# Nanotechnology for Future Force Armaments

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

**Presented by:**
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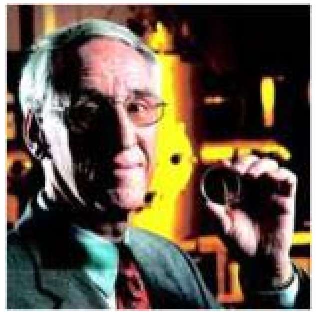
**Picatinny Arsenal, NJ**

# Outline of the Talk

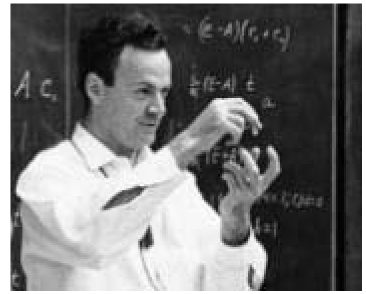
- Brief Intro to “Nano”
- DoD’s interest in Nanotechnology
  - Various Nanopowders produced at ARDEC
  - Structural Materials
  - Green Primers and Initiators
  - Sensor Electronics & Power Supplies for Munitions & Fuzing components
  - Reactive Structural Materials
  - Novel Energetic Compounds
    - Greener
    - Less Sensitive
    - More Energy
- Futuristic Technologies (Pie-in-the-sky)
- Summary
- Acknowledgements

# Brief History of Nanotechnology

The Lycurgus Cup (Rome) is an example of dichroic glass ($7^{th}$ C)

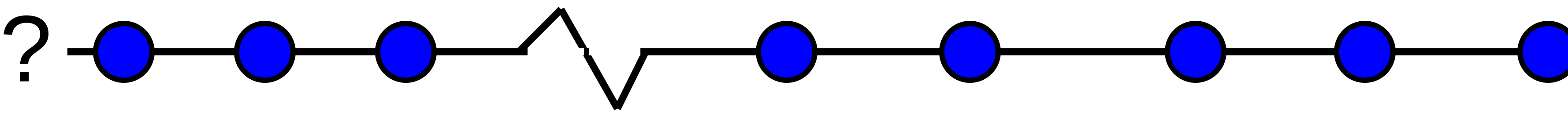


Erwin Müller, Siemens invents the FE-SEM (1936)



"There's Plenty of Room at the Bottom" (1959)

IBM researchers spell out IBM w/ 35 Xenon atoms (1989)



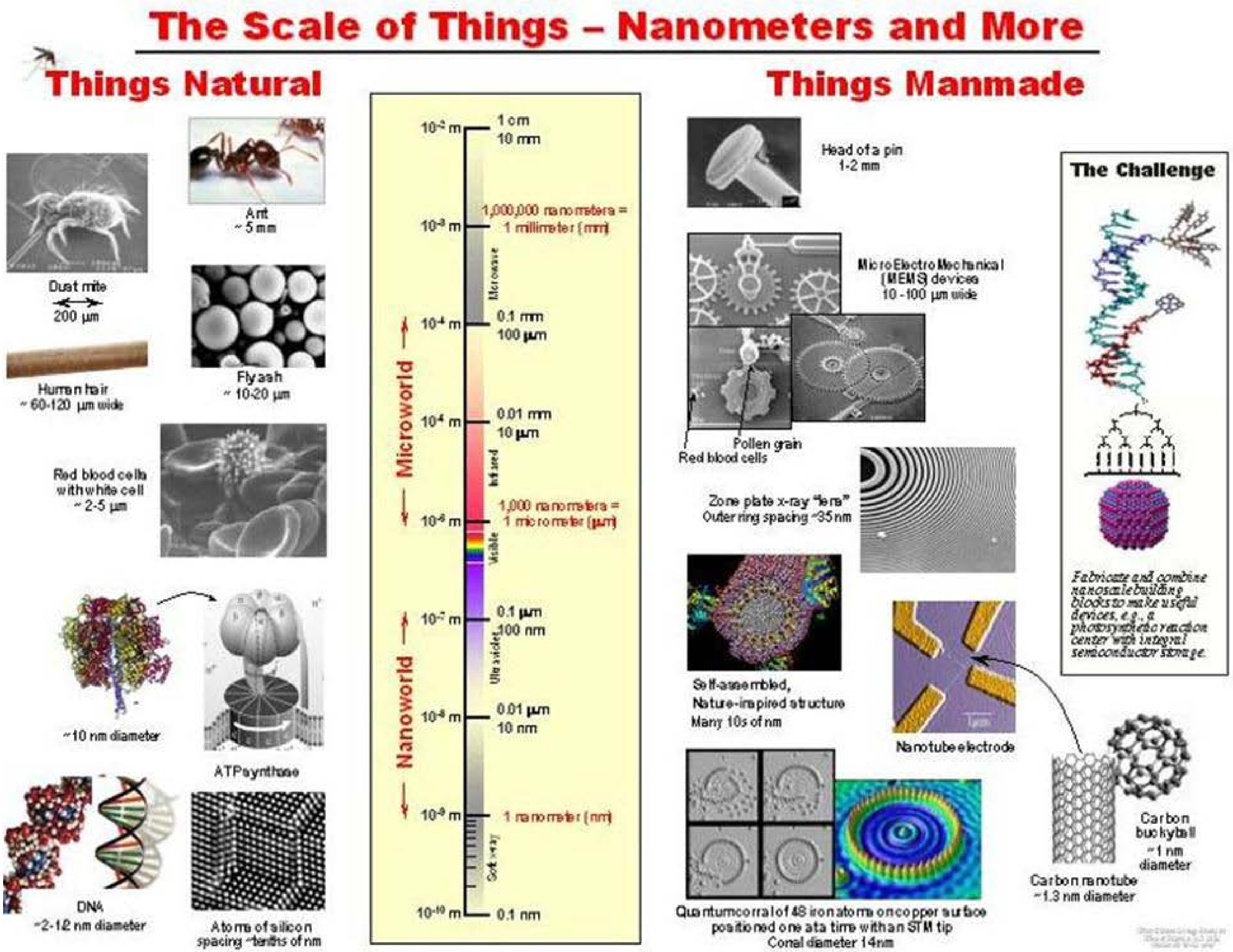

Norio Taniguchi coins the term "nanotechnology" (1974)

Nanotechnology enhanced products hit the market ('99 – 03)

Stained glass windows in European cathedrals Au NPs – ($6^{th}$ -$15^{th}$ C)

"Damascus" saber blades contained carbon nanotubes and cementite nanowires ($13^{th}$ – $18^{th}$ C)

# "The Scale of Things"



# DoD's Interest in Nanotechnology

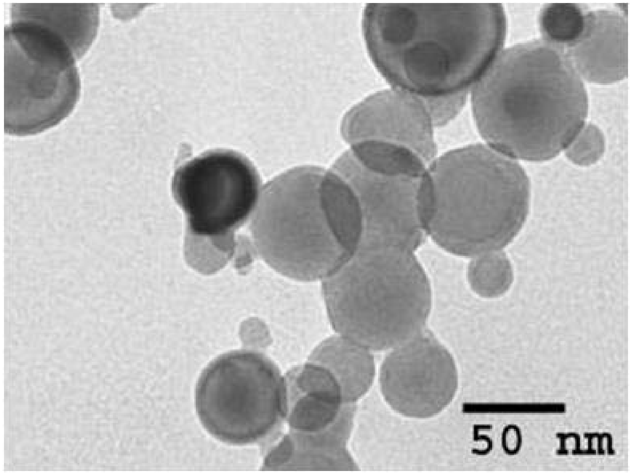
- Increased lethality
- Increased survivability
- Lightweight materials
- Multifuctional materials
- Tunable Materials
- Novel Materials
  - Structural
  - Electrical
  - Optical
  - Magnetic
  - Etc

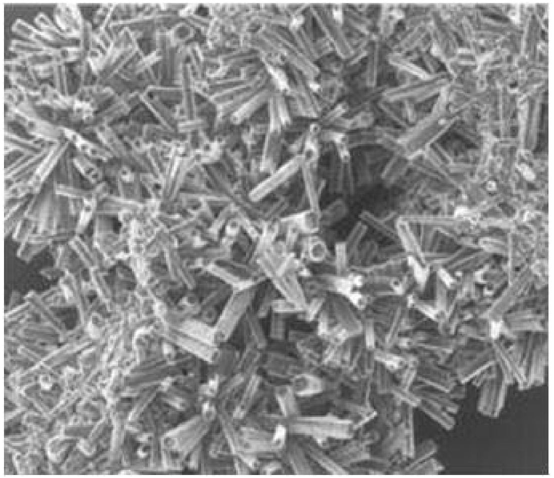
Improving Legacy Items

Developing New Items

# Tunability of Nanomaterials

- Tunability arises from:
  - Size effects - 20nm particle Δ 100nm particle
  - Chemistry - highly tailorable, precise control
  - Morphology – spherical, platelets, rods, etc.



