CONTACT: Research in Power Generation and Storage for the Air Force

John Ferraris
University of Texas at Dallas

Jack Agee
Director, