DRIVING TECHNOLOGY. MATERIALS FOR THE WARFIGHTER.

US Army Research Office
Materials Science Division

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Revolutionary Materials are the Basis for Army Transformation

Today

~100 lb. load

70+ tons

0 mph

Fit the C-130 "crucible"

Objective force

< 30 lb. effective load

< 20 tons

> 40 mph

Innovation -- Accelerating the pace of Army transformation

ARO Materials Science Vision

To identify and enable basic research opportunities in materials science that have the potential to transform Army capabilities and help maintain U.S. technological superiority

To lead the Army by embracing long-term, high risk, high-payoff opportunities with special emphasis on: Materials Design, and Mechanical Behavior of Materials, Physical Properties of Materials, and Synthesis and Processing.

ARO Materials Science Division Staff

Materials Design

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Synthesis and Processing

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ARO Materials Science
Army Impact

	Materials Design	Mechanical Behavior	Physical Properties	Synthesis and Processing
Firepower		■		■
Mobility		■	■	■
Armaments	■		■	
Communica-tions	■	■	■	
Personnel Protection	■	■		■
Logistic Support	■		■	■

Motivation: The Soldier of 2033
"Unprecedented Material Properties"

ARO Materials Science Research Subfields

Materials Design

- Growth and Processing Design
- *In-situ* and *Ex-situ* Characterization

Mechanical Behavior of Materials

- High Strain-Rate Phenomena
- Materials Enhancement Theory
- Tailored Functionality

Physical Properties of Materials

- Engineering of Nanostructured Materials
- Defect Engineering
- Multifunctional Materials
- Spin-Based Phenomena

Synthesis and Processing

- Metastable Materials and Structures
- Novel Processing Strategies

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Materials Design Vision

Application specific properties tailored to material performance requirements through materials design; the ability to predict and control material property changes during synthesis, processing and operation, based on science rather than statistics.

Materials Design Opportunities

- **Growth and Processing Design**
  - Develop robust synthesis procedures, with complementary simulations, to enable precise engineering of materials surfaces and interfaces
  - Realize real-time property control and predictive capabilities, including nonequilibrium processing approaches

- ***In-situ* and *ex-situ* Characterization**
  - Realize novel material analysis approaches emphasizing *in-situ* techniques and nanometer scale resolution capabilities
  - Demonstrate ability to monitor properties of interest throughout synthesis to guide process and control optimization

Multiscale Surface-Structuring for Infection Control (M. Libera: Stevens Institute of Technology)

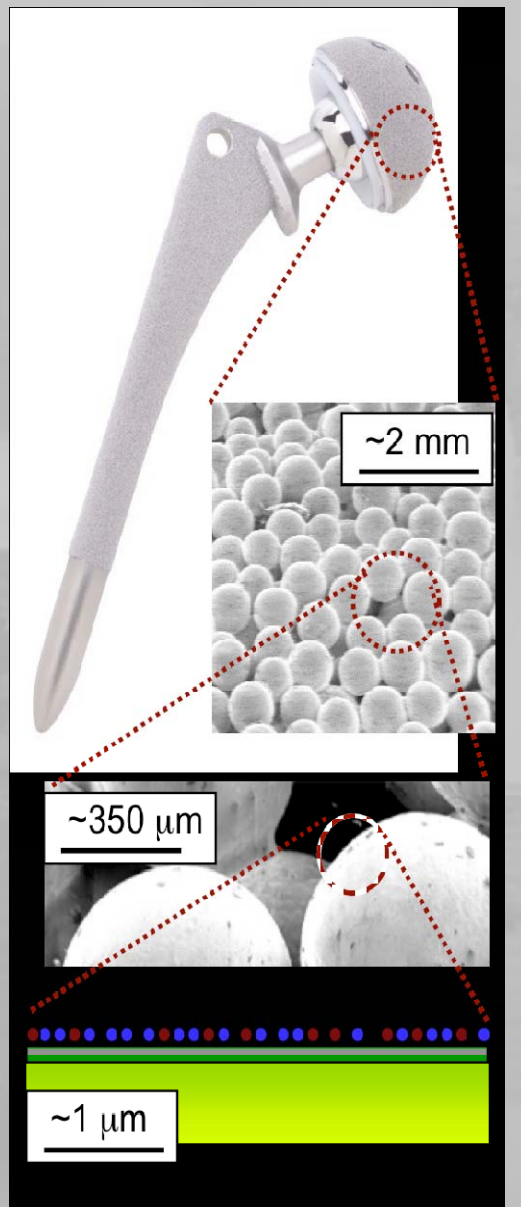
Objective: Determine the fundamental differences between bacterial cells and eukaryotic cells to create synthetic surfaces where eukaryotic cells can adhere while bacterial cells are repelled

