



**4<sup>th</sup> Indo-US Round Table**  
**Bangalore, India**  
**21-23 September 2010**

# **AOARD Overview**

## **Power and Energy Emphasis**

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**Program Manager**  
**AOARD**

**Air Force Office of Scientific Research**

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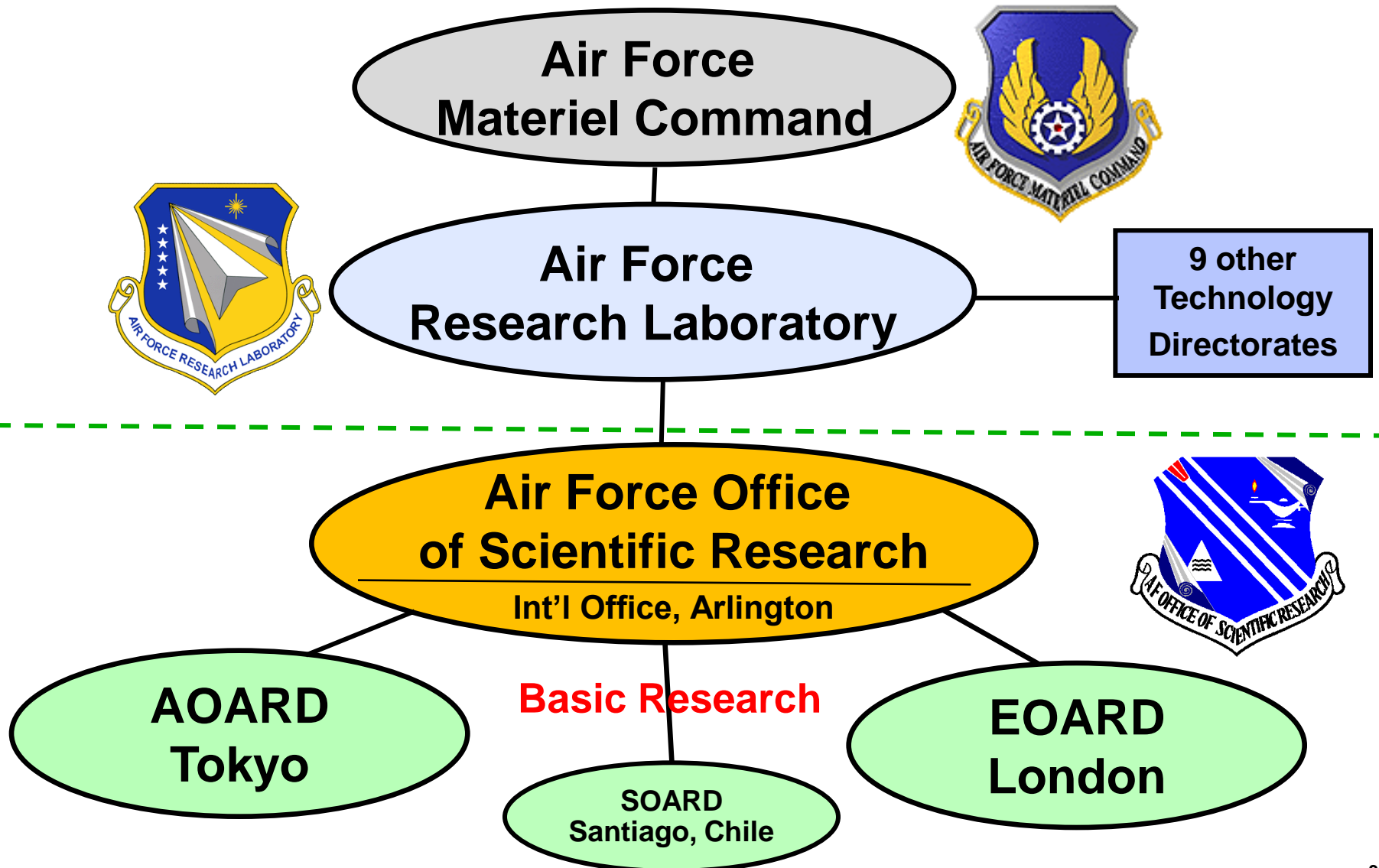
# Presentation Outline

- ☐ **Our Organization**
- ☐ **Our Mission**
- ☐ **Resources &  
Opportunities**
- ☐ **AOARD\* Project Examples**
- ☐ **Message to Researchers**

**\*AOARD = Asian Office of Aerospace Research and Development**



# Where AOARD (Tokyo) Fits





# AFRL Supports International Research Efforts



*Conference Support, Window-on-Science,  
Research Grants*



# AFOSR Mission



**AFOSR discovers, shapes, and champions basic science to profoundly impact the future Air Force**

- Identify Breakthrough Research Opportunities – USA & Abroad
- Foster Revolutionary Basic Research for Air Force Needs
- Transition Technologies to DoD and Industry

**TODAY'S BREAKTHROUGH SCIENCE FOR TOMORROW'S AIR FORCE**





# AFOSR Basic Research Areas



## Aerospace, Chemical & Materials Sciences (RSA)

- Materials & Structures
- Chemistry
- Fluid Mechanics
- Propulsion

## Physics & Electronics (RSE)

- Physics
- Electronics
- Space Sciences
- Applied Math

## Math, Information & Life Sciences (RSL)

- Info Sciences
- Human Cognition
- Mathematics
- Biomimetics

## AREAS OF EMPHASIS INCLUDE:

- Complex Networks
- Robust Decision Making
- Socio-Cultural Modeling

- Energy & Thermal Management
- Agile, Autonomous Flight
- Space Situational Awareness



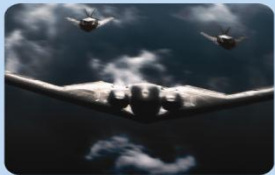
# 60 Years of AFOSR Breakthroughs



1950s



Maser/Laser

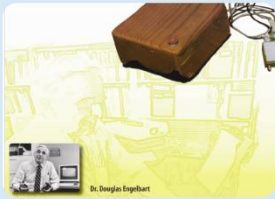


Stealth



Kalman Filter

1960s



The Computer Mouse

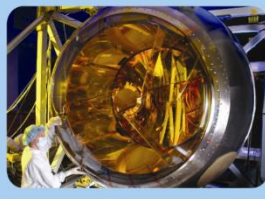


Code Division Multiple Access System for GPS



Viterbi Decoding Algorithm

1970s



Chemical Oxygen Iodine Laser (Coil)

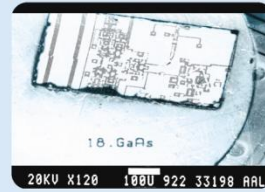


Superplastics Forming

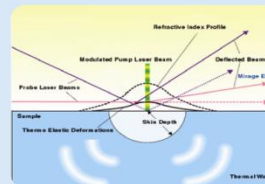


Air Fracture Mechanics Methodology

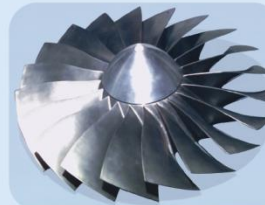
1980s



Low-Temperature Gallium Arsenide



Laser Diagnostics



High-Efficiency Compressor Blades

1990s



Self-healing Plastics

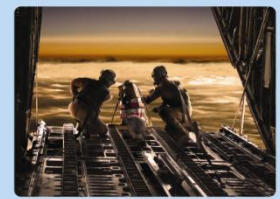


Dip-pen Nanolithography

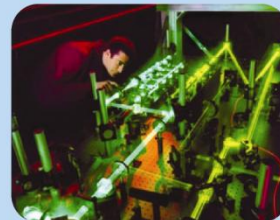


Laser Trapping

2000+



Joint Percision Airdrop System



Electric Oxygen Iodine Laser

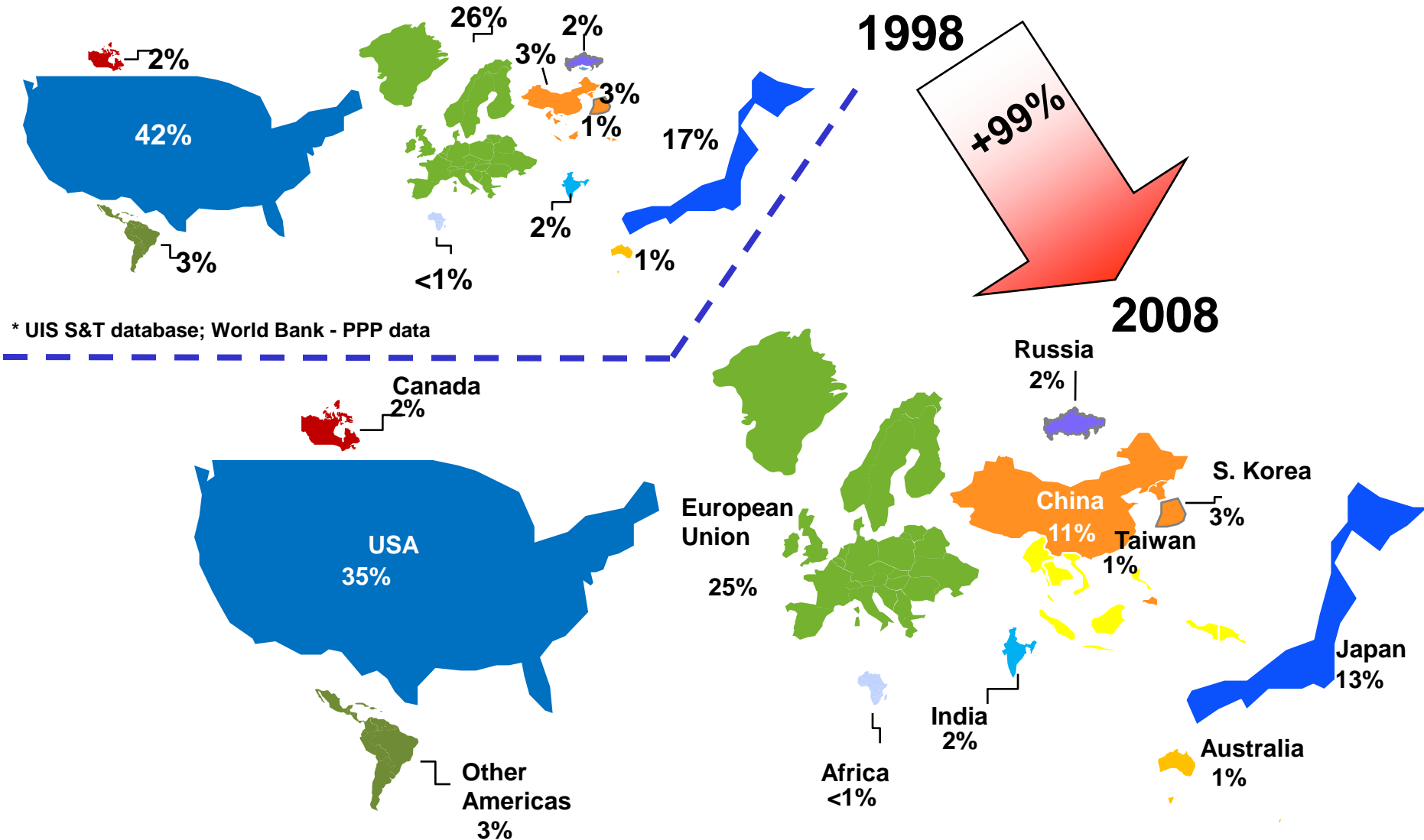


Laser Propulsion





# World S&T Investment 1998\* to 2008\*\*



\*\* OECD 2007 PPP; 2009 Global R&D Projection (Battelle and R&D Magazine) – Graphics Ms. Jeanette Romero



# AOARD's S&Es – January 2010



## Program Management:

- Dr Ken Goretta
- LtCol Dave Sonntag
- LtCol John Seo
- Dr Pon Ponnappan
- Dr Kumar Jata
- Dr Gregg Jessen
- New (*Summer 2010*)
- Dr Dave Atkinson
- Dr Tom Erstfeld
- Dr Hiroshi Motoda

Director, Materials Science  
Deputy Director, Biology & Informatics  
Technical Director, Aerospace & Nanoscience  
**Energy, Power, Thermal & Space Sciences**  
Materials Science & NDE  
Solid-State Physics & Electronics  
Structural Sciences and Modeling  
Mathematics & Information Sciences  
Taiwan Nanoscience, Chemistry & Munitions  
Information Sciences

## Scientific Advice:

- Dr Takao Miyazaki
- Dr Ken Boff
- Dr Peter Friedland
- Dr Alex Glass
- Maj Joe Tringe (USAFR)
- Maj Glenn Coleman (USAFR)

Electronics, Physics & Japanese Prospector  
Life Sciences  
Information Sciences  
Lasers & Physics  
Physics, Directed Energy & Nanoscience  
Aerospace Sciences & S Asia Expert



# AOARD Mission



## **WOS** Lead time: At least 40 days before travel start date

- AOARD invites prominent Asian scientists to USAF Labs/Centers
- Visitor (usually a non-govt scientist) provides a seminar
- Visitor engages in technical discussions with USAF S&E's
- AOARD reimburses travel expenses to WOS visitor

## **CSP** Lead time: As early as possible














- AOARD funds (typical is \$5K) workshops and conferences in Asia
- Support paid directly to conference organizers
- Support may be for a stand-alone workshop or for an individual session within a large conference

## **R&D** Lead time: Usually 60-90 days to complete the process

- AOARD funds basic research proposals in response to AFOSR BAA
- USAF S&Es evaluate the proposals
- The Proposer's Guide is on the AFOSR webpage
- Follow-on grants must be cost-shared by other USAF organization
- AOARD administers larger grants on behalf of AFOSR and AFRL



# FY09 Outreach

	Country	CSP	Inv Orders	R&D	Total
	Japan	11	18	24	53
	Australia	2	18	29	49
	Taiwan	2	18	20	40
	United States	5	27	8	40
	Korea	3	11	21	35
	India	3	11	16	30
	Singapore	3	5	10	18
	Europe	2	3	2	7
	Thailand	2	0	2	4
	New Zealand	0	2	2	4
	Malaysia	0	1	2	3
	Canada	0	1	1	2
	Vietnam	1	0	0	1
	<b>Total</b>	<b>34</b>	<b>115</b>	<b>137</b>	<b>286</b>



# Portfolio Thrust

## Scientific Areas

### *Aerospace, Chemical & Material Sciences*

- Materials
- Fluid Mechanics
- Propulsion

### *Physics & Electronics*

- Space Sciences
- Others

## Areas of Enhanced Emphasis

### Propulsion:

- Hypersonics, Scramjet Engine Design, Modeling

### **Power & Energy:**

- energy production, storage, utilization
- materials for P&E
- thermal management
- scaling laws
- modeling & simulation





# P&E Research Challenges

- ✓ **Overlap with material/thermal sciences**
- ✓ **Need innovative concepts and basic research**
- ☐ **High power/energy density batteries,**
- ☐ **High power/energy density fuel cells**
- ☐ **High efficiency solar cells**
- ☐ **Advanced materials to enable the above**
- ☐ **Novel energy storage concepts and related studies**
- ☐ **Innovative energy transfer processes such as**
  - **energy harvesting from waste heat,**
  - **thermoelectric co-generation and**
  - **bio-inspired concepts**
- ☐ **Modeling and simulation**

**Innovation is key to success**



# AOARD Funded Grants



## POWER & ENERGY

- |   |           |
|---|-----------|
| <input type="checkbox"/> Lithium-air battery research   | India     |
| <input type="checkbox"/> Hydrogen storage in SWCNT for fuel cells                                       | India     |
| <input type="checkbox"/> ZnOS nanophosphor coating for UV energy harvesting in Si solar cells           | USA/India |
| <input type="checkbox"/> Mathematical modeling and optimization<br>Studies on development of fuel cells | India     |
| <input type="checkbox"/> Carbon- and sulfur-tolerant anodes for SOFC                                    | Singapore |
| <input type="checkbox"/> Li-rechargeable battery with ultrafast charge rate                             | Singapore |
| <input type="checkbox"/> Magnetocaloric Cooling   | Singapore |
| <input type="checkbox"/> Development of high ZT<br>thermoelectric materials for energy applications     | Taiwan    |



# Scientific Challenges



## Evolutionary Research (Incremental Advances)

### P&E Materials Including Fluids:

- Tunable thermal conductivity
- Large CTE material matching
- Nanofluids

### Processes:

- Energy harvesting from waste heat
- TE/TI/Co-generation concepts
- Non equilibrium thermal process

### Basic Understanding of Physics:

- Scaling laws
- Computational tools for non-homogeneous conditions
- Measurement tools for new materials



**Good**

## Revolutionary Research (Game Changing)

- Designer fluids
- High 'k' compliant interface
- Super-conductor/ insulator
- Solid state refrigerant

- Phonon engineering
- Thermal percolation
- Thermal transport between interfaces
- Bio-inspired concepts

- Physics of thermal percolation
- Physics of phonon scattering
- M&S: MD modeling tools



**Better**



# **Examples of AOARD Power & Energy Projects in Asia**



# Lithium - Air Battery

## WHY LITHIUM-ION BATTERY?

- Uses  $O_2$  in air; no need to store  $O_2$
- High electrochemical equivalence of Li: **3850 mAh/g at -3.05 V**
- High specific energy achievable:

Li-ion battery  
**200Wh/kg**

Vs.

Li-air battery  
**>500Wh/kg**

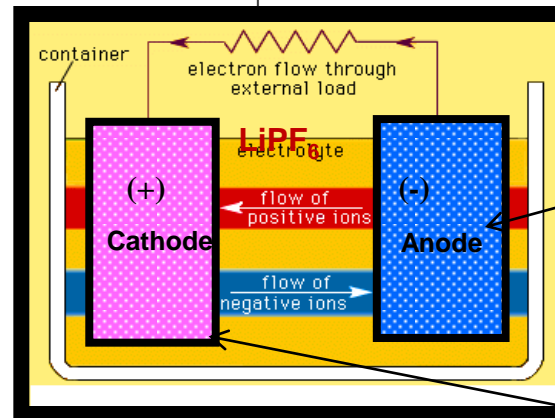
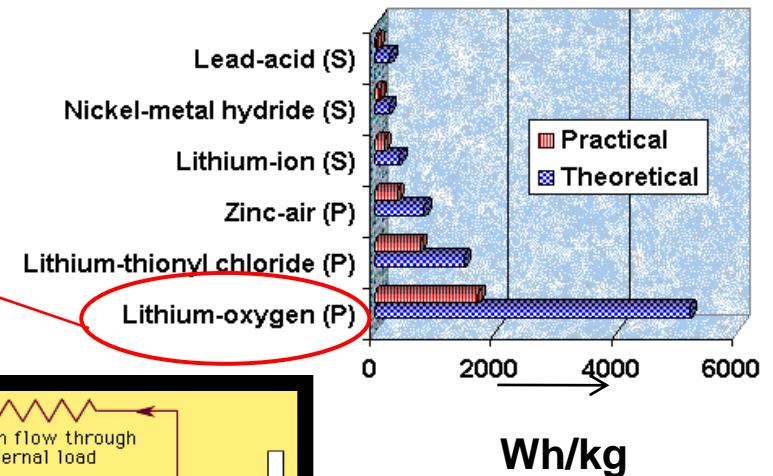
## RESEARCH CHALLENGE:

- Power density
- Rechargeability
- Charge/discharge cycles

## APPLICATIONS:

- Portable power
- UAV power
- Aircraft applications

## Specific Energy (Wh/kg) Comparison



Anode: Li on Ni mesh

Cathode: materials tested in this study include China carbon

## ACCOMPLISHMENTS:

- Good results w/ china carbon electrode
- Capacity 3000 mAh/g of carbon





# H<sub>2</sub> Storage in SWCNT for Fuel Cells

## RESEARCH CHALLENGE:

- Can CNTs be functionalized to store H<sub>2</sub>?
- What type & how?
- Desorption at near-room temp
- H<sub>2</sub> storage capacity > 5.5 wt% (US DOE target 2015)
- Keep H<sub>2</sub> binding energy range 0.2-0.4 eV
- Current technologies inadequate

## SCOPE:

- Perform theoretical & experimental research on SWCNTs as H<sub>2</sub> storage medium

## APPROACH:

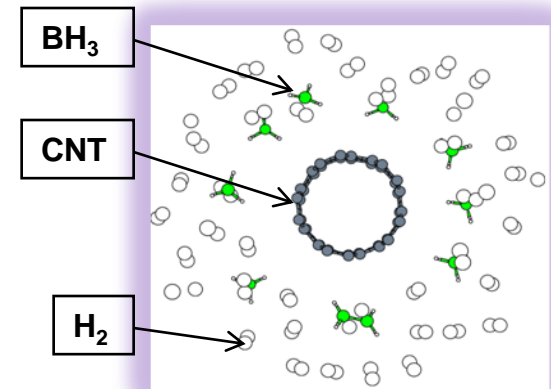
- Identify different SWCNTs and directly attach metal hydrides on them
- Perform MD simulation using,
  - Density Functional Theory (DFT);
  - Vienna Ab-initio Simulation Package (VASP)

## RESULTS:

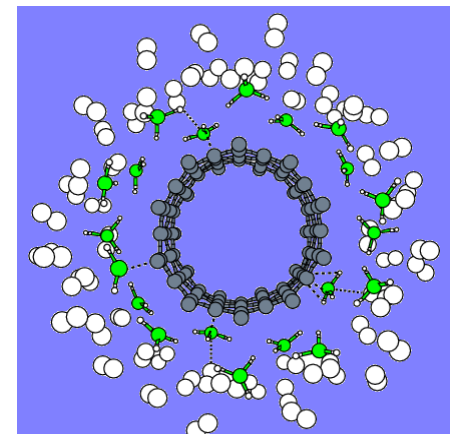
(BE = Binding Energy)

HSM SWCNT	Radius, Å	System having BE in the range 0.2-0.4 eV	BE per BH <sub>3</sub> , eV	BE per H <sub>2</sub> , eV	Storage capacity, wt%
(5,5)	3.44	CNT(5,5)+10(BH <sub>3</sub> +4H <sub>2</sub> )	1.22	0.24	11.5

CNT(5,5)+10(BH<sub>3</sub>+4H<sub>2</sub>)



CNT(10, 0)+20(BH<sub>3</sub>+3H<sub>2</sub>)





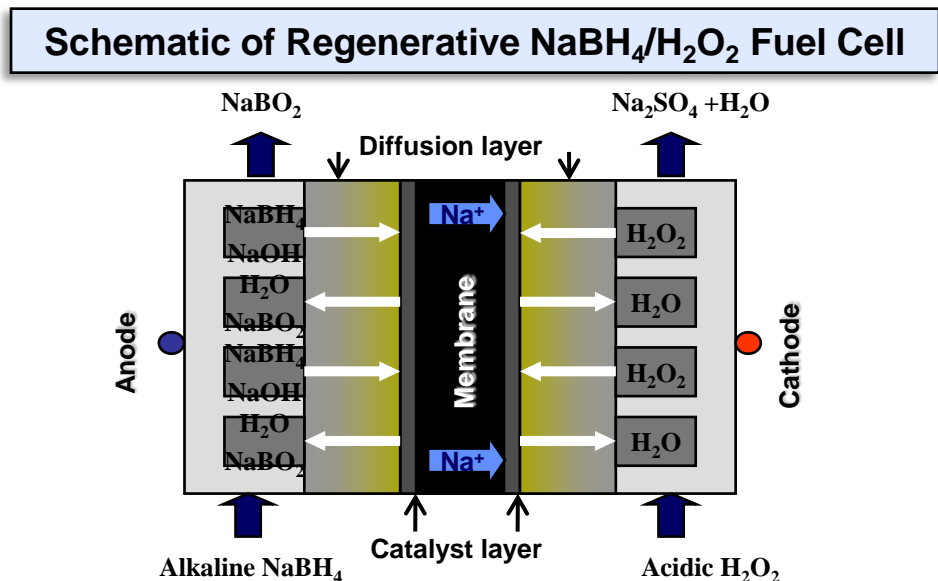
# DBFC Fuel Cells Modeling Study



## RESEARCH CHALLENGE:

- Hydrogen-carrying fuels vs. stored-hydrogen for fuel cells
- Achieve specific energy of DBFC close to that of  $H_2 - O_2$  Fuel Cell

Specific Energy Comparison	
Energy Systems	Specific Energy kWh/kg
Li-ion battery	0.25
DMFC	6.10
DBFC - $O_2$ (air)	9.30
DBFC - $H_2O_2$ (neutral)	12.00
<b>DBFC - <math>H_2O_2</math> (acidic)</b>	<b>17.00</b>
<b><math>H_2 - O_2</math> Fuel Cell</b>	<b>33.00</b>



## SCOPE:

- Develop analytical tool to screen potentially promising material systems such as metal hydrides, alanates, amides, imides of alkalis or rare earths
- Develop a generalized mathematical model for solid polymer electrolyte DBFC

