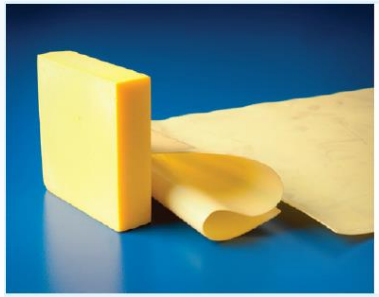


NASA developed strong silica aerogel

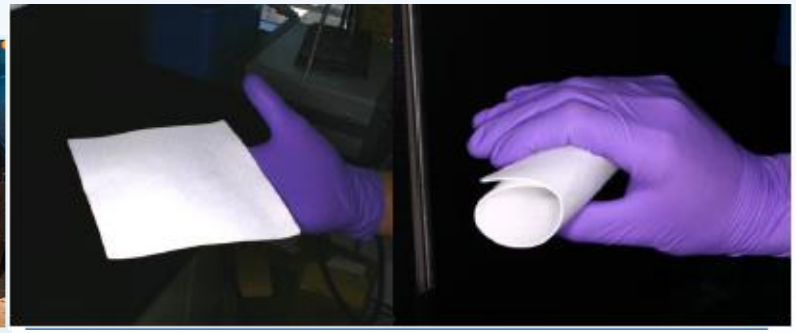
Sandwich Structure Incorporating Aerogels

Aerogel insulation on cryotank

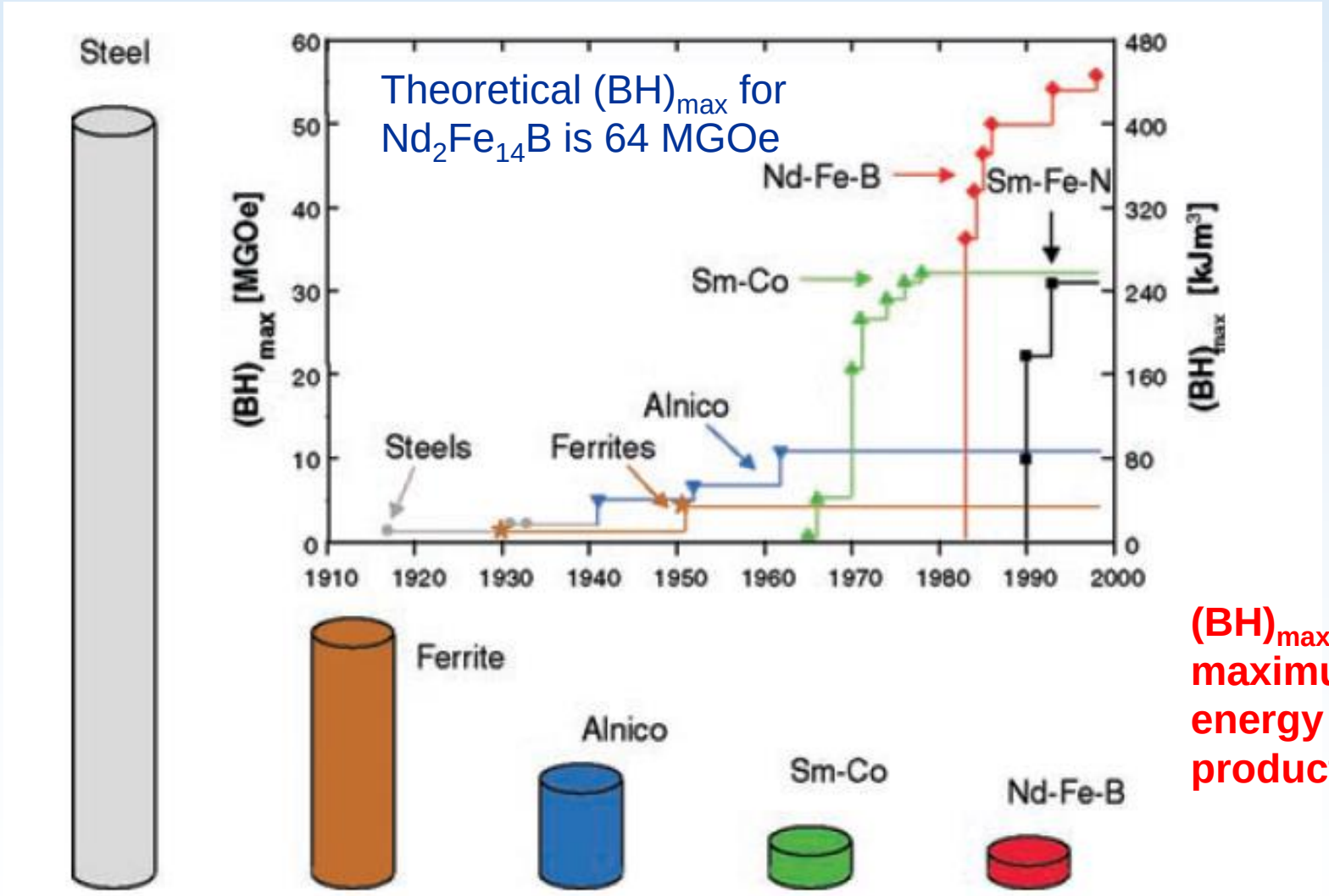
Polyimide aerogel



High temperature ceramic aerogel

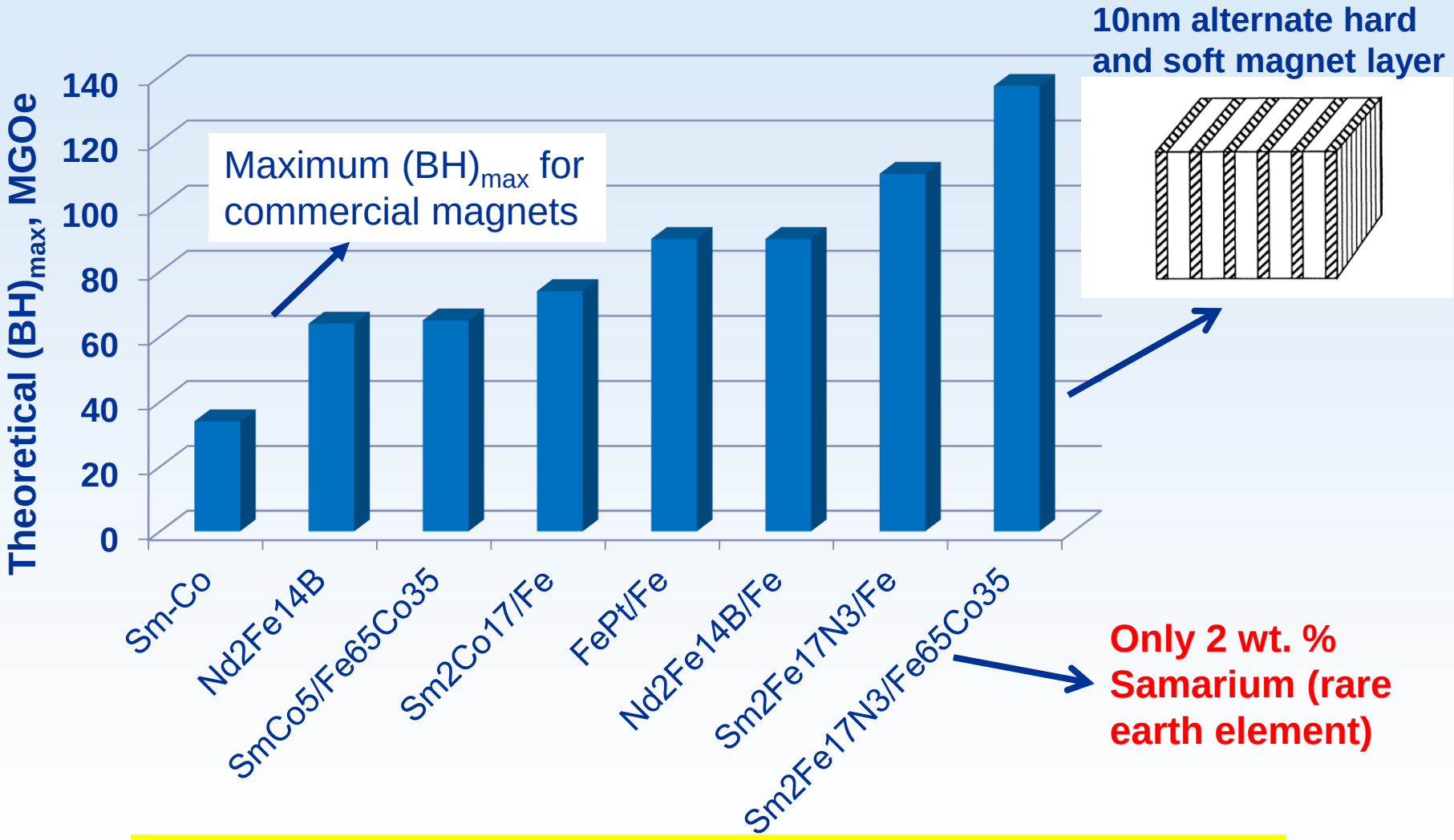


Advances in Permanent Magnets



$(BH)_{max}$ = maximum energy product

Promise of Nanocomposite Magnets



Significant manufacturing challenges to achieve theoretical $(BH)_{max}$ in nanocomposites

