4th Indo-US Round Table
Bangalore, India
21-23 September 2010

AOARD Overview
Power and Energy Emphasis

R. Ponnappan, PhD
Program Manager
AOARD
Air Force Office of Scientific Research

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2010**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **AOARD Overview Power and Energy Emphasis**		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) **AOARD Air Force Office of Scientific Research**		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
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA560467. Indo-US Science and Technology Round Table Meeting (4th Annual) - Power Energy and Cognitive Science Held in Bangalore, India on September 21-23, 2010. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**27**	

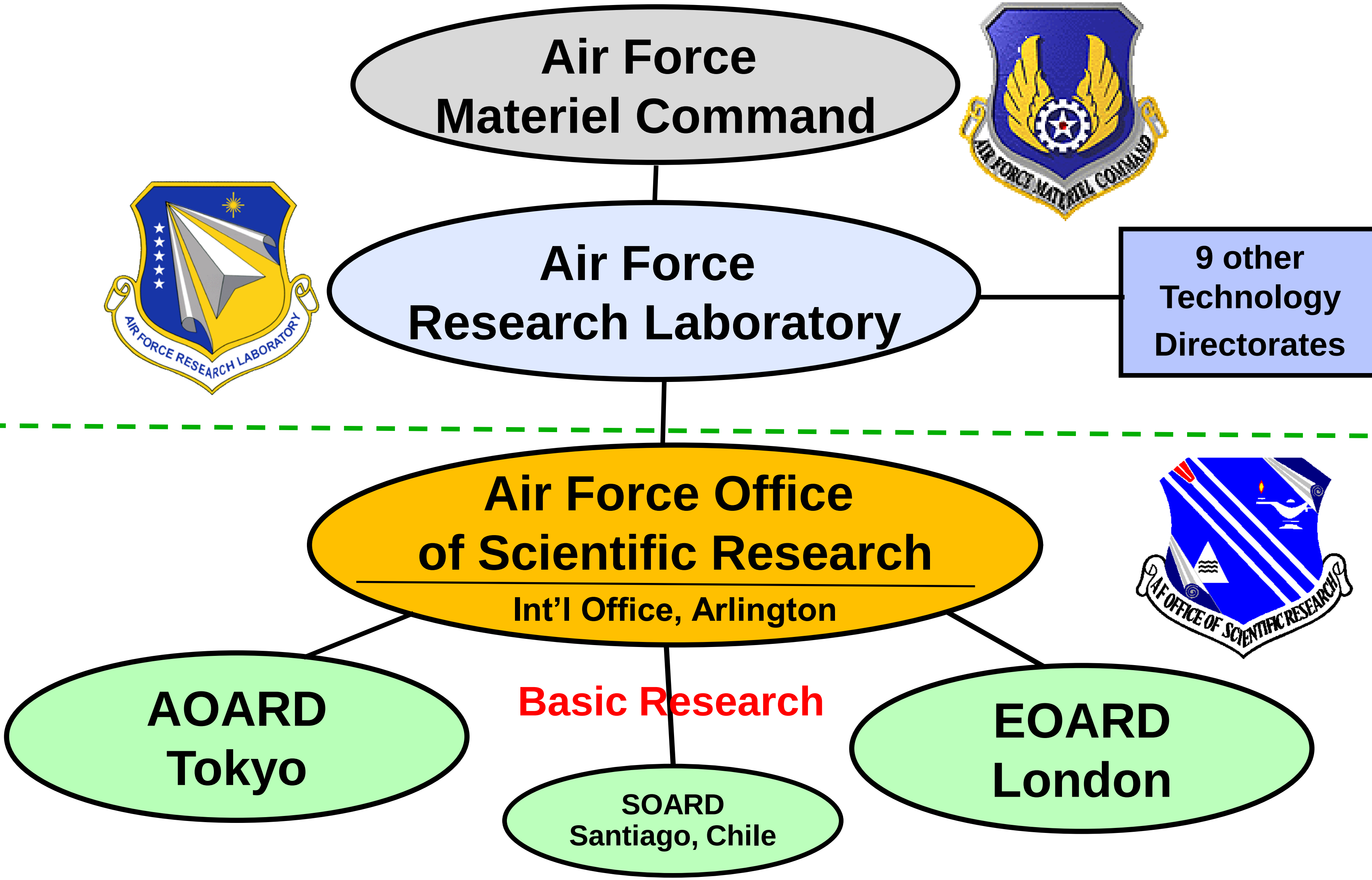
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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

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

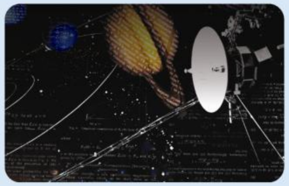
Stealth

Kalman Filter

1960s

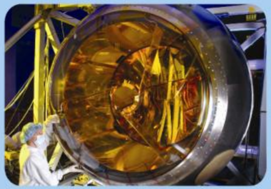
The Computer Mouse

Code Division Multiple Access System for GPS



Viterbi Decoding Algorithm

1970s

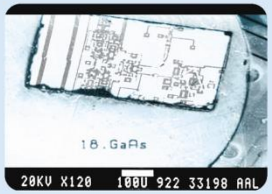


Chemical Oxygen Iodine Laser (Coil)

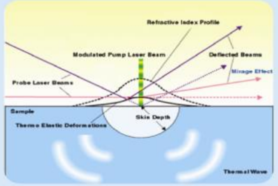
Superplastics Forming

Air Fracture Mechanics Methodology

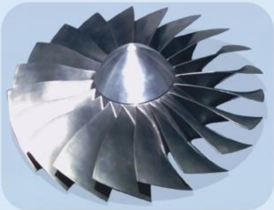
1980s



Low-Temperature Gallium Arsenide

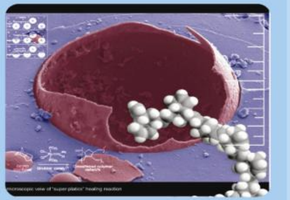


Laser Diagnostics

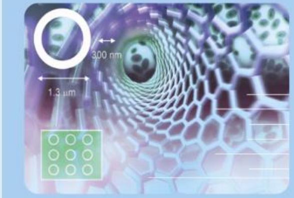


High-Efficiency Compressor Blades

1990s



Self-healing Plastics

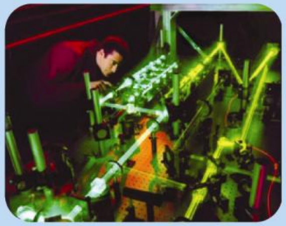


Dip-pen Nanolithography

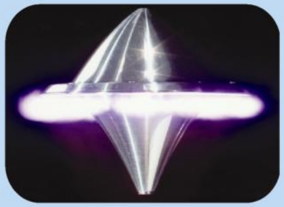
Laser Trapping

2000+

Joint Percision Airdrop System



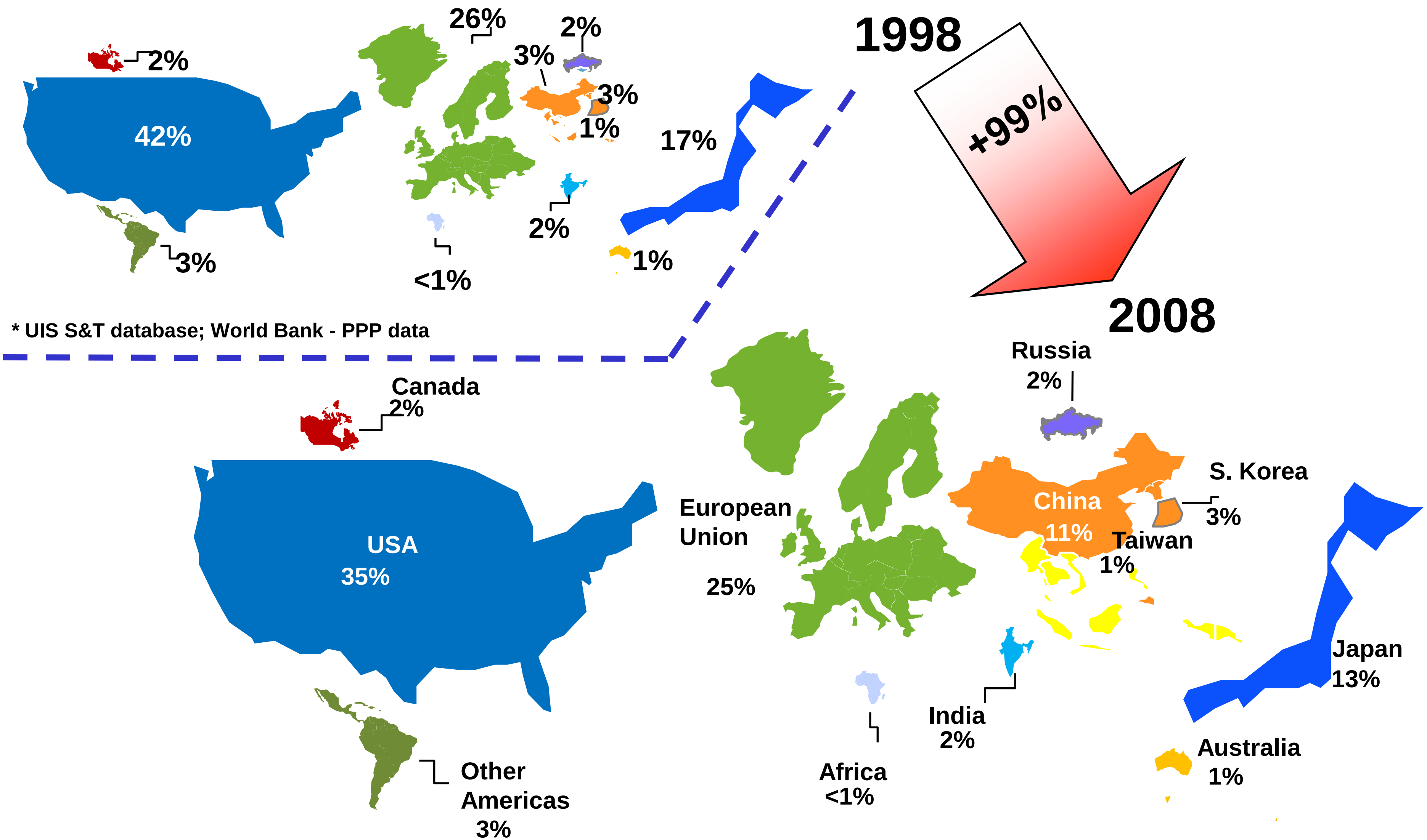
Electric Oxygen Iodine Laser



Laser Propulsion

Partial List

World S&T Investment 1998* to 2008**



* UIS S&T database; World Bank - PPP data

** 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	Director, Materials Science
▪ LtCol Dave Sonntag	Deputy Director, Biology & Informatics
▪ LtCol John Seo	Technical Director, Aerospace & Nanoscience
▪ Dr Pon Ponnappan	Energy, Power, Thermal & Space Sciences
▪ Dr Kumar Jata	Materials Science & NDE
▪ Dr Gregg Jessen	Solid-State Physics & Electronics
▪ New *(Summer 2010)*	Structural Sciences and Modeling
▪ Dr Dave Atkinson	Mathematics & Information Sciences
▪ Dr Tom Erstfeld	Taiwan Nanoscience, Chemistry & Munitions
▪ Dr Hiroshi Motoda	Information Sciences

Scientific Advice:

• Dr Takao Miyazaki	Electronics, Physics & Japanese Prospector
• Dr Ken Boff	Life Sciences
• Dr Peter Friedland	Information Sciences
• Dr Alex Glass	Lasers & Physics
• Maj Joe Tringe (USAFR)	Physics, Directed Energy & Nanoscience
• Maj Glenn Coleman (USAFR)	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
Total	**34**	**115**	**137**	**286**

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

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

Scientific Challenges

Evolutionary Research (Incremental Advances)	Revolutionary Research (Game Changing)

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

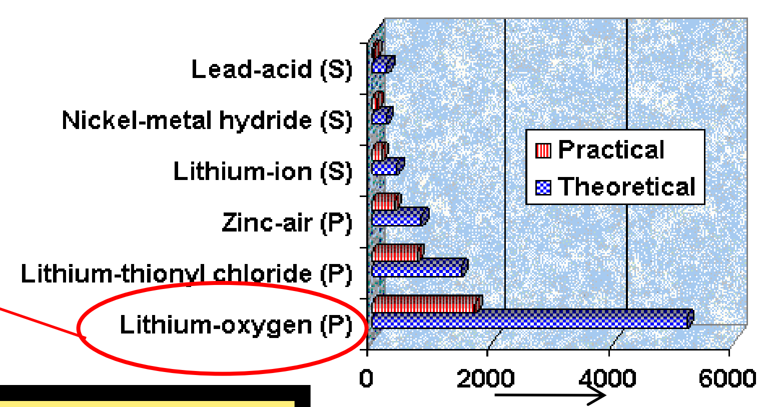
Lithium - Air Battery

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		Li-air battery
200Wh/kg	Vs.	>500Wh/kg

Specific Energy (Wh/kg) Comparison



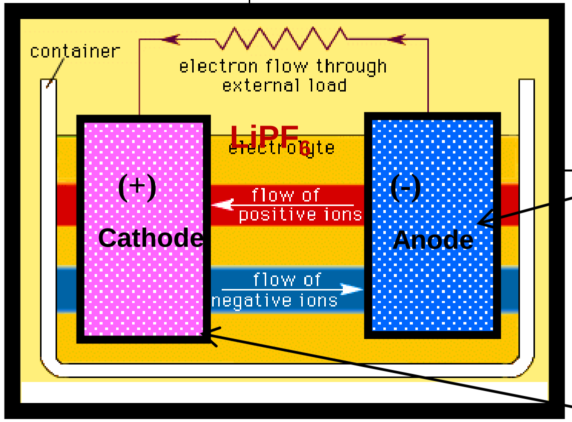
Wh/kg

RESEARCH CHALLENGE:

- Power density
- Rechargeability
- Charge/discharge cycles

APPLICATIONS:

- Portable power
- UAV power
- Aircraft applications



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

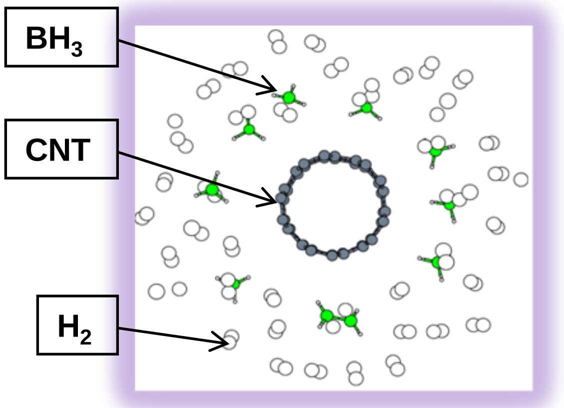
PI: N. Munichandraiah, Indian Institute of Science, Bangalore, India

H_2 Storage in SWCNT for Fuel Cells

RESEARCH CHALLENGE:

- Can CNTs be functionalized to store H_2?
- What type & how?
- Desorption at near-room temp
- H_2 storage capacity > 5.5 wt% (US DOE target 2015)
- Keep H_2 binding energy range 0.2-0.4 eV
- Current technologies inadequate

CNT(5,5)+10(BH_3+4H_2)



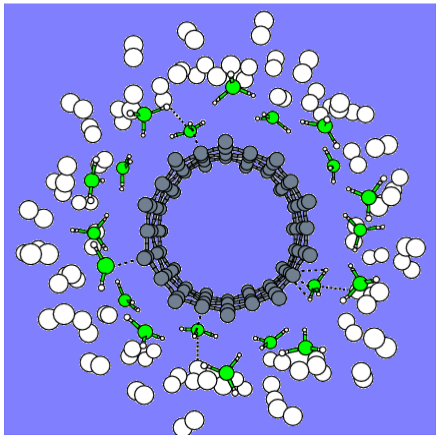
SCOPE:

- Perform theoretical & experimental research on SWCNTs as H_2 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)

CNT(10, 0)+20(BH_3+3H_2)



RESULTS:

(BE = Binding Energy)

HSM SWCNT	Radius, Å	System having BE in the range 0.2-0.4 eV	BE per BH_3, eV	BE per H_2, eV	Storage capacity, wt%
(5,5)	3.44	CNT(5,5)+10(BH_3+4H_2)	1.22	0.24	11.5

PI: K. Iyakutti, Madurai Kamaraj University, Madurai, India

DBFC Fuel Cells Modeling Study

Fuel cells → Electrochemical Engines ⇨ Chemical Energy → Electricity

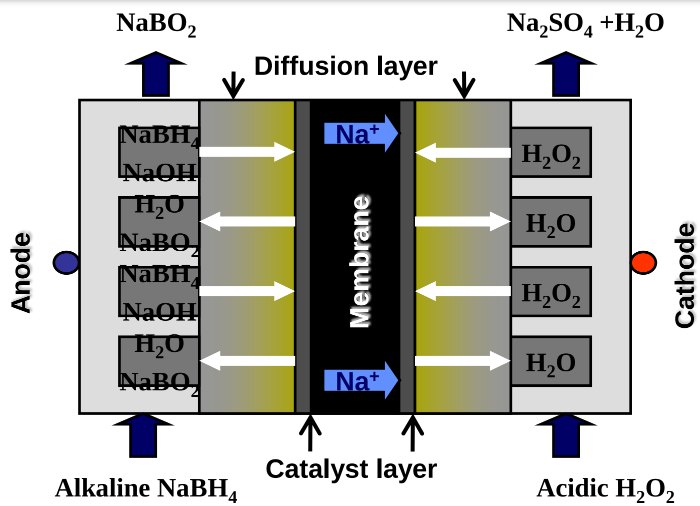
RESEARCH CHALLENGE:

- **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
DBFC - H_2O_2(acidic)	**17.00**
H_2 - O_2 Fuel Cell	**33.00**

Schematic of Regenerative $NaBH_4/H_2O_2$ Fuel Cell



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

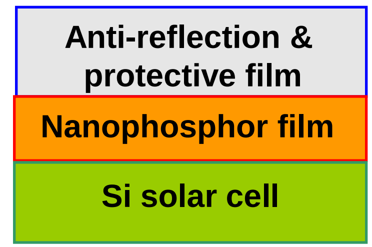
PROGRESS: Delivered prototype units to US for T&E at Army and U Conn labs

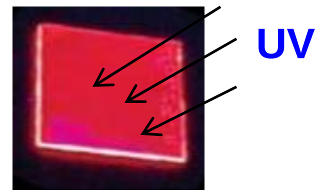
PI: A. K. Shukla and Alok Paul; IISc, Bangalore, India

Performance Enhancement of Solar Cells by Nanophosphor Coating

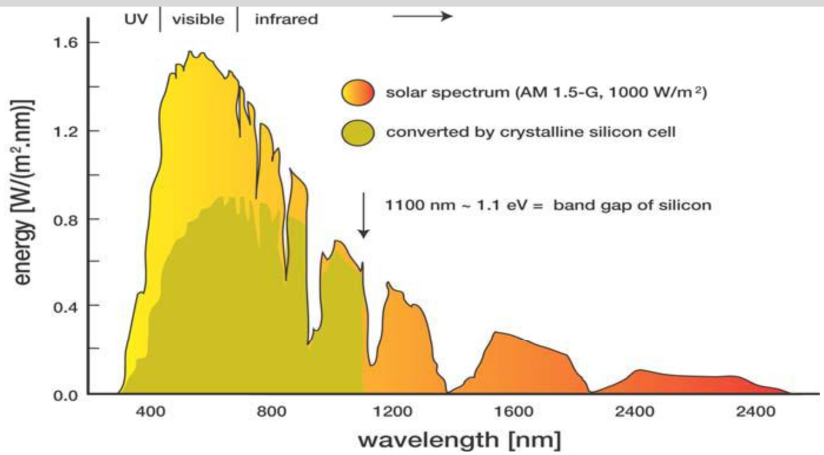
SCOPE: - Increase power conversion efficiency of large-area Si solar panels from 15 to 16.8%
- Develop nanophosphor coating to down-convert solar UV to visible in an affordable manner

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





$YVO_4:Eu^{3+}$ nanophosphor
(λ ~ 310 nm)



Silicon Solar Cell Material	Laboratory efficiency %	Production efficiency %
Monocrystalline	24	14 - 17
Polycrystalline	18	13 - 15
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

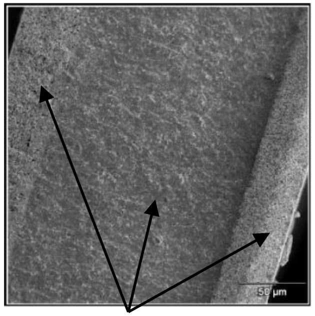
PROGRESS/RESULTS:
- Identified three potential nanophosphors: $YVO_4:Eu^{3+}$, $La_2O_2S:Eu^{3+}$ and ZnO_xS_{1-x}
- Film deposition and characterization in progress
- Integration with solar cell and measurements planned

PI: Avinash Pandey, Univ of Allahabad, India; R. Bhargava, Nanocrystals Tech Inc., NY

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

PROBLEM:

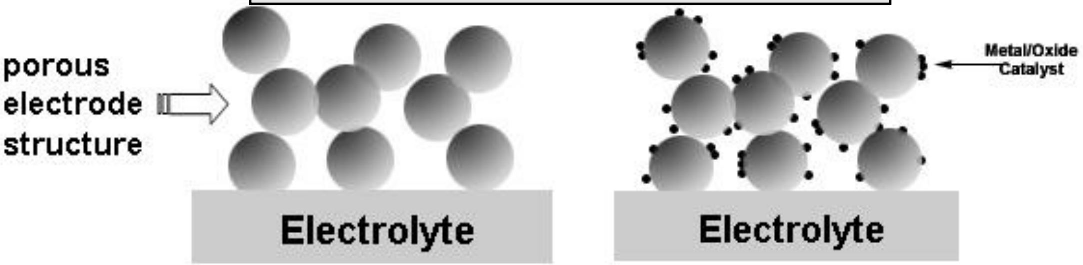
- Use of ethanol & diesel to produce portable power
- S and C poison the catalysts in fuel cell electrodes
- Decrease operating temp down to 600-800°C



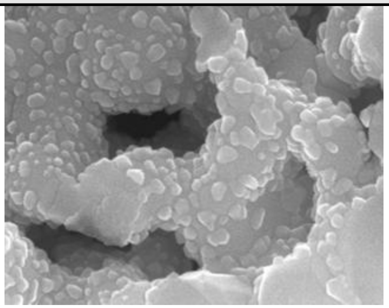
Three ceramic layers (anode/electrolyte/ cathode) of a SOFC

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

$La_{0.75}Sr_{0.25}Ti_{0.3}Mn_{0.5}V_{0.2}O_{3-d}$



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

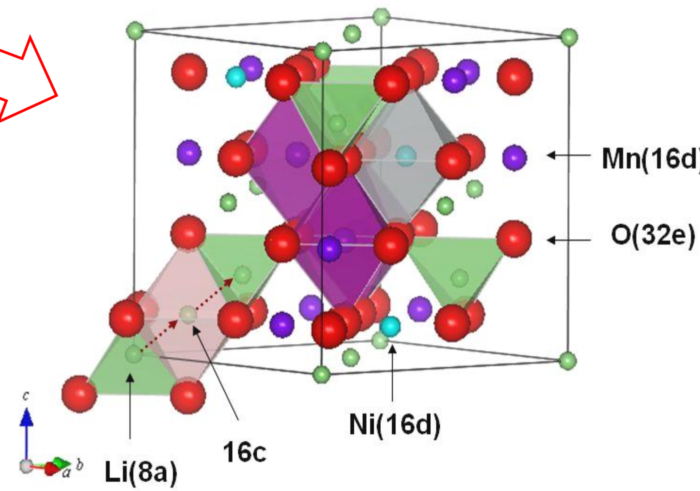
PI: Jiang San Ping, Nanyang Tech University (NTU), Singapore

