Technology and Research for Advanced National Security of Inter-modal Transportation

National Transportation Security
Center of Excellence

Mehdi Anwar

REPORT CARD for America's INFRASTRUCTURE

ASCE American Society of Civil Engineers

★ HOME ★ REPORT CARD ★ SOLUTIONS ★ TAKE ACTION ★ NEWSROOM ★

2009 Report Card for America's Infrastructure

Produced by the American Society of Civil Engineers

The Report Card is an assessment by professional engineers of the nation's status in 15 categories of infrastructure. In 2009, all signs point to an infrastructure that is poorly maintained, unable to meet current and future demands, and in some cases, unsafe. Since the last Report Card in 2005, the grades have not improved. ASCE estimates the nation still stands at a **D** average. Deteriorating conditions and inflation have added hundreds of billions to the total cost of repairs and needed upgrades. ASCE's current estimate is $2.2 trillion, up from $1.6 trillion in 2005.

A healthy infrastructure is the backbone of a healthy economy. In these challenging times, infrastructure is essential to reviving the nation's fortunes, and in maintaining our high quality of life.

- Find out 5 Key Solutions for raising the grades.
- Take action today! Ask your legislator to support infrastructure.
- Watch ASCE's Report Card announcement, joined by Pa. Gov. Ed Rendell (see a shortened version here).
- View and read a CNN report on the Report Card and its findings here.
- See previous Report Cards.
- Need more information? Contact ASCE.

2009 GRADES

Aviation	D
Bridges	C
Dams	D
Drinking Water	D-
Energy	D+
Hazardous Waste	D
Inland Waterways	D-
Levees	D-
Public Parks & Recreation	C-
Rail	C-
Roads	D-
School	D
Solid Waste	C+
Transit	D
Wastewater	D-

Click Here for Grade definitions

America's Infrastructure
GPA = D

Estimated 5 Year Investment Need
$2.2 Trillion

GET INVOLVED

Post Your Photos & Videos

- Share your comments and track the progress of action in Washington in ASCE's blog, **Our Failing Infrastructure**
- Join Our Facebook: **Save America's Infrastructure**
- **Tell a friend** about the Report Card
- ASCE member? **Join the Key Contact program**
- **Submit photos or video** of failing infrastructure

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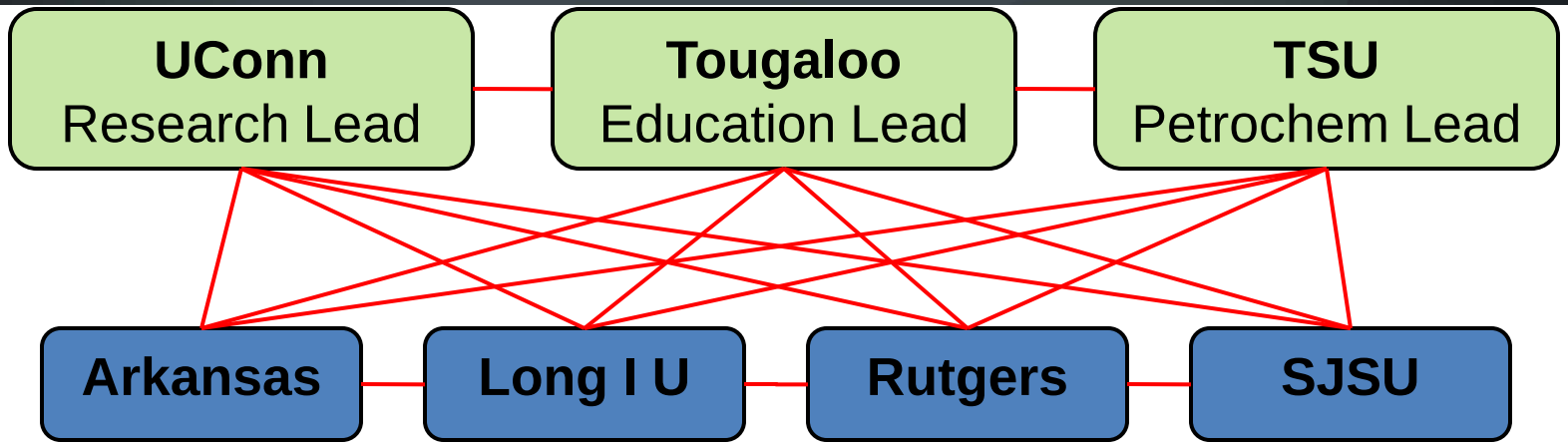
Transportation Infrastructure - Graduate decline over the years

Metrics
- Capacity
- Condition
- Funding vs. need
- Operation/Maintenance
- Public Safety/Resilience

- Substandard Transportation Infrastructure
  - Drain Resources
  - Inhibit Commerce
  - Threaten Public Safety

Development of a Resilient Intermodal Transportation Infrastructure

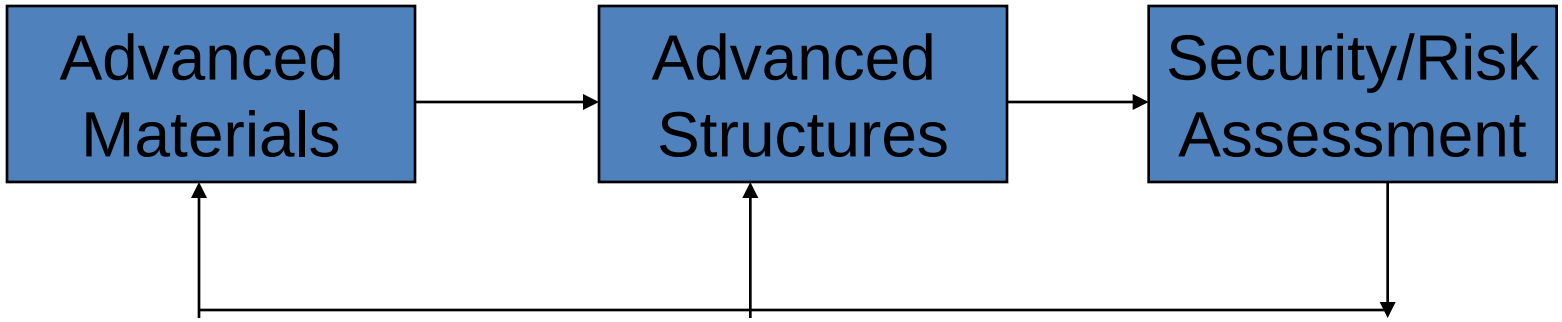
- How to Raise our Grades
  - Increase Federal Leadership
  - Promote Sustainability and Resilience
  - Develop Federal, Regional and State Infrastructure Plans
  - Address Life Cycle Costs and Ongoing Maintenance
  - Increase and Improve Infrastructure Investment



- Motivation
  - Provide Secure and Safe Transportation for the Nation
- Mission is to enable
  - Resilient & Smart Transportation Infrastructure
  - Prediction
  - Protection
  - Preparedness
  - Partnership

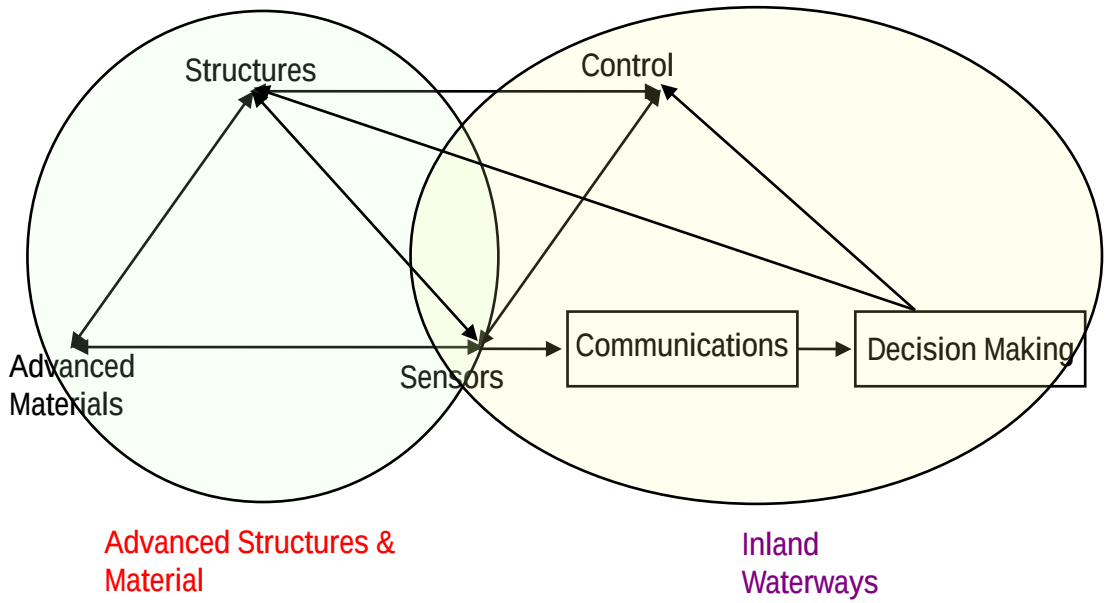
TRANSIT: Progress

- Mechanical Characterization of Ultra-High Performance Concrete for Sustainable Transportation Infrastructure – Michael Accorsi, Adam Zofka and Jim Mahoney
- Advanced Embedded Sensors and Control for Transportation Infrastructure Monitoring and management – Jiong Tang, Richard Christenson and Nejat Olgac
- Impact Resistant Multifunctional Composite Sensor for Structural Monitoring – Rainer Hebert, Bryan Huey, Jeong-Ho Kim, George Rossetti and Mehdi Anwar
- Inland Waterways: Sensing, Monitoring and Strengthening of Levees – Maria Chrysochoou & Ross Bagtzoglou
  - Localization in UnderWater Sensor Networks for Waterway Monitoring and Harbor Protection – Shengli Zhou & Jun-Hong Cui
  - Multi-modal Transportation Systems Vulnerability Assessment Using Real-Time Collection, Fusion and Analysis – Reda Ammar & Sanguthevar Rajasekaran



Advanced Multi-Functional Materials (Vertical Integration from Design to Manufacture)
Inexpensive
New Material and Synthesis Techniques
Environmentally Friendly
Constructable Features

Research Gaps



Sensing, monitoring of inland waterways

Team Leader Ross Bagtzoglou

Team Members
- Maria Chrysochoou
- Shengli Zhou
- Jung-Hong Cui
- Reda Ammar
- Sanguthevar Rajasekaran

Sensor Development
Ross/Maria

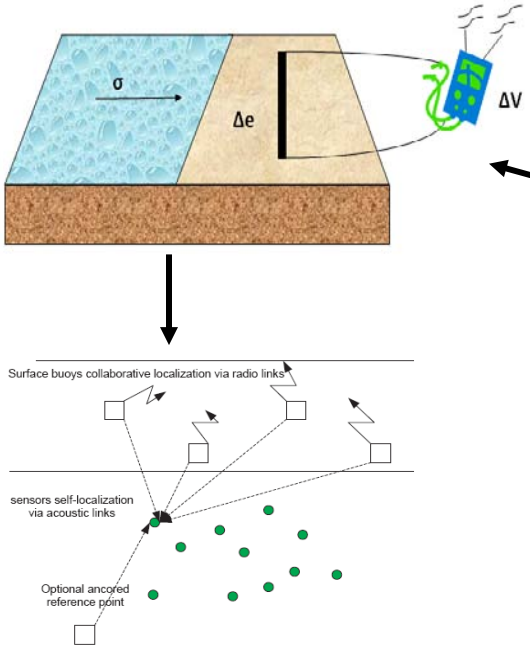


Figure 1: A typical USWN setup for high-precision localization

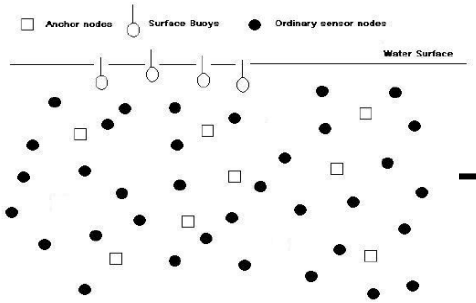


Figure 2: Large-scale UWSN with three types of nodes

Data Processing, Visualization and Decision Making

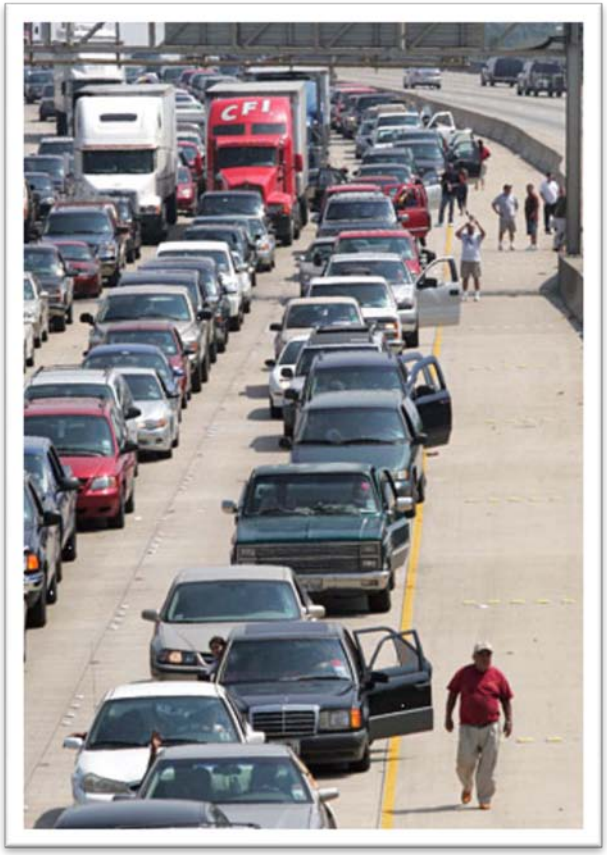
Reda/Raj

Underwater Sensor Network Shengli/Cui

Diversifying the nation's transportation portfolio is key to national security

UConn Capabilities

- Bridge Inspection & Diagnostics
- Remote Sensing & Diagnostics
- Congestion Research and Policy
- Research on Adaptive Organizations
- Risk Assessment & Management
- Adaptive Safety Analysis & Monitoring
- Intelligence, Surveillance & Reconnaissance Coordination
- Positioning Navigation & Timing Systems
- Alternative Energy For Transportation
- Advanced Sensors
- Interactive – Distributed & Grid Computation & Communications

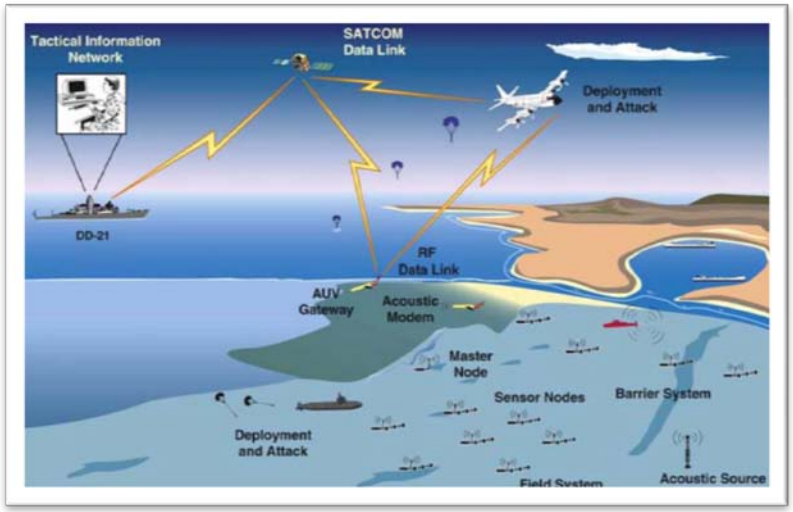


UConn Research Centers

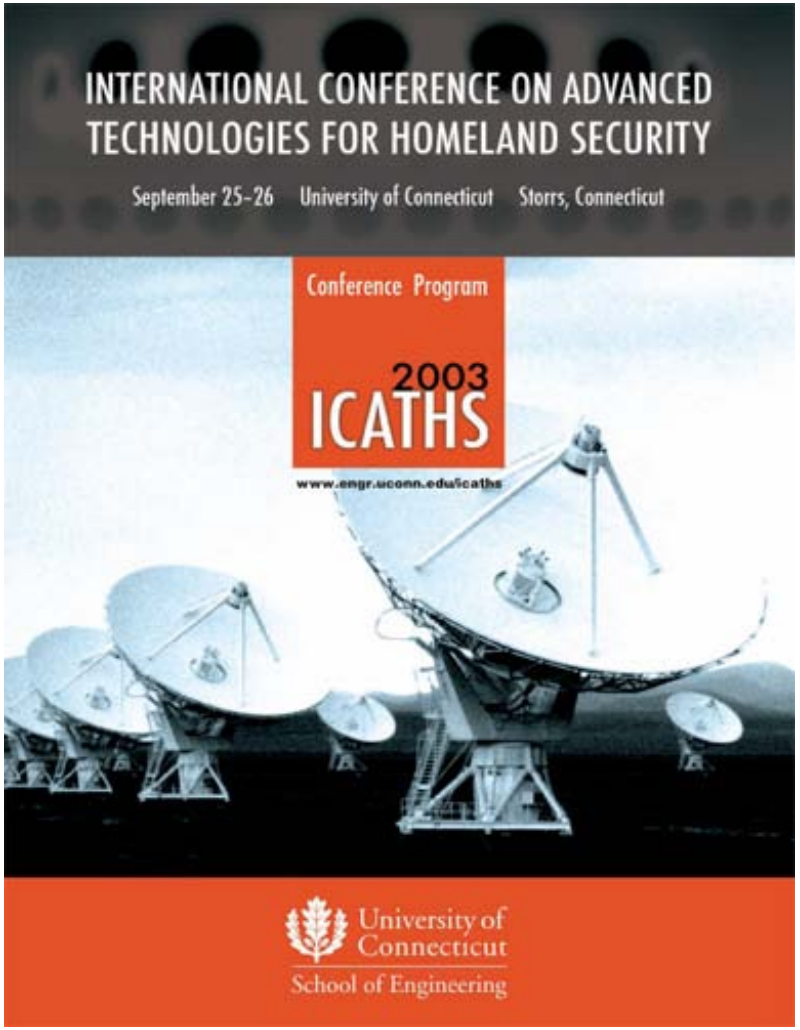
- Connecticut Transportation Institute (CTI)
  - Connecticut Advanced Pavement Laboratory (CAP Lab)
  - Connecticut Cooperative Highway Research Program
  - Technology Transfer Center (CT T^2)
- University Transportation Center (UTC)
- Connecticut Global Fuel Cell Center (CGFCC)
- Booth Engineering Center for Advanced Technologies (BECAT)
- Institute of Material Science (IMS)

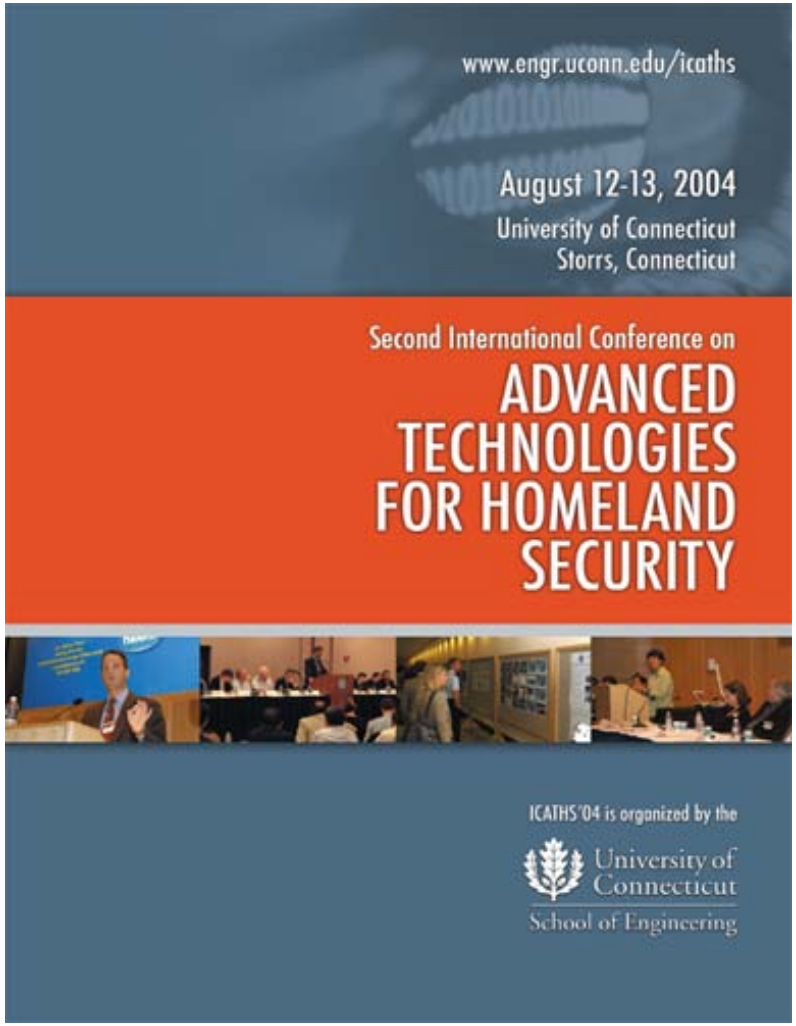
Relevant Research

- Bridge Inspection & Diagnostics
  - Remote Sensing & Diagnostics
  - Vibration signatures
  - Prediction of failures
- Port Protection
  - Underwater Sensor Network
  - UAV/UUV/UWV Coordination



Outreach, Education and Training





R&D Framework for Future Infrastructure

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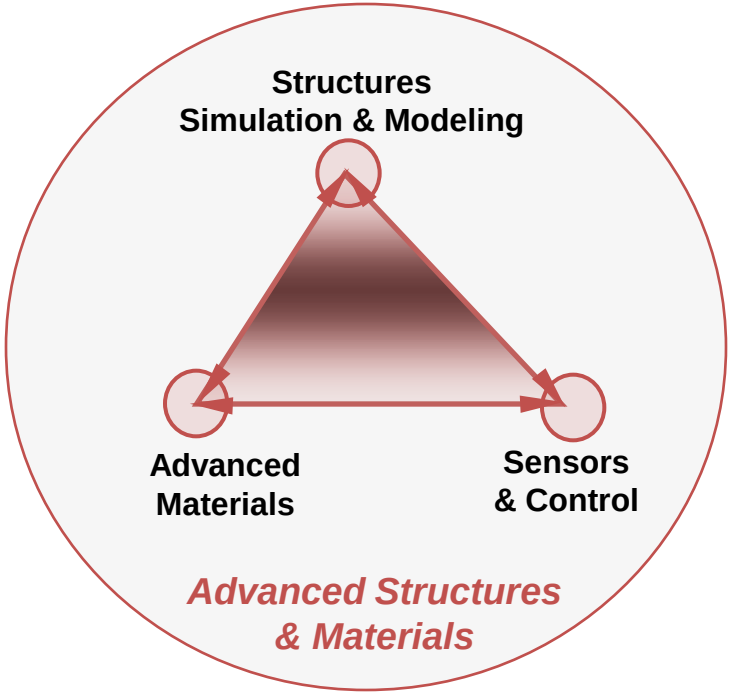
Michael L. Accorsi
Civil & Environmental Engineering

R&D Framework for Future Infrastructure

- Portions of this framework already exist but better integration is needed
- Multidisciplinary research is needed to achieve this integration
  - Civil, Mechanical, Materials & Electrical Engineering

What are the research needs?

- Utilization of advanced materials
- Complete characterization of materials for modeling & simulation
- More comprehensive structural modeling
- Integrated sensing & control in the structural design
- Modeling & simulation of sensing & control



Example: Design Philosophy for Composite Materials Subjected to Blast Loading

- Design for service loads is well established
- No validated design approach for extreme loads (blast)
- Design criteria - Structure must survive an extreme event with damage allowed. Damaged structure must carry regular service loads after an extreme event (resiliency & recovery)
- Goal - Develop and validate a modeling & simulation capability for material damage

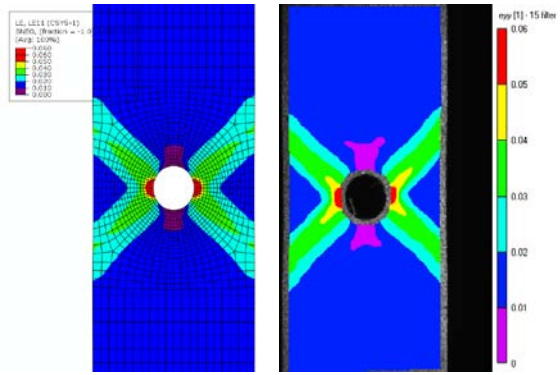
Service Loads

Extreme Loads

Validation

- Simulation (FEA)
- Testing (Digital Imaging)

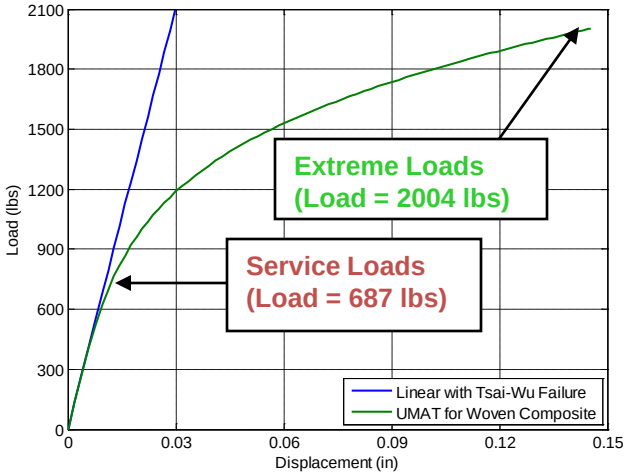
Contour plots of axial strain field



Simulation Test

Resiliency

- Validated tool to design for extreme events



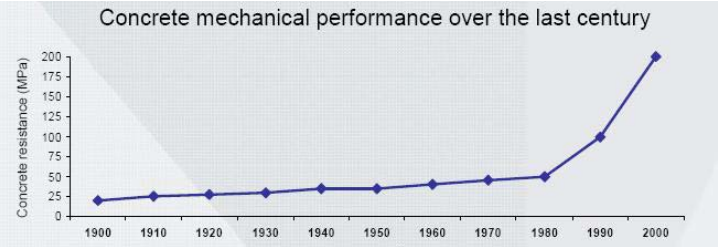
Advanced Materials: Ultra- High Performance Concretes

- Ultra fine, highly homogeneous and dense microstructure – advanced admixtures – fiber reinforcement
- Superior strength & ductility, excellent durability, fire & blast resistant, passive self-healing properties, highly aesthetic

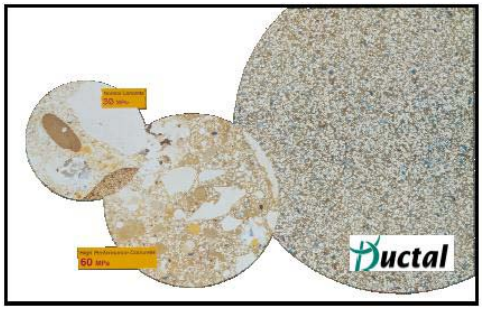
What are the research needs?

- Comprehensive material characterization
  - Thermomechanical, blast, environmental, etc.
- Develop & validate modeling and simulation capability
- Benchmark design problems for transition

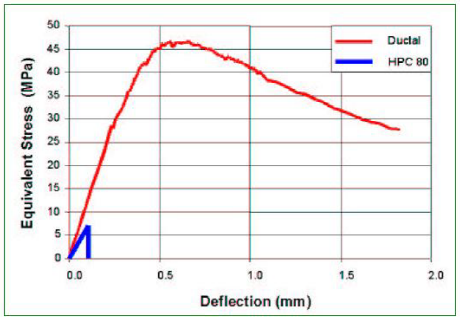
Development of advanced concrete materials – strength history



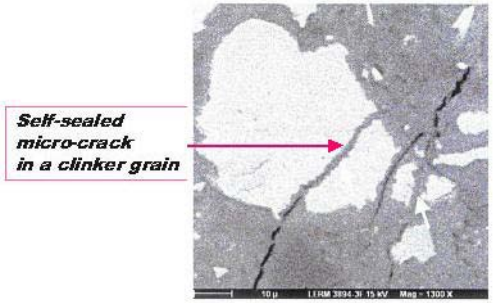
Ductal microstructure vs. regular concrete



Ductility of *Ductal* vs. regular concrete

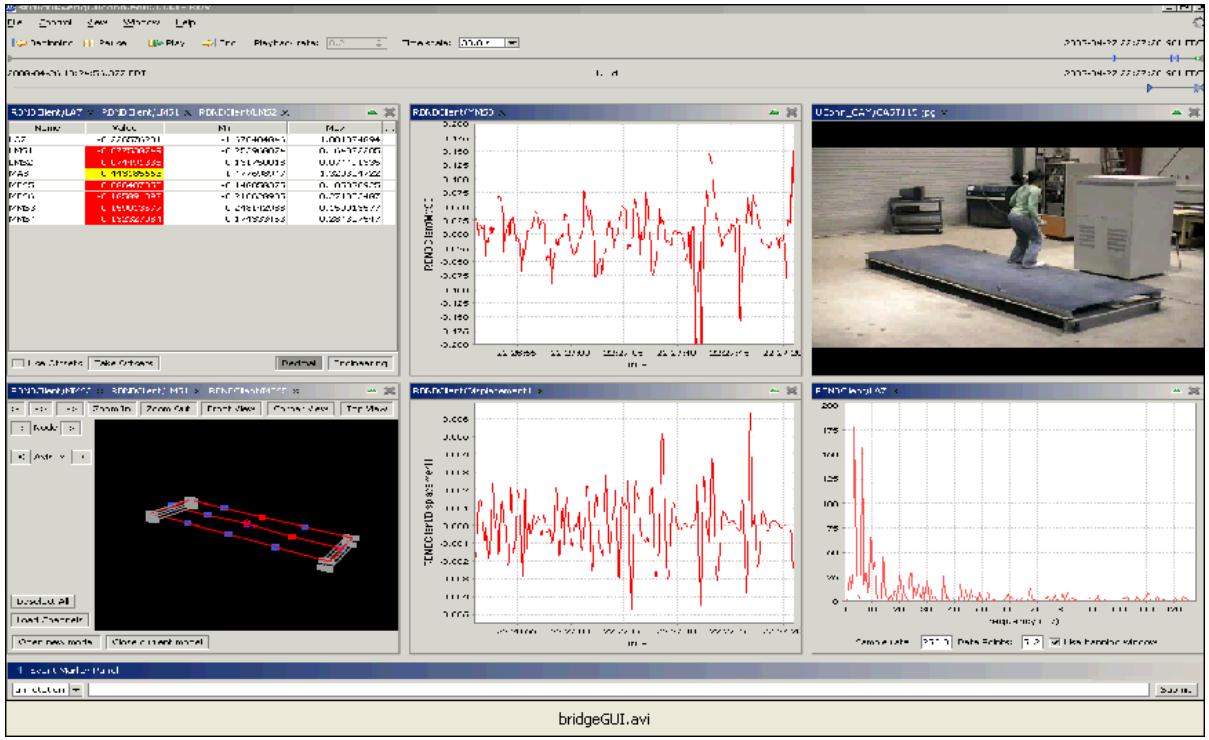


Ductal self-healing properties



Sensing & Modeling

- Real- time sensing & modeling of scale model bridge
- Measured structural response & modeling integrated for structural health monitoring
- System based on discrete conventional sensors (accelerometers, strain gages, etc)
- System deployed on 6 highway bridges



bridgeGUI.avi

Sensing & Modeling

- Long- term continuous structural health monitoring systems on 6 Connecticut bridges
- System based on discrete conventional sensors

Goldstar Bridge,
New London, CT

System Components

System Energy
(Solar Panels)

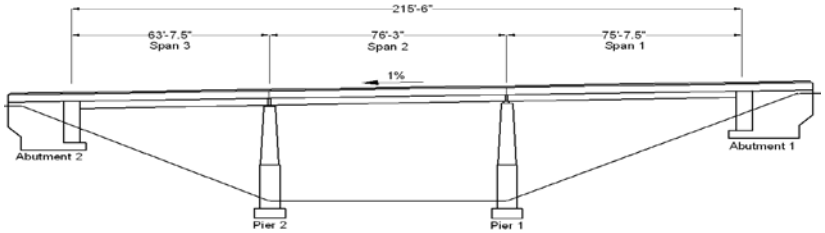
Sensor
Installation

What are the research needs?

- Modeling of highly complex structures
- Distributed sensor system integrated with structural design

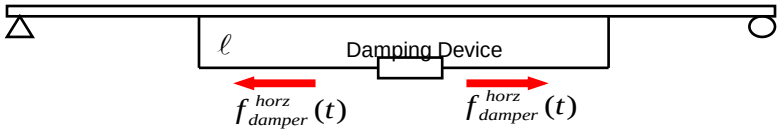
Structural Control

- Structural control of bridges for service loads using magneto- rheological fluid damper
- Study based on hybrid testing (model structure & actual MRF damper)
- Significant reduction (33%) in controlled response of bridge

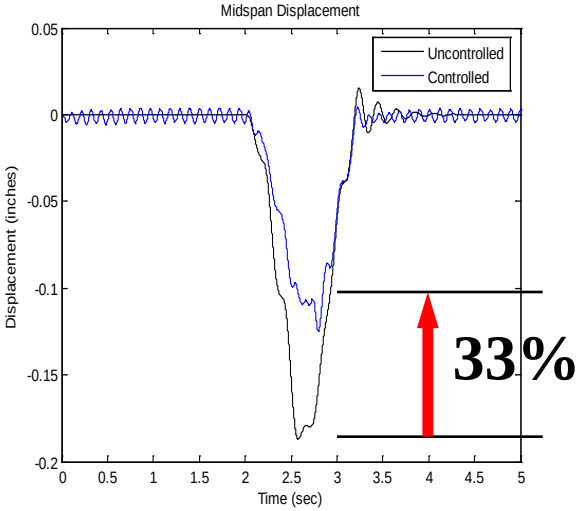


Bridge Model

Control Strategy



MRF Damper Test



Controlled vs. Uncontrolled Response

What are the research needs?