Nanotechnology in Consumer Products

www.nanotechproject.org/consumerproducts

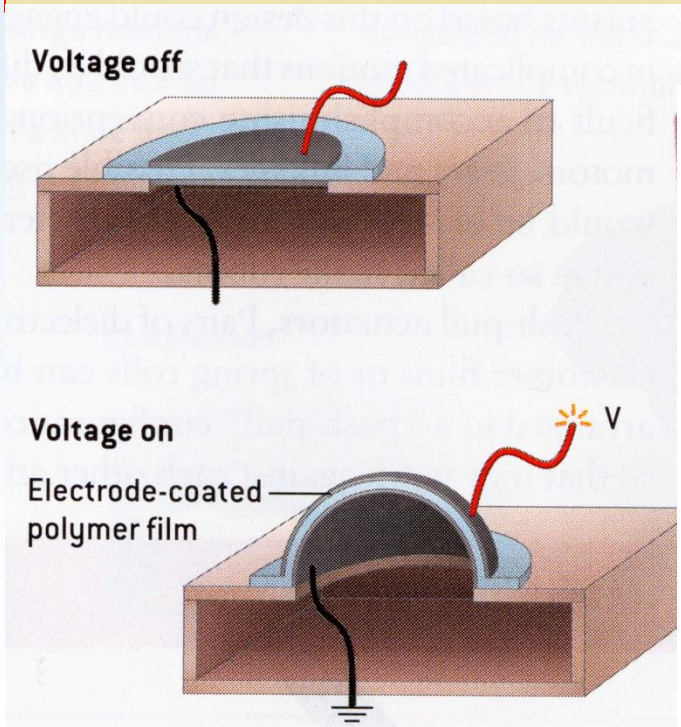
Outline

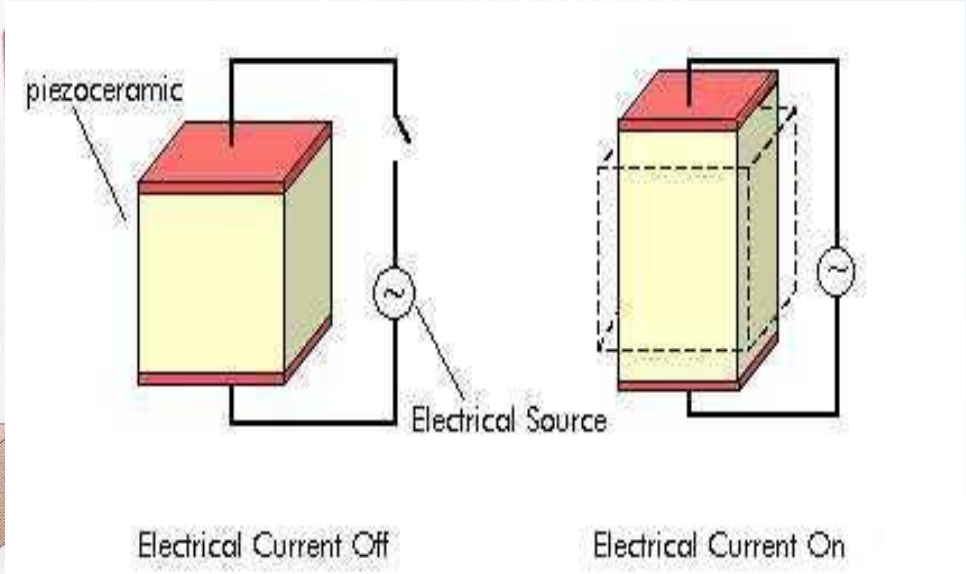
- Nanomaterials
- **Smart materials**
- Sensor materials
- Multifunctional and hybrid structures/materials
- Additive manufacturing of composite materials
- Material Informatics

Piezoelectric Materials

PIEZO MATERIALS ARE ACTUATORS AND SENSORS

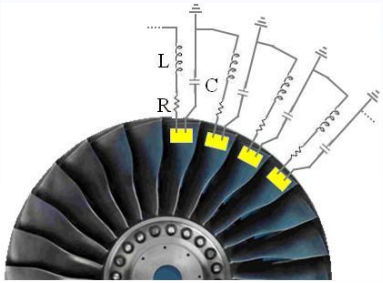
In piezoelectric materials, mechanical stress causes crystals to electrically polarize and vice versa. Hit them with electric current and they deform (actuator); deform them and they generate electricity (sensor).

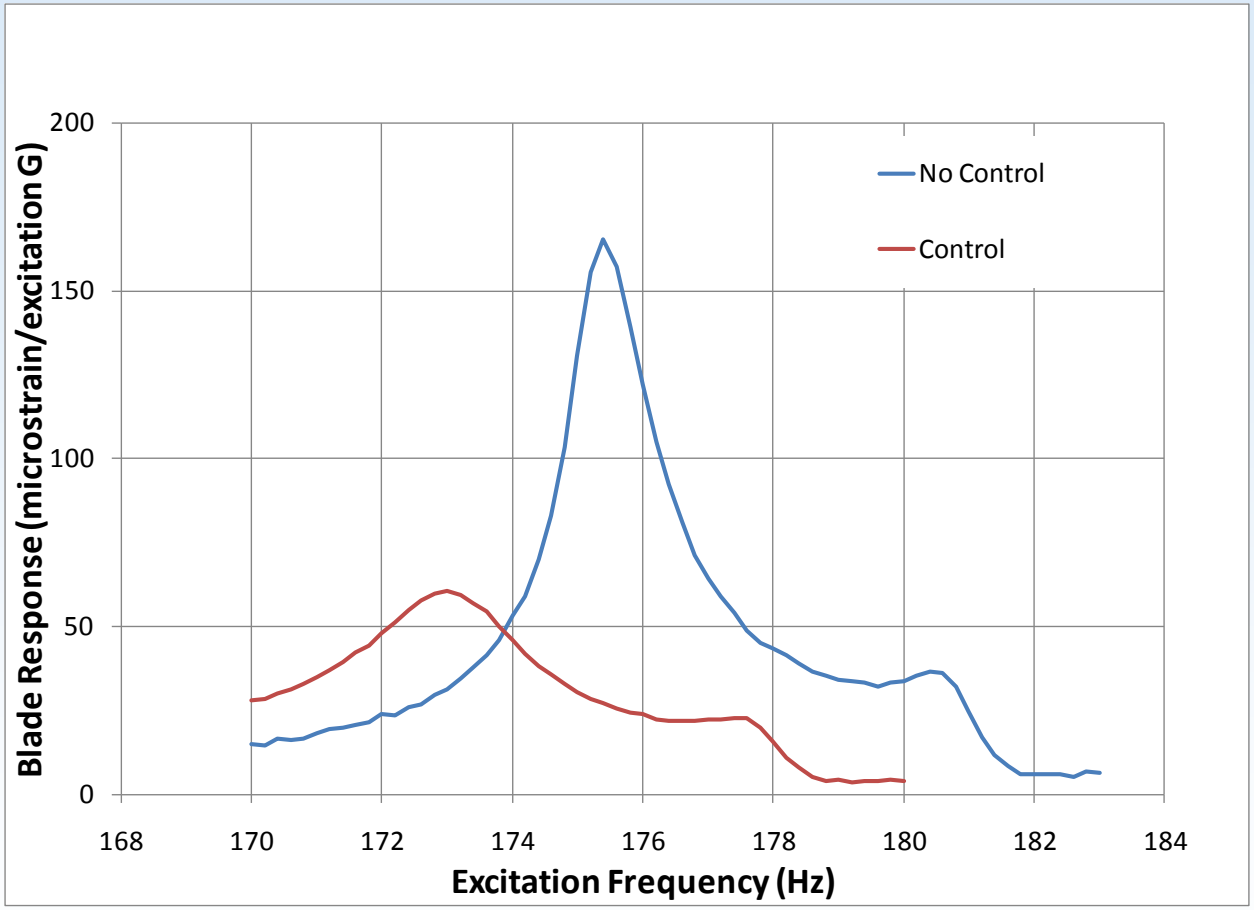




Piezoceramic for Control of Vibration in Gas Turbine Engine Fan Blade

Fan Blade with Piezo patches

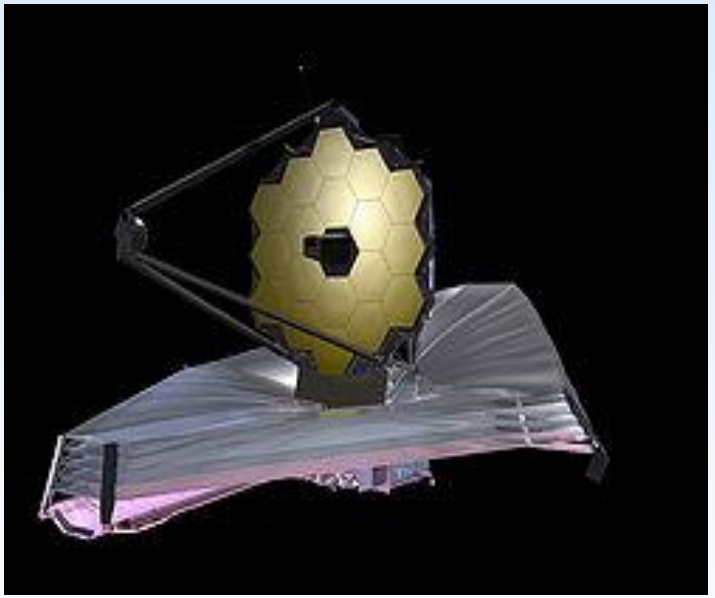




Applicable to vibration control in machining processes enabling precision machining

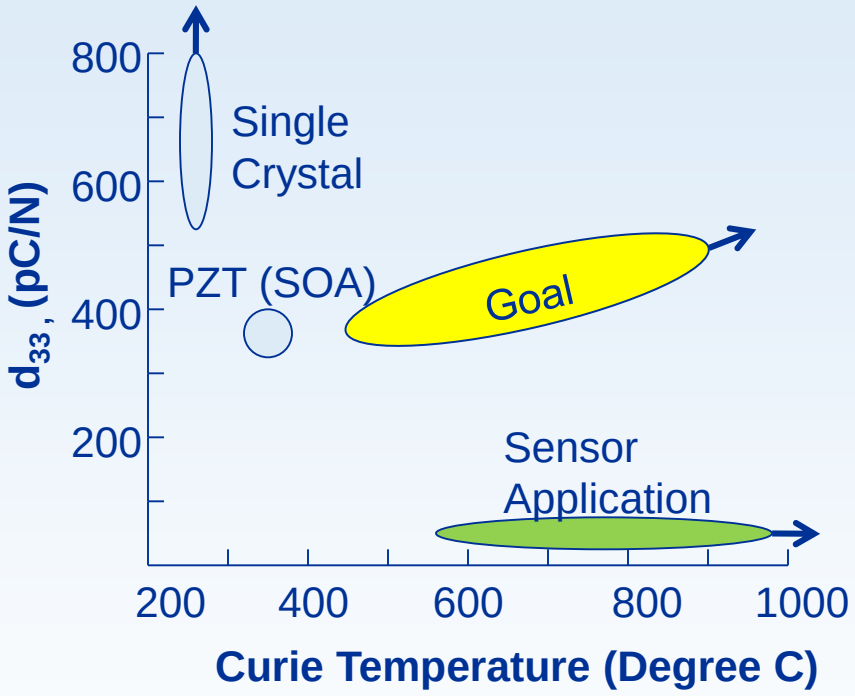
Aerospace Application of Piezoceramic Materials

Smart helicopter blade for noise and vibration control

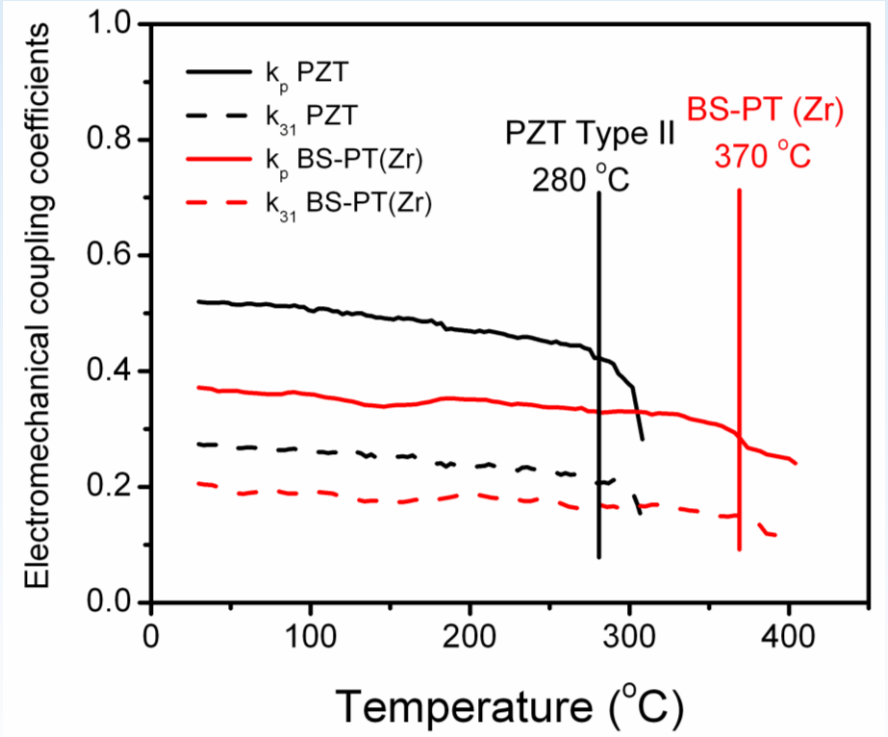


James Webb Telescope, electrostrictive ceramic actuator to control the shape of mirrors

Development of High Temperature Piezoceramic Materials for Aerospace Applications



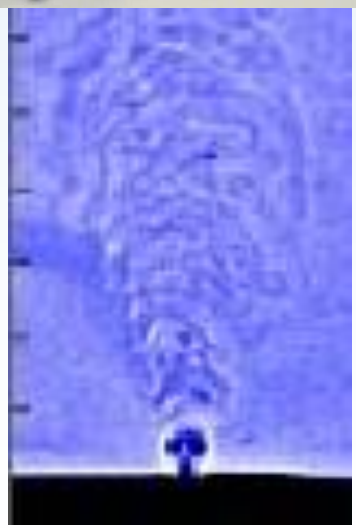
Operating Temperature typically half of curie temperature



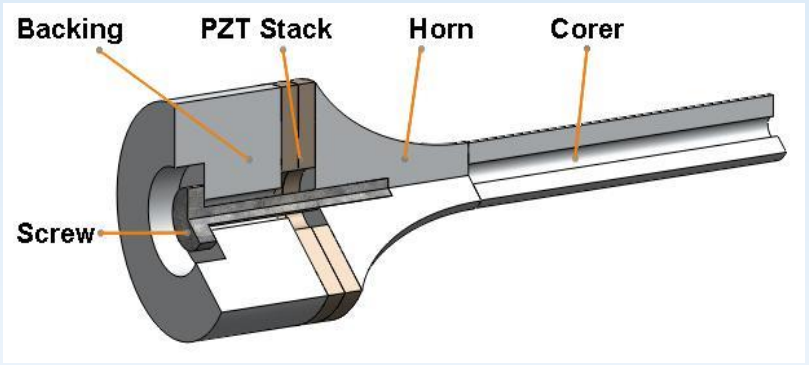
New complex ceramic chemistries and fabrication process being developed to increase use temperature of piezoceramic materials