Li-Battery with Ultrafast Charge Rate

Objective:

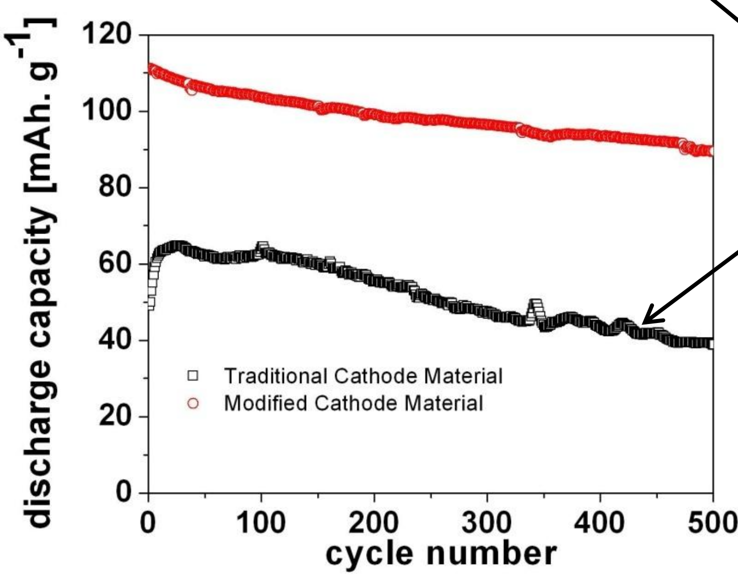
- Investigate 10-20x smaller nano-powder particle sizes to shorten charging rate
- Study doping **transition metal**s into the traditional spinel cathode material

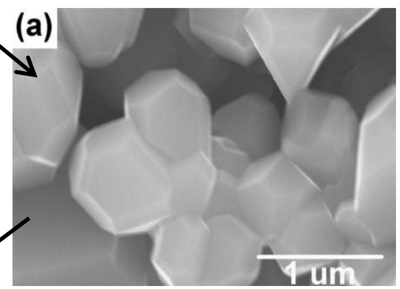
Spinel cathode



Problem:

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





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**;

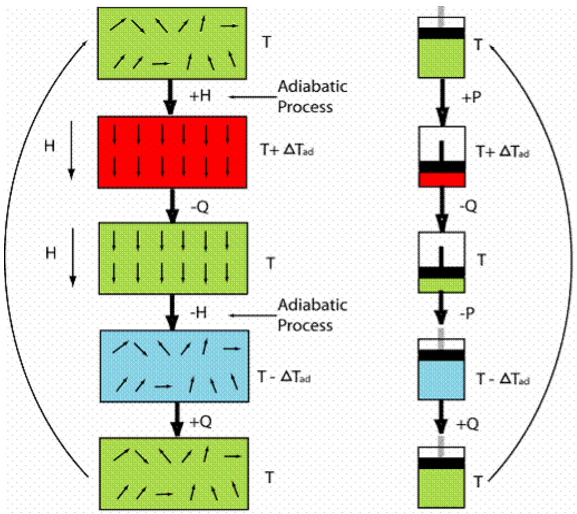
- Possess electron-rich and easy loss electrons to increase **electronic conductivity**.

PI: Li Lu, National University of Singapore, Singapore

Magnetocaloric Cooling System

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

Magnetic Refrigeration Principle



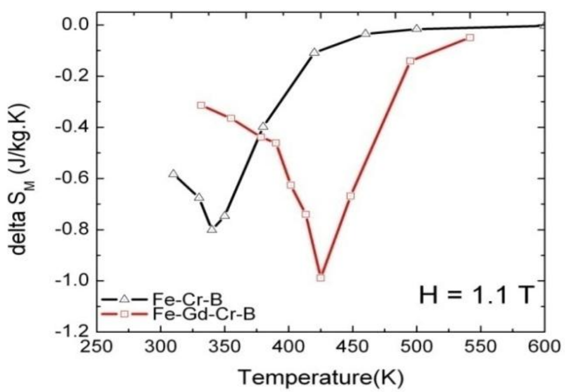
T= temperature
H= applied mag field
Q= heat
P= pressure
ΔT= change in temp