Approach:

- Multiscale surface-structuring technology
- Cell-repulsive and cell-adhesive nanohydrogels
- Electrostatic self-assembly

Results:

- Established protocols to create innocula that mimic single-cell planktonic bacteria
- Established nanopatterning methods to create model surfaces patterned at nano and micro length scales
- Demonstrated ability to promote restoration of normal physiological function but simultaneously resist bacterial adhesion and biofilm formation



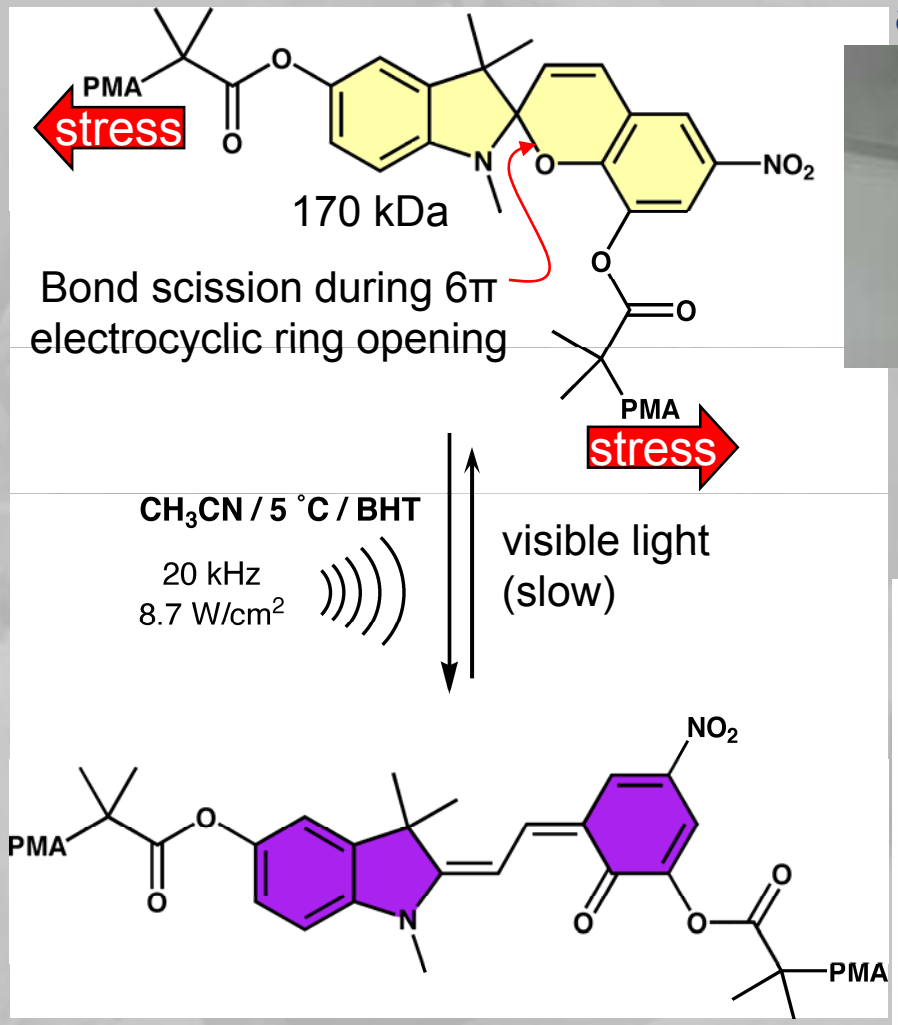
Mechanical Behavior of Materials Vision

Materials with unprecedented formulations of mechanical and complementary properties for enhanced war fighter and battle systems capabilities.

