

# ***Institute for Soldier Nanotechnologies***

**John D. Joannopoulos**

Director, Institute for Soldier Nanotechnologies

*Francis Wright Davis Professor of Physics*

*Massachusetts Institute of Technology*

## **Selected Research Highlights & Potential Impact for Army Applications**

**Army Science Conference**

December 1-4, 2008



**Massachusetts  
Institute of  
Technology**

# Report Documentation Page

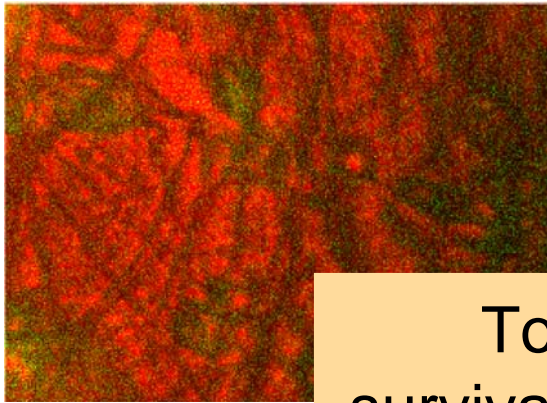
Form Approved  
OMB No. 0704-0188

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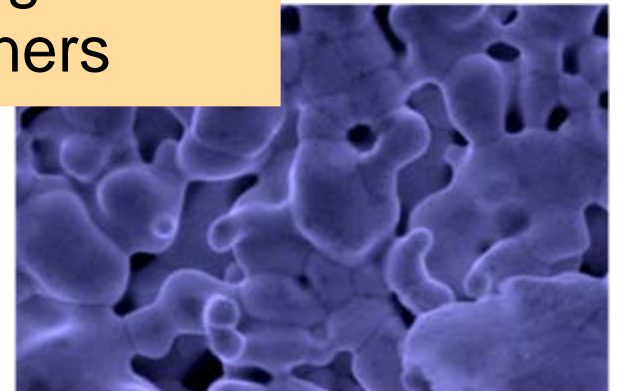
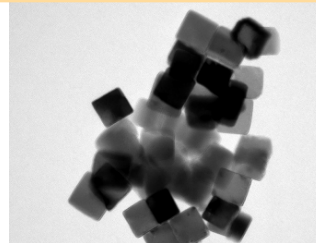
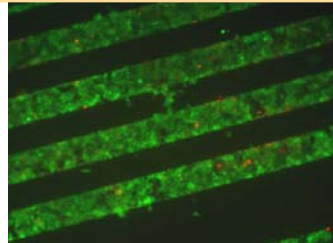
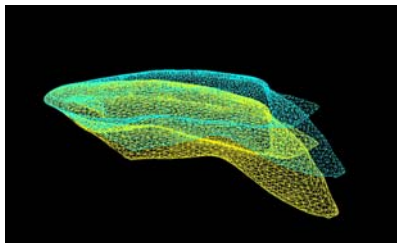
1. REPORT DATE <b>DEC 2008</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Selected Research Highlights &amp; Potential Impact for Army Applications</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Institute for Soldier Nanotechnologies</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002187. Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



# Mission & Goals



To dramatically improve the survivability of the Soldier by working and extending the frontiers of **Nanotechnology** through fundamental research ... and transitioning with our Army & Industry Partners





# *What is Nanotechnology?*



Properties of materials (e.g. electronic, photonic, mechanical, magnetic) become **size dependent** below a critical length scale of ~ **500 nanometers**.

*(The diameter of a human hair is about 80,000 nanometers)*

## **Opportunities:**

- **New** materials, **new** phenomena, **new** properties  
**unattainable** in nature



# A Three-Member Team



## ISN Dedicated Facility

State of the art instrumentation



- 47 Faculty (10 Departments)
- 80 Grad students
- 30 Post-docs
- 2 Uniformed Army Scientists
- 3 Civilian Army Scientists
- 2 Industry Scientists
- 1 USN/MC TTS
- 1 Uniformed Army Liaison

## Industry Consortium



## Army Sci & Tech Labs





# Potential Impact for Army App's

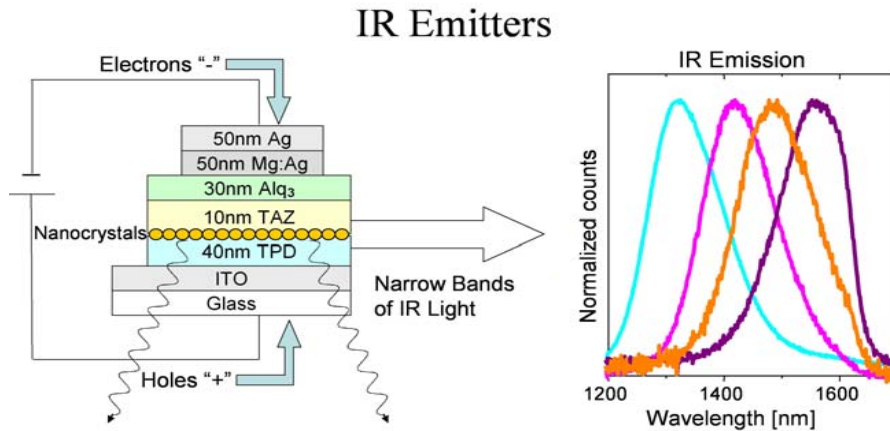


- 1 – Low-cost, room-temperature night-vision and communications in the infrared (IR) for **increased Soldier situational awareness**
- 2 – Autonomous and self-administered medical care for **faster, more extensive, far-forward medical treatments**
- 3 – Lightweight, flexible & breathable structural materials for **comfortable blast & ballistic protection**
- 4 – Flexible, lightweight nano-coatings for **multiple survivability capabilities** *e.g., against moisture, bacteria, spores, hazmats, fire, EMI ...*
- 5 – Multi-functional *full-body* battlesuit to **enhance the Soldier's senses of light, heat, and sound**
- 6 – Ultra-sensitive explosives sensors for **accurate hand-held, robot-integrated, and stand-off IED detection**

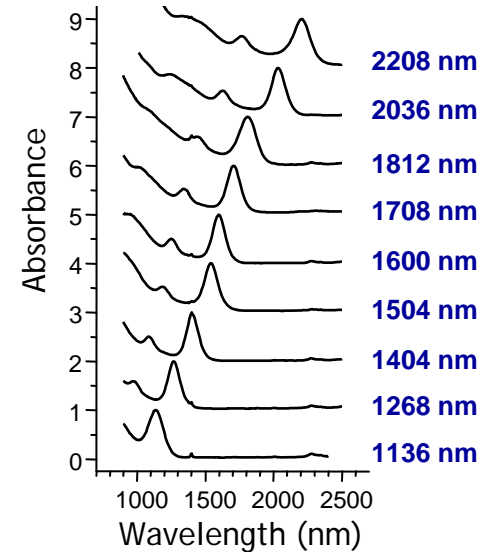
*Supporting FOC's: Battlespace Awareness, Battle Command, Human Dimension, Maneuver Support, Maneuver Sustainment, Protection*

★ **Nanoparticle systems as low-cost room-T devices for IR sensing & comms:**  
*Enhance situational awareness in the battlespace*

**Band-Gap Engineered Nanocrystals (aka QDs)  
 & Low-Cost Polymer Processing**



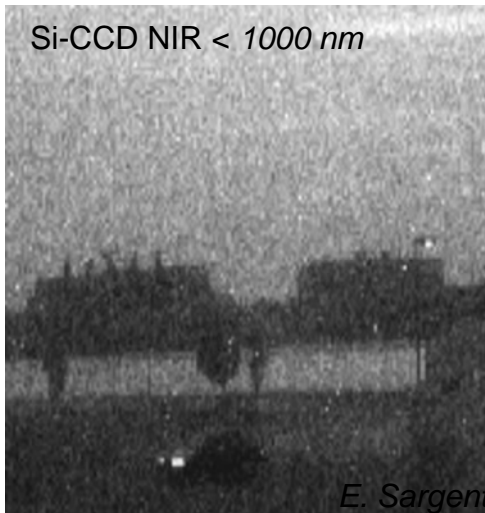
**PbSe NanoXtals 3 nm to 10 nm**



- Develop low-cost QD-based optoelectronic devices in the visible & IR

★ Nanoparticle systems as low-cost room-T devices for IR sensing & comms:  
*Enhance situational awareness in the battlespace*