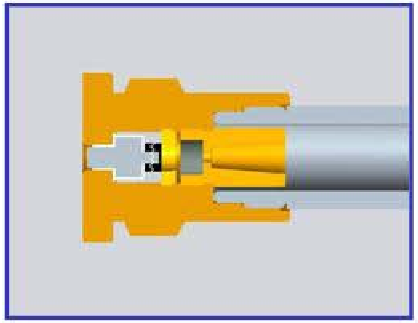
# Applications

## Armor Materials



## Anti-Armor Materials

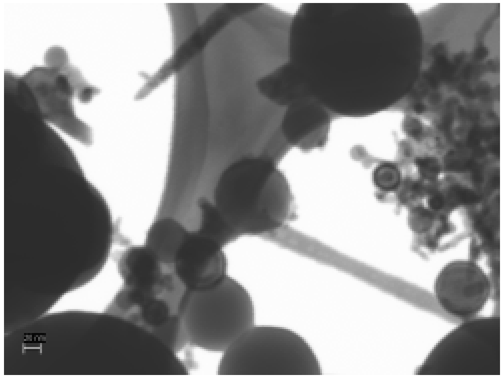
## Novel Energetics



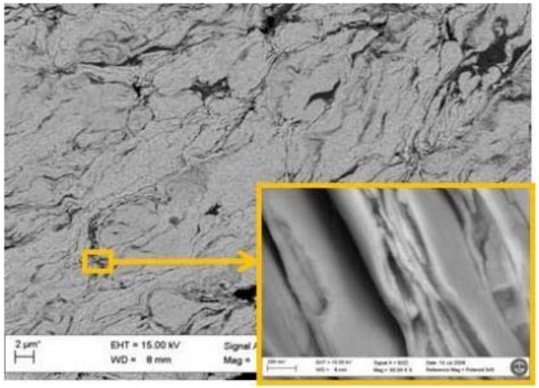

## Pyrotechnics

# Defining “Nanomaterial”

- Nanomaterial – A material having *at least* one dimension in the 1 – 100 nm size range
  - Nanophase material – This consists of materials where the primary particle size is nanoscale
  - Nano*structured* material – Materials which are not necessarily nanoscale, but possess features (e.g. grain size) which are nanoscale



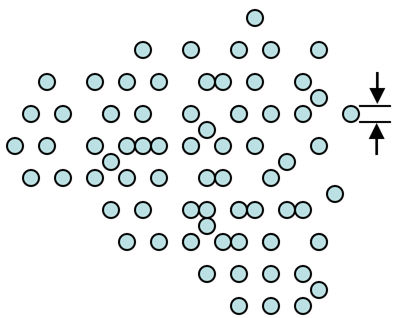
Nanophase powder




Nanostructured material

# Nanoscale vs. Nanostructured

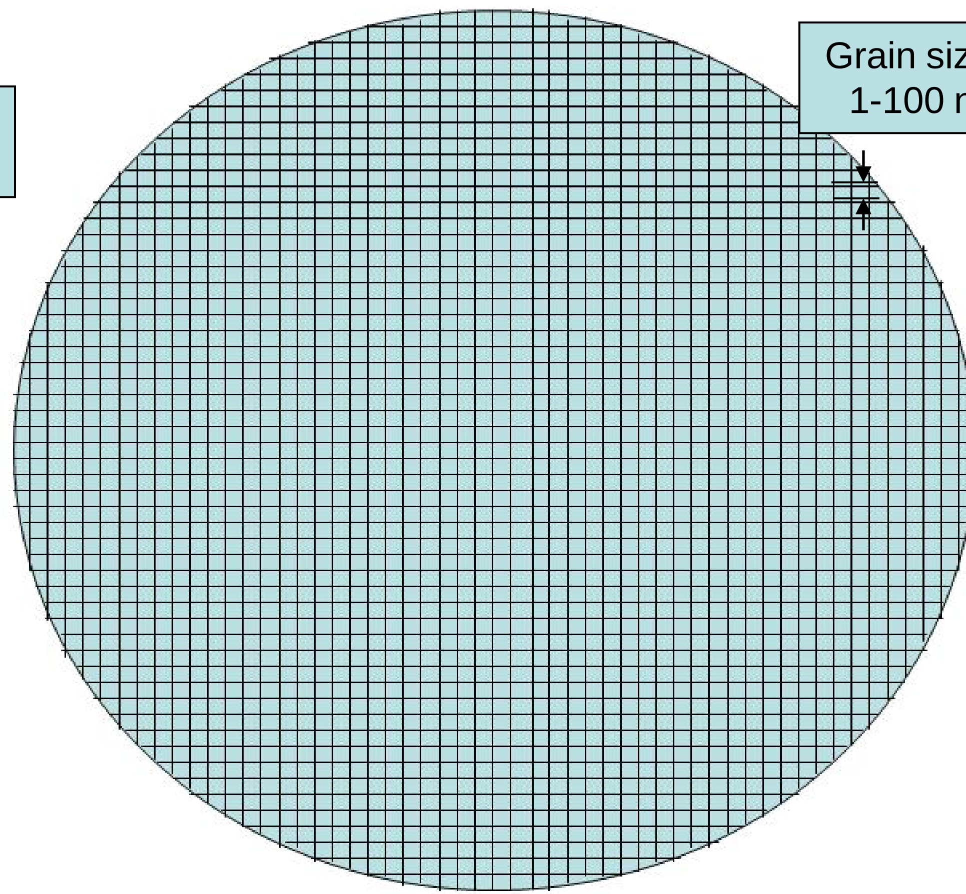
## Nanoscale powder



Particle size is 1- 100 nm

ESOH best practices still being developed

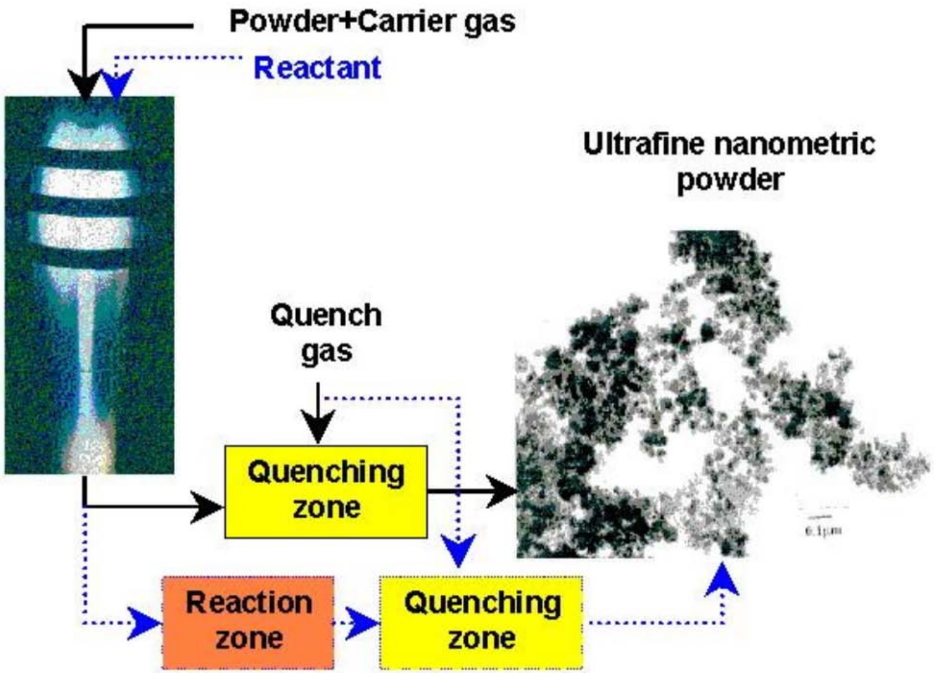
## Nano-*structured* Powder



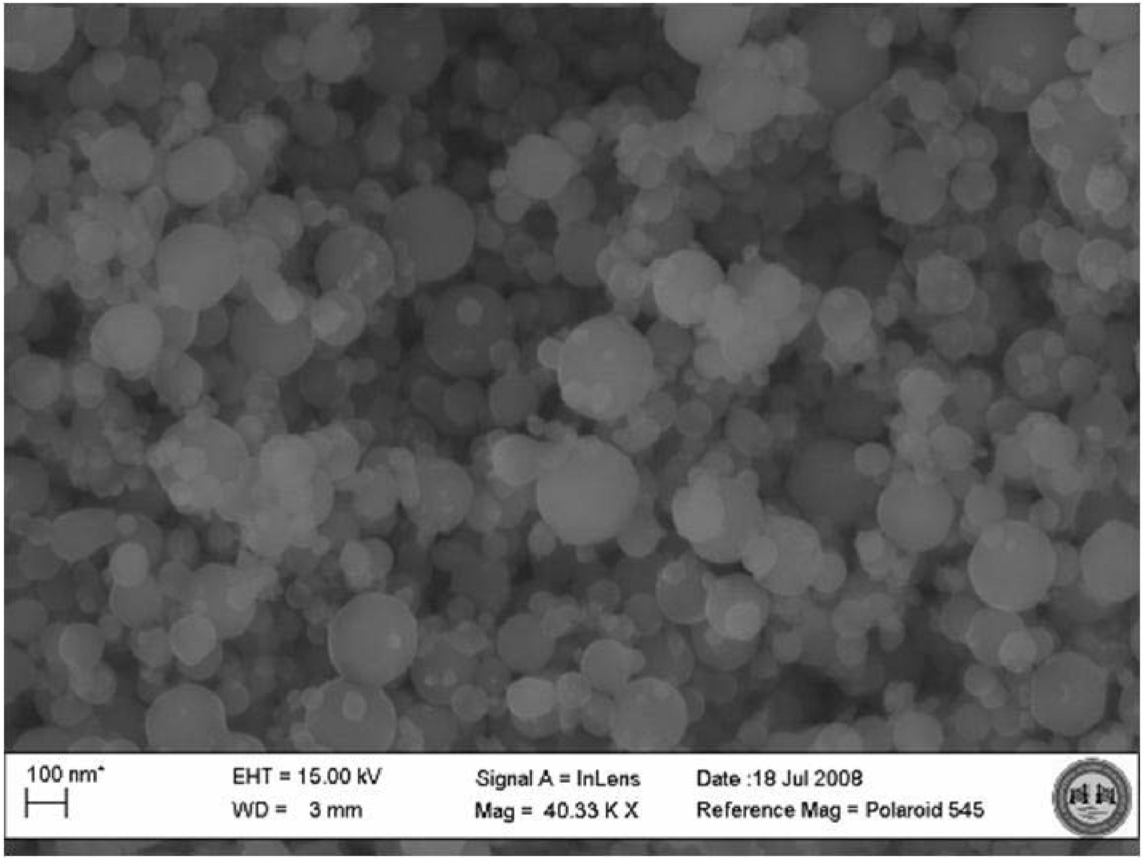
Grain size is 1-100 nm

As safe as conventional materials

# Nanopowder Synthesis – Plasma Reactors




# Aluminum Nanopowder



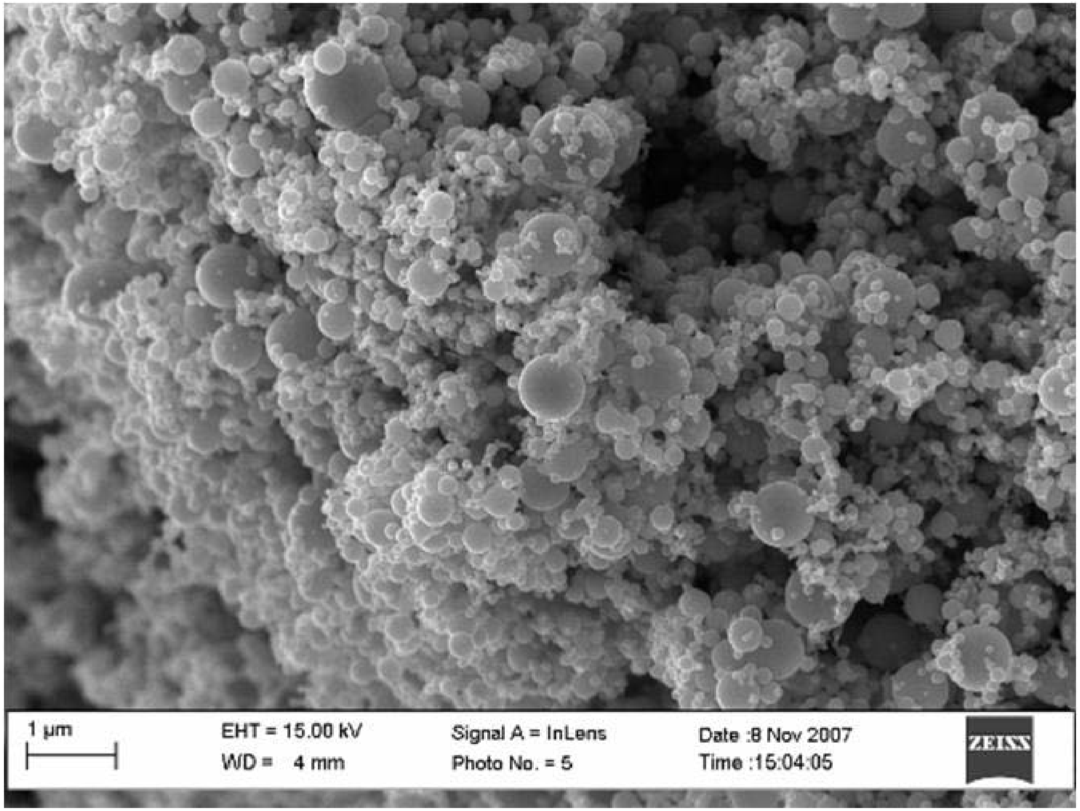

Applications:

✓Propellants

✓Energetics

- Primers
- Explosives
- Pyrotechnics

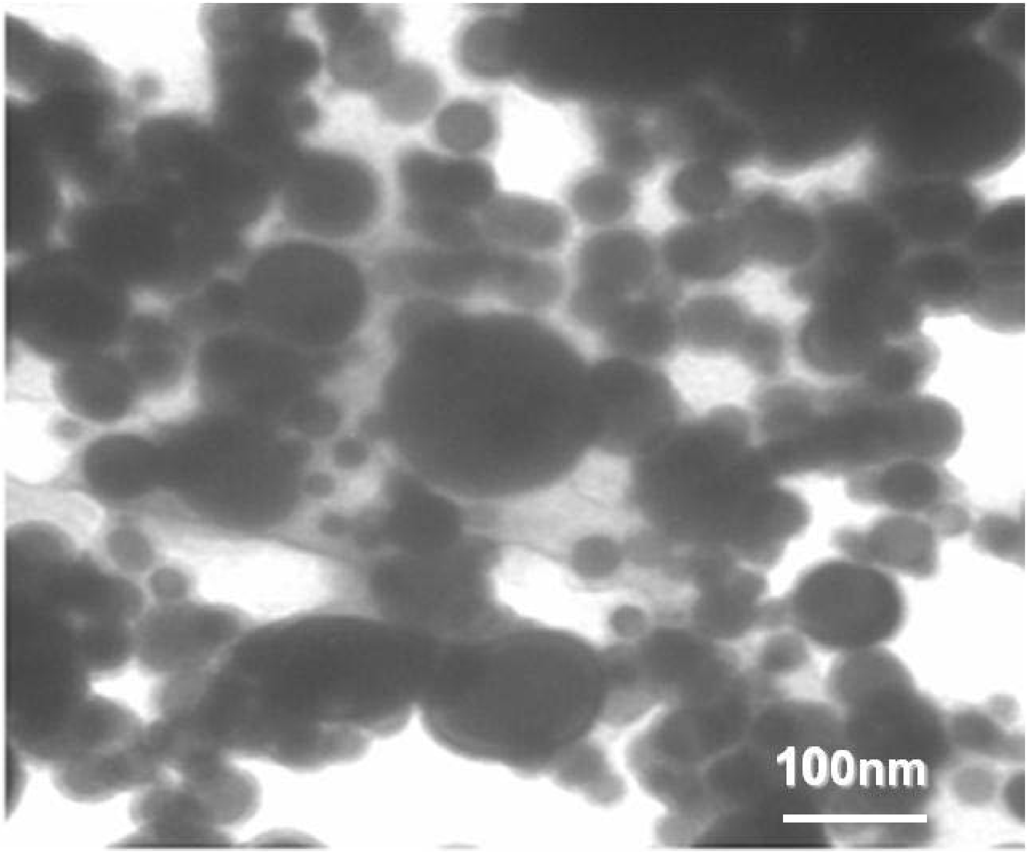
# Iron Nanopowder




Applications:

- Infrared materials (for countermeasures, etc)
- Potential use for remediation of contaminated soils/water

# Tungsten Nanopowder (MMA Coated)

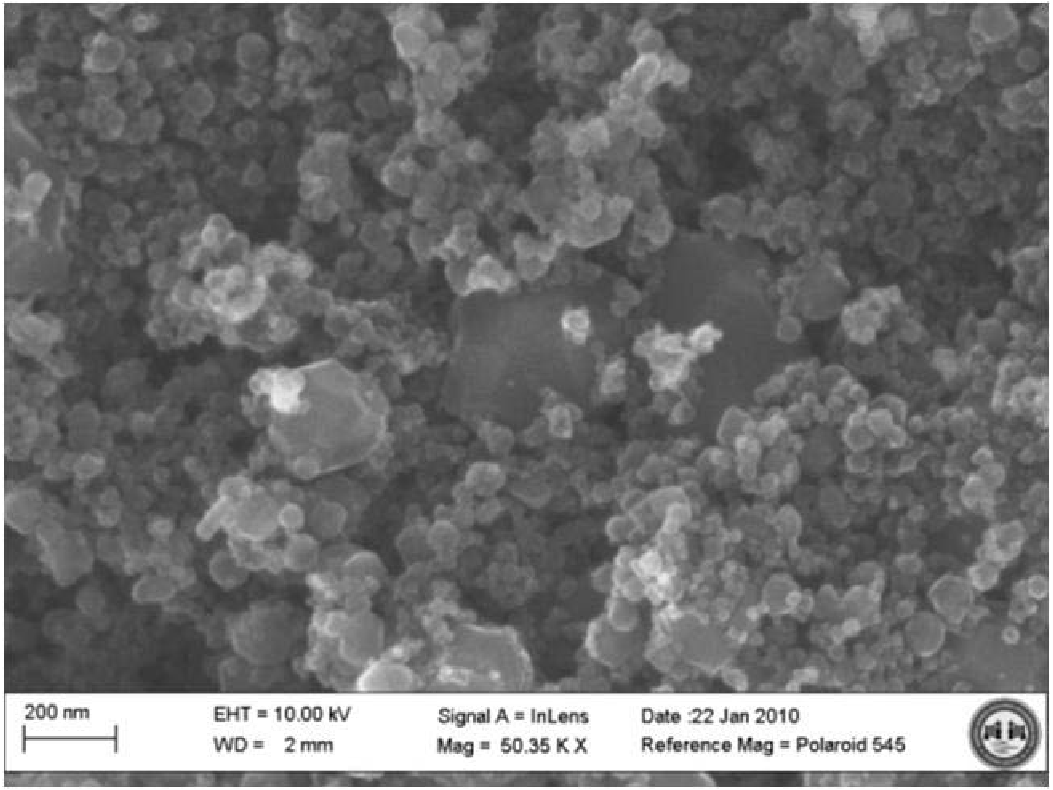



Applications:

•Primarily uses of W include Kinetic Energy (KE) Penetrators and Rigid Body Penetrators

•Potential for more ductility that conventional materials

# Boron Carbide ($B_4C$) Nanopowder

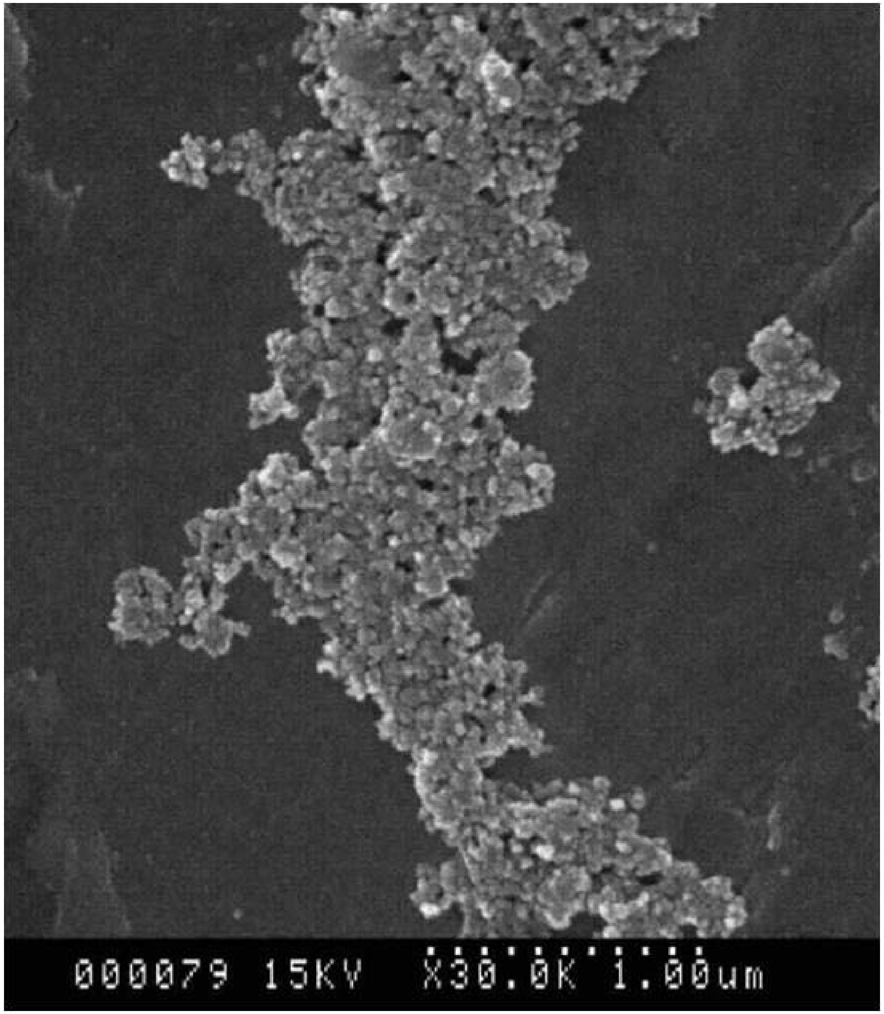



Applications:

- Boron Carbide ($B_4C$) is a lightweight armor material.
- Reinforcement phase in MMC[1,2]
- Novel pyrotechnics[3]

1. *Zhang et al., Scripta Materialia*, Vol. 65, No. 8. (October 2011), pp. 652-655.
2. Haines et al., US Patent Application, USPTO Serial # 61/446,521
3. Sabatini et al., *Angew. Chem. Int. Ed*. 2011, 50, 1 – 4

# Nano Boron



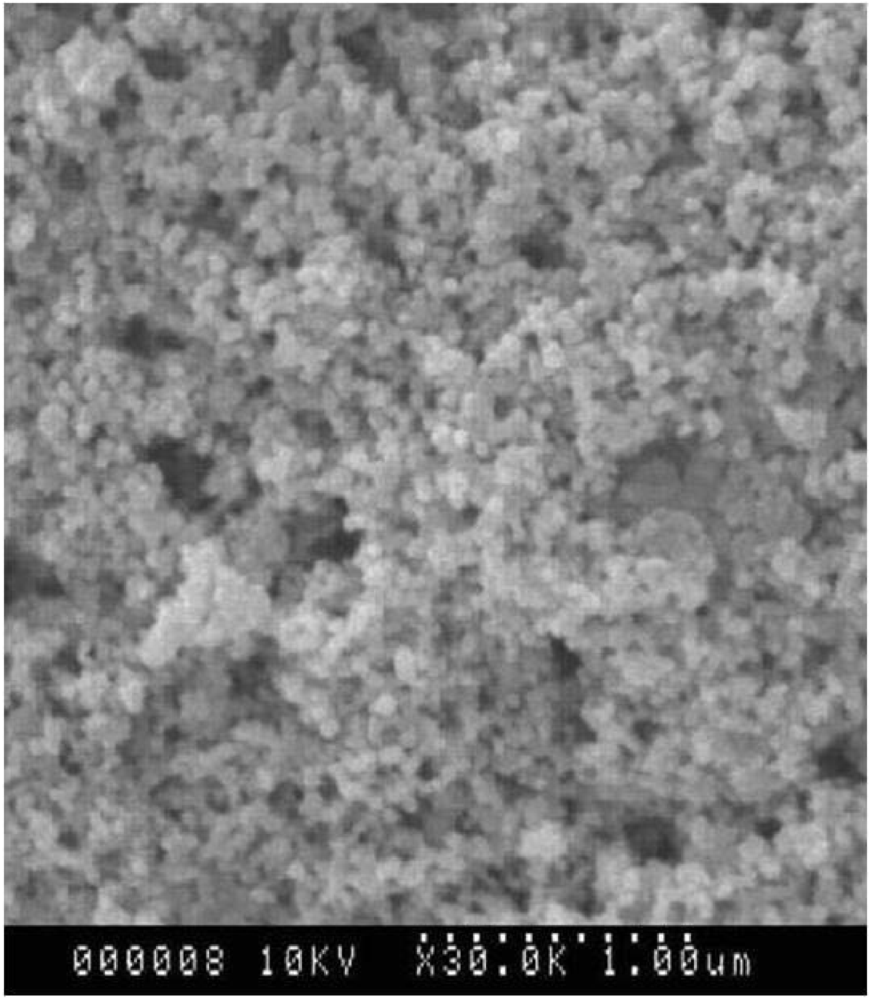

Applications:

✓Energetics

✓Pyrotechnics

✓Structural Reactive Materials

# Nano Tantalum



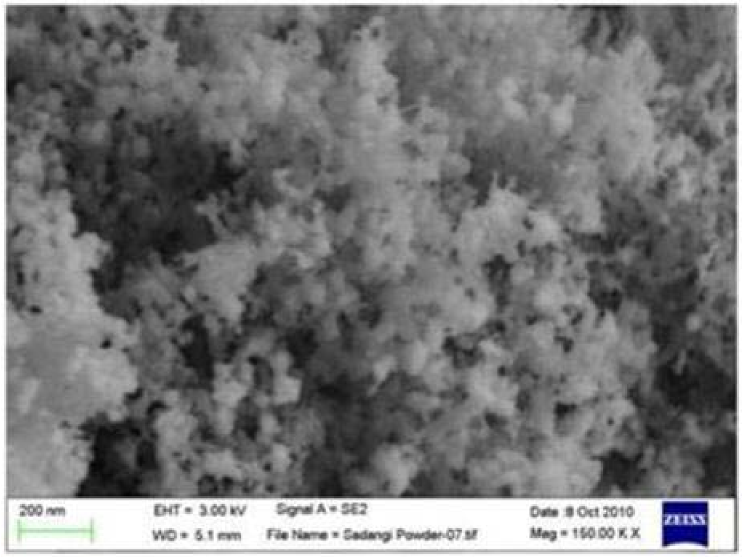

Applications:

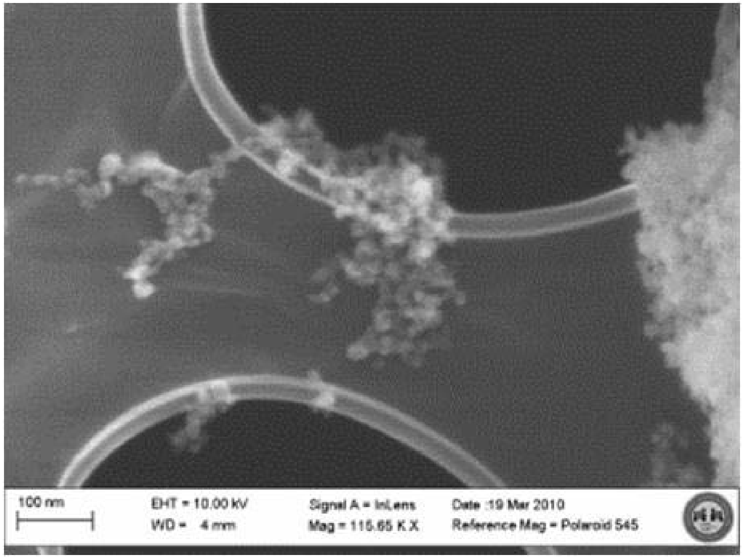
✓Warheads

- Shaped-Charge Liners
- EFPs

✓Reactive Materials

# Nano Mixed Oxides




- Optical materials
- Catalysts
- Magnets
- Piezoelectrics

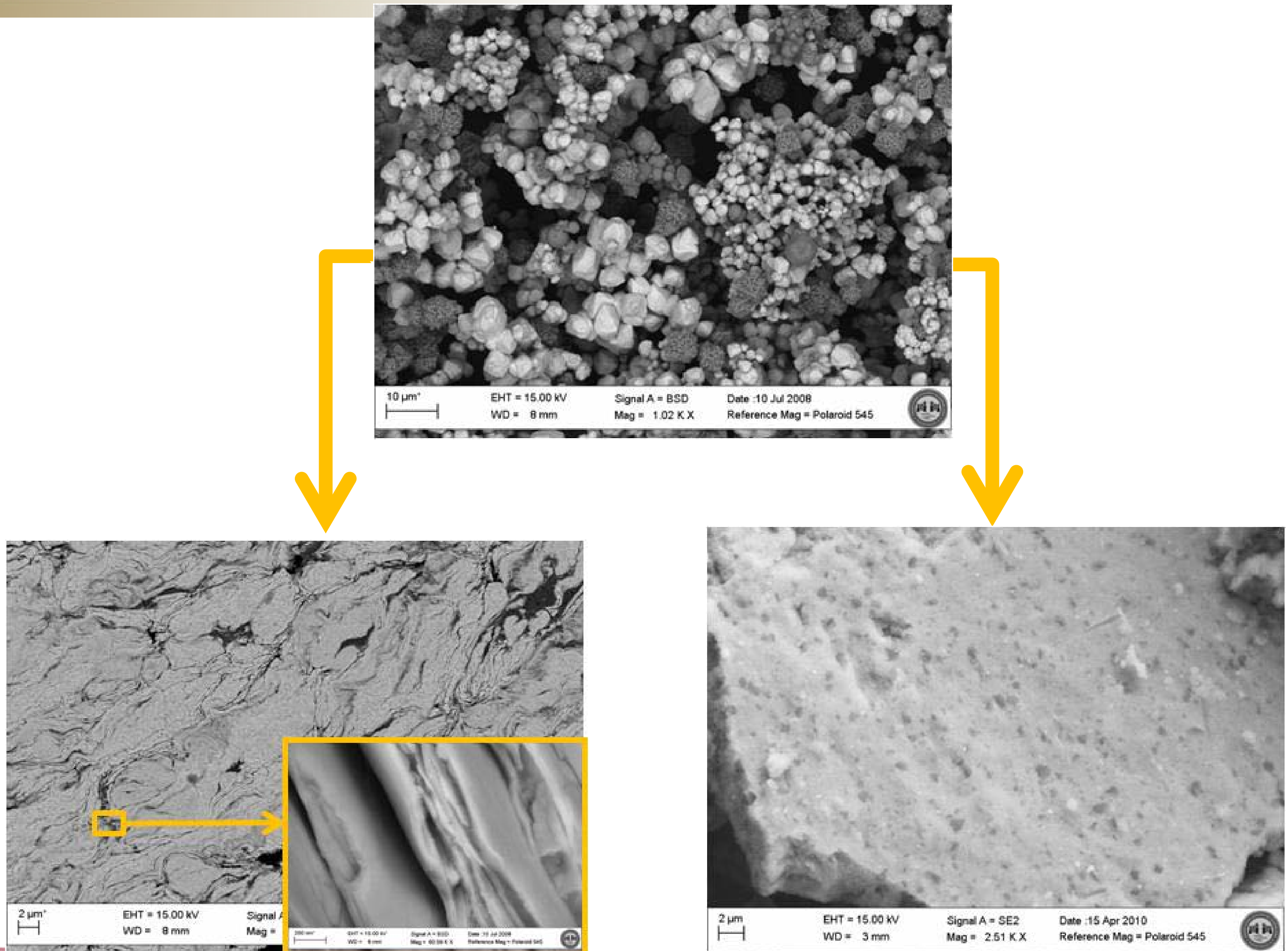
# Mechanical Alloying (MA) Capability (Nanostructured)

Dry high-energy mills


Wet high-energy mill

Concept: Impart nanostructure into conventional material via a mechanical route (break-weld)

# Nanostructured Powders

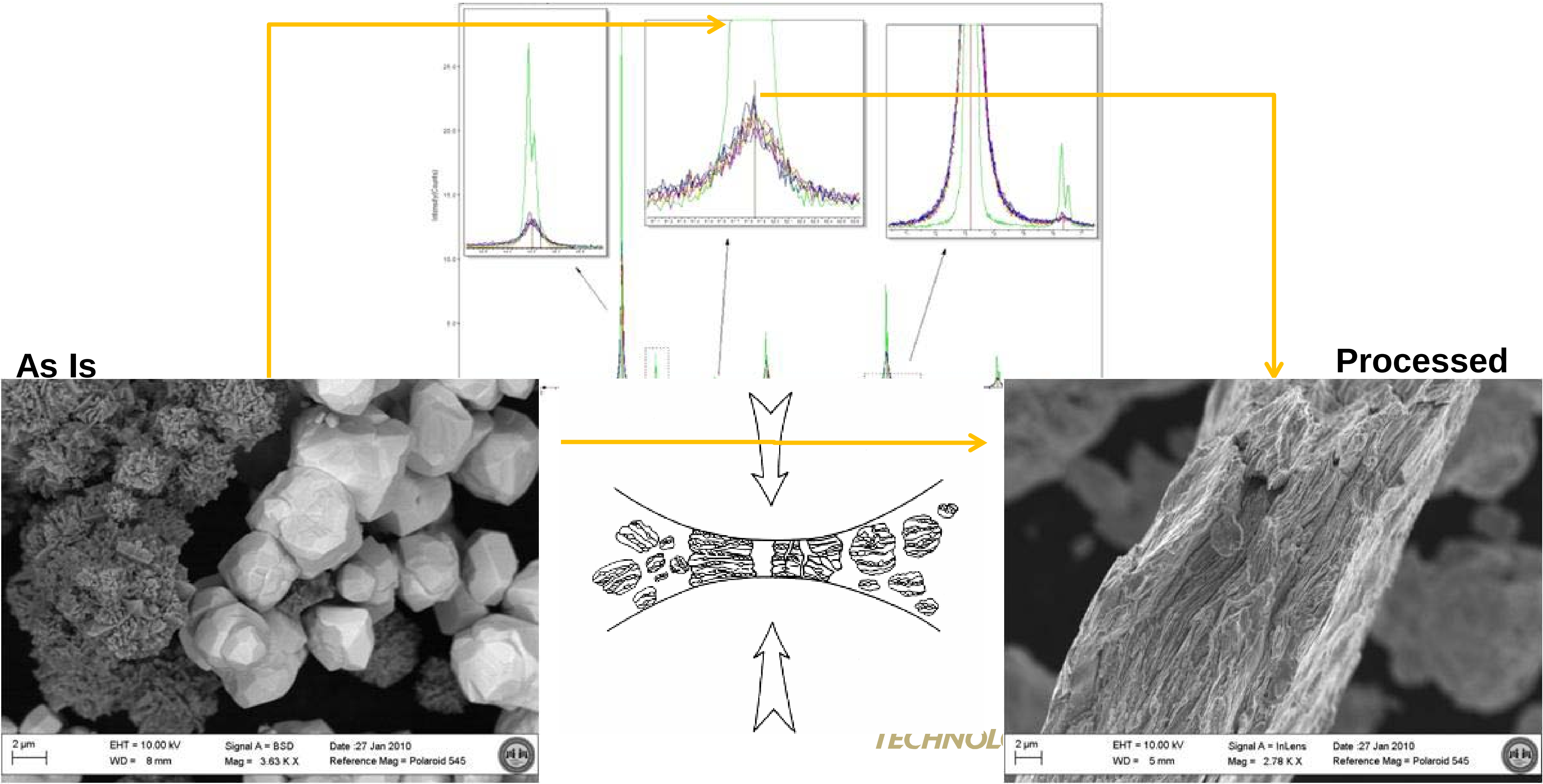



**Solid Solution**

**Dispersion Strengthened**

# Characterization

- Materials Characterization
  - Scanning Electron Microxcopy and X-Ray Diffraction confirm nanostructure



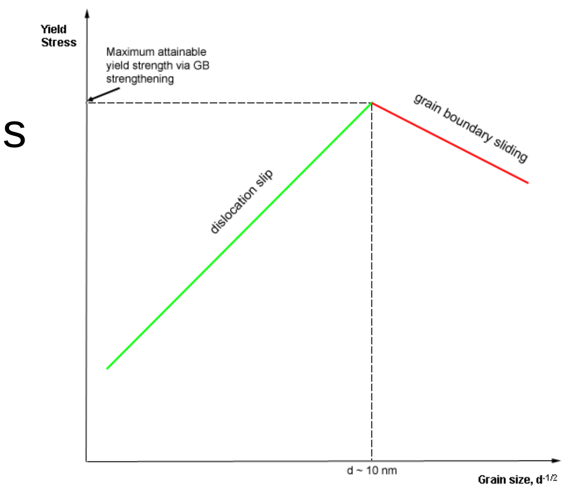
# Structural Materials

# Structural Materials

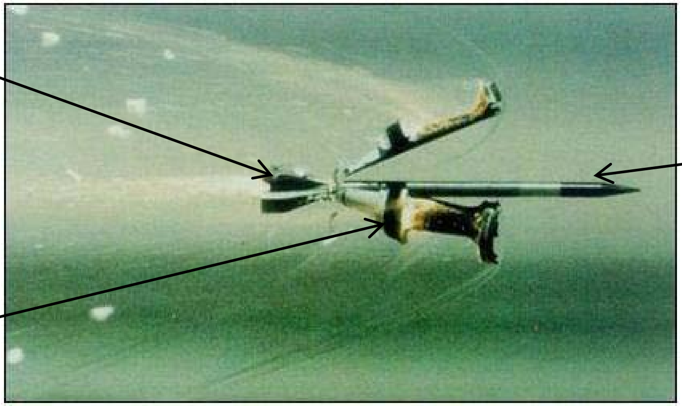
## What material properties can nanomaterials affect?

- Mechanical
  - Strength - Smaller grain size → stronger materials
    - ➢Lightweight materials & composites
    - ➢Increased survivability
  - Toughness
    - ➢Nanocomposite materials

Hall-Petch Strengthening Limit




Stronger, Lighter Fins?



Higher Performance KE Penetrator Materials?

Cheaper Sabots?

# Consolidation of Powders

## Field Assisted Sintering

**Advantages**:

•Rapid Volumetric Heating

•Sintering times measured in **minutes**, not hours

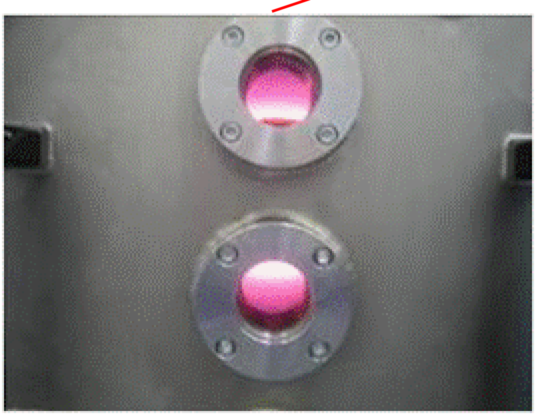
•Provides pportunity to preserve nanostructure

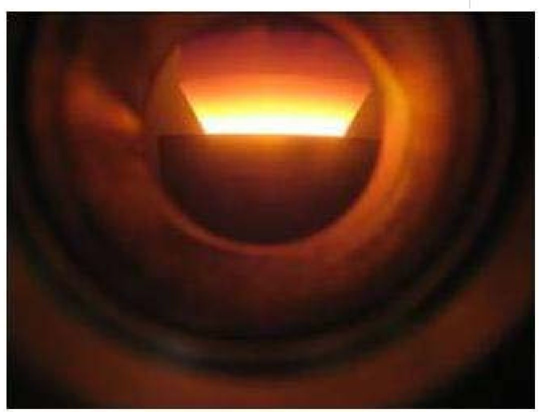
•Cost savings due to shortened cycle times

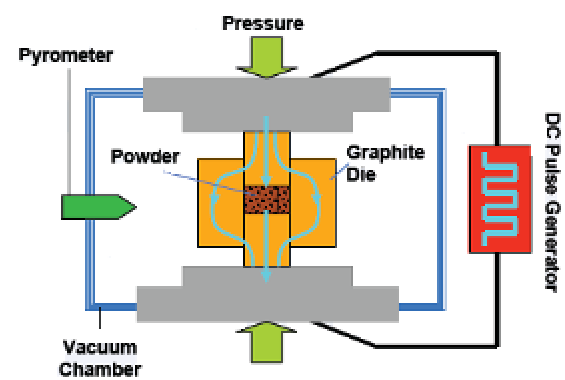
**Disadvantages:**

•Shape limitations

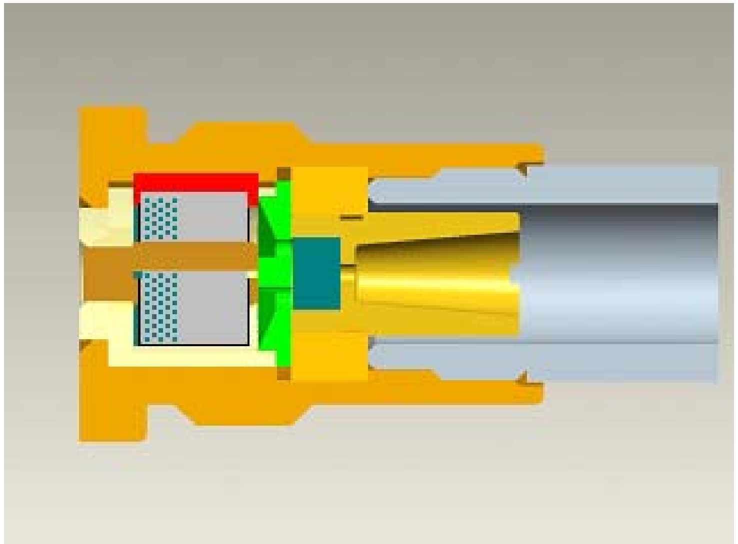
•Emerging technology – not mature







# Green Primers & Initiators



# Green Primers

Overarching Goal: Replace hazardous materials found in conventional ammunition with more benign nanomaterials for legacy and future armaments

**Successes:**

- **Testing shows evidence that lead thiocyanate based ignition mixture and black powder in tank artillery primers can be replaced with environmentally benign nanothermite (Al-$Fe_2O_3$)**

- **Nanoscale metallic (fuel) / metal oxides (oxidizer) mixtures are being investigated for potential replacement lead azide / lead styphanate**

- **MIC (nanomaterials) materials were successfully loaded into small caliber primers and passed sensitivity requirements**

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# "Drop-in" Nanomaterials

**GREEN NANO igniter material replaces sensitive ignition composition**

**FILM BAND IGNITER**

**Meets HERO requirement**

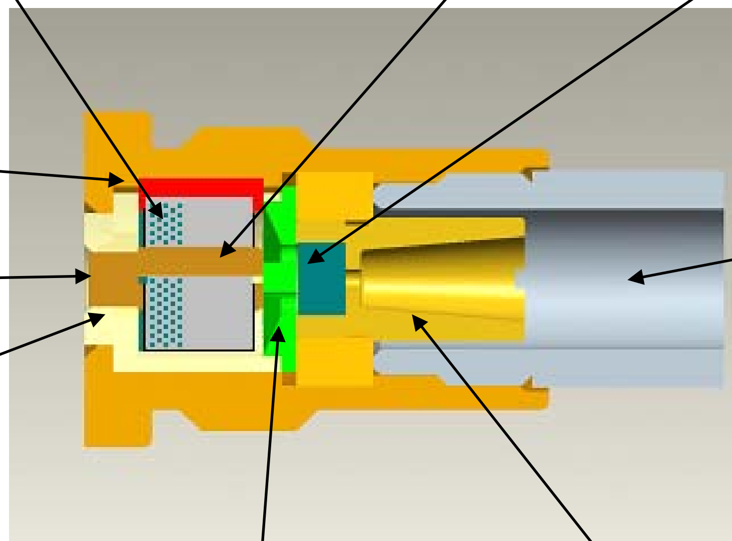
**Al + Iron Oxide Mixture replaces Black powder**

**Demonstrated with Ignition comp replacement Aug 06:**

**IGNITION FILM CONNECTOR**

**IGNITION PIN**

**INSULATOR CUP**



**INSULATOR VENT RING**

**CLOSING PLUG**

**PRIMER BODY**
PACKED WITH BENITE STRANDS

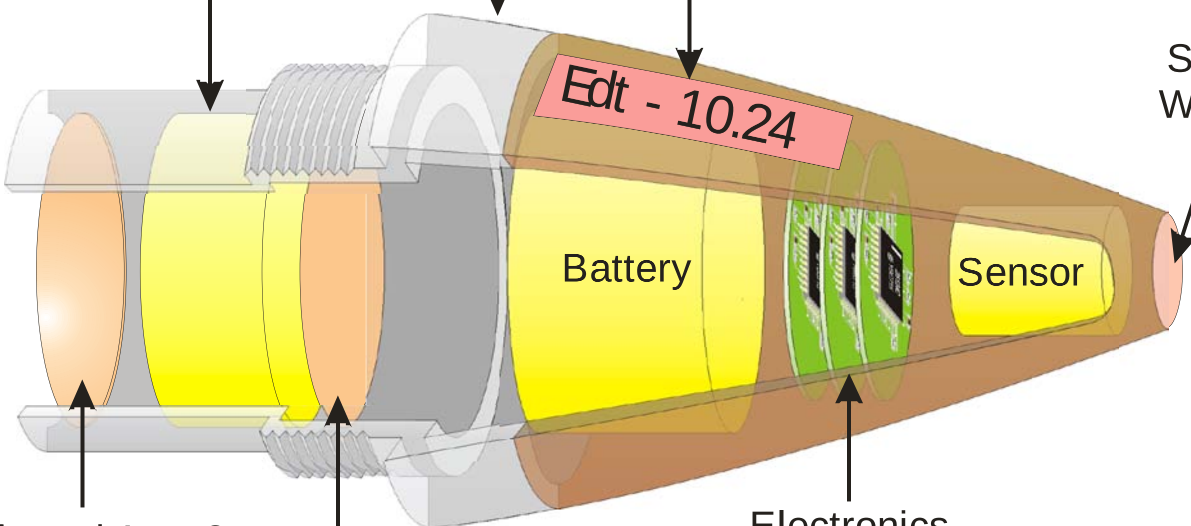
TO BE REPLACED BY HOT PARTICULATE **NANO TYPE MIXTURE**:

- **SUPPORTING ACADEMIA:**
  - **South Dakota School of Mines**
  - **University of Missouri**

# Sensor Electronics & Power Supplies for Munitions & Fuzing components

# Fuze Components – Need for Miniaturization

Fuzes: In layman's terms…a lot of stuff in a little bit of real-estate



# Novel Energetic Compounds

# Pyrotechnics

Why nanomaterials?

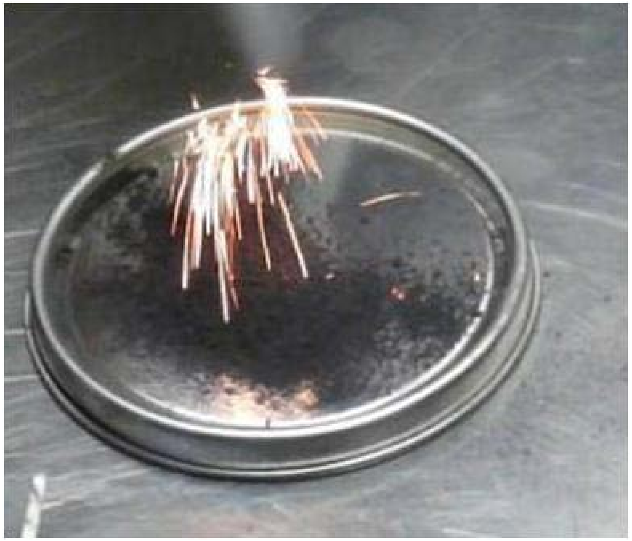
•Surface Area – high SA translates into enhanced reactivity

•Pyrophoricity – many materials are inherently pyrophoric at the nanoscale

•Versatility – chosen synthesis routes allow for compositional flexibility

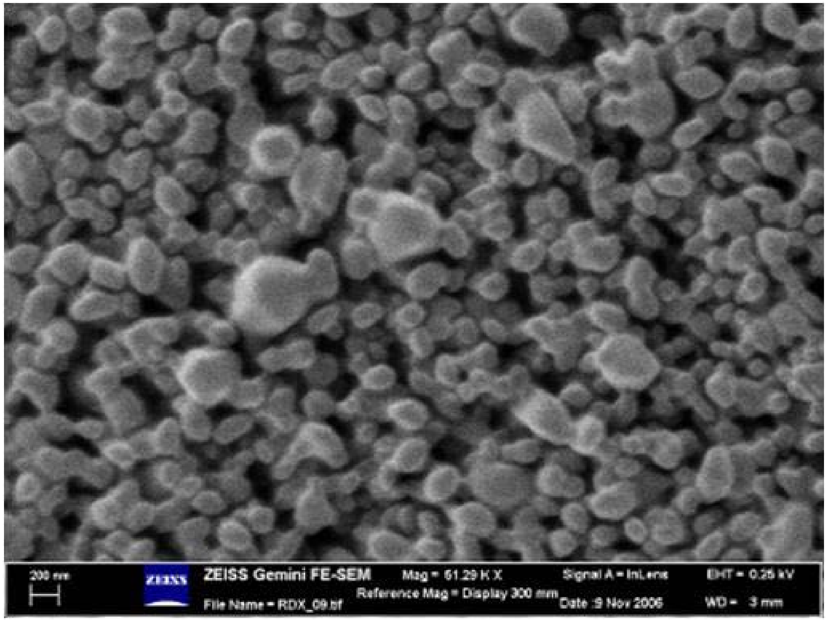
•Tunability – ability to tailor the output

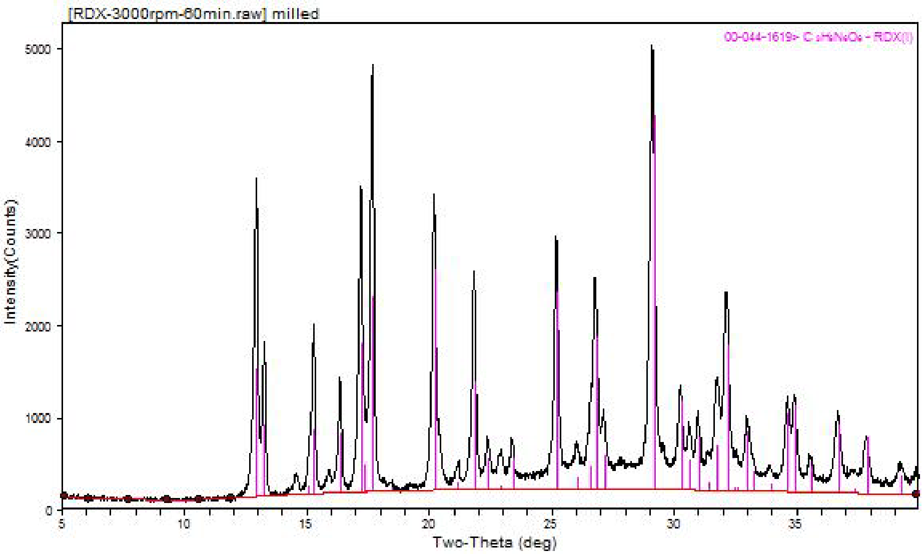
Countermeasure Flare Deployment



ARDEC Nano Fe

# Nano-RDX via a “Top-Down” Approach



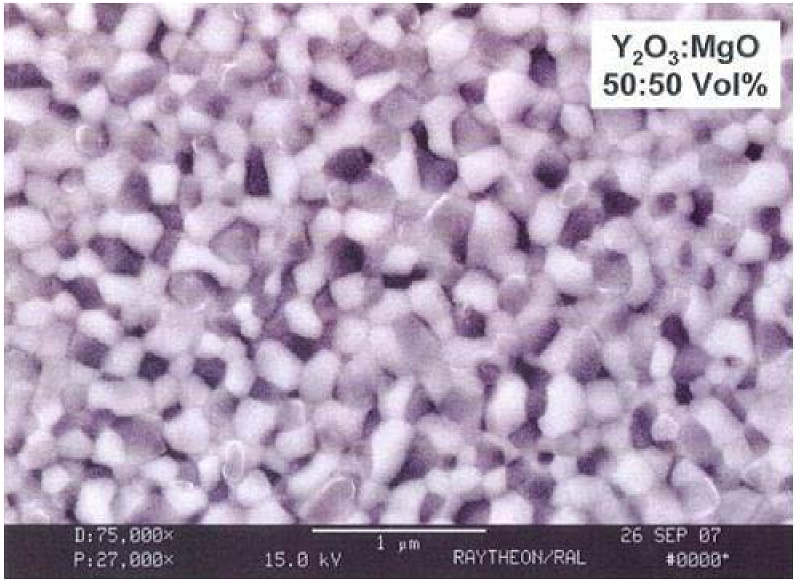



# Novel Transparent Ceramics

Raytheon nanocerox

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Various EM windows used in DoD systems



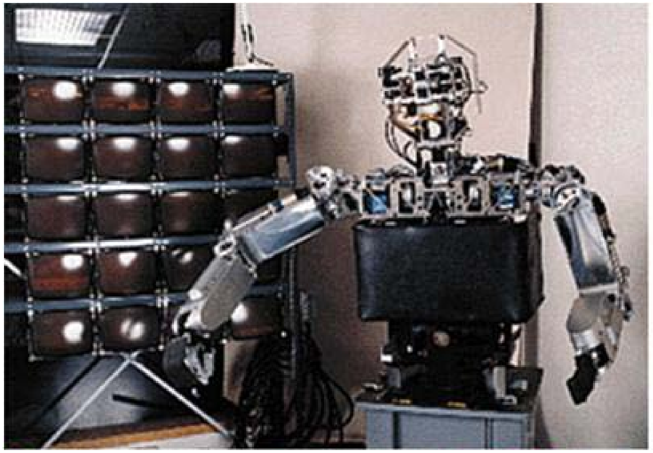

DARPA

# Futuristic Technologies (Pie-in-the-sky)

# Futuristic Technologies

## Active Camouflage?

## Autonomous Warfare?



Raytheon Systems Co. / MIT

## Soldier Exoskeletons?

## Instant Armor?

MIT- Institute for Soldier Nanotechnologies

# Summary

- ✓ Nanomaterials are of significant interest to DoD and are slowly making their way into end items
- ✓ DoD is investing substantial resources into nanotechnology in an attempt to stay “ahead of the curve”
- ✓ Nanotechnology will play a substantial role in future combats systems
- ✓ Our industry/academia partnerships are instrumental to our success