Aerospace Application of High Temperature Piezoceramic Materials

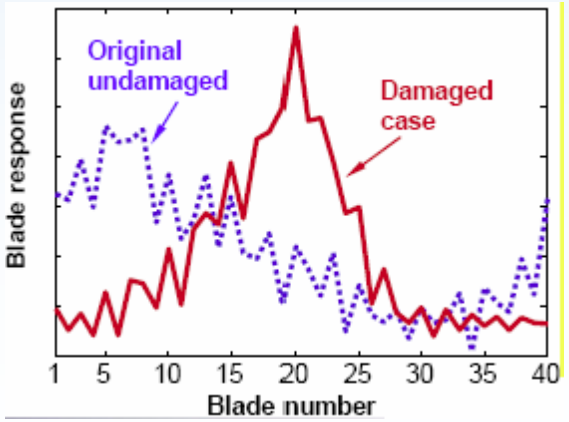
Active combustion control through fuel flow modulation



Ultrasonic drilling on Venus surface

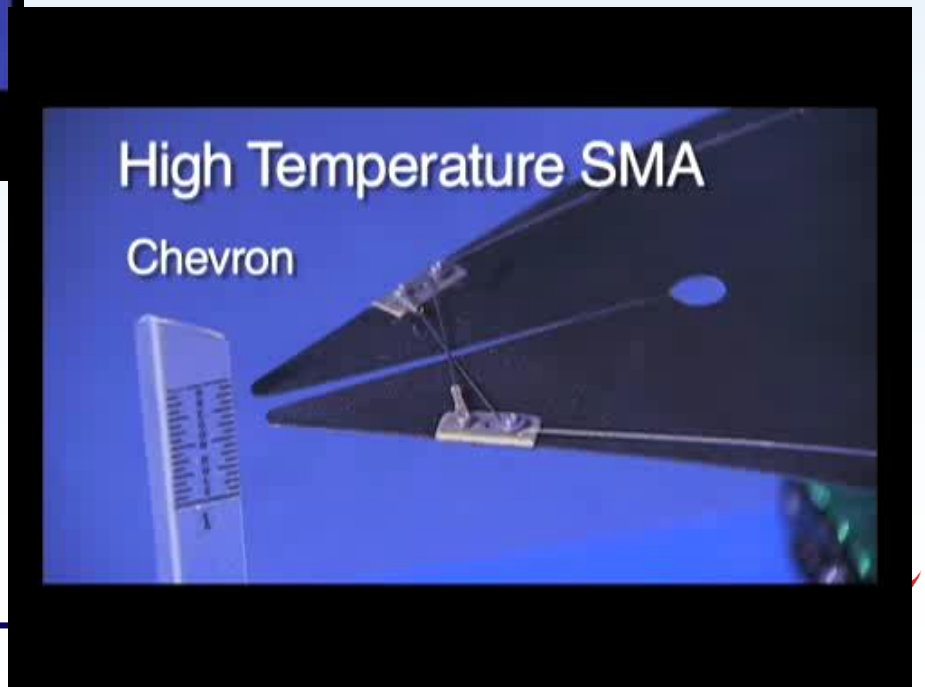


Damage sensing for engine components



Actuation Based on Shape Memory Alloys

- **A special type of metallic alloy that when deformed at low temperatures is capable of “remembering” and recovering its original shape upon heating**



Shape Memory Alloy Applications

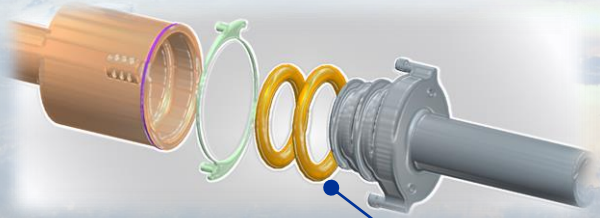
Space

SMA Bellows

- Dynamic sealing
- Fluid handling
- Flexibility (structure alignment)

SMA Spring Tire

- Superelastic technology
- Lunar rovers
- Terrestrial tires



SMA Docking Coupling

- Cryogenic transfer coupling
- Orbital propellant depots
- Propellant handling/protection

SMA Thermal Switch

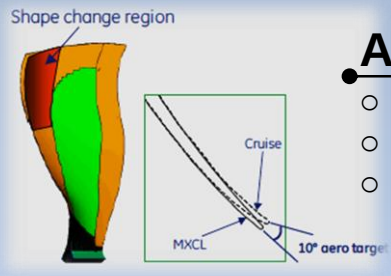
- Thermal management
- Clean & spark-free operation
- Passive or active control

SMA Bearings

- Corrosion resistant
- Non-galling properties
- High yield

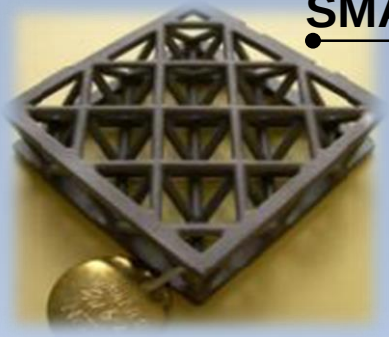
Shape Memory Alloy Applications

Aero



Adaptive Fan Blade

- Embedded SMA actuators
- Aerodynamic efficiency
- Specific fuel consumption reduction



SMA Cellular Structures

- Airframe and engine components
- Morphing airfoils
- Light weight trusses

Boeing

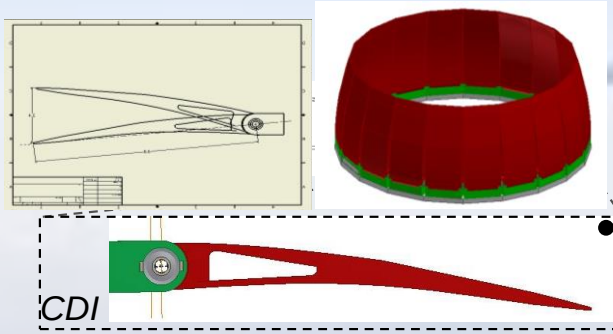
Variable Geometry Chevron

- SMA actuators morph the chevron
- Noise reduction at takeoff
- Shock cell noise reduction at cruise

Smart Fastening Systems

- Latches
- Oxygen masks
- Seat configurations

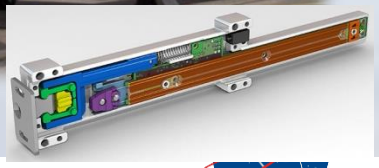
TZ



CDI

Variable Area Nozzle

- High bypass turbofan
- SMA torque tubes provide flap rotation
- Engine noise reduction



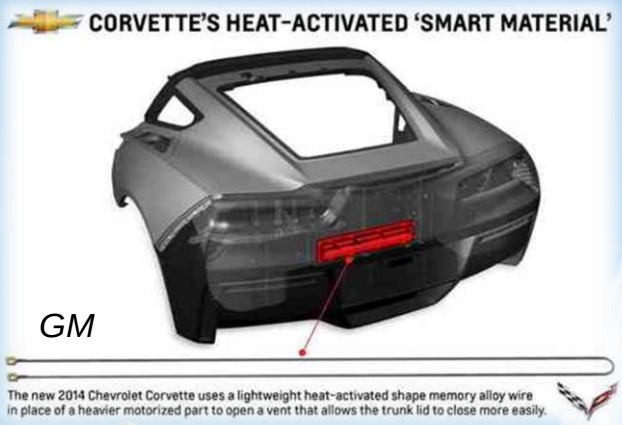
Shape Memory Alloy Applications
Non-Aerospace Potential

Oil and Gas Industry

- SmartRAM™ actuators (*LMP*)
- SMA couplings (Aerofit Inc)
- Deep-water valves/shut off valves
- Self-torquing fasteners