Hydroxyl nightglow dominates  $\sim 1000 - 2300 \text{ nm}$



- Develop low-cost QD-based optoelectronic devices in the visible & IR



## Development of IR imager based on solution synthesized colloidal nanocrystal quantum dots



**M. Bawendi**  
**V. Bulovic**  
**M. Kastner**  
**S. Geyer**

- Nanocrystal Synthesis
- Photodetector Fabrication
- Electro-Optic Response

**AL** SEDD  
**P. S. Wijewarnasuriya**  
**V. J. Nathan**



NVSED  
**R. Littleton**

**Raytheon**

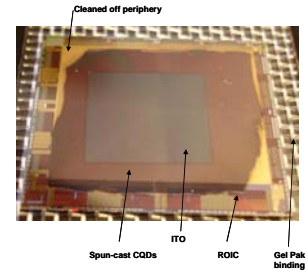
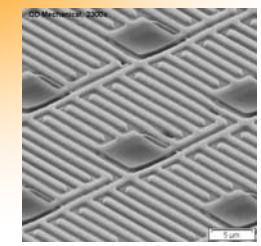
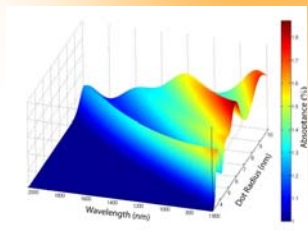
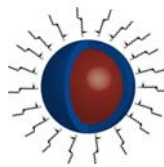
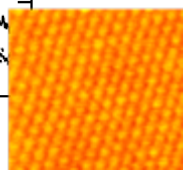
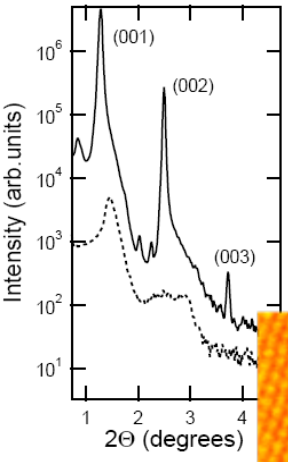
**F. B. Jaworski**

- Focal Plane Array Design
- Read Out Electronics

Figures of Merit Determination

Test Device & Focal Plane Arrays

Nanocrystal Based IR Imager





## Novel QD(nanoparticle)/Dye Constructs as Environmental Reporters for Medical Diagnostics & Toxin Sensing



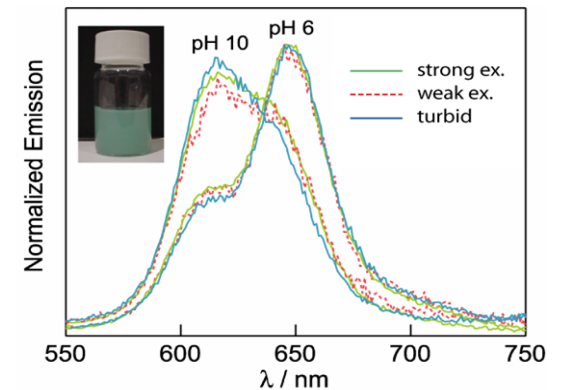
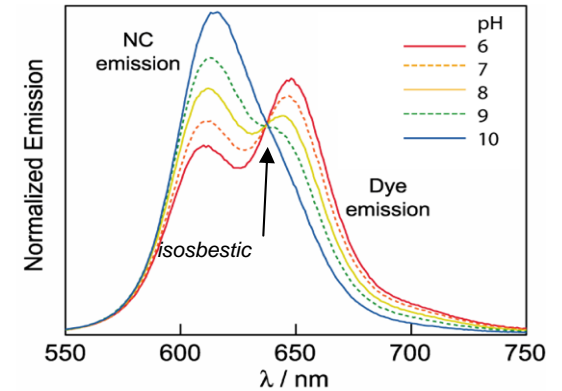
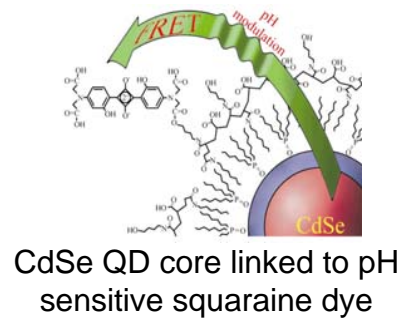
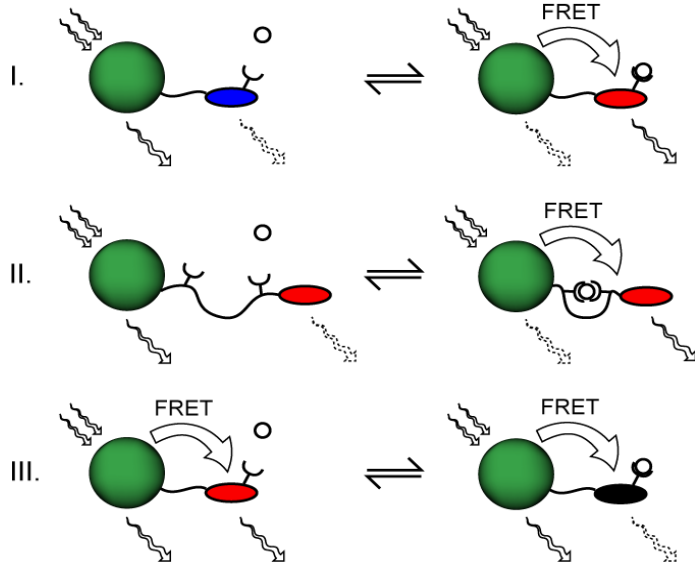
M. Bawendi  
D. Nocera

*Ratiometric, quantitative FRET between QD & sensing dye molecules: measure pH, blood O<sub>2</sub> & glucose, or detect hazardous substances*



ERDC/CERL  
A. Kumar

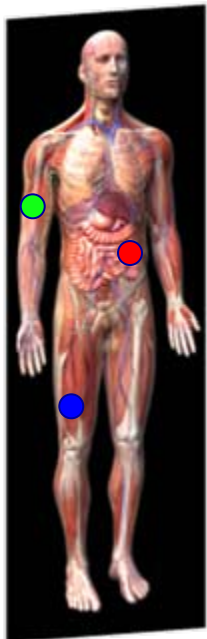
### Reversible sensing modalities



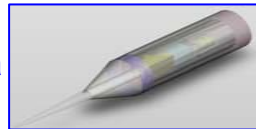
**★ Development of autonomous & self-injected drug delivery with wearable & implantable MEMS-based devices in the battle space:**

**M. Cima**  
**N. Elman**

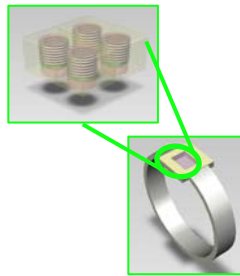
**Develop Rapid Reconstitution Packages (RRP's) to improve drug instability & deployment logistics: e.g. use for hemorrhagic shock, TBI, chem/bio agents**



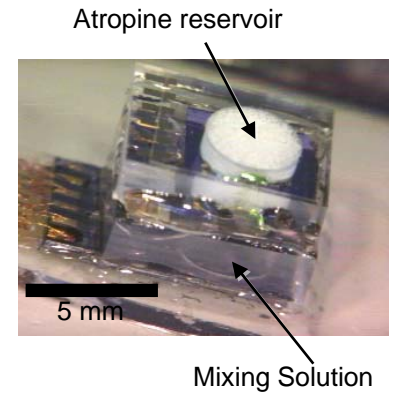
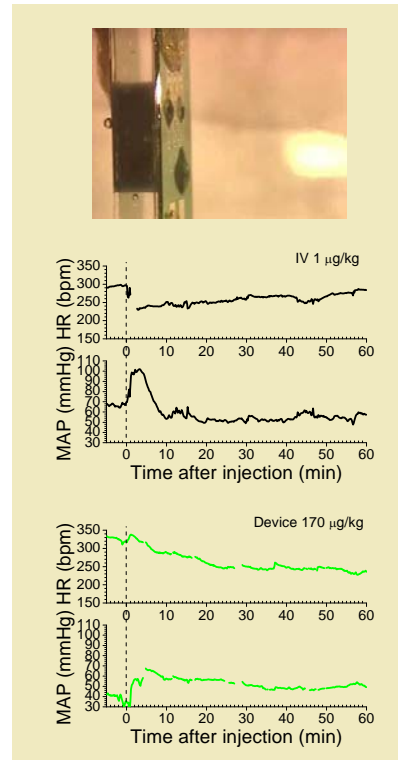
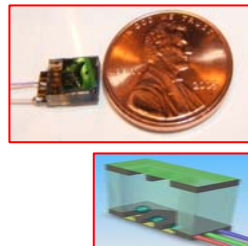
**Auto-injection (RRP) for trauma**



**Wearable (RRP) for auto/remote actuation**



**Implantable SubQ device**



Rapid Reconstitution of Atropine

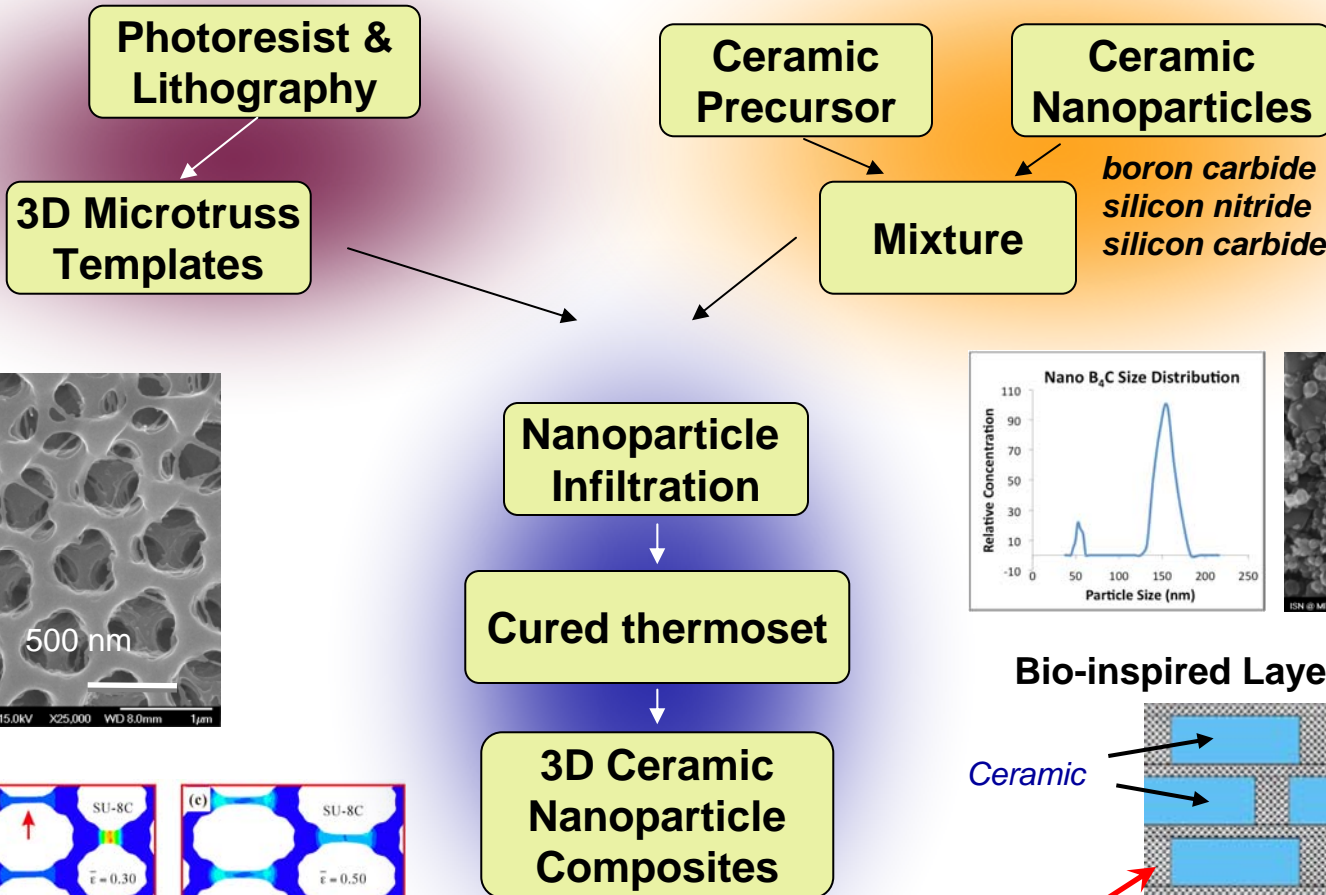




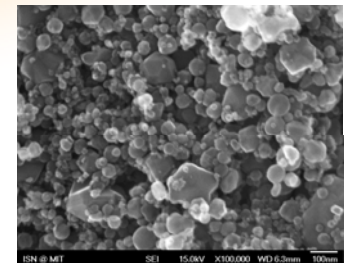
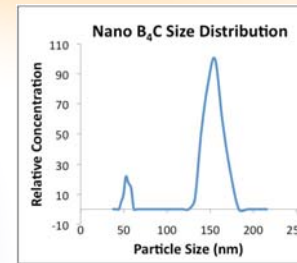
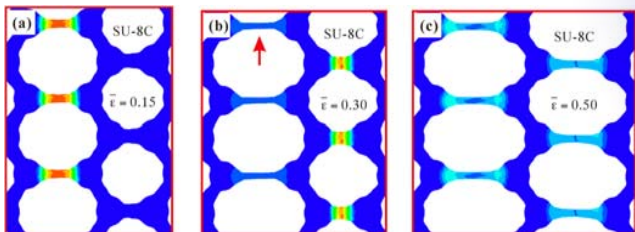
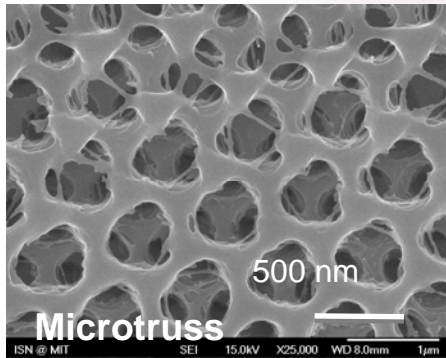
## Development of ceramic nanoparticle-reinforced novel architectures for potential flexible, lighter-weight & stronger armor