Magnetic Cycle **Vapor cycle**

HOW IT WORKS:
Applied H orients 'magnetic dipoles' ….T ↑
Removal of H increases magnetic entropy… T↓

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

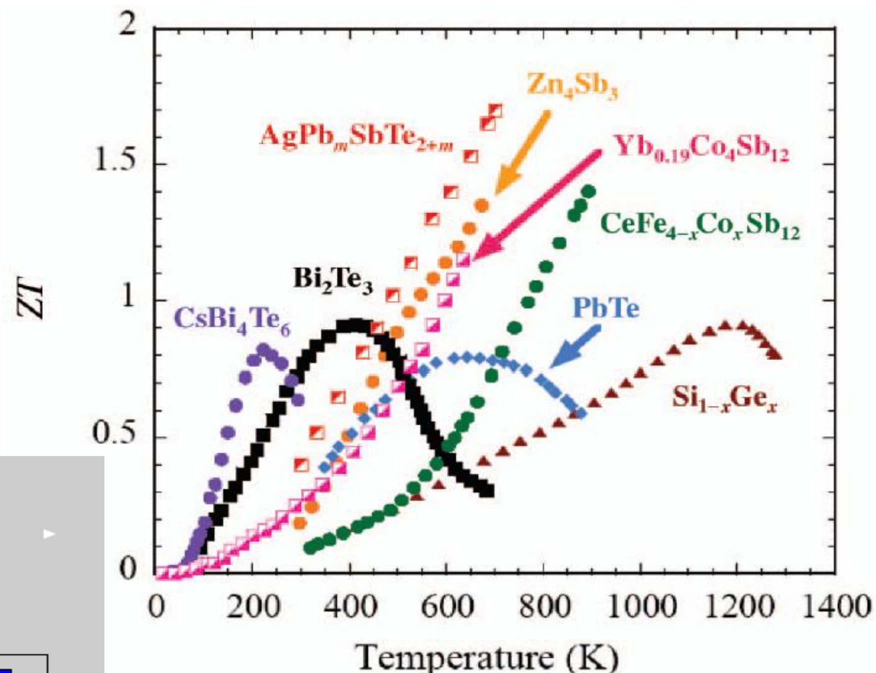
PI: Ramanujan, Nanyang Technological University, Singapore

High ZT Thermoelectric Materials for Energy Applications

PROBLEM:

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

- ZT < 1; Useful temp range:
- Bi_2Te_3 T~ *250-600 K ; $Si_{1-x}Ge_x$ T > 700-1300 K.*
- Applications require ZT > 2, for practical use



ZT Vs Temperature Plot for known TE materials

APPROACH:

Investigate systems of …

- surface modified nanostructured bulk $CuFeSe_2$
- one-dimensional Bi_2Te_3 nanowires
- Directional dependency of thermal conductivity

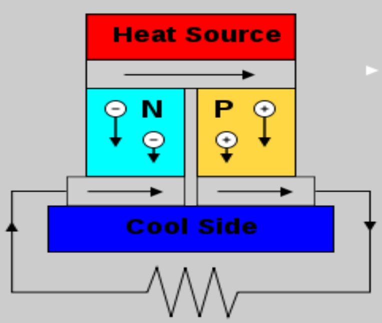
Figure of merit

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

T = Average temp; S = seebeck;

σ = electric conductivity;

κ_e , κ_p = electron and phonon thermal conductivity



PROGRESS:

- Employed direct write lithography to produce nanostructured devices
- Hopes to achieve super lattice of Bi_2Te_3/Sb_2Te_3 with ZT ~ 2.4

PI: Maw-Kuen Wu, Institute of Physics, Academia Sinica, Taiwan

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**

Contact Information

Dr. R. Ponnappan, Program Manager
Propulsion, Power & Space Sciences
Asian Office of Aerospace R&D (AOARD)
7-23-17 Roppongi, Minato-ku
Tokyo 106-0032, JAPAN

Telephone: +81-3-5410-4409; Fax: +81-3-5410-4407
Email: rengasamy.ponnappan@aoard.af.mil;
Website: http://www.wpafb.af.mil/AFRL/afosr/

Thank You