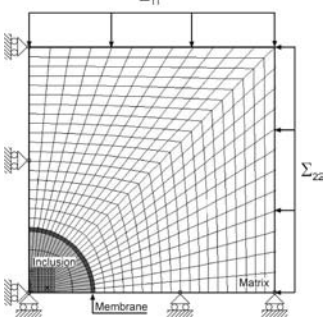
- Distributed versus discrete control strategy
- Integration of control strategy with structural design

Sensing & Modeling – same concept but different structure

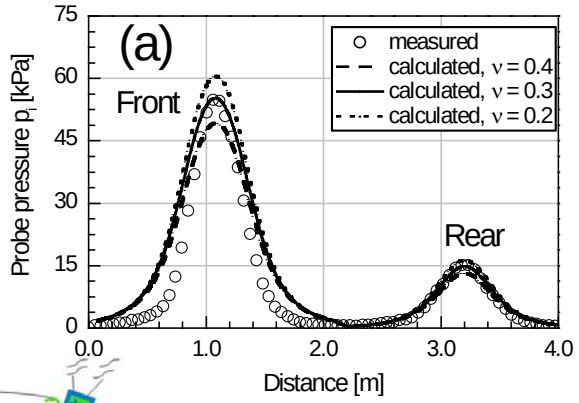
- Modeling & simulation of earth structures (levees)
- Development of sensors for earth structures

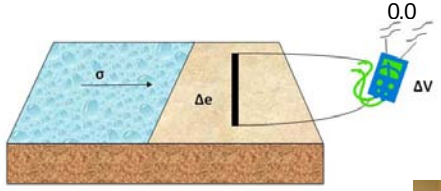
Levee Breach

Soil Modeling & Simulation

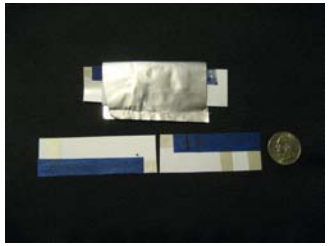


Soil Model Validation Test





Soil Sensor



Soil Sensor Testing

What are the research needs?

- Advanced materials – improve soil properties
- Develop earth structure control strategy
- Integrate sensing & control with design

Advanced Materials

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George A. Rossetti, Jr.
Chemical, Materials and Biomolecular Engineering
& Institute of Materials Science

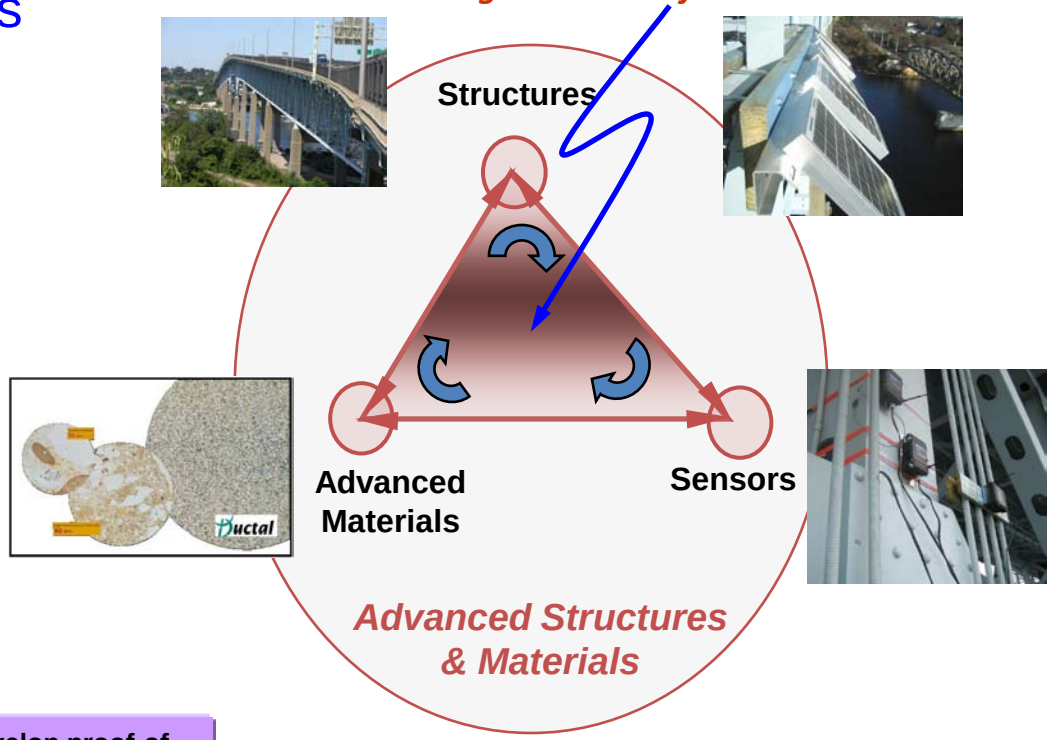
Vision: Integrate Functionalities in Materials for Advanced Structures

Material Capabilities

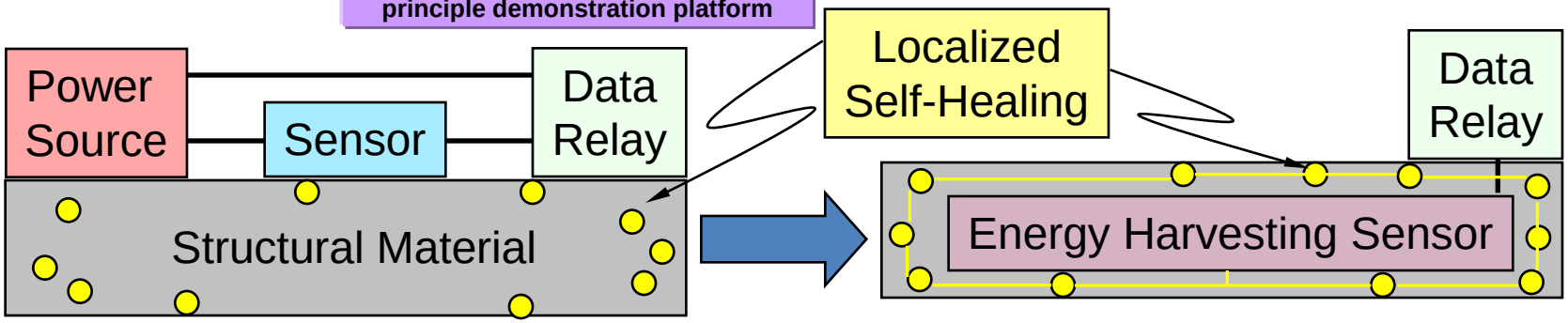
- ⇨ Self-Monitoring
- ⇨ Self-Diagnostic
- ⇨ Self-Healing
- ⇨ Self-Actuating
- ⇨ Self-Powering

Advanced Materials

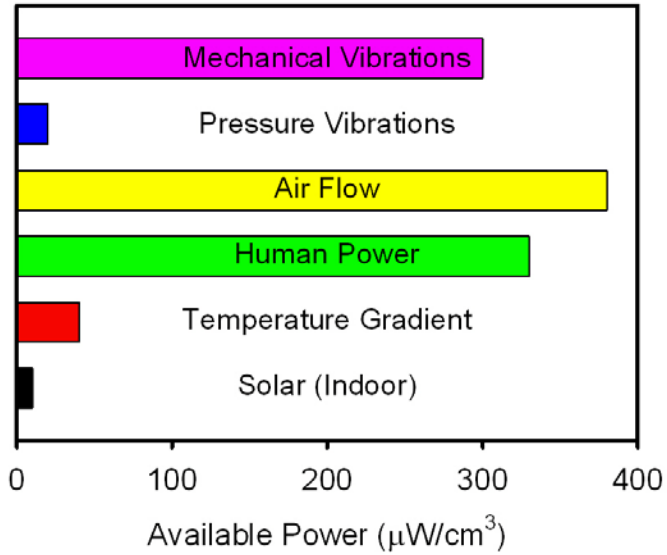
Autonomous & Integrated Multifunctional Materials



Research Goal: Develop proof-of-principle demonstration platform



Energy Harvesting Opportunities and Demonstrated Capabilities



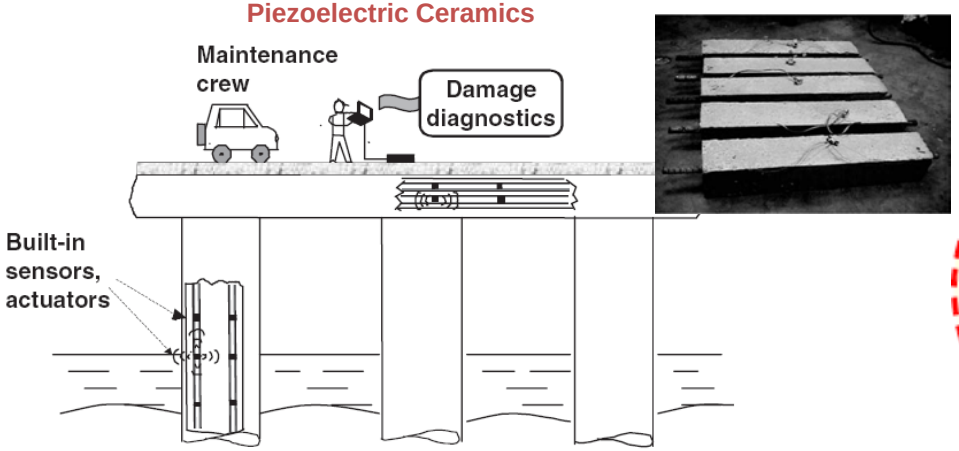
Source: VT Center for Energy Harvesting Materials & Systems

⇨ Piezoelectric transducers offer one possible platform for integrated solid-state energy harvesting and sensing functionalities

Energy Source	Performance
Ambient radio frequency	< 1 μW/cm^2
Ambient light	100 mW/cm^2 (directed toward bright sun) 100 μW/cm^2 (illuminated office)
Thermoelectric	60 μW/cm^2
Vibrational microgenerators	4 μW/cm^3 (human motion—Hz) 800 μW/cm^3 (machines—kHz)
Ambient airflow	1 mW/cm^2
Push buttons	50 μJ/N
Hand generators	30 W/kg
Heel strike	7 W potentially available (1 cm deflection at 70 kg per 1 Hz walk)

Source: J. A. Paradiso and T. Starner, Pervasive Computing (2005).

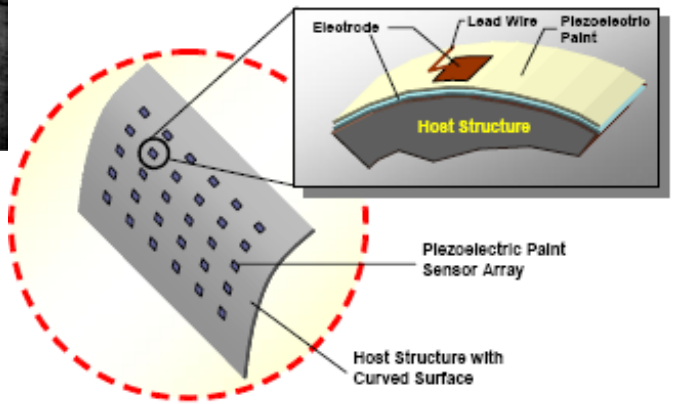
Embedded Monolithic Piezoelectric Ceramics



⇨ Debond detection in reinforced concrete

Source: F. Wu and F.-K. Chang, SHM 5 (2006) 5

0-3 Composite Piezoelectric Paint

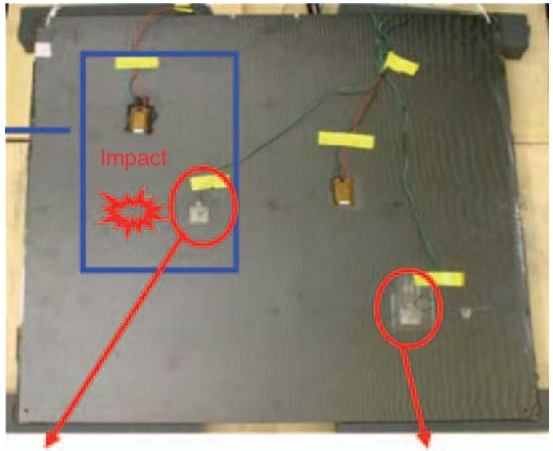


⇨ Vibration and structural health monitoring

⇨ Surface crack / overstress, impact or blast event detection

Source: Y. Zhang, Proc. SPIE 5765 (2005) 1095

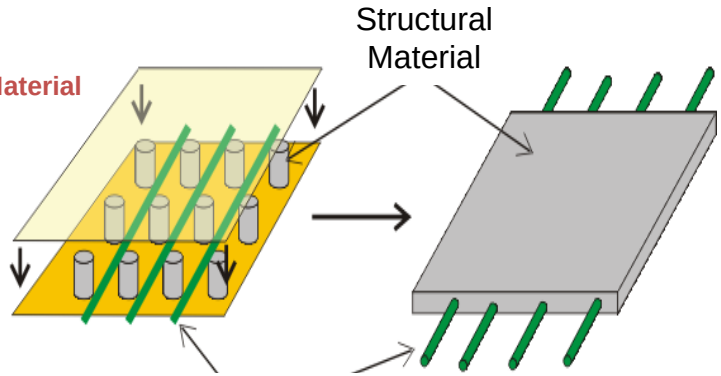
Piezoelectric Sensor Self-Diagnostics



⇨ Faulty piezoelectric sensor detection

Source: S. Park et al. SHM 8 (2009) 71

Multifunctional Material



Structural Element Sensor

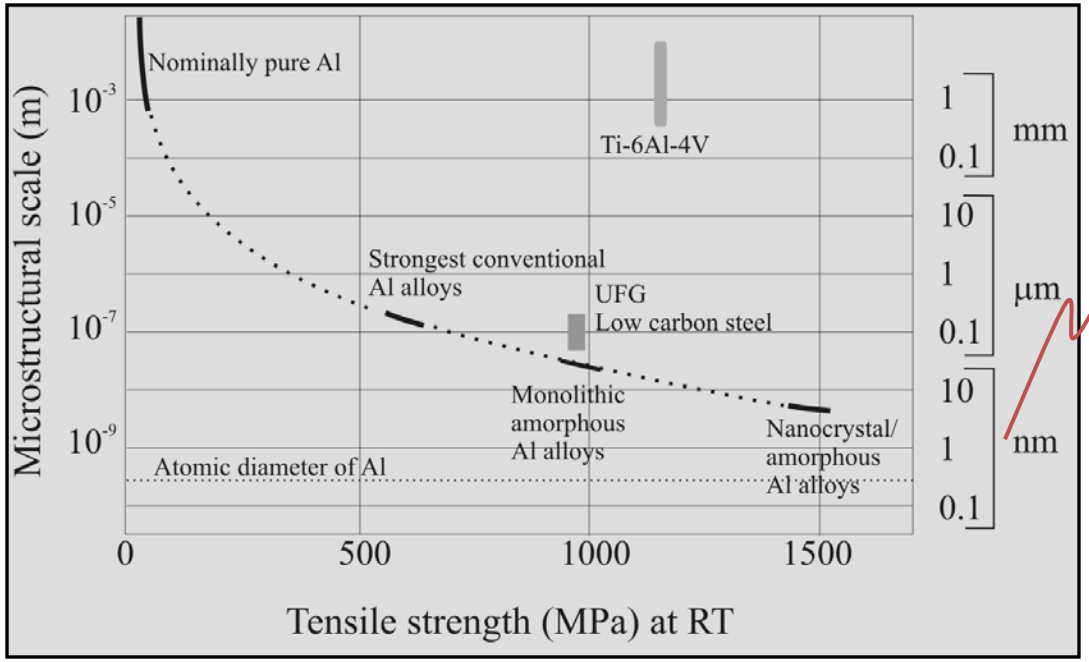
⇨Monitoring

Energy harvesting transducer

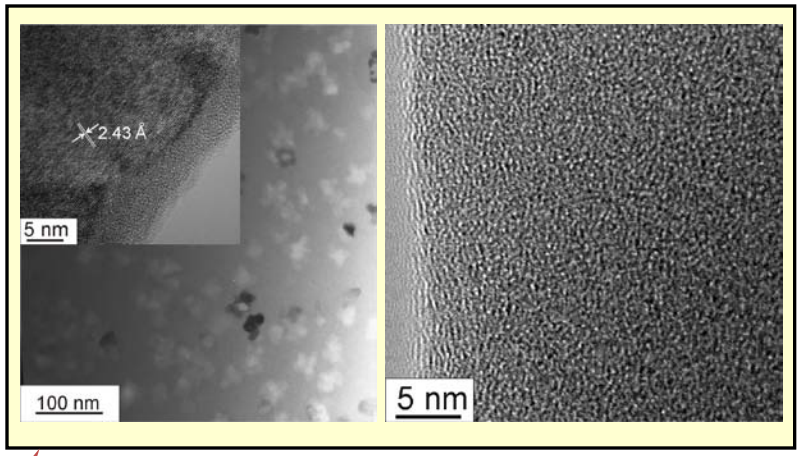
⇨ Diagnostics, Actuation, Healing

Bulk Metallic Glasses (BMGs)

- ⇨ High strength due to amorphous / nanocrystalline state
- ⇨ High wear resistance for some alloys
- ⇨ High corrosion resistance for some alloys



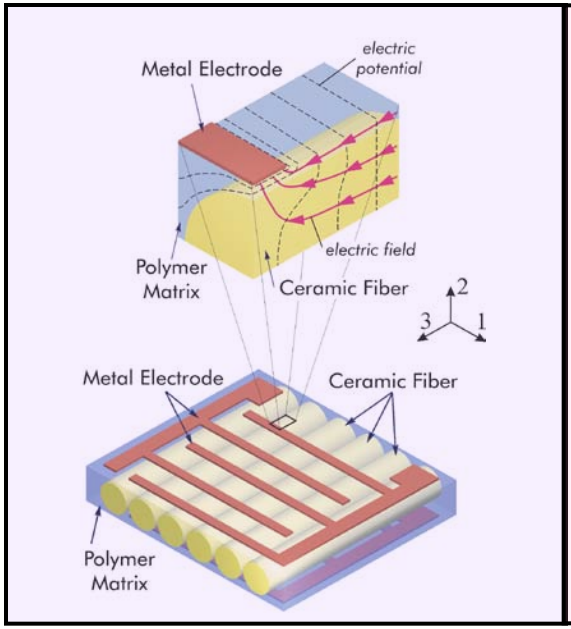
Source: Greer, Nature 368 (1994) 688.



BMG Attributes

- ⇨ Excellent mechanical properties
- ⇨ Low temperature processing
- ⇨ Integration with active materials
- ⇨ Healing through localized flow

Piezoelectric Fiber Composites (PFCs)



- ⇨ Robust and conformable
- ⇨ Directional
- ⇨ Architectural flexibility
- ⇨ Ease of integration
- ⇨ Damage Tolerance
- ⇨ COTS

Demonstrations

Rotorcraft

Dynamic twist control

Twin Tail Aircraft

Active buffet load alleviation

Payload Fairings

Structural-acoustic noise transmission reduction

Commercial Products

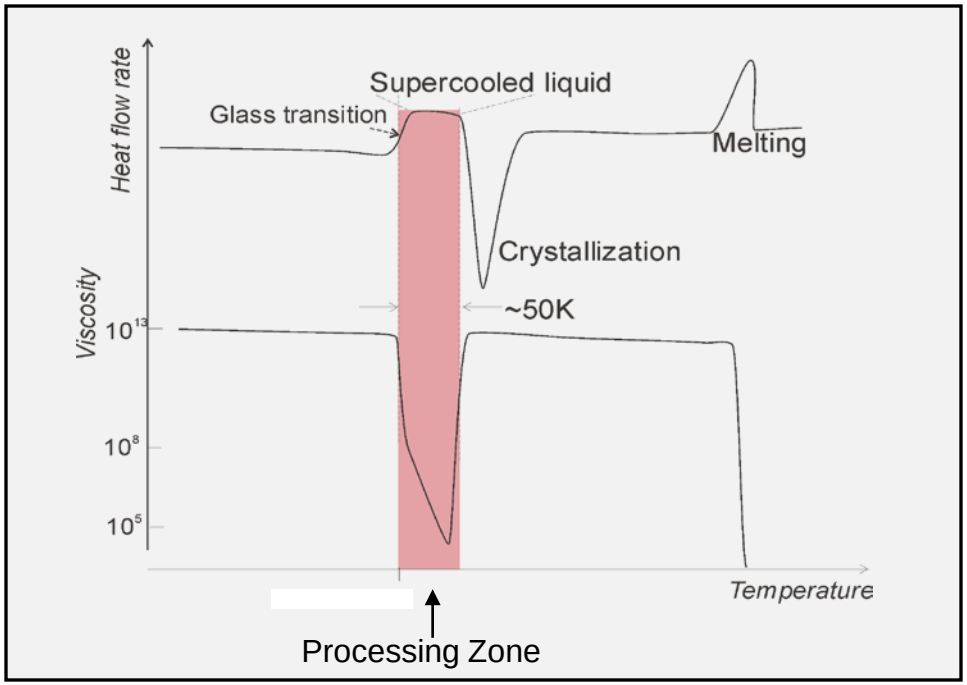
Head Intelligence™ Sporting Goods

Active Damping

ACI Harvestor™

Energy Harvesting

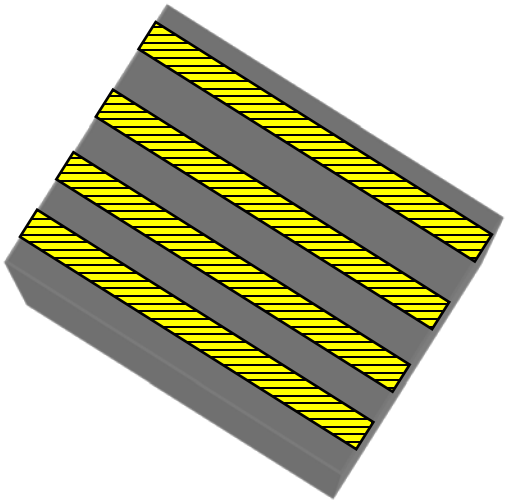
Hybrid Materials: Integration of Piezoelectric Fiber Composites in Bulk Metallic Glasses

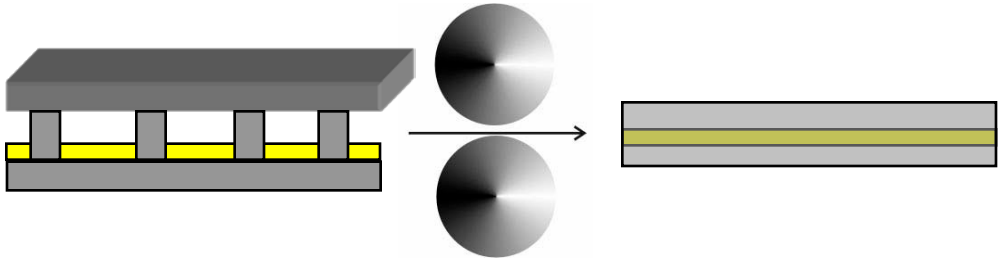


Research Goal: Develop alloys compatible with PFC transducers

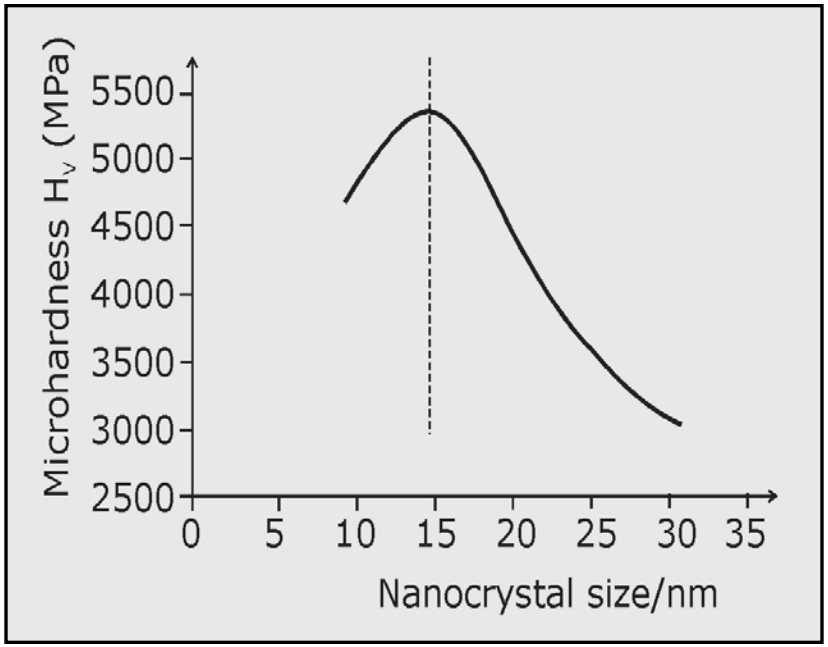
⇨ Metallic glasses can be cast or molded similar to polymeric materials at modest temperatures

⇨ A wide array of architectures are possible to optimizes surface, bulk and interfacial properties





Property Control: Bulk Metallic Glasses



Source: W.S. Sun, M.X. Quan, Mater. Lett. 27 (1996) 101

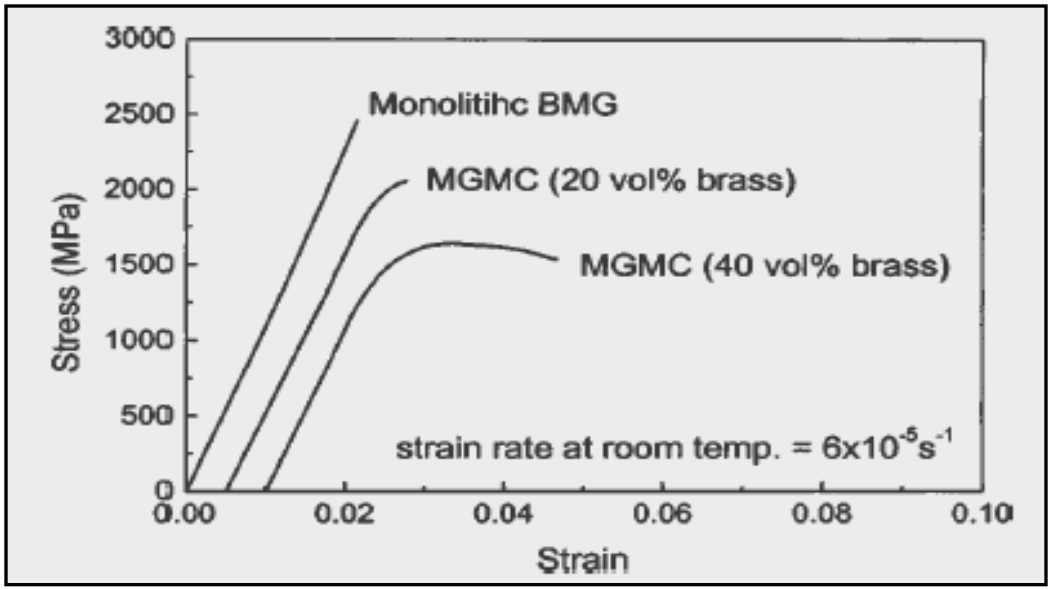
Compositional Design

⇨ Alloy composition controls melting and glass transition temperatures

⇨Process temperatures as low as 200 °C can be achieved under appropriate conditions

Nanostructure Engineering

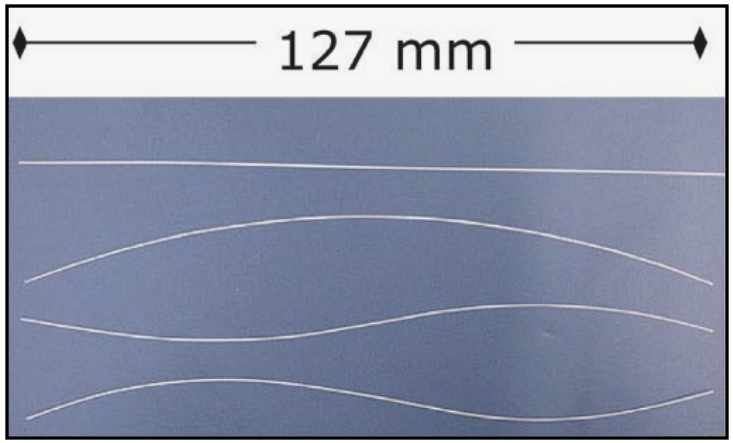
⇨ Size, volume fraction and spatial arrangement of nano-crystals controls hardness and ductility



Source: Bae, Lee, Kim, Sordelet, APL 83 (2003) 2312

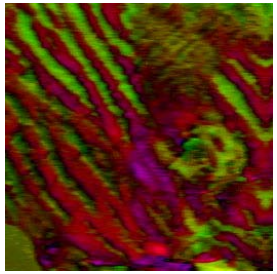
Property Control: Piezoelectric Ceramic Fibers

Large Non-linear / Remanant Deformation

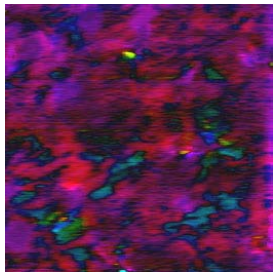


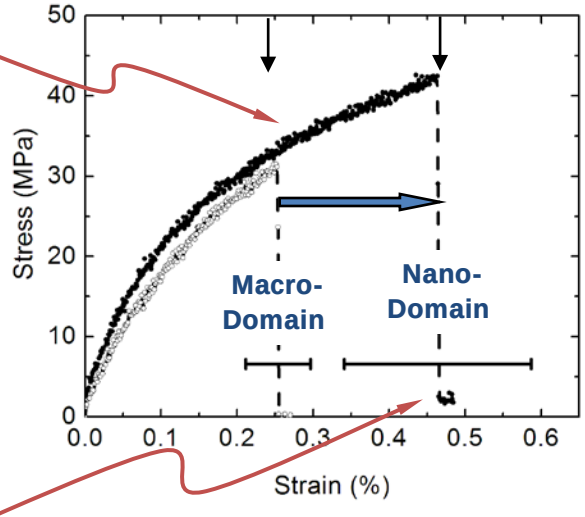
Research Goal: Develop piezofiber materials with enhanced mechanical & electromechanical properties

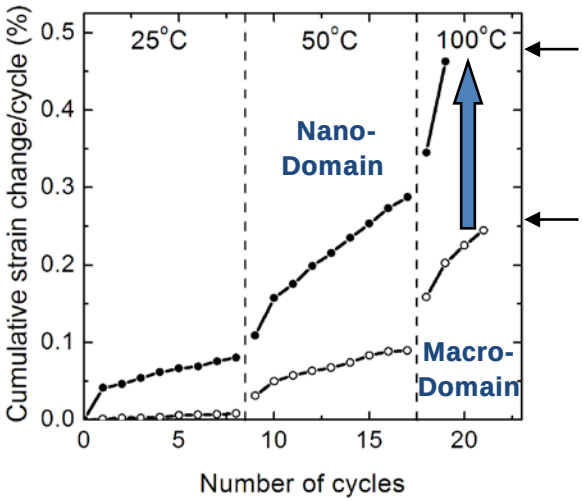
Macro-Domain



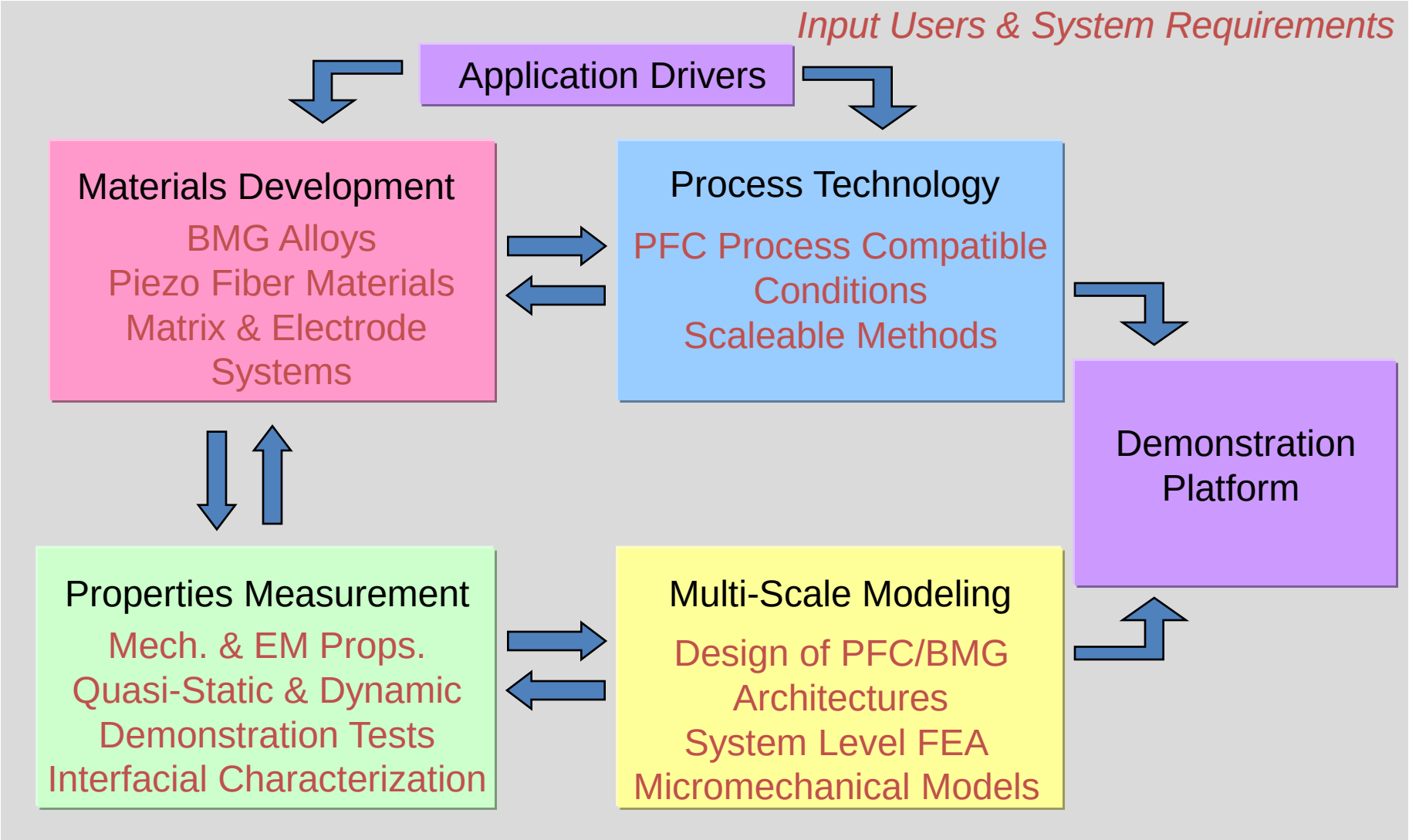
Nano-Domain







Nanostructure Engineering

⇨ Phase composition, size, volume fraction and architecture of nano-domains controls stress accommodation, strain-to-failure and piezoelectric properties

Advanced Materials R & D Program