Other Applications

- Home appliances
- Electronics
- Transportation
- Air conditioners



Cleveland Clinic

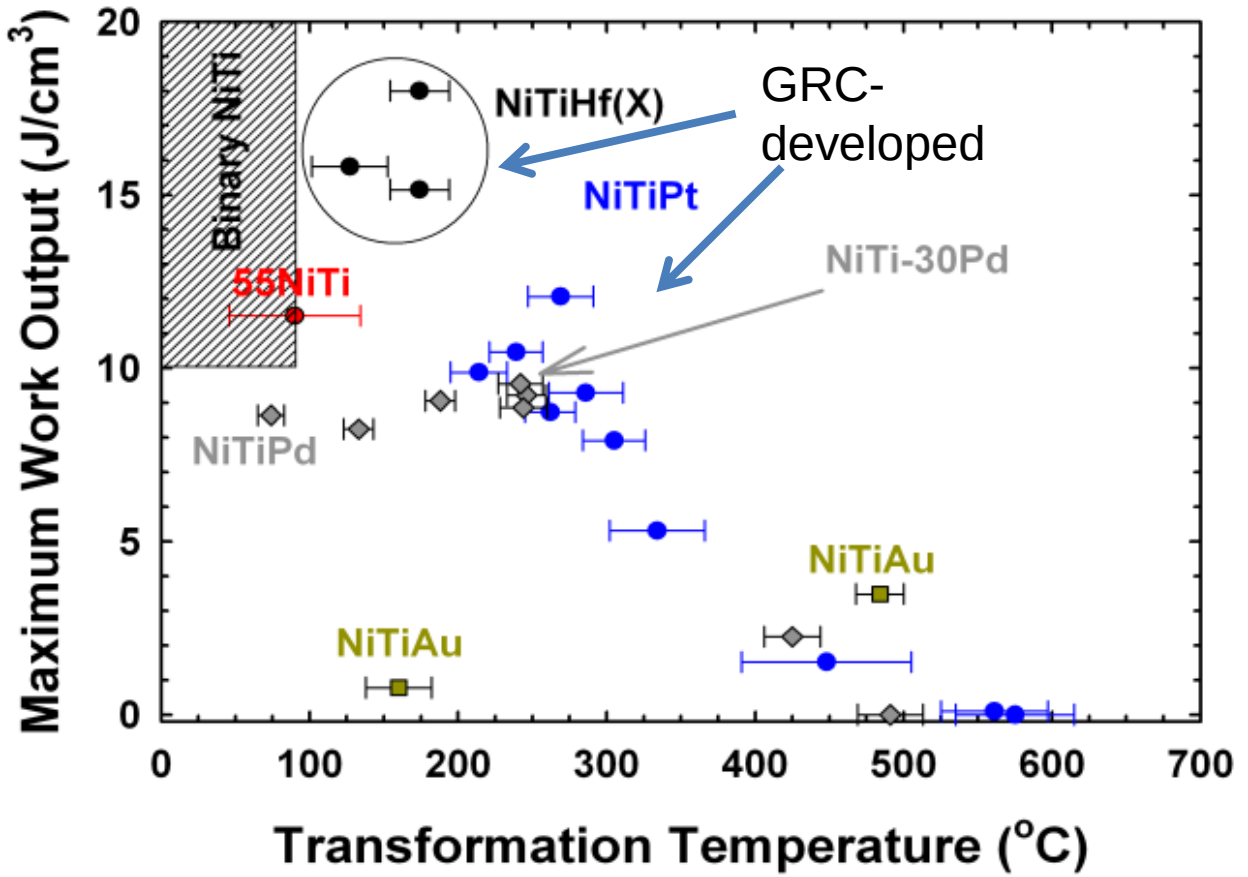
Medical Industry

- Surgical tools
- Stents and implants
- Glasses frames

Automotive Industry

- Louvers
- Quiet actuators
- Door handle

Development of High Temperature Shape Memory Alloys



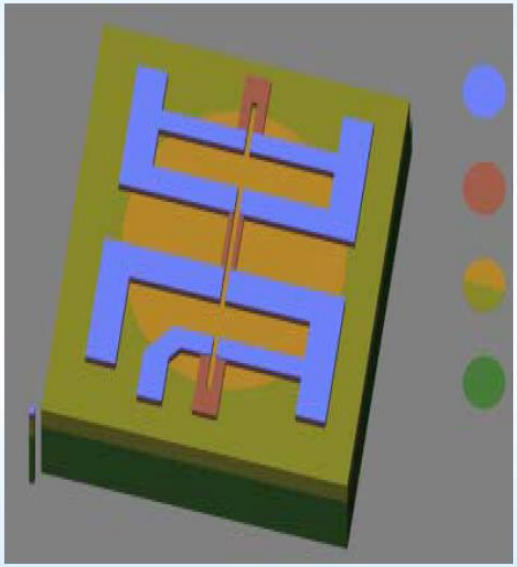
High temperature shape memory alloys will enable new aerospace and automotive applications

Outline

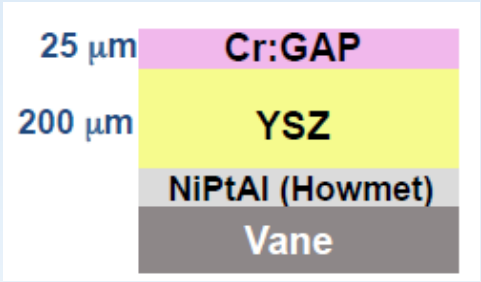
- Nanomaterials
- Smart materials
- **Sensor materials**
- Multifunctional and hybrid structures/materials
- Additive manufacturing of composite materials
- Material Informatics

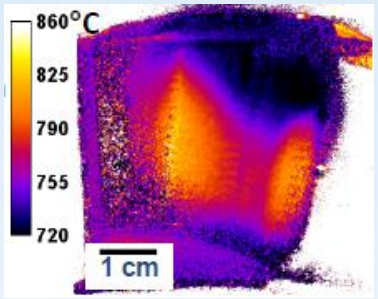
High Temperature Thin Film Ceramic Sensors

SiC Pressure Sensor



Cr-doped $GdAlO_3$ Coating for Temperature Measurement

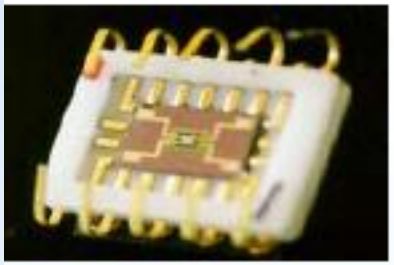




Multifunctional
TaN-Based Sensors

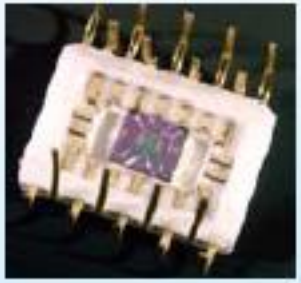
Ceramic Sheath for
2400°C – Capable
Temperature Probe

Chemical Sensors

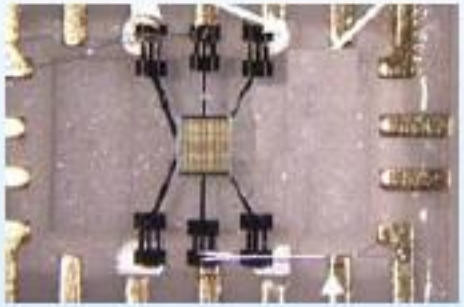


Oxygen Sensor

SiC Hydrocarbon Sensor

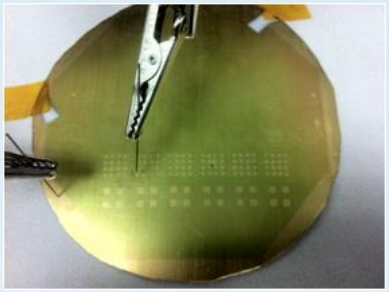


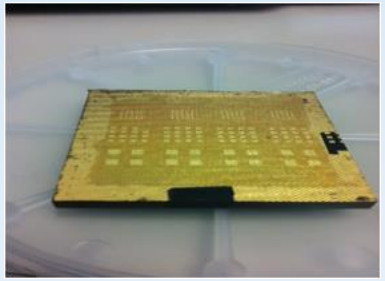
H2 Sensor



Nanocrystalline Tin Oxide NOx and CO Sensor

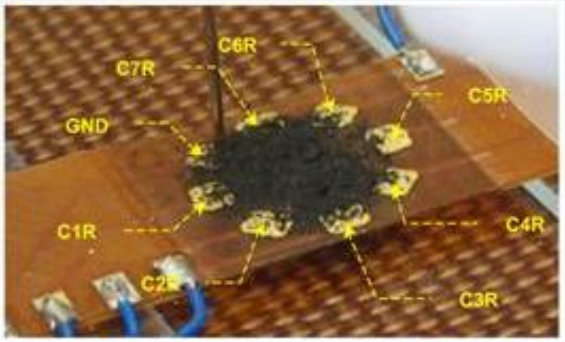
Carbon Nanotube(CNT)-Based Strain, Damage, and Chemical Sensors



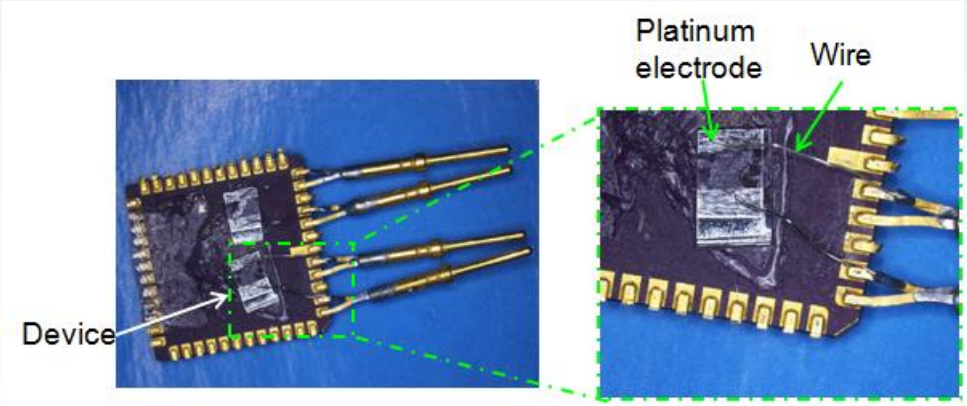


Capacitance Based Strain Sensor on Teflon (left) and CFRP (right)

CNT Gas/Chemical Sensor



CNT Strain Sensor

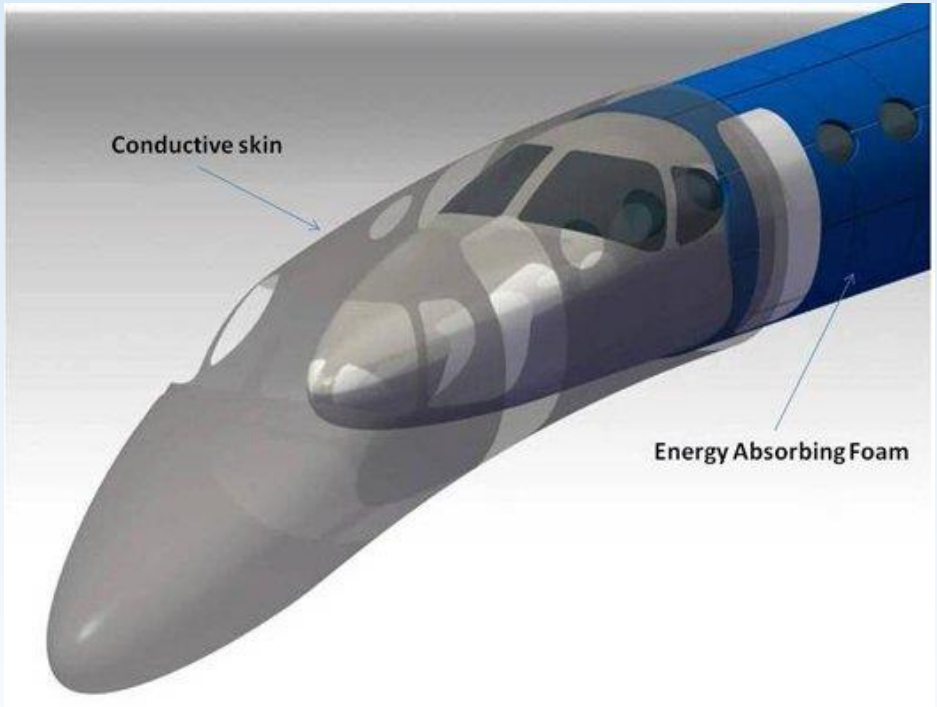


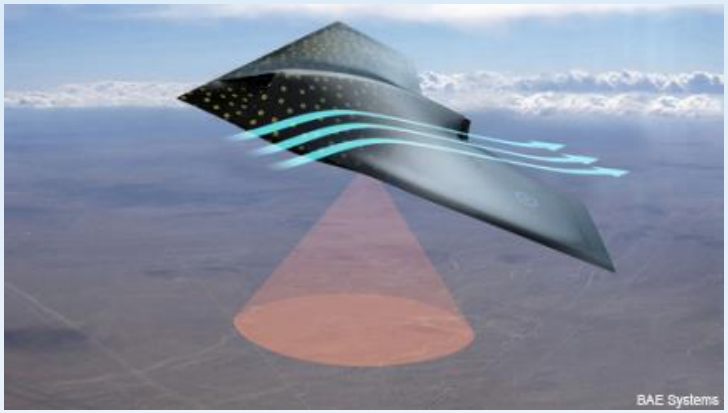
Graphene Strain Sensor

Outline

- Nanomaterials
- Smart materials
- Sensor materials
- **Multifunctional and hybrid structures/materials**
- Additive manufacturing of composite materials
- Material Informatics

Multifunctional Structures





BAE smart skin – sense own health like human skin, thousands of microsensors

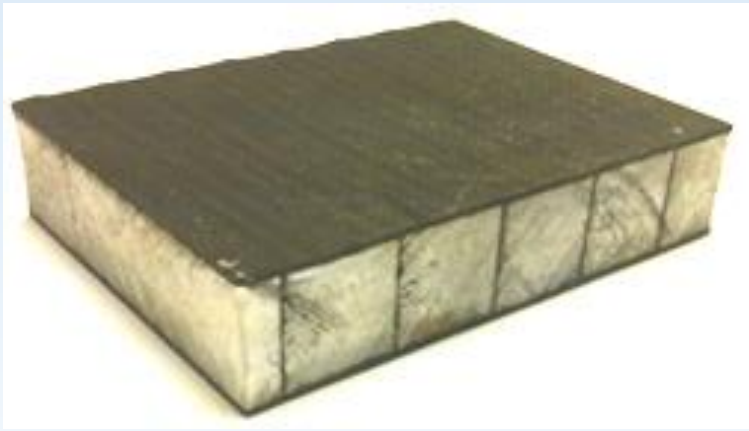
Cessna smart skin - STAR-C2, which stands for “smoothing, thermal, absorbing, reflective, conductive, cosmetic

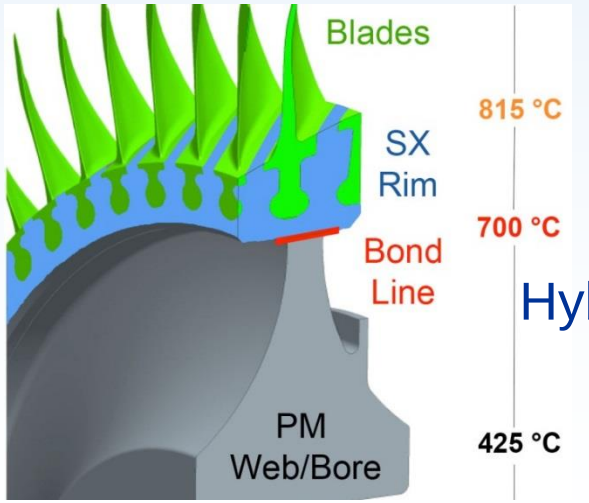
Multifunctional structure with energy storage capability

Increasing Use of Hybrid Materials

Hybrid Composite Gear

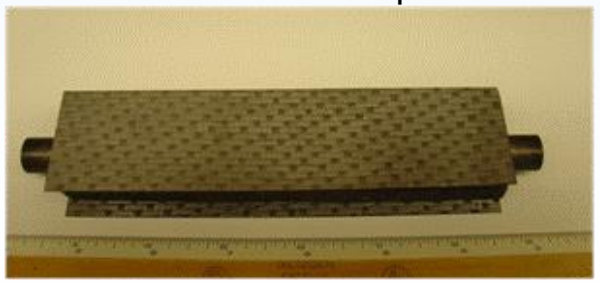
Fiber Reinforced Foam Core (FRF)Structure





Hybrid Disk

C-C Composite/Foam/Titanium tube assembly bonded with CuSil-ABA braze paste



Outline

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- **Additive manufacturing of composite materials**
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Trend Toward Non-Metallic Gas Turbine Engine

Extensive use of ceramic matrix composite (CMC) in gas turbine engines

Extensive use of polymer matrix composite (PMC) in gas turbine engines cold section with increase in PMC temperature capability

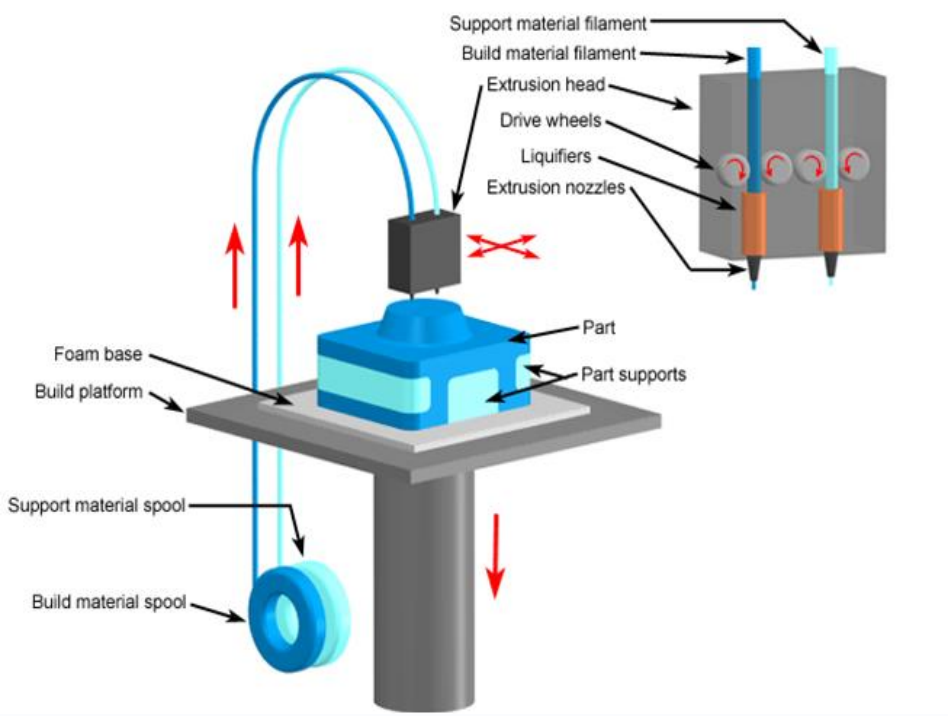
- Increasingly non-metallic gas turbine engine
- Economical composite manufacturing process will be required
- Additive manufacturing potential solution

Additive Manufacturing of Polymer Matrix Composites

Melts polymer filament and deposits it layer-by-layer following CAD files

Fabrication of high temperature PMC was enable by:

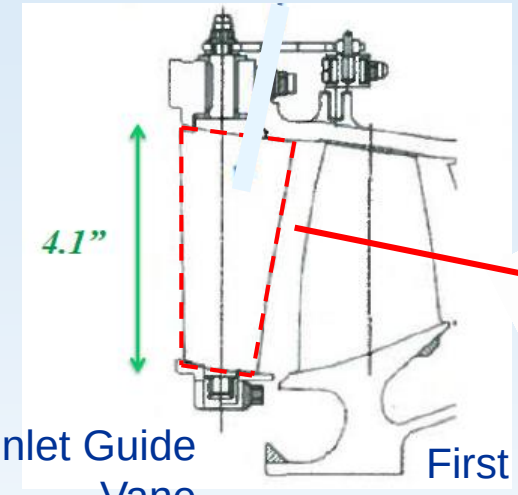
- Chopped-fiber reinforcement
- Moisture reduction in FDM filament
- Versatile printing pattern design



Benefits:

- Quick turn around time for complex parts
- Shorter component production and testing cycle
- Reduced cost of low production volume components

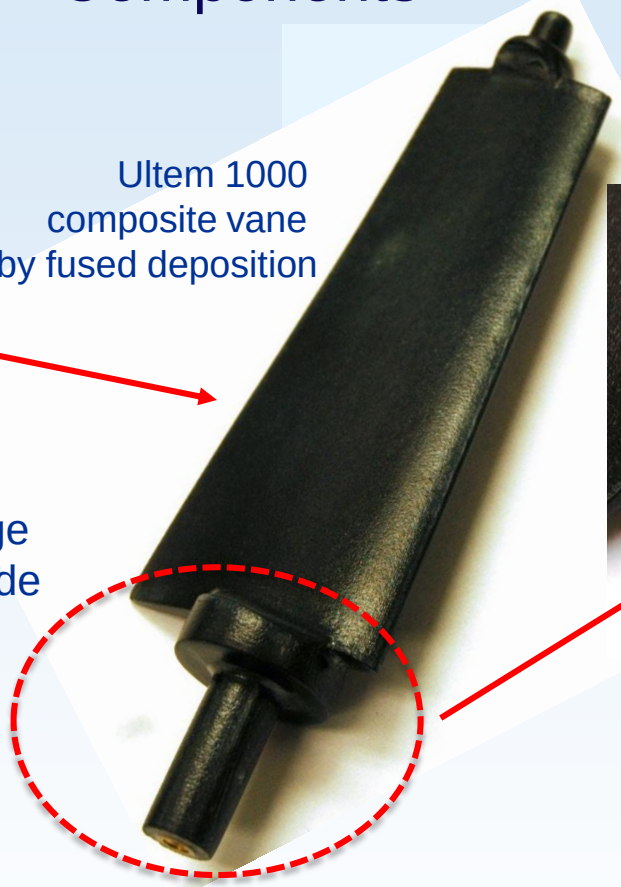
Additive Manufacturing of Polymer Matrix Composite Components