RDECOM

# Acknowledgements


- The whole “Nano Team” at ARDEC: Deepak Kapoor, Paul Redner, Darold Martin, Joe Paras, Ryan Carpenter, Lauren Armstrong, Kendall Mills, Rajendra Sadangi
- Mr. Jim Zunino and Dr. Iqbal (NJIT) for coatings/nano-inks
- Mr. Robert Braun for nano-inks/futuristic technologies
- Mr. Paul Redner & Mr. Raj Patel for nano-RDX
- Mr. Mike Donadio for LEI
- Dr. Jan Puszynski for green primers
- Dr. Jim Sears (SDSMT*) for Direct Write

*South Dakota School of Mines & Technology

# Contact Information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# Backup Slides

# Printing with Nanoinks

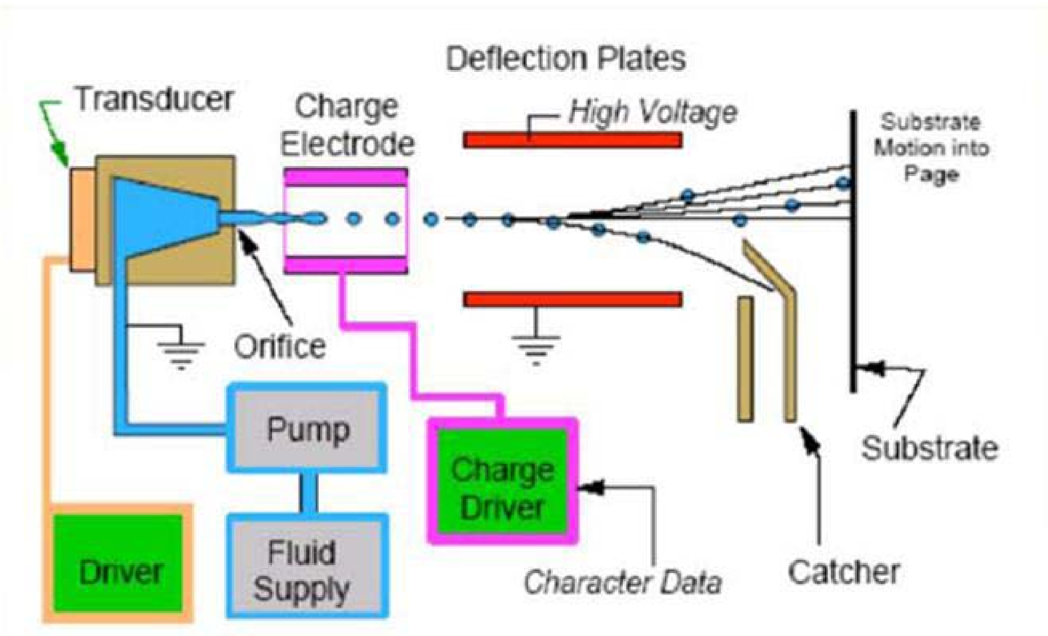
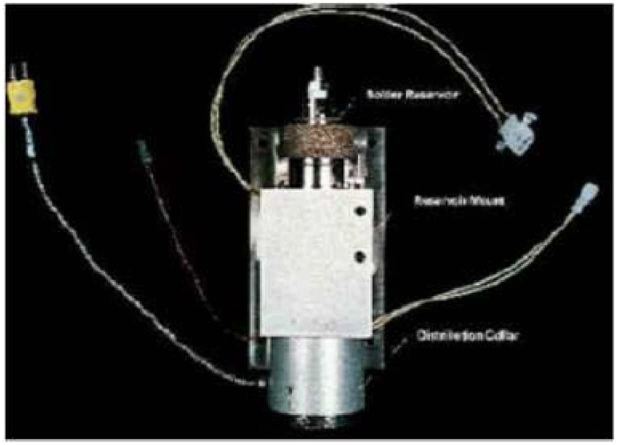
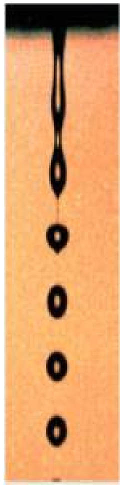
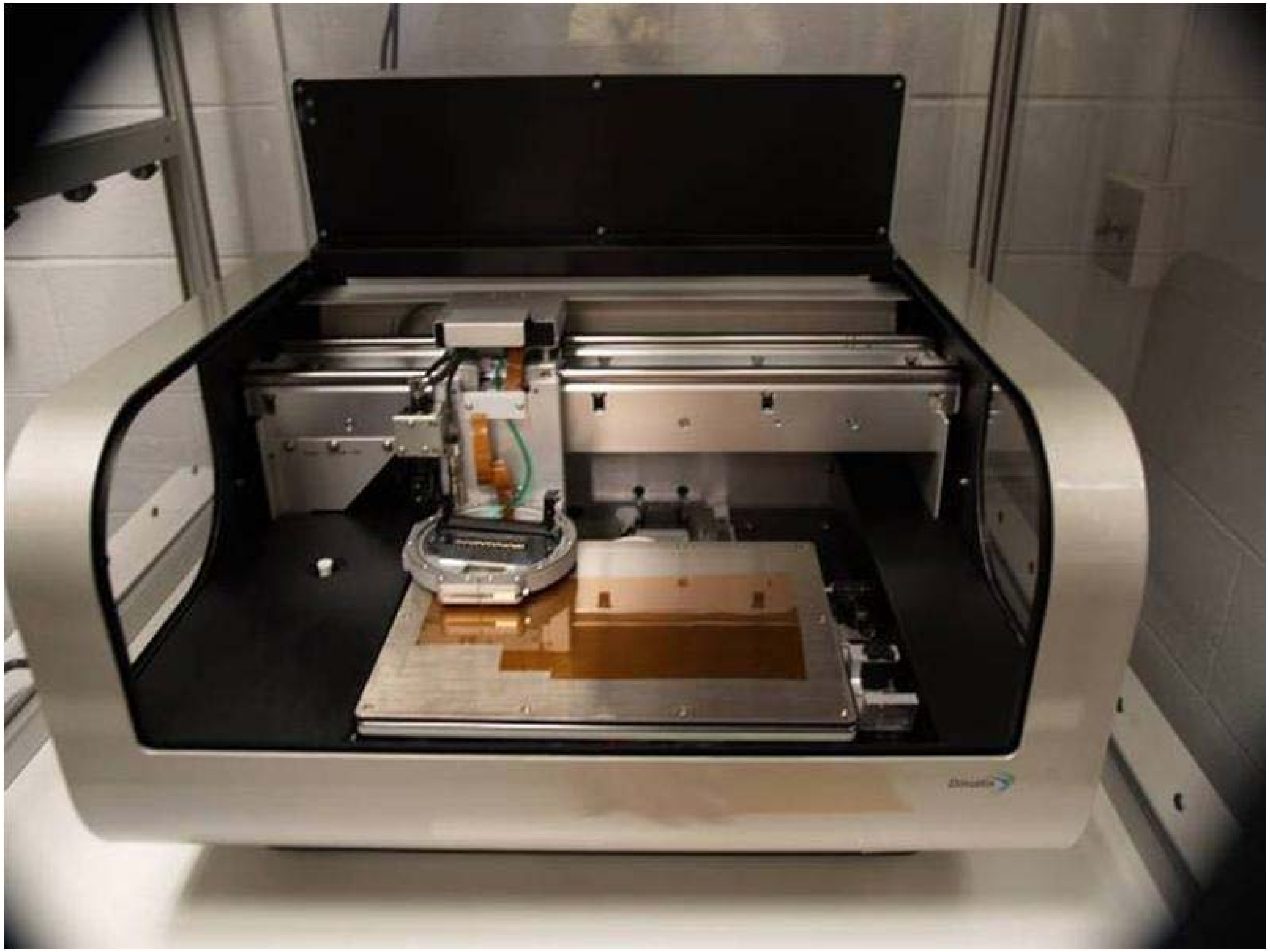



*Figure 1: Schematic of a continuous type ink-jet printing system.*





# Printing with Nano-Inks



# Direct Write Technology

- Pneumatic & Ultrasonic Atomizers
- Laser Sintering
- Heated Platen
- 0.1 μm Stage Positional Resolution
- CAD/CAM Interface
- Wide Material Range (1 -1000 cp)
- Nano-particles (30 - 100 nm)
- Non-Contact (5 mm stand-off)
- Conformal

# 3-D Printing

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## Maskless Mesoscale Material Deposition (M3D) System


- Pneumatic & Ultrasonic Atomizers
- Laser Sintering (2W Nd:YAG @ 532 nm)
- Heated Platen
- 0.1 μm Stage Resolution
- Profilometer – 3 μm min., 0.01 μm Res.
- AutoCAD translator
- Material Range (1 - 1000 cp)
- Nano-particles (30 - 100 nm)
- Non-Contact (5 mm standoff)
- Conformal
- Top Mounted HEPA Filters