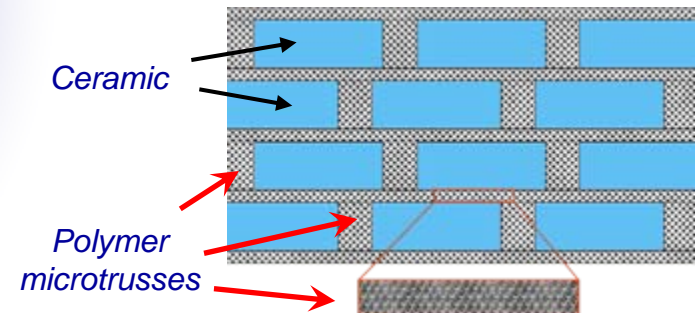
N. Thomas  
M. Boyce  
S. Kooi



Picatinny  
Arsenal  
D. Kapoor

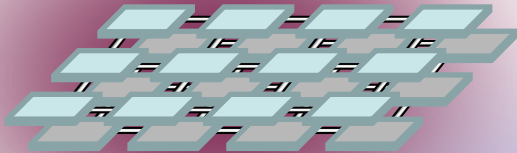


### Bio-inspired Layered Composites



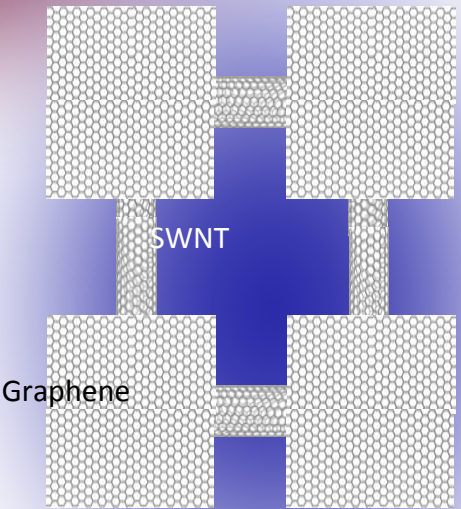
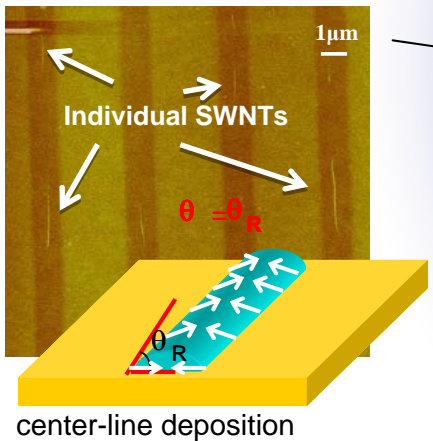
★ Enable the first CNT/graphene-linked flexible “Chain Maille” structures using precision placement of anisotropic nanostructures

**M. Strano**



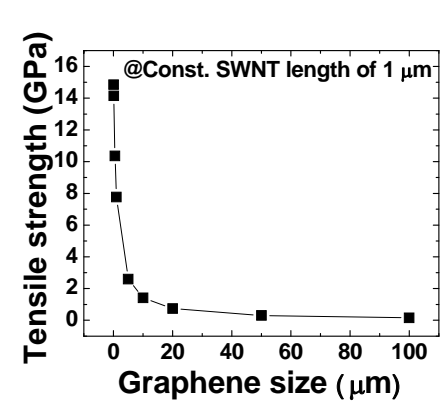
$\pi$ - $\pi$  Stacking of Alternating Chain Maille Layers

Micro-hydrodynamic Placement Allows Massively Parallel Alignment/Placement



Pattern Chain Maille Networks of Carbon Nano-materials

Atomistic Modeling & Mechanical Testing



US Army Corps of Engineers®

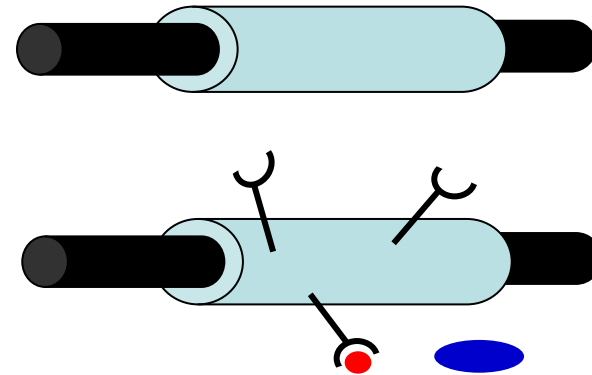
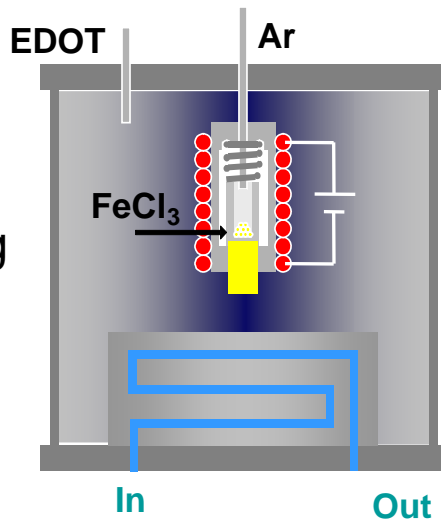
**CERL/ITL**  
*C. Marsh*  
*C.R. Welch*

**WMRD**  
*A.J. Hsieh*

- ★ **Gentle** Chemical Vapor Deposition (CVD) methods for enabling **multi-functional** polymer coatings of fibrous & hard surfaces:

*CVD processing for both **insulating** & **conducting** polymers!*

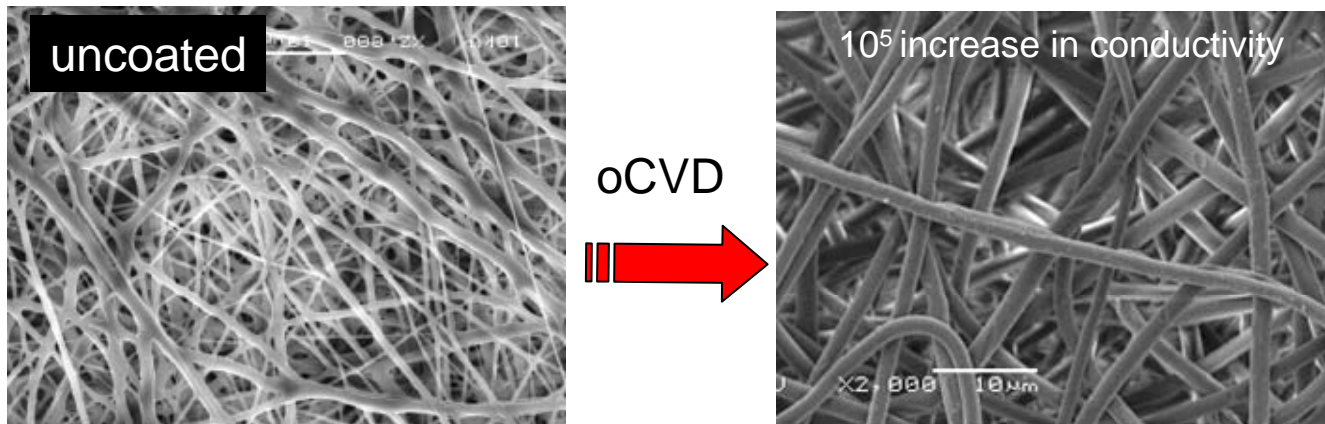
oCVD for  
conducting  
polymers



*Conformal coverage!*

- ★ **Gentle** Chemical Vapor Deposition (CVD) methods for enabling **multi-functional** polymer coatings of fibrous & hard surfaces:

**CVD processing for both *insulating* & *conducting* polymers!**



with **K. Senecal**



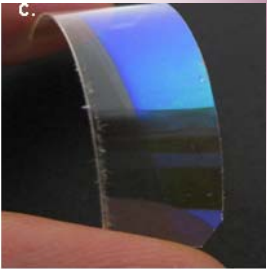
: **develop resistivity-based sensor for pathogens**

- Develop for a broad-range of sensing and protective coatings ( toxic agents, water-repellency, fire-retardency, EMI-shielding, etc .. ) for the battle-suit and face shields