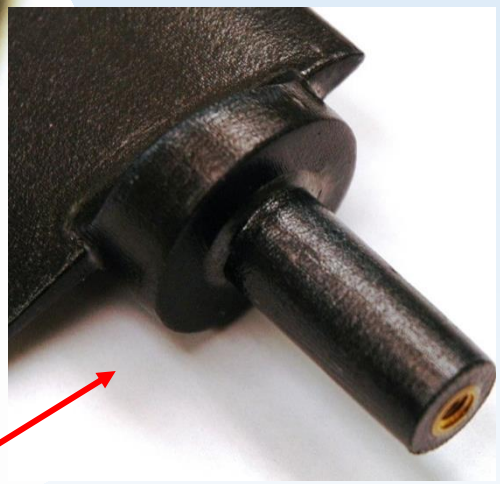


Inlet Guide Vane

First Stage Compressor Blade

Ultem 1000 composite vane by fused deposition



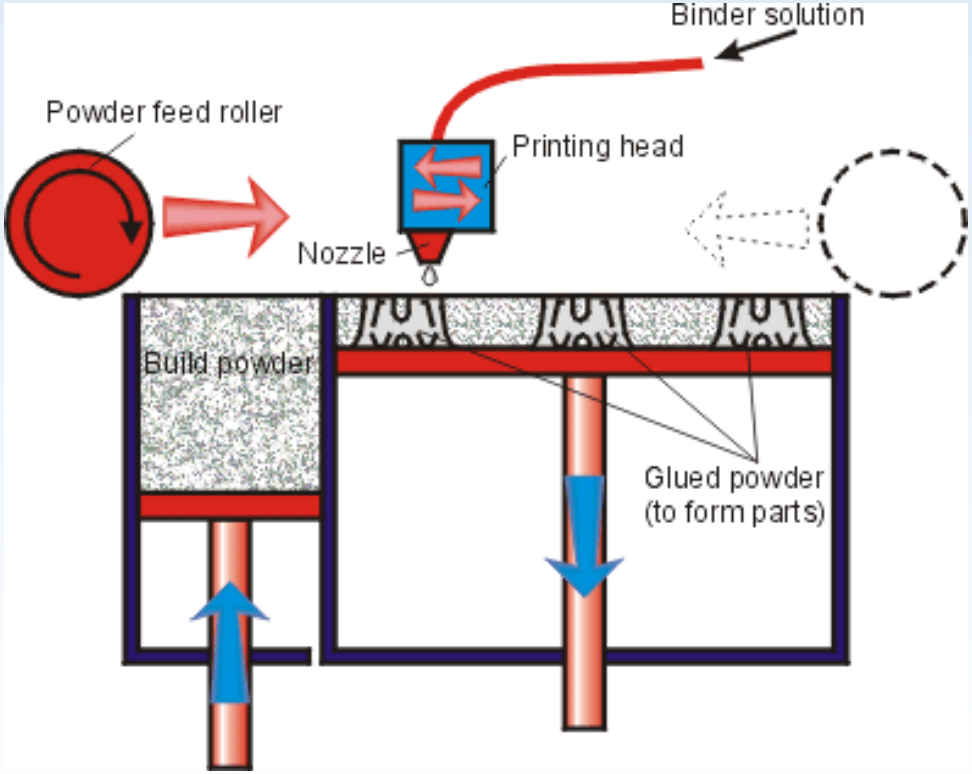


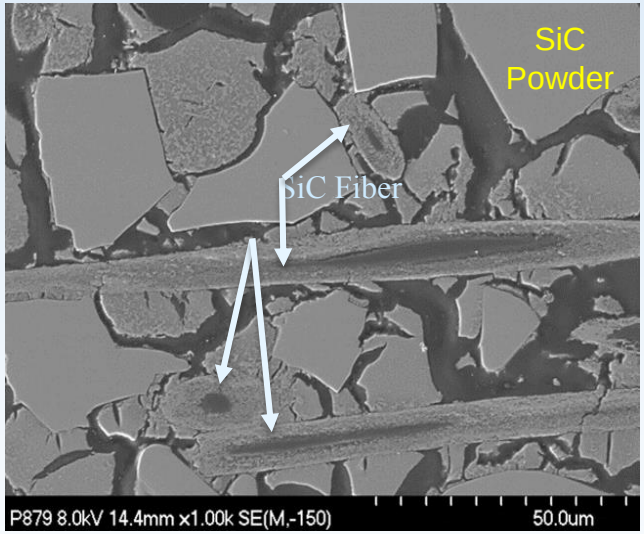
Attachment detail

400^{0}F operating temperature

- Ultem 1000 (T_g = 423^{o}F) with chopped carbon fiber
- First Polyetherimide composite fabricated

Additive Manufacturing of Ceramic Matrix Composite (CMC)

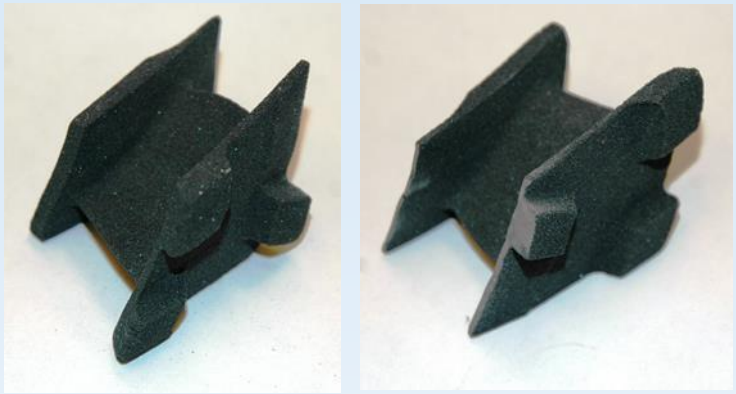




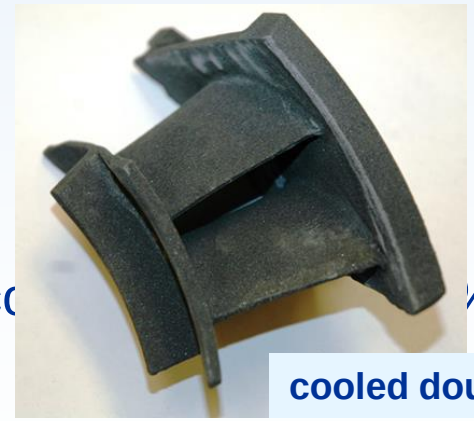
Binder jet printing allows for powder bed processing with *tailored binders* and *chopped fiber reinforcements* for fabricating advanced ceramics

Additive Manufacturing of Ceramic Matrix Composites

high pressure turbine nozzle segments



first stage nozzle segments



cooled doublet nozzle sections

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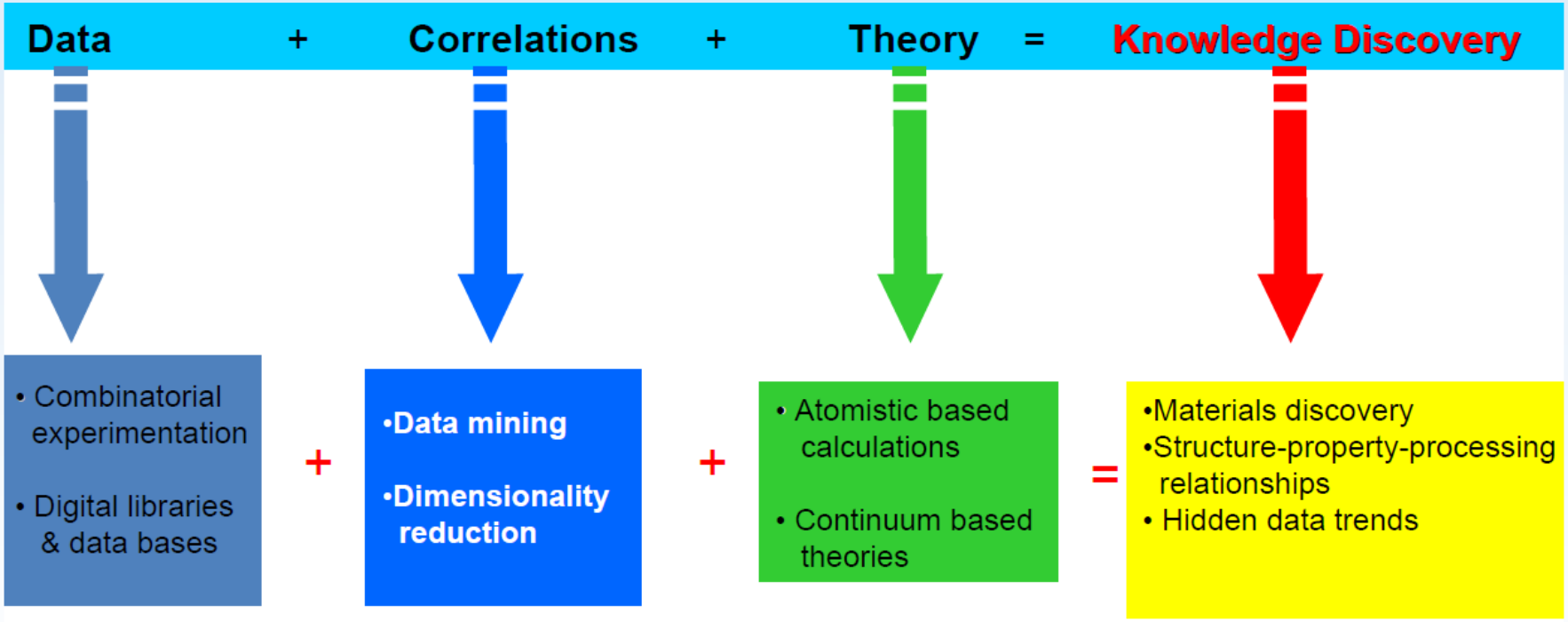
Material Informatics – Data Driven Materials Science



Concluding Thoughts

Future will be integration of

- Computational material design and big data analytics
- Nanomaterials as building blocks
- Sensors and actuators for adaptability and self healing
- Additive manufacturing
- Multifunctionality

to create materials with engineered and tailored properties