



Materials Research Overview

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16 November 2016

The Nation's Premier Laboratory for Land Forces



Materials Research



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Research Areas

Photonics	Electronics	Energy and Power	Bio and Bio-Inspired	Manuf. Science	High Strain Rate and Ballistics	Structural
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Research Areas

	Photonics	Electronics	Energy and Power	Bio and Bio-Inspired	Manuf. Science	High Strain Rate and Ballistics	Structural
	Energy-efficient electronics and photonics						
			Agile expedient manufacturing				
			Materials for Soldier and platform power systems				
	Quantum sciences				Energy-coupled-to-matter for responsive materials		
				Lightweight materials for Army platforms			

Key Campaign Initiatives



Materials Research



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Research Areas

Photonics	Electronics	Energy and Power	Bio and Bio-Inspired	Manuf. Science	High Strain Rate and Ballistics	Structural
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Energy-efficient electronics and photonics

Agile expedient manufacturing

Materials for Soldier and platform power systems

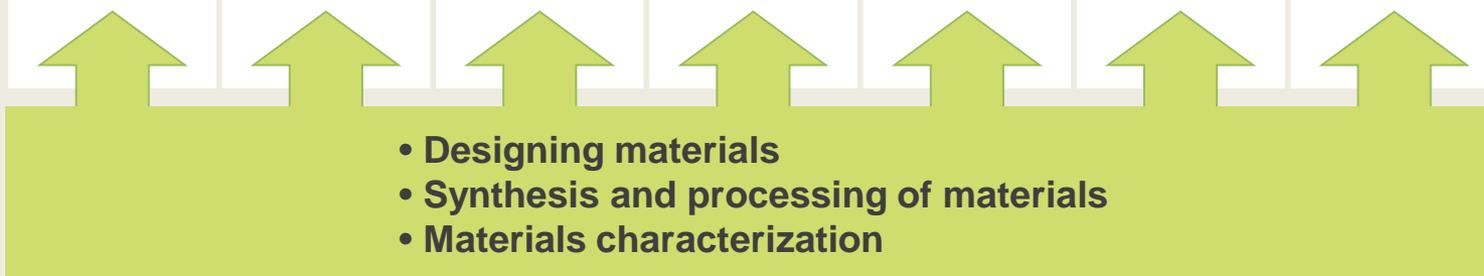
Quantum sciences

Energy-coupled-to-matter for responsive materials

Lightweight materials for Army platforms

Key Campaign Initiatives

Core Campaign Enablers





Materials Research Posters & Tours



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Research Areas

Photonics	Electronics	Energy and Power	Bio and Bio-Inspired	Manuf. Science	High Strain Rate and Ballistics	Structural
Imaging Sensor & Optics (2)	Energy Efficiency (4+1 tour)	Power Generation/ Harvesting (5+1 tour)	Technology from Biology (2 tours)	Advanced & Additive Manuf. (6)	Ceramics & Transparent (4)	
Sensor Protection (1)	RF Active & Passive (2)	Energy Storage (1+1 tour)		Energy Coupled to Matter (7)	Lightweight & Specialty Materials (3)	
Quantum Information Science (2 tours)	MEMS (2 tours)	Fuel Cells (1)		Corrosion & Fatigue (1)	Fabrics & Wearables	
	Nano & 2D (1 tour)			Polymer Coatings (1)		

Alternative Energy

S&T Campaign: Materials Research Energy & Power
Power Generation & Energy Harvesting

Cindy Lundgren, (301)-394-2541
cynthia.a.lundgren2.civ@mail.mil
Kimberly A. Sablon, (301)-394-5791
kimberly.a.sablon.civ@mail.mil

Research Objective

- Develop compact, portable power sources that can sustain long mission times (>72hrs) while reducing the physical burden to the Warfighter.
- Reduce logistic resupply of fuel by producing fuel on the battlefield with readily available resources.
- Improve overall operational energy efficiency (OEE)

ARL Facilities and Capabilities Available to Support Collaborative Research

- State of the art III-V MBE system for PV, PEC materials and IV-VI MBE system for TE materials.
- Ultrahigh vacuum variable temperature STM for



234 Student Interns 2014-'16

- Joint-authored journal, conference papers, and book chapters
- ARL staff serving on Ph.D. committees

4 Student Visiting Researchers

- Penn State (former ARO MURI performer)
- U. of Maryland (former Collaborative Technology Alliance performer)
- Bowie State U. (HBCU outreach via Collaborative Technology Alliance)

13 PI Visiting Researchers 2014-'16

- U. of Maryland, Northwestern, GWU, UT, Lehigh, Naval Academy, CERDEC, and others

Future Personnel Exchange Opportunities

- ARL West (Los Angeles, CA)
Human information interaction for effective mission command
- ARL South (Austin, TX)
Additive manufacturing
- ARL Central (Chicago, IL)
High performance computing, materials characterization for battlefield protection



Playa Vista

USC University of Southern California

El Paso
College Station
San Antonio
Austin

Univ. of Chicago
Illinois Inst. of Tech.
Illinois Res. Corr.
Marquette Univ.
Univ. of Wisconsin
Univ. of Illinois
Northwestern Univ.
Indiana Univ.
Purdue Univ.
Univ. of Michigan
Notre Dame Univ.
Argonne National Lab
Fermi National Lab