**PROGRESS:** Delivered prototype units to US for T&E at Army and U Conn labs

**PI: A. K. Shukla and Alok Paul; IISc, Bangalore, India**

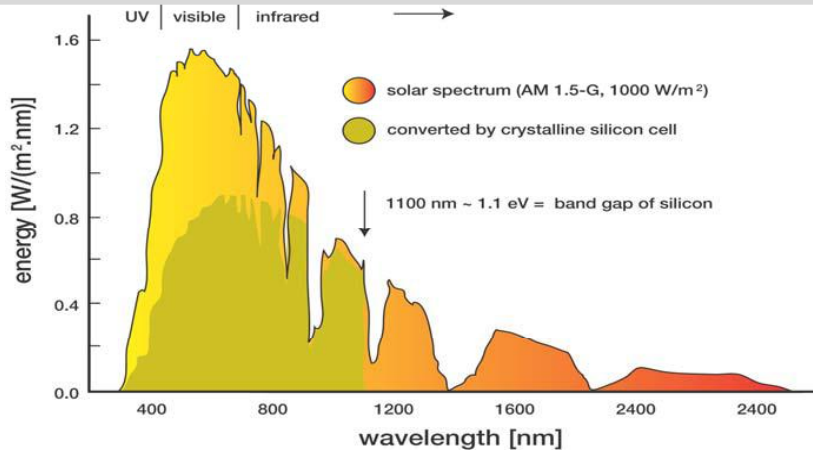
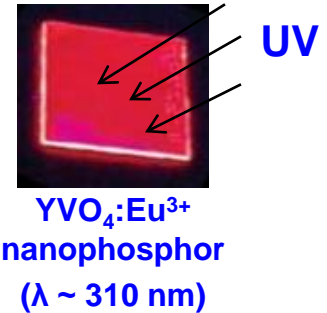
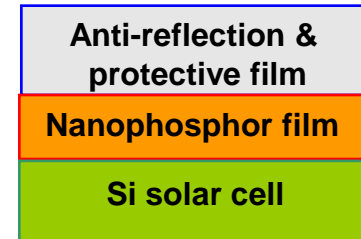


# Performance Enhancement of Solar Cells by Nanophosphor Coating

- SCOPE:**
- Increase power conversion efficiency of large-area Si solar panels from 15 to 16.8%
  - Develop nanophosphor coating to **down-convert** solar UV to visible in an affordable manner

**APPROACH:**

- Determine & optimize the composition (within 2%) of nanophosphors to maximize cell efficiency
- Move the absorption from **335 nm to 440 nm** by synthesizing nanoparticles to <5 nm size



Silicon Solar Cell Material	Laboratory efficiency %	Production efficiency %
Monocrystalline	24	14 - 17
<b>Polycrystalline</b>	<b>18</b>	<b>13 - 15</b>
Amorphous	13	5 - 7

**REQUIREMENTS FOR THE NP COATING:**

- Coating thickness <100 nm
- Down-conversion efficiency >70%
- Doesn't absorb / scatter visible solar-radiation
- Doesn't degrade operating life of solar cells

**PROGRESS/RESULTS:**

- Identified three potential nanophosphors: YVO<sub>4</sub>:Eu<sup>3+</sup>, La<sub>2</sub>O<sub>2</sub>S:Eu<sup>3+</sup> and ZnO<sub>x</sub>S<sub>1-x</sub>
- Film deposition and characterization in progress
- Integration with solar cell and measurements planned



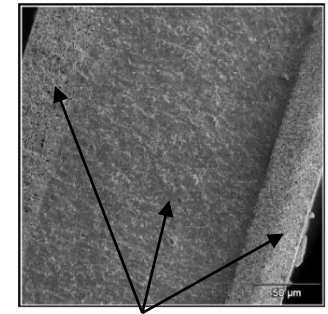
# Solid Oxide Fuel Cell (SOFC) Carbon- & Sulfur-Tolerant Anodes



## PROBLEM:

- Use of ethanol & diesel to produce portable power
- S and C poison the catalysts in fuel cell electrodes
- Decrease operating temp down to 600-800°C

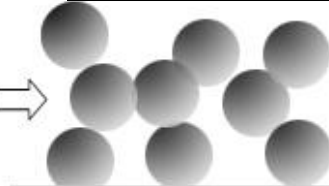
- SCOPE:**
- Evaluate six different V- & Ti-based perovskite oxides as S-tolerant anode
  - Evaluate Pd as C-tolerant high-performance anode



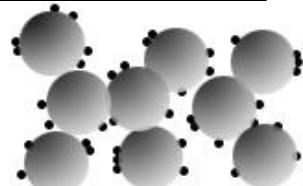
Three ceramic layers  
(anode/electrolyte/ cathode)  
of a SOFC



porous  
electrode  
structure



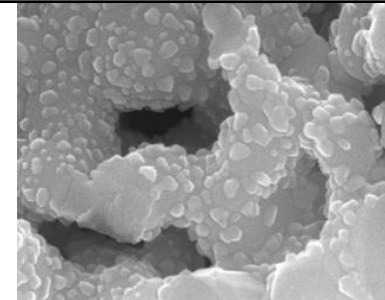
Electrolyte



Metal/Oxide  
Catalyst

Electrolyte

## Nano-structured Pd-YSZ Electrode



## PROGRESS:

- Pd nanoparticles addition significantly reduced the electrode polarization resistance for the oxidation in hydrogen, methane and ethanol fuels
- A new material system with higher activity & stability and better S-tolerance has been developed



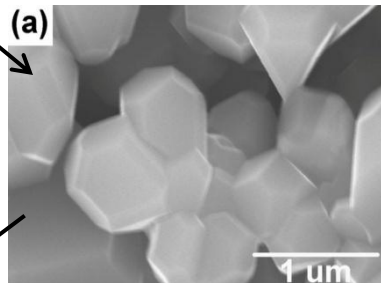
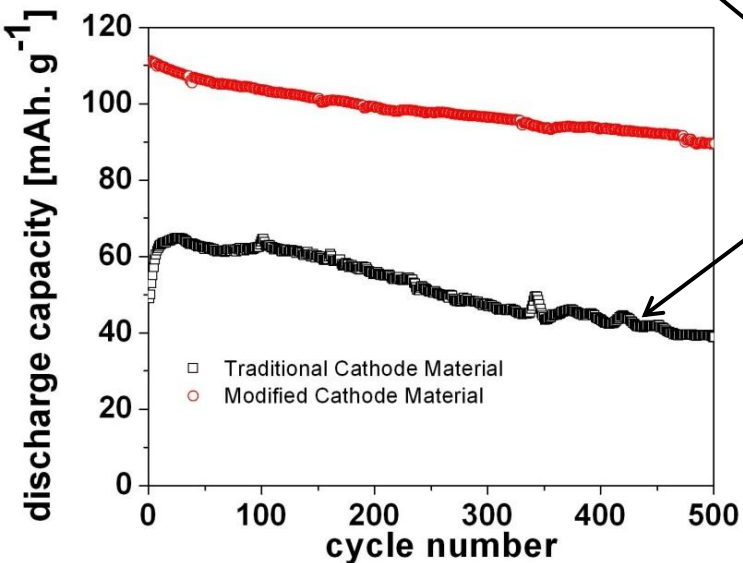
# Li-Battery with Ultrafast Charge Rate

## Objective:

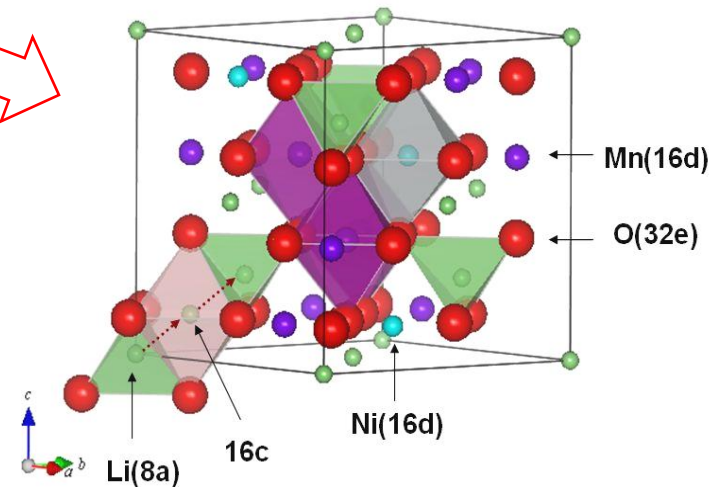
- Investigate 10-20x smaller nano-powder particle sizes to shorten charging rate
- Study doping **transition metals** into the traditional spinel cathode material

## Problem:

The **traditional material** shows lower rate capability as well as poor capacity retention



## Spinel cathode



**Proposed Approach:** Select dopants that will ...

- Create defective structure in the lattice so that activation energy for Li transportation can be reduced and hence to **increase ionic conductivity**;
- Possess electron-rich and easy loss electrons to increase **electronic conductivity**.



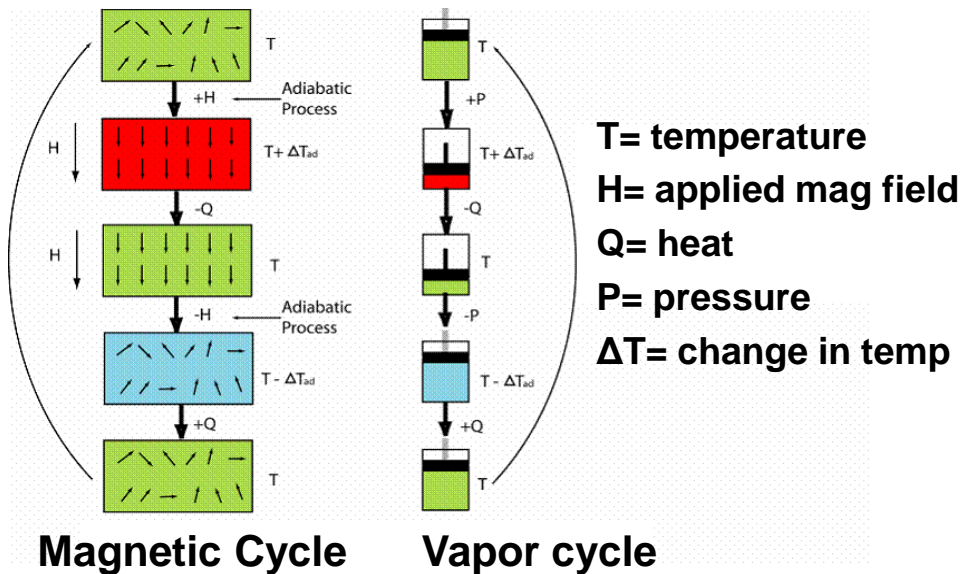


# Magnetocaloric Cooling System



**WHY MAGNETOCALORIC?** No liquid refrigerant; will eliminate CFCs and compressor; can revolutionize current refrigeration industry

## Magnetic Refrigeration Principle



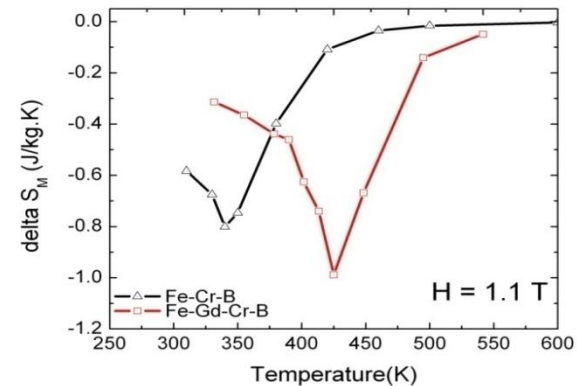
## HOW IT WORKS:

Applied  $H$  orients 'magnetic dipoles' ....  $T \uparrow$   
Removal of  $H$  increases magnetic entropy...  $T \downarrow$

## FEATURES:

- Carnot efficiencies possible
- Uses benign heat transfer media
- Tunable Curie temperature
- Large entropy change of induced martensitic transitions

## Entropy Change Vs. Temp (Fe-Co-B and Fe-Gd-Cr-B alloys)



**PROGRESS:** - NTU has developed Fe-(Gd)-Cr-B alloy system  
- Projected cooling capacity at 342K for this alloy w/o Gd = 545 J/kg



# High ZT Thermoelectric Materials for Energy Applications



## PROBLEM:

SOA thermoelectric materials used for refrigeration and power generation has limitations,

- $ZT < 1$ ; Useful temp range:
- $\text{Bi}_2\text{Te}_3$   $T \sim 250\text{-}600\text{ K}$ ;  $\text{Si}_{1-x}\text{Ge}_x$   $T > 700\text{-}1300\text{ K}$ .
- Applications require  $ZT > 2$ , for practical use

## APPROACH:

Investigate systems of ...

- surface modified nanostructured bulk  $\text{CuFeSe}_2$
- one-dimensional  $\text{Bi}_2\text{Te}_3$  nanowires
- Directional dependency of thermal conductivity

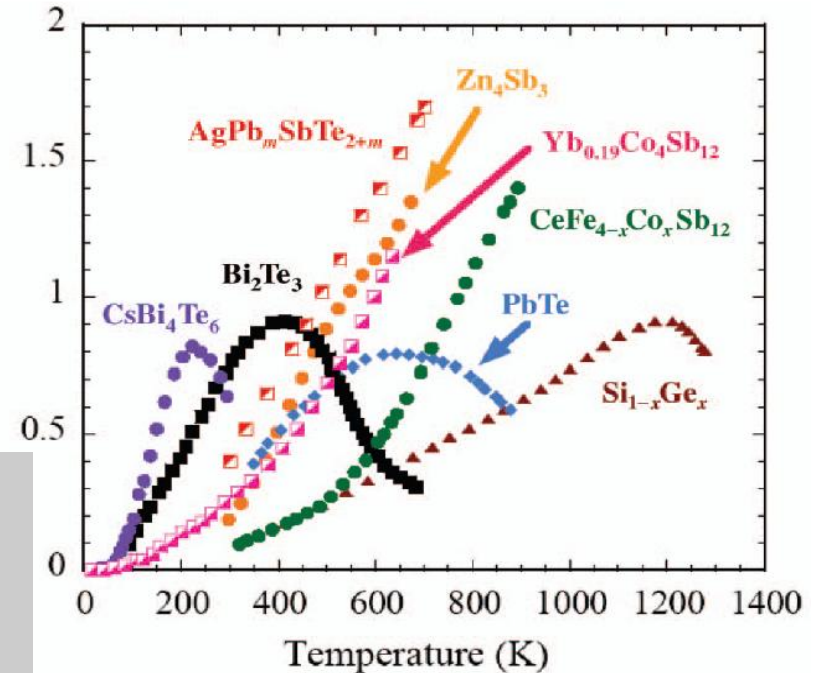
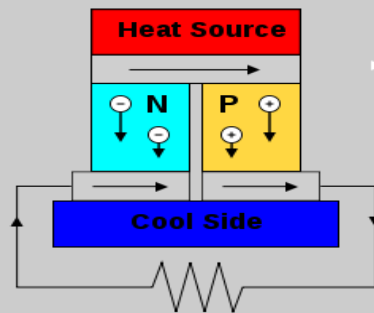
### Figure of merit

$$ZT = S^2 \sigma T / (\kappa_e + \kappa_p)$$

$T$  = Average temp;  $S$  = seebeck;

$\sigma$  = electric conductivity;

$\kappa_e, \kappa_p$  = electron and phonon thermal conductivity



**ZT Vs Temperature Plot  
for known TE materials**

## PROGRESS:

- Employed direct write lithography to produce nanostructured devices
- Hopes to achieve super lattice of  $\text{Bi}_2\text{Te}_3/\text{Sb}_2\text{Te}_3$  with  $ZT \sim 2.4$



# Summary

## Message to Researchers

**AOARD seeks innovation in  
“FUNDAMENTAL, BASIC, SCIENTIFIC RESEARCH”**

- ☐ Use AOARD's three primary vehicles  
R&D..... WOS..... CSP.....
- ☐ Networking & Leveraging encouraged
  - Internal
    - AFRL Tech Directorate(TD) S&Es
    - AFOSR and XOARD PMs
  - External
    - University/ Non-Profit Orgs (USA and Foreign)
    - Other Gov't Agencies
- ☐ With your participation, AOARD can foster basic science breakthroughs in India

**Creating Revolutionary Scientific Breakthroughs for the Air Force**



# Contact Information



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**Website: <http://www.wpafb.af.mil/AFRL/afosr/>**





# Thank You



## Questions

## Welcome!