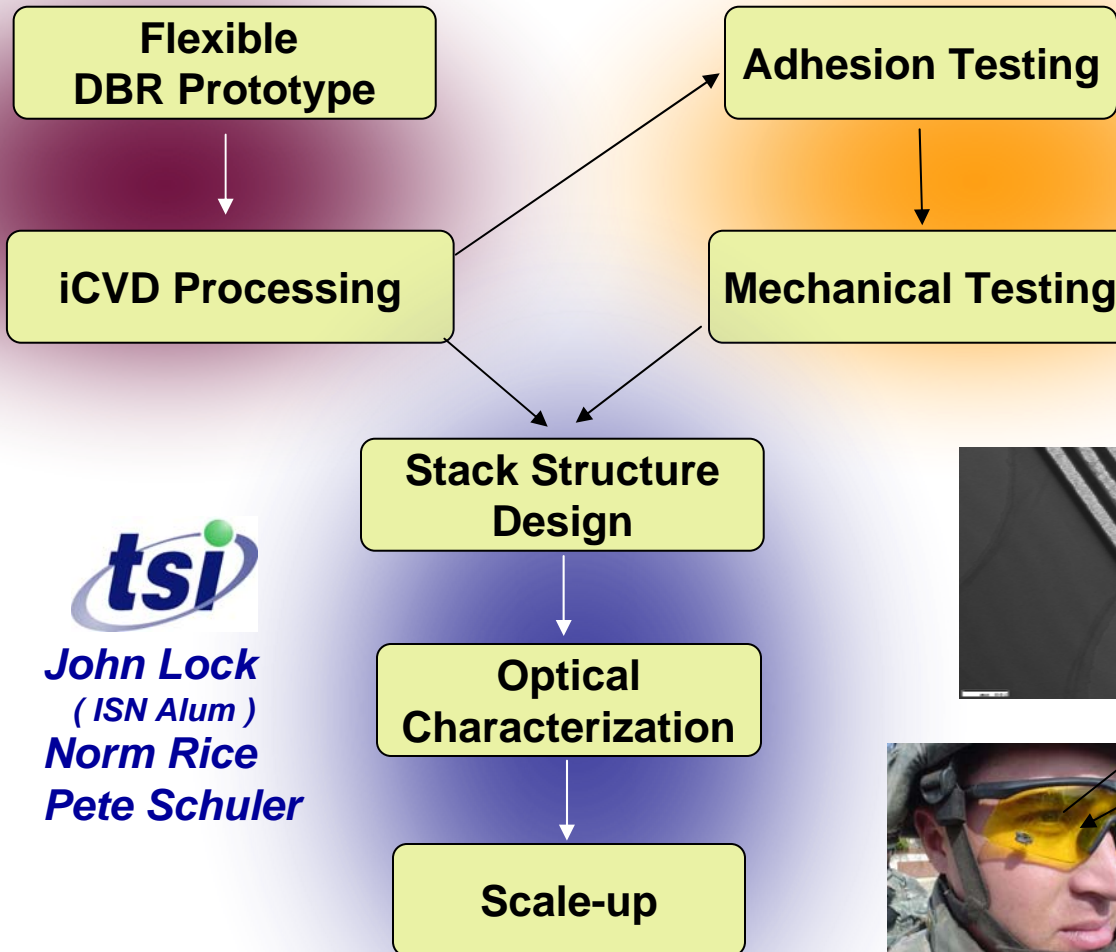
## ★ Flexible dielectric Bragg reflectors (DBRs) for laser eye protection



**K. Gleason**



Room-T deposition of flexible polymer layers sandwiching thin inorganic layers



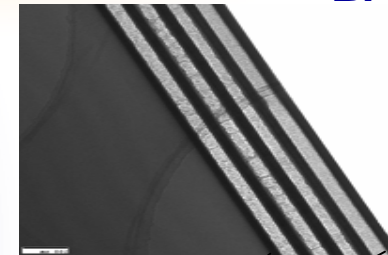
**John Lock**  
( ISN Alum )  
**Norm Rice**  
**Pete Schuler**



**WMRD**  
**A. Rawlett**



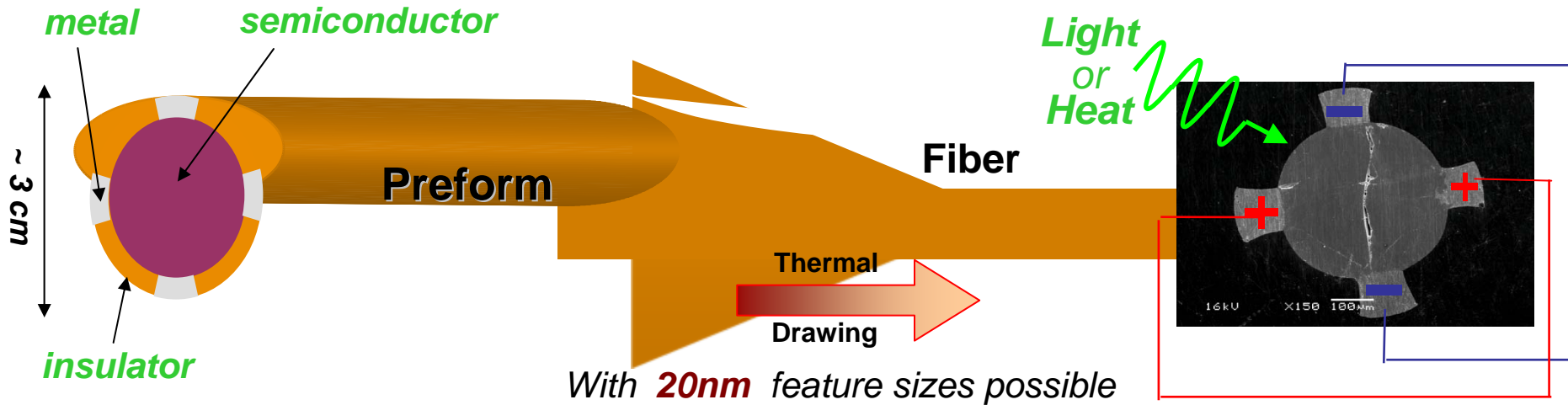
**NSRDEC**  
**B. Kimball**





Towards novel optoelectronic **fiber-devices**:

*Full-body sensing – new paradigm fibers & fabrics that can see, feel, hear...*

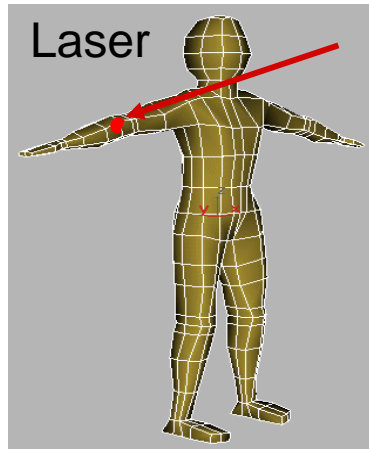


Full Body Combat ID;

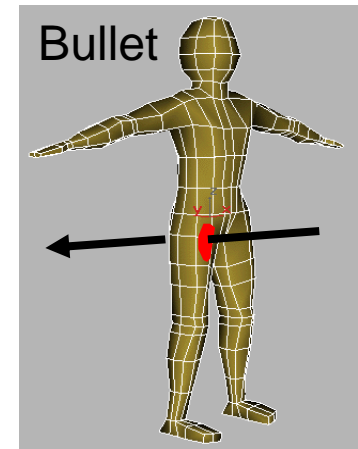
Laser-to-Uniform  
Non-RF

Communications;

Improved MILES



Full Body  
Thermal Sensing  
Remote Combat  
Triage



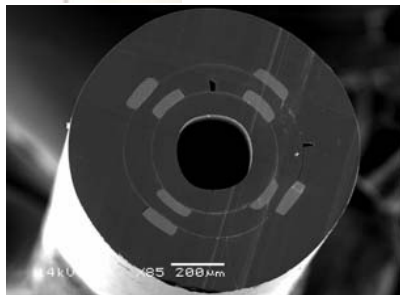
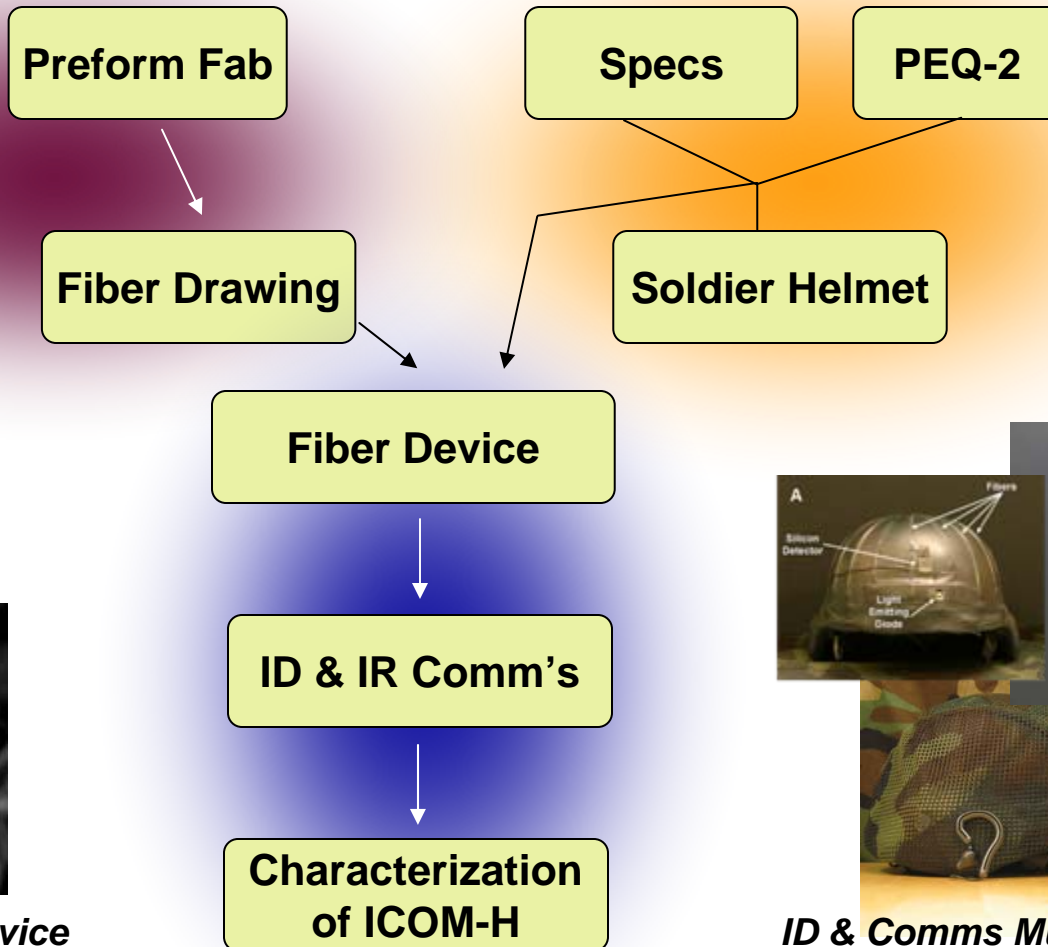
★ Design, fabricate, and implement an optoelectronic **fiber-device** covering for combat ID and line-of-sight IR communication



Y. Fink  
J. Joannopoulos  
MAJ R. Blair



NSRDEC  
R. Elder  
R. Masadi  
K. Shukla  
A. Taylor

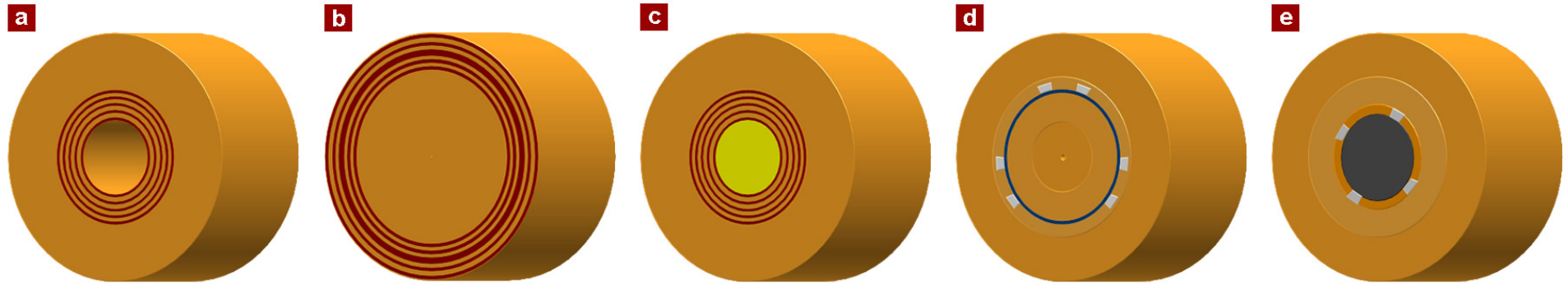


Optoelectronic Fiber-Device



ID & Comms Multifunctional Helmet





■ Insulating Polymer    
 ■ Gain Medium    
 ■ Amorphous Semiconductors    
 ■ Metal



f Hollow transmission fibers    
 g Optical cavity fibers    
 h Surface emitting fiber lasers    
 i Thermal detector fibers    
 j Optical detector fibers

- **Transition to civilian medical community: Fibers for novel CO<sub>2</sub> laser endoscopic surgery**
  - Fibers for acoustic detection, photovoltaic & thermoelectric (cooling) applications
  - Fibers for improved FIDO sensing element



Development of *Amplifying Fluorescent Polymers* for high-sensitivity detection of chemicals:

*Ultra-sensitive IED detection in theater and ... US ports of entry*

*Championed by HQDA*



**Transportation  
Security  
Administration**

“TSA ... announced operational pilot testing ... of a technology capable of screening sealed bottled liquids... Fido PaxPoint .”

- Develop AFP's for broad range of explosives

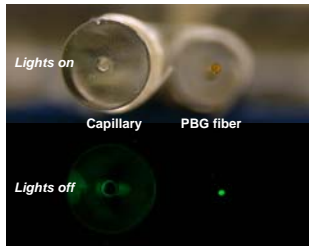
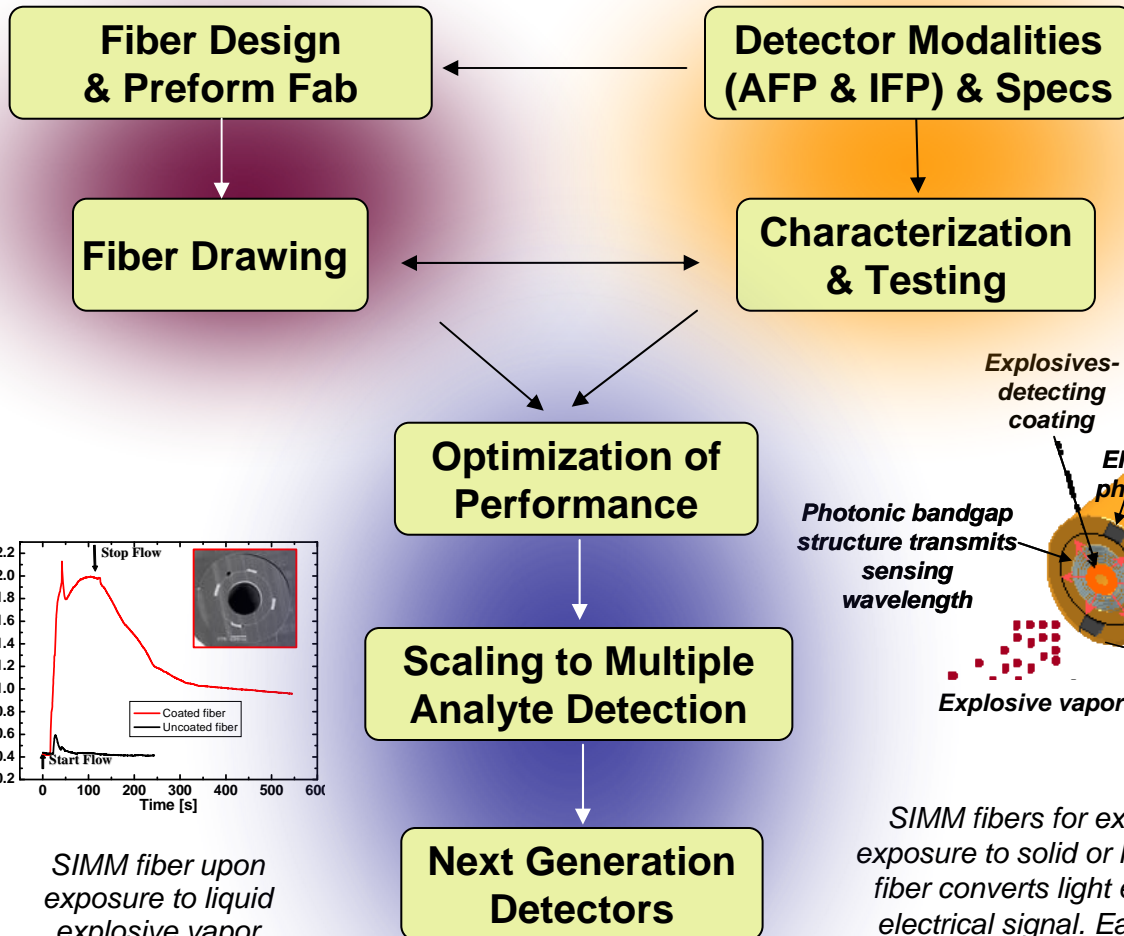
★ **Versatile lightweight small form-factor ISN-fiber explosives sensors with high-sensitivity, multi-analyte and “stand-off” detection capabilities**



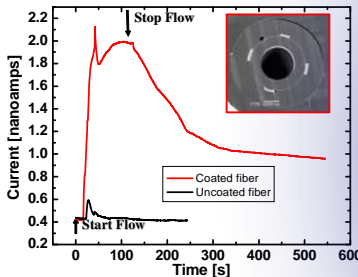
**Y. Fink**  
**J. Joannopoulos**  
**O. Shapira**



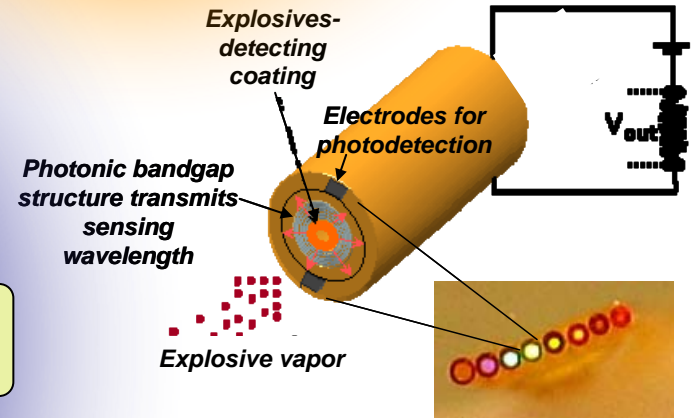
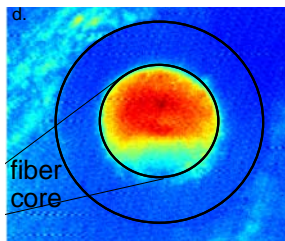
**L. Takiff**  
**A. Rose**



*PBG fiber provides 15-fold signal enhancement*



*SIMM fiber upon exposure to liquid explosive vapor*

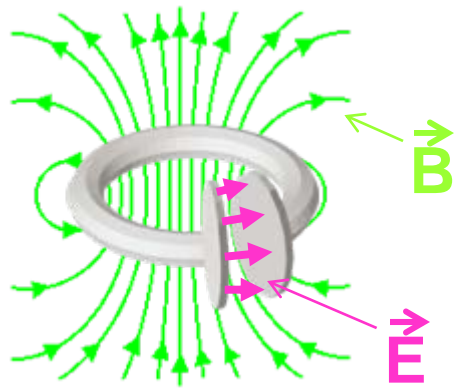


*SIMM fibers for explosives detection: upon exposure to solid or liquid explosive vapors, the fiber converts light emission at the core to an electrical signal. Each fiber in bundle can be designed sensitive to a different type of explosive*

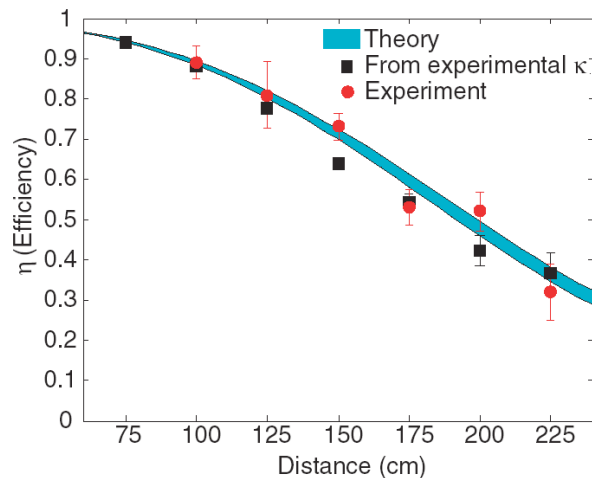
Resonant cavities in **photonic crystal** nanostructures can be tuned to almost “any” desired frequency, “any” evanescent tail extent, and can exhibit **magnetic** resonant behavior even in a purely dielectric material

As a first step & simple proof of principle: explore energy transfer through evanescent-tails of **simple** self-resonant magnetic coils:

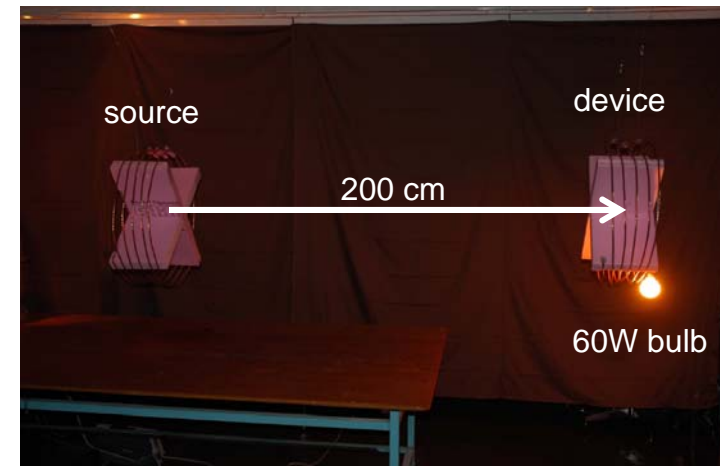
Exploit “**strong coupling**” regime: coupling strength » loss rate for **efficient** energy transfer



Magnetic Resonance



SCIENCE, 317, 83 (2007)



## **Nanotechnology-Enabled Enhanced Survivability for the Soldier by Exploiting:**

- ***Synergistic MIT, Army, Industry Partnership***
- ***Innovative Cutting-edge 6.1 Research Portfolio  
to Help Identify “Revolutionary” Opportunities***





Develop flexible nanoparticle metal-alloy fibers that combine high strength with toughness to resist impact and blast:

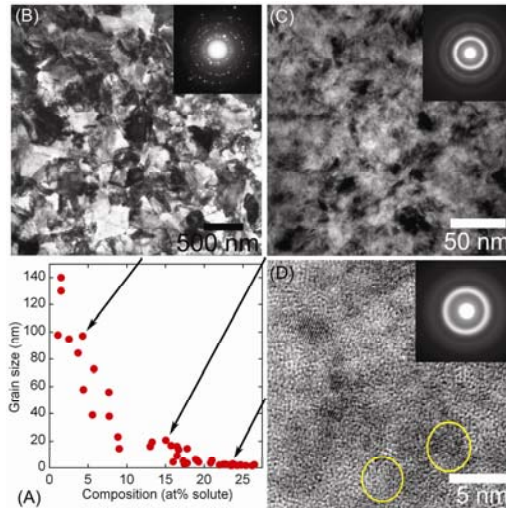
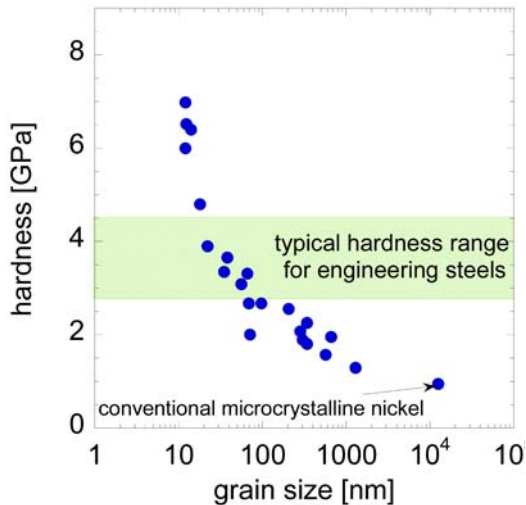
*Exploit unique deformation mechanisms at the **nano-scale** that can operate at high strength levels and dissipate significant energy without fracture*