Mechanical Behavior of Materials Opportunities

- **High Strain-Rate Phenomena**
  - Elucidate the physical mechanisms which govern high strain-rate deformation in advanced materials
  - Realize novel mechanisms of energy absorption and dissipation
- **Materials Enhancement Theory**
  - Establish new materials science theory capable of predicting processing-property relationships for engineering materials
  - Identify design rules for enhancing specific toughness
- **Tailored Functionality**
  - Demonstrate materials containing unique and specifically designed chemical and biological functionalities and activities while maintaining (and preferably enhancing) requisite mechanical properties

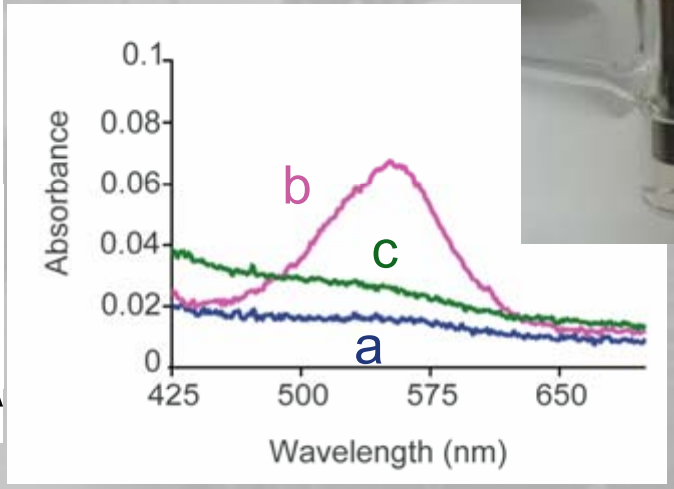
Color-Generating Mechanophores
(J. Moore, N. Sottos, P. Braun: U. Illinois U-C)



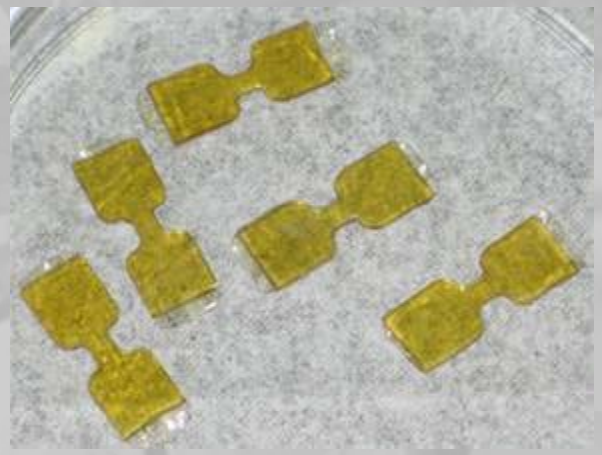
a) before

b) after

c) 2 hours ambient light

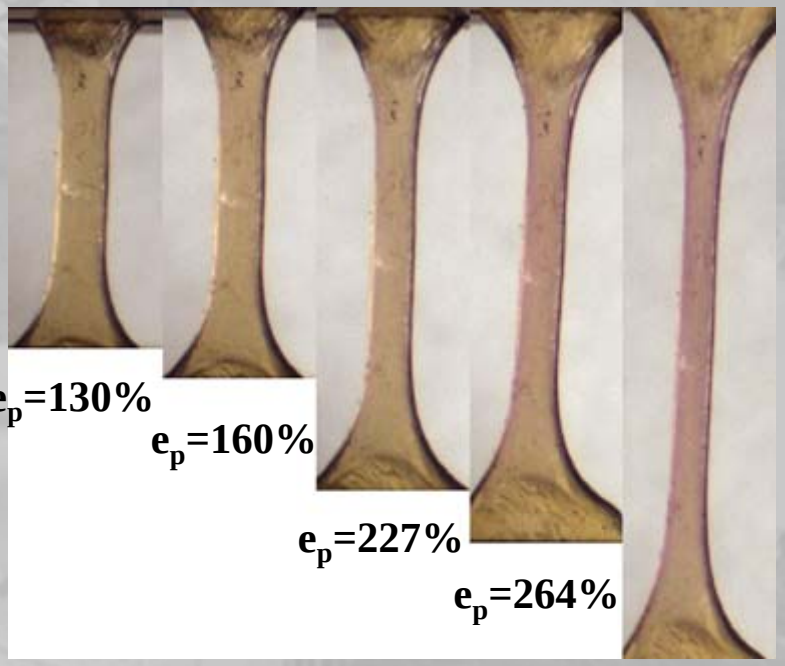


Damage Sensing Composites
(J. Moore, N. Sottos, P. Braun: U. Illinois U-C)



Cycles: 16 18 20 22 23

5 mm



After failure

(Images taken at initial yield point for each loading cycle)

Physical Properties of Materials Vision

Novel electronic, optical, magnetic and actuator materials derived from defect engineering and materials integration; materials theory to guide and predict optimization.

Physical Properties of Materials Opportunities

- **Engineering of Nanostructured Materials**
  - Realize control of material structure at the nanoscale that provides significant enhancements in performance beyond simple scaling laws
- **Defect Engineering**
  - Utilize and manipulate defects to control the behavior and properties of novel material systems
- **Multifunctional Materials**
  - Demonstrate material systems with unique EMO properties, particularly those with extensive coupling between interacting elements that lead to complex behaviors
- **Spin-Based Phenomena**
  - Exploit spin -mediated processes for future multifunctional, spin-based devices

Lattice-Mismatched Substrate Engineering (E. Fitzgerald: MIT; S. Ringel: OSU)

Objective: Grow any III-V or II-VI Semiconductor on Si Substrates

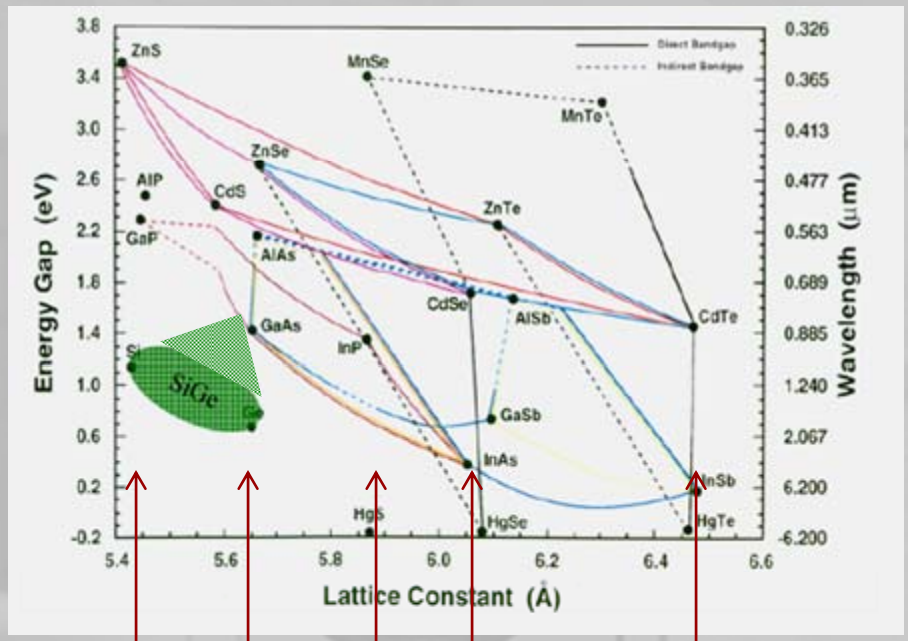
Approach: Combine Relaxed Graded Buffer Layer Growth and Layer Release and Transfer Technologies to Methodically Move Towards Larger Mismatched Systems

Fitzgerald Lab: MOCVD
Ringel Lab: MBE

Technology Transitions

SOITEC: SOLES substrate
IQE: III-V epi-growth supplier
DARPA: COSMOS Demo
(Raytheon Lead)

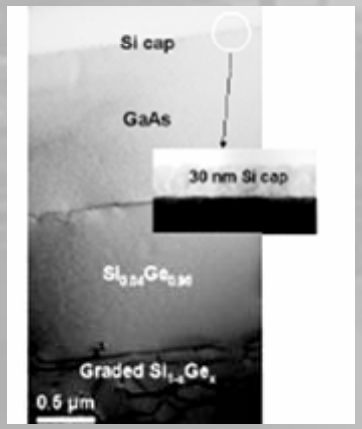
13 Patents Awarded



Nodes: ***Si*** ***Ge*** ***InP*** ***InAs*** ***CdTe***

GaAs

Graded SiGe and epi GaAs – DONE !



Synthesis and Processing Vision

Innovative approaches to the synthesis of reliable, low cost, and environmentally friendly new materials; robust application of thermo kinetics to provide metastable materials with unprecedented properties.