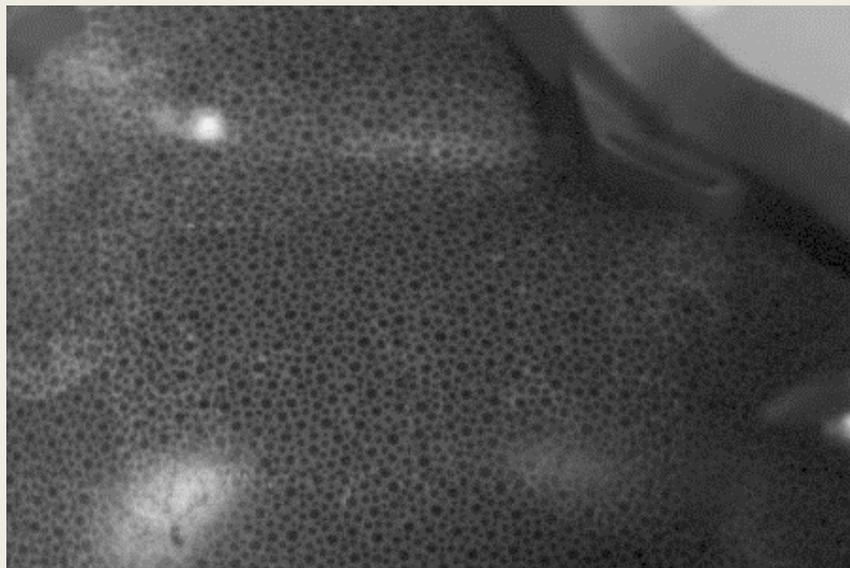




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Industry / Government / Academia
Partnership

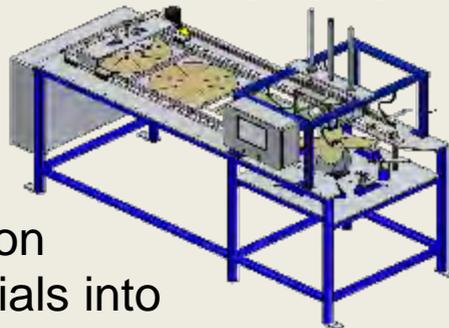
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Interior of Helmet after Exterior Bullet Impact

Key External Collaborators:

- 3M Ceradyne (formally Diaphorm LLC): Automated ultra-high pressure consolidation of thermoplastic ballistic materials into helmet shells
- University of Alabama (Birmingham): Novel long fiber thermoplastics for carbon shell



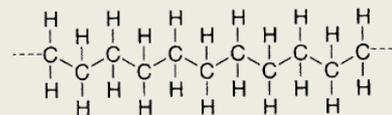
**Top 100
Innovations
award,
Popular
Science 2013**



Enhanced Combat Helmet (ECH)

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ARL and collaborators identified process/property performance correlation for Ultra High Molecular Weight Polyethylene (UHMWPE)



ECH fielded by Marines and Army with first ever small arms specification

- Soldier's life saved by ECH as documented by 7.62 mm bullet strike in August 2014



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Joint ARL / Industry Proposals

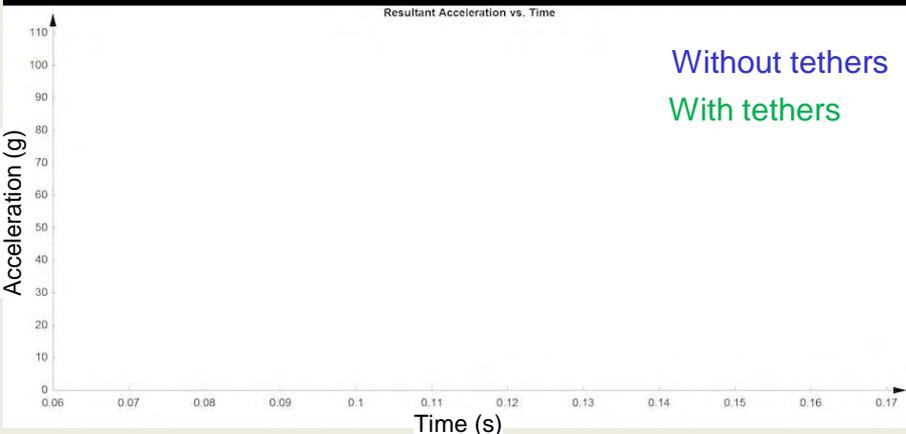
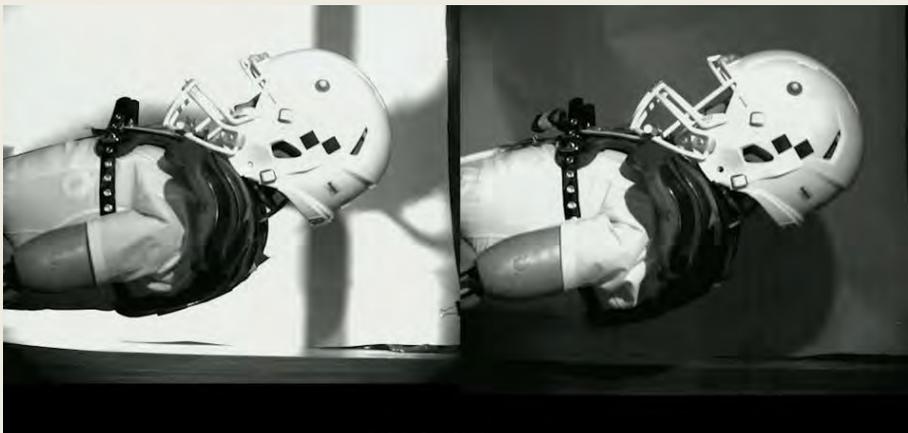
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Without tethers