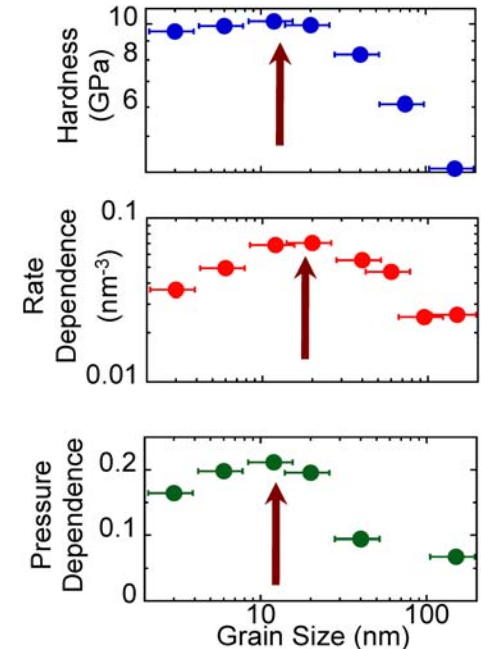
**C. Schuh**  
**N. Marzari**  
**R. Radovitzky**

**BUT...** nanocrystalline metals are thermodynamically unstable due to high volume fraction of grain boundaries

**D. Kapoor**



**Demonstration of stable Ni nanoparticles in a Ni-W alloy**

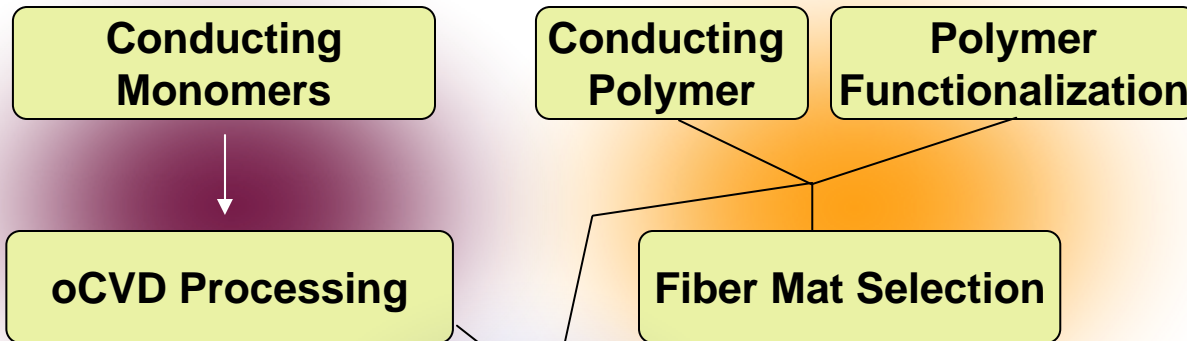


**Strength increased with strain-rate**  
**Strength increased with pressure**

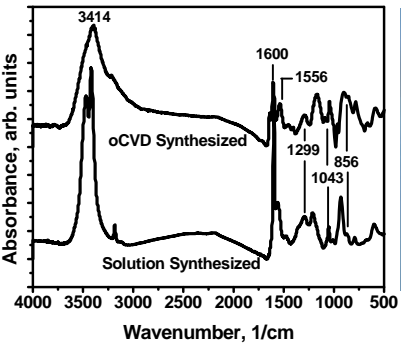
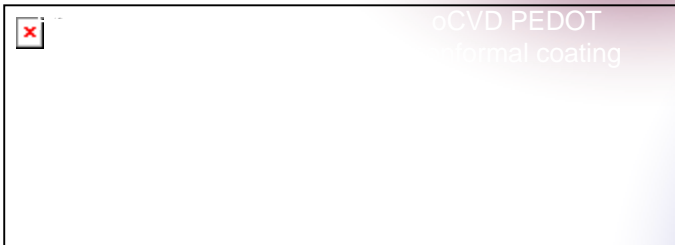
★ **Development of resistivity-based sensors for pathogens**



**K. Gleason**



**NSRDEC  
K. Senecal**



Poly(pyrrole-co-thiophene-3-acetic acid) functionalized conducting polymer film obtained by oCVD

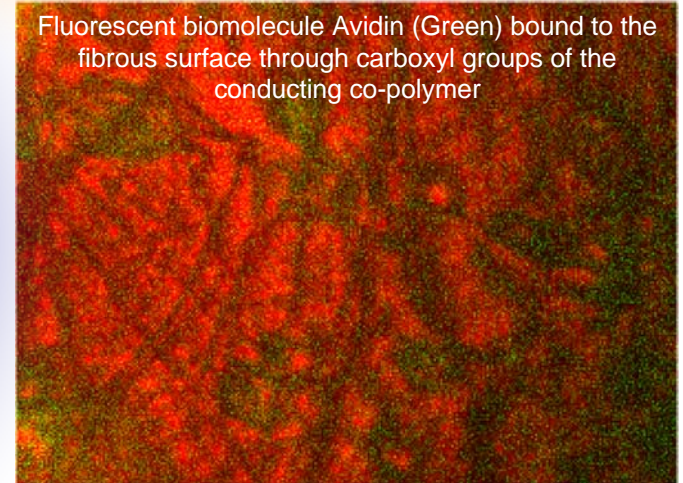
**1 cm**

**Excellent uniformity !**

**Fiber Mat Coating**

**Characterization**

**Pathogen Sensor**



*Optical micrograph of cond. polymer coated fiber mat*



## Novel QD(nanoparticle)/Dye Constructs as Environmental Reporters for Medical Diagnostics & Toxin Sensing



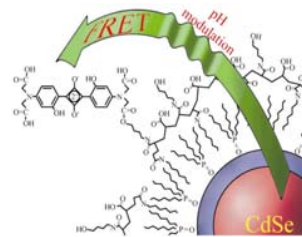
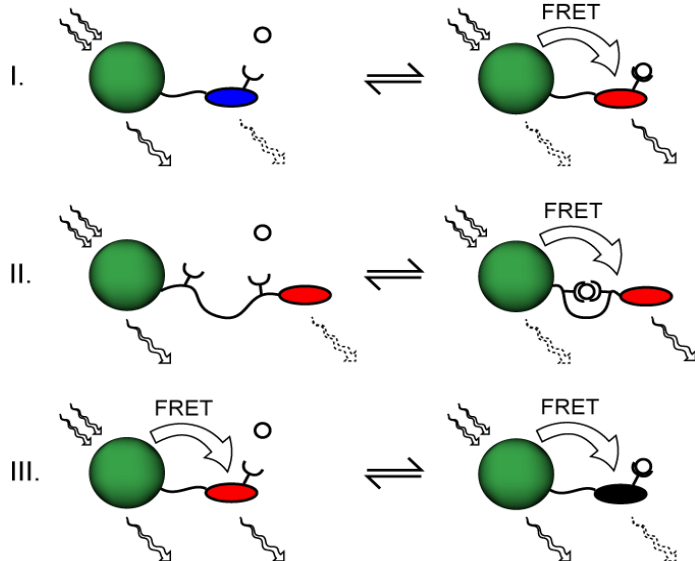
M. Bawendi  
D. Nocera

*Ratiometric, quantitative FRET between QD & sensing dye molecules: measure pH, blood O<sub>2</sub> & glucose, or detect hazardous substances*

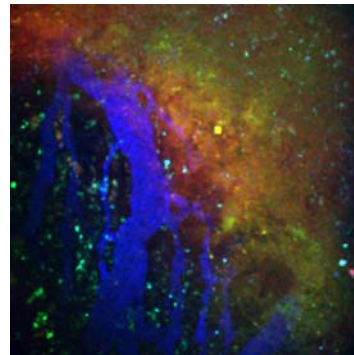


ERDC/CERL  
A. Kumar

### Reversible sensing modalities



CdSe QD core linked to pH sensitive squaraine dye



In vivo MPLSM of sensors (dye & QD emission) in murine tumor