Synthesis and Processing Opportunities

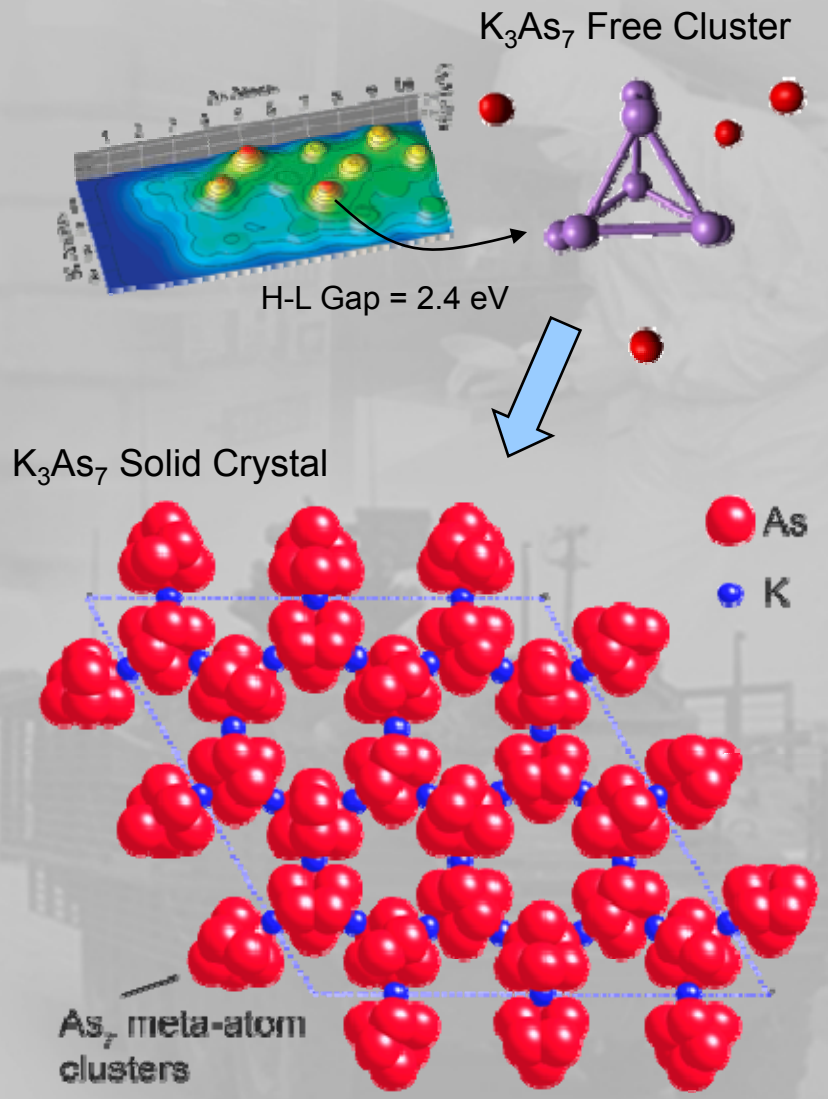
- **Metastable Materials and Structures**
  - Develop superior and affordable alloys, fibers, and composites with highly controlled and meta-stable structures
  - Demonstrate *ab initio* theoretical approaches to design target electronic structures for functional moieties, and synthesize materials that exhibit these units to produce novel properties

- **Novel Processing Strategies**
  - Establish and utilize advanced and innovative processing approaches to develop unique combinations of materials, particularly those which offer enhanced repair or self-healing capabilities

Cluster Materials
(A. Castleman: Penn State; S. Khanna: VCU)

- **Accomplishments**
  - **Discovery of stability of metallic $Al_{13}K$**
  - **Discovery of stable K_3O clusters and prediction of $(K_3O)(Al_{13})$ as a stable material**
  - **Characterization of Al_xAu_y clusters on SAM surfaces**
  - **Growth of K_3As_7 crystals from hydrazine solution**

- **Motivating novel electronic and optical devices for sensors and communications; new spintronics materials**



ARO Perspective: A Few Common Misunderstandings

1. “The program manager is too busy to talk to me”
2. “The program manager wants to tell me what to study”
3. “My white paper isn’t complete, or in the right format”
4. “Mission agencies really want devices and products”
5. “Nanotechnology will make my proposal better”

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Complementary RDECOM Mechanics Research

Materials Design
- ARO Life Sciences Division
- ARL WMRD
- ARL SEDD
- ARDEC
- NSRDEC

Mechanical Behavior of Materials
- ARO Mechanics Division
- ARO Life Sciences Division
- ARO Chemistry Division
- ARL WMRD
- TARDEC
- NSRDEC

Physical Properties of Materials
- ARO Physics Division
- ARO Electronics Division
- ARL SEDD
- CERDEC

Synthesis and Processing
- ARO Chemistry Division
- ARL WMRD
- ARDEC
- NSRDEC
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