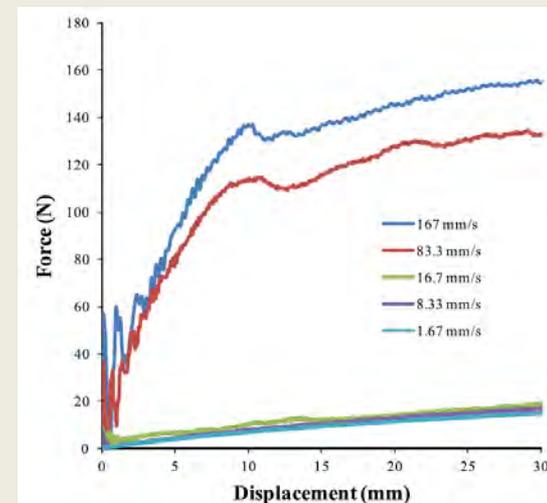
With tethers



Rate-activated tethers reduce peak head acceleration from 99g to 53g



- “Shear thickening” fluid-filled tubes contain CaCO_3 particles (>50% volumetric loading)
- 10-100X higher resistance to displacement when pulled quickly



Next Steps:

- Partnering with sporting goods manufacturer for planned garment prototype demo at Super Bowl 2017
- Four industry CRADA partnerships in place; two in negotiation for alternative applications





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Small Business Partnership

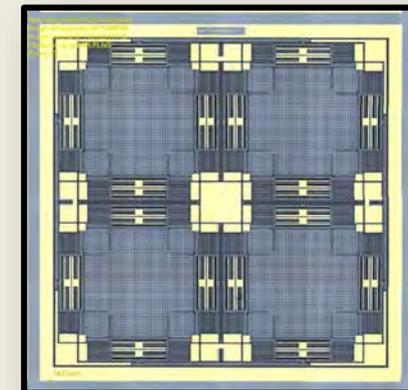
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Collaborative Efforts:

- CRADA with Kurt J Lesker, Inc. (KJLC) to explore ALD equipment and processing
- Customized KJLC Vacuum Package Bonder purchased for MEMS inertial sensor work
- ARL worked with KJLC to develop new packaging process for CERDEC MEMS quad mass gyroscope (QMG)
- ARL offering sub-mT vacuum packaging for other inertial sensors from DARPA programs
- At least three are interested in procuring their own system from KJLC, with more sales likely to follow



Generation 1 QMG

KJLC vacuum packaging tool – base vacuum 1.5E-8 Torr

Technical Results:

- Milli-Torr level vacuum packaging of the QMG expected to enable < 0.01 deg/hr bias instability, 10X better than any current MEMS-scale gyroscope



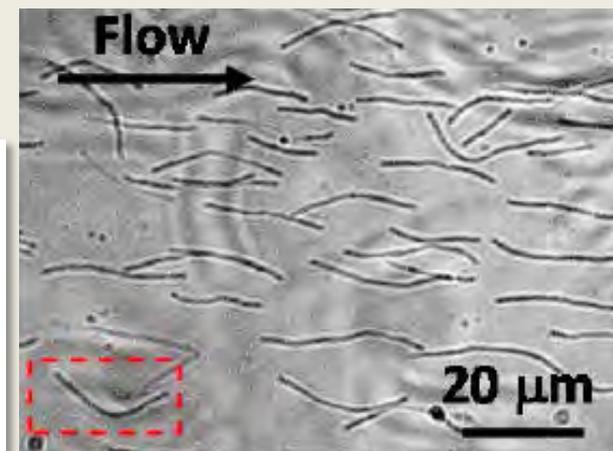
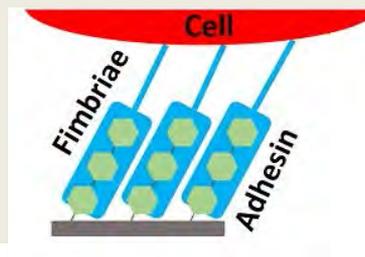
Process chamber



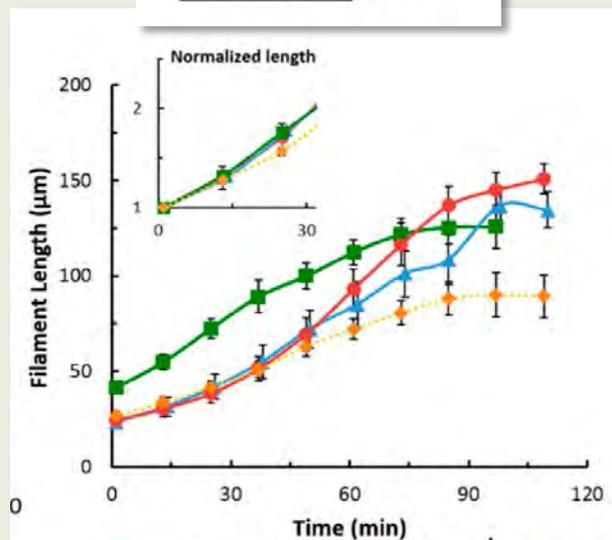
Lower platen w/ ceramic chip carriers



Measurement & setup with waveguide in microfluidic channel



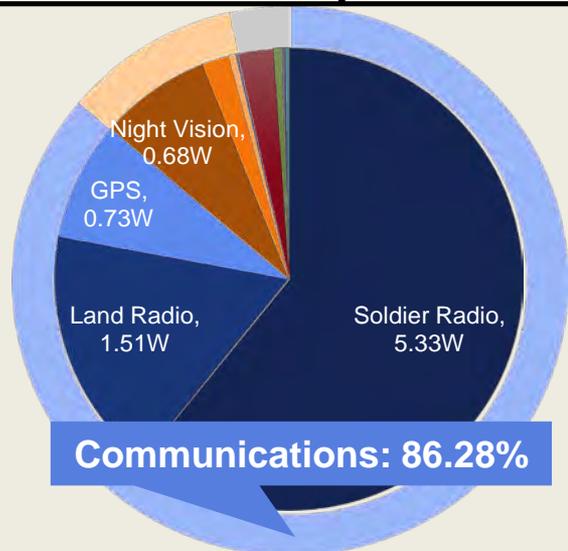
Elongated bacterial filaments grown under shear flow conditions



- Collaboration with Lehigh University's Prof. Cheng, on sabbatical at ARL
- Microfluidic channel experimental expertise enabled recent publication in *Molecules* highlighting:
 - Engineered cell adhesion under shear flow conditions dramatically increased control over filament length.
 - "Living" filaments could lead to new sensing, actuating, or self-healing structures
 - Research could also lead to better understanding of immune system response to long, narrow structures



Current Soldier power draw



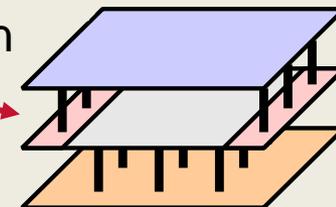
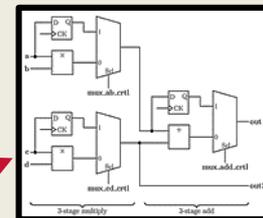
- 16 lbs in batteries required for 72 hr
- Requirements continue to increase

Collaborative Efforts:

- U. of Maryland summer student 2016, two more planned in 2017
- ARL West campus focus on efficient electronics for mission command
- CRADAs with Semiconductor Research Corporation and other companies planned

Initial Research Focus

- Increase Soldier Radio efficiency >10X within the next 5 years
- Initial design simulation:
 - Dedicated flexible accelerators
 - Memory integration with application specific IC memory controller
 - **72x efficiency improvement** over conventional FPGA implementation of FFT (Gadfort et al., IEEE SOCC)

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Future Research





New Open Campus Facilities

Open Campus Access Door

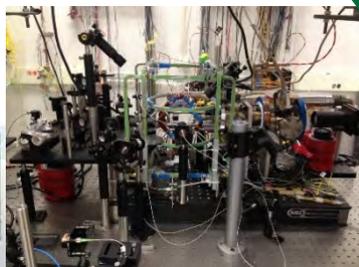
Rare Earth
Crystal
Qubits

Neutral Atoms

Trapped
Ions

Solid-State Qubits
Quantum Optics &
Materials

SiC Reactor



Collaborative Activities

- Collaborative basic research on multi-node quantum entanglement to enable unprecedented warfighting applications impossible to achieve classically
 - Collaborations with over 20 universities, industries and OGAs
 - International collaborations with the UK, Australia, Canada, Spain, Ireland, Germany, South Korea
 - 19 joint publications in 2015-2016, including Science publication on quantum spin dynamics and entanglement generation with hundreds of trapped ions
 - 7 foreign national Postdocs working at Adelphi and UMD-JQI
 - 3 Faculty and 4 Students on summer research sabbaticals at ALC
- New state-of-the-art ARL facilities at Adelphi and UMD-JQI
- Dark fiber links to NRL and UMD-JQI
- 9 new government FTE's in quantum theory and experiment



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Open Campus Center: CREB

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Open Campus Activity:

- Center for Research in Extreme Batteries (CREB) established with 5 core members
- Non-profit CREB consortium in negotiation
 - To be funded by industry, academic, and government members
 - Interest expressed by over 300 organizations
- ARL, UMD, and NIST funded initial cohort of 4 Post-docs (including two international researchers), led to larger ARPA-E grant



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NIST

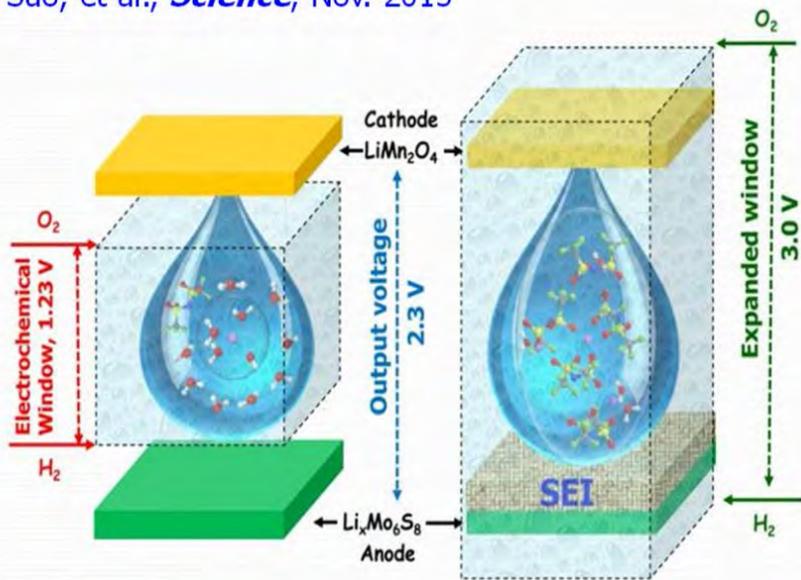
National Institute of
Standards and Technology



NEW YORK BATTERY
AND ENERGY STORAGE
TECHNOLOGY CONSORTIUM



L. Suo, et al., *Science*, Nov. 2015



Technical Accomplishments:

- “Water-in-salt” electrolytes dramatically **increase electrochemical stability to 3 V** over previous state of the art (1.23 V)
- **Breakthrough 200 Wh/kg** energy density demonstrated with **non-flammable** electrolytes (approaching commercial Li-ion)
- Joint ARL/UMD patent filed
- High impact publications including *Science*, *Nature Energy*, *Angewandte Chemie*



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Center for Agile Materials
Manufacturing Science (CAMMS)

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New building sites in office park for consortium facility

**Consortium Partnership:
CRADA + Individual CRADAs**

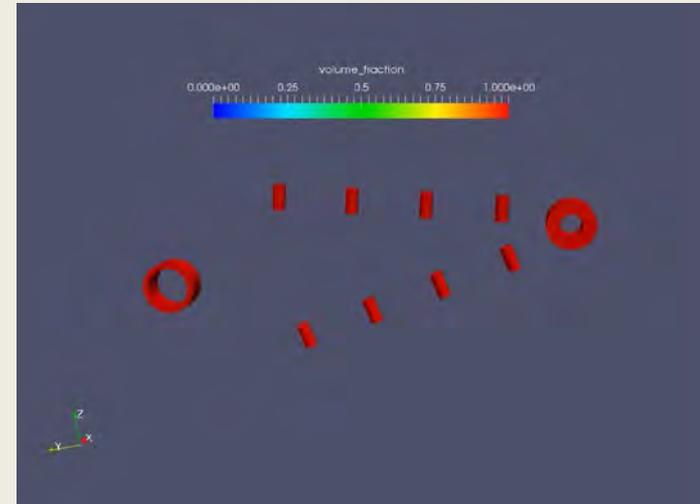
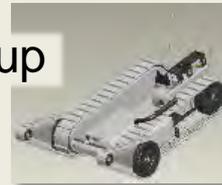


Cold Spray Laboratory

>\$1M in equipment installed to date by industrial partners

Technical Accomplishments:

- 3D printing feedstock from waste MRE bags, water bottles, & other waste demonstrated
- Packbot part design optimization resulting in up to **70% weight savings** with same performance



Design optimization to minimize weight



Fiber and Film Processing Lab



Micro Dispense System



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Materials Campaign Research Centers

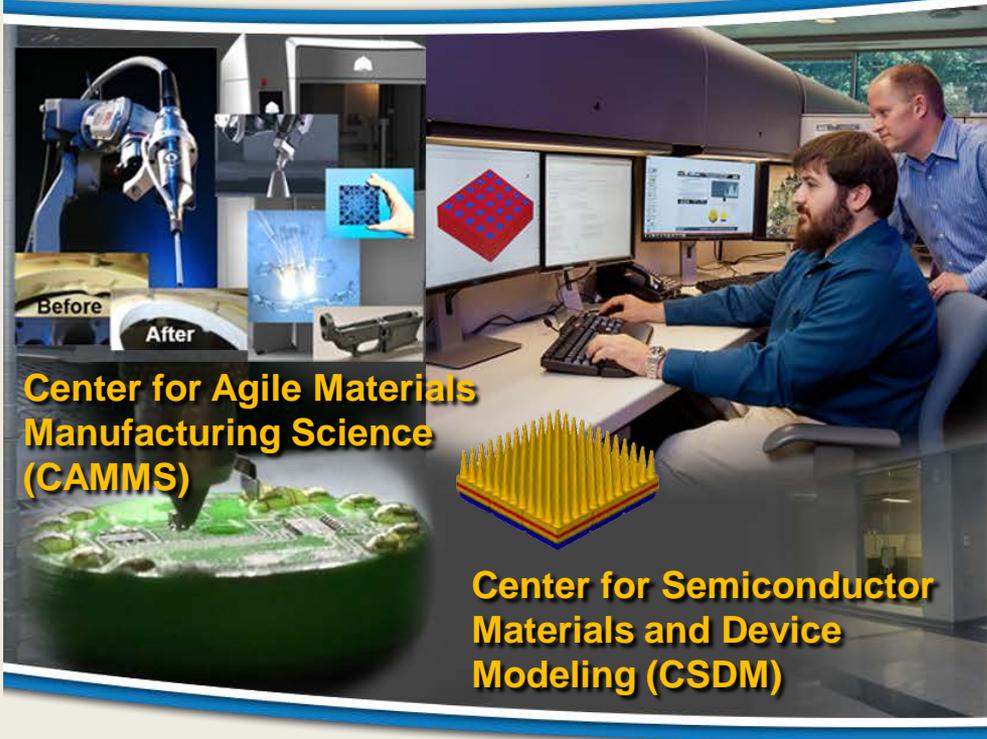
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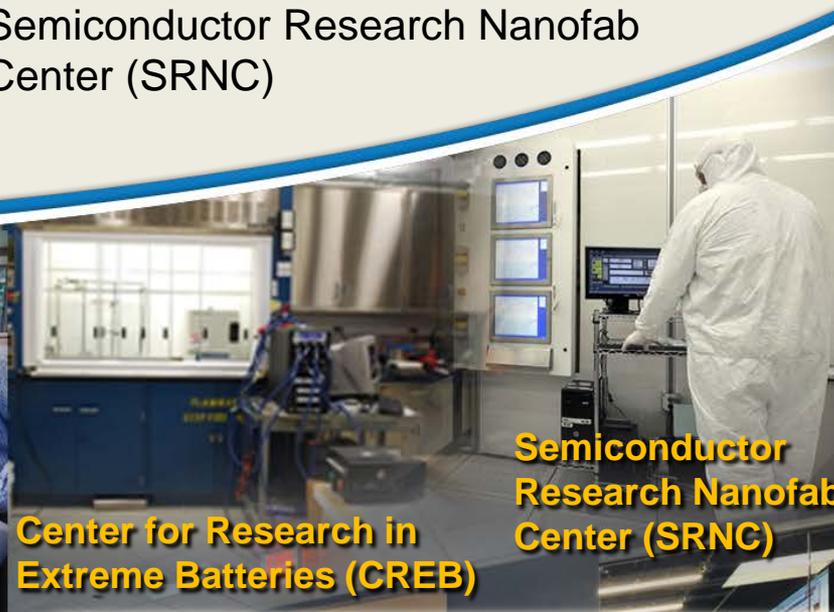
Adelphi, MD

- Center for Extreme Batteries (CREB)
- Center for Semiconductor Materials and Device Modeling (CSDM)
- Semiconductor Research Nanofab Center (SRNC)



**Center for Agile Materials
Manufacturing Science
(CAMMS)**

**Center for Semiconductor
Materials and Device
Modeling (CSDM)**



**Center for Research in
Extreme Batteries (CREB)**

**Semiconductor
Research Nanofab
Center (SRNC)**

Aberdeen Proving
Ground, MD

- Center for Agile Materials Manufacturing Science (CAMMS)



Posters: 39

Tour Stops: 11

Photonics	Electronics	Energy and Power	Bio and Bio-Inspired	Manufacturing Science	High Strain Rate and Ballistics
Imaging Sensor & Optics (2)	Energy Efficiency (4)	Power Generation/ Harvesting (5)		Advanced & Additive Manuf. (6)	Ceramics & Transparent (4)
Sensor Protection	RF Active & Passive (2)	Energy Storage		Energy Coupled to Matter (7)	Lightweight & Specialty Materials (3)
		Fuel Cells		Corrosion & Fatigue	Fabrics & Wearables
				Polymer Coatings	
Quantum Information Science (2)	Energy Efficiency	Power Generation/ Harvesting	Technology from Biology (2)		
	MEMS (2)	Energy Storage			
	Nano & 2D				
Semiconductor Research and Nanofabrication Center					



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Questions?



Full Poster List



Bio/abio Interfaces and Applications	Stratis-Cullum, Dimitra (Dr.)	Biological and Bio-inspired	Technology from Biological Systems Tour	
Systems Biology from Single Species to Consortia	Sund, Christian (Dr.)	Biological and Bio-inspired	Technology from Biological Systems Tour	
Microsystems and Wireless Power Components	Bedair, Sarah (Dr.)	Electronics	Energy Efficient	Poster
Energy Efficient Electronics	Wilson, James (Dr.)	Electronics	Energy Efficient	Poster
Emerging Electronic Devices	Ivanov, Tony (Dr.)	Electronics	Energy Efficient	Poster
High Power Electronics	Tipton, (Wes) Charles (Dr.)	Electronics	Energy Efficient	Poster
Wide Bandgap Power Electronics and Thermal Science	Lelis, Aivars (Dr.)	Electronics	Energy Efficient	Tour
Precision Measurement Technologies for Contested Environments	Polcawich, Ronald (Dr.)	Electronics	MEMS	Tour
RF MEMS Technology	Polcawich, Ronald (Dr.)	Electronics	MEMS	Tour
Nanoelectronics Team Efforts in 2D Materials and Electronics	Dubey, Madan (Dr.)	Electronics	Nano & 2D	Tour
Metaferrite Enhanced Antennas	Mitchell, Gregory (Dr.)	Electronics	RF Active & Passive	Poster
Microwave/Millimeter-wave Electronics & Integration Technologies	Viveiros, Edward (Mr.)	Electronics	RF Active & Passive	Poster
Energy Storage Materials	Allen, Jan (Dr.)	Energy & Power	Energy Storage	Poster
Advanced Battery Chemistries	Read, Jeffrey (Dr.)	Energy & Power	Energy Storage	Tour
Fuel Cells	Grew, Kyle (Dr.)	Energy & Power	Fuel Cells	Poster
Alternative Energy	Lundgren, Cynthia (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Poster
Ultra-Energy Materials and Nuclear Science	Carroll, (Jeff) James (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Poster
Catalysis and Reaction Technology	Lee, Ivan (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Poster
Enabling Desulfurization Materials for Future Compact Jet Fuel (JP-8) Power Sources	Tran, Dat (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Poster
Center for Research in Extreme Batteries (CREB)	Lundgren, Cynthia (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Poster
Compact Power	Waits, (Michael) Christopher (Dr.)	Energy & Power	Power Generation & Energy Harvesting	Tour
TEM Characterization of Deformation Mechanisms in Sharp-Indented Ceramics	Hirsch, Samuel (Mr.)	High Strain Rate & Ballistics	Ceramics & Transparent	Poster
Materials Characterization Under Multi-Axial Stress States at Various Loading Rates	Walter, Timothy (Dr.)	High Strain Rate & Ballistics	Ceramics & Transparent	Poster
Development of Advanced Ceramics for Future Protection Technologies	LaSalvia, Jerry (Dr.)	High Strain Rate & Ballistics	Ceramics & Transparent	Poster
Computational Materials Research: Boron Suboxide Ceramic Armor	Synowczynski-Dunn, Jennifer (Ms.)	High Strain Rate & Ballistics	Ceramics & Transparent	Poster



Full Poster List (cont'd)



Damage Tolerant Adhesives	Jensen, Robert (Dr.)	High Strain Rate & Ballistics	Fabrics & Wearables	Poster
Stabilizing and Synthesis of Nanocrystalline Alloys for Future Army	Darling, Kristopher (Dr.)	High Strain Rate & Ballistics	Lightweight & Specialty Metals	Poster
Deformation Processing of Lightweight Materials	Doherty, Kevin (Dr.)	High Strain Rate & Ballistics	Lightweight & Specialty Metals	Poster
Ultra-Lightweight Magnesium Alloys for Enhanced Protection	Kecskes, Laszlo (Dr.)	High Strain Rate & Ballistics	Lightweight & Specialty Metals	Poster
Flex Hybrid Electronics	Forsythe, Eric (Dr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
Additive Manufacturing Research	Holmes, (LJ) Larry (Mr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
Cold Spray for Additive Manufacturing	Champagne, Victor (Mr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
X-Ray Computed Tomography for Materials Science	Sietins, Jennifer (Dr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
Advanced Materials and Processing for Soldier Protection	Vargas-Gonzalez, Lionel (Dr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
Topology Optimization	Wildman, Raymond (Dr.)	Manufacturing Science	Advanced & Additive Manufacturing	Poster
Corrosion Science and Electrochemistry	Labukas, Joseph (Dr.)	Manufacturing Science	Corrosion & Fatigue	Poster
Electric Field Assisted Conductive Ceramic and Metal Manufacturing	McWilliams, Brandon (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
Energy Coupled to Matter (ECM)	Brennan, Raymond (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
Enhancement of Fracture Toughness in Presence of Microwave Field	Shreiber, Daniel (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
ECM: Thermomagnetic Processing of Ceramic Materials	Blair, Victoria (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
Atmospheric Plasma Modification of Materials	Bujanda, Andres (Mr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
EM Energy Coupled to Finitely Deforming Matter	Powers, Brian (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
Novel Electromagnetic Interactions with Matter Laboratory	Griep, Mark (Dr.)	Manufacturing Science	Energy Coupled-to-Matter	Poster
Chemical Agent Resistance Coatings (CARC) Development	Escarsega, John (Mr.)	Manufacturing Science	Polymer Coatings	Poster
Specialty Electronics and Sensors Cleanroom (SEMASC)	Sunal, Paul (Dr.)	Multiple	Multiple	Tour
Advanced Solid-State Lasers	Fleischman, Zackery (Dr.)	Photonics	High Energy & Tactical Laser	Poster
Superconductors, Topological Insulators and Related Heterostructures	Rong, Charles (Dr.)	Photonics	Imaging Sensors & Optics	Poster
Center for Semiconductor Modeling of Materials and Devices (CSM)	Reed, Meredith (Dr.)	Photonics	Imaging Sensors & Optics	Poster
Solid State Materials as Quantum Information Platforms	Lai, (CW) Chih-Wei (Dr.)	Photonics	Quantum Information Science	Tour
Magnetometry Based on Quantum Interference	Kunz, Paul (Dr.)	Photonics	Quantum Information Science	Tour
Organic Materials for Non-Linear Optics	Ensley, Trenton (Dr.)	Photonics	Sensor Protection	Poster



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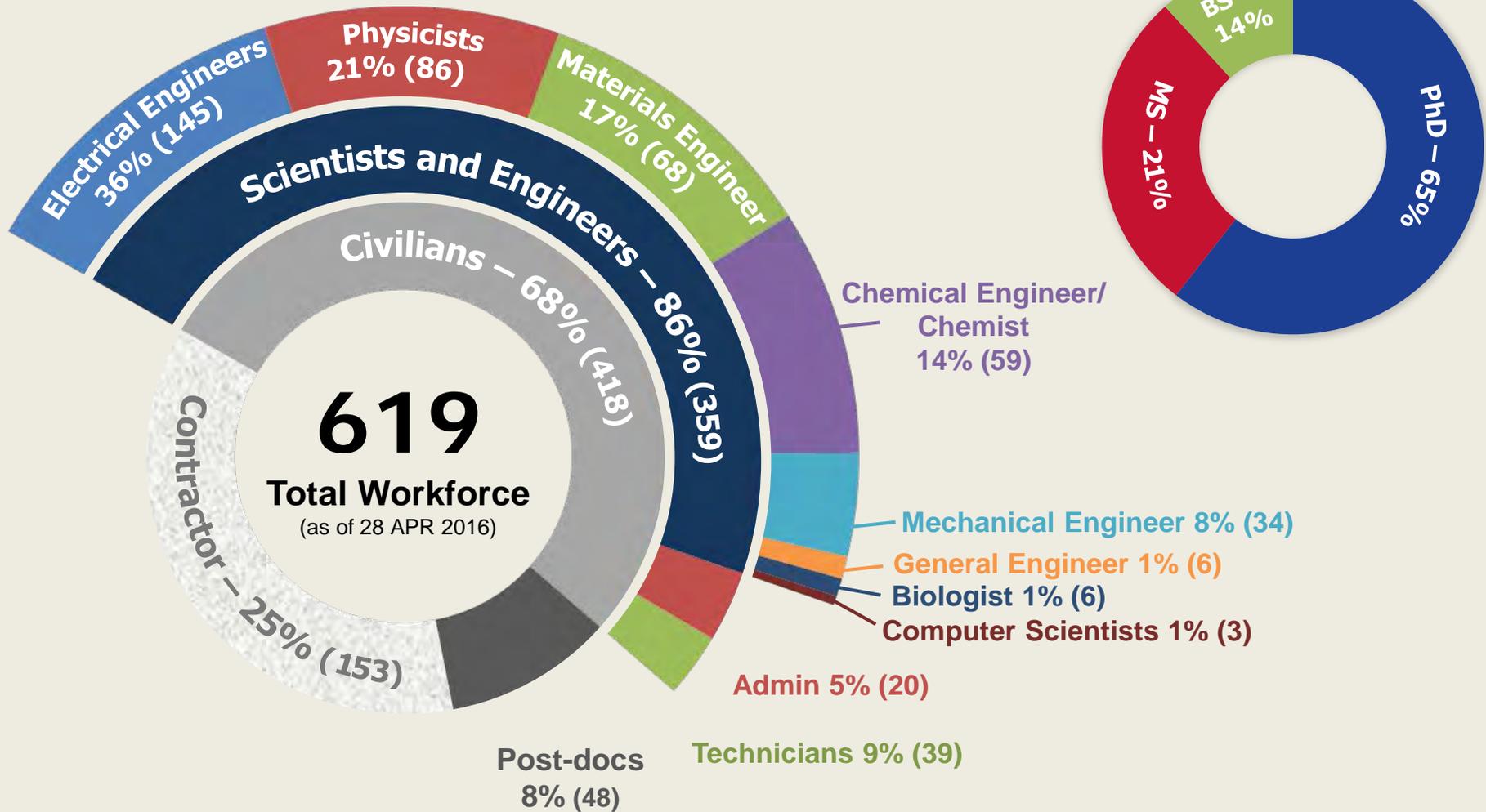
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Materials Campaign Expertise

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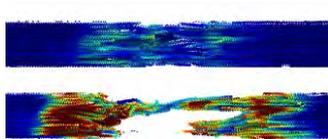


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**CCE: Designing Materials**

Resist and perform under extreme dynamic, thermal, mechanical, chemical, or biological environments



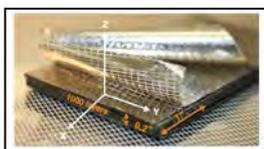
Loaded Ultra-high molecular weight polyethylene



Through Thickness Ceramic Tile Reinforcement



Bacterial Healing of Concrete

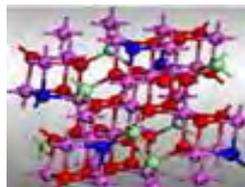


Low-Profile Metaferite Antenna

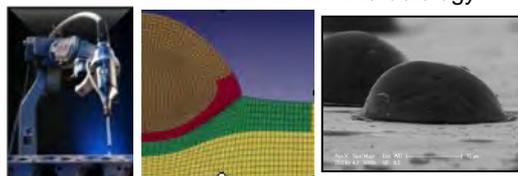
Absorb, divert, convert, emit, detect, and direct electromagnetic space

**CCE: Materials Synthesis & Processing**

Manipulate atoms, molecules, and other building blocks additively via growth or deposition, chemical or biological synthesis, or precursor materials for additive manufacturing



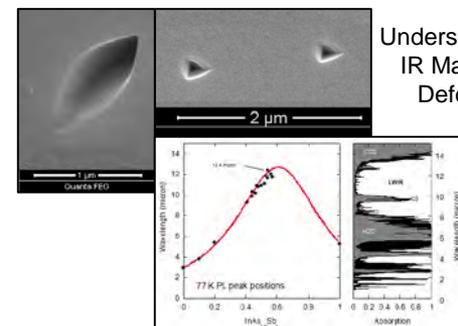
Microbiology



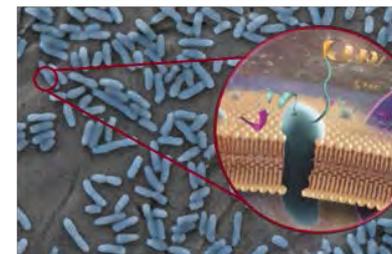
Modify or tailor existing materials for devices (e.g., thermomechanical treatments, composite processing, sintering, joining, nano and microfabrication)

CCE: Materials Characterization and Discovery

Spectroscopy, microscopy, and experimental characterization



Understanding IR Material Defects



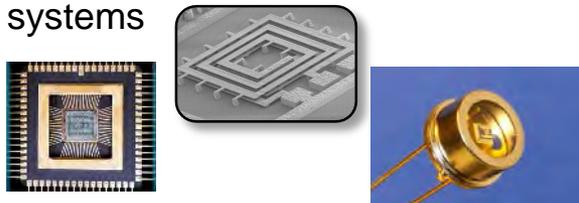
Understanding Structure-Function Relationships at the Bio-Interface

Real-time full spectral probing, sensing, analytics and informatics to enable discovery of the unexpected



KCI: Energy-Efficient Electronics and Photonics

Novel materials to reduce the power demand of future Soldier systems



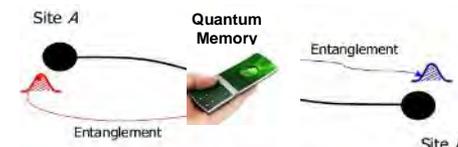
KCI: Agile Expedient Manufacturing

Rapid, adaptable production of consumable parts through development of new synthesis and processing capabilities



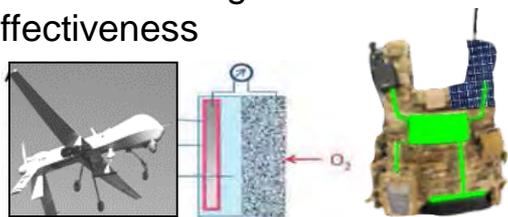
KCI: Quantum Sciences

Materials to exploit quantum phenomena to enable exponential increases in capabilities for command, control, communications, intelligence, surveillance, & reconnaissance



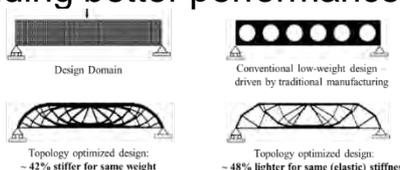
KCI: Materials for Soldier and Platform Power Systems

Power generation and storage technologies that simultaneously reduce hazards, the logistics tail, and the burden on the Soldier while increasing mission time and effectiveness



KCI: Lightweight Materials for Army Platforms

Lightweight materials stronger than conventional counterparts to reduce the logistics tail while providing better performance.



KCI: Energy-Coupled-to-Matter for Responsive Materials

Application of high energy fields during materials processing to beneficially alter the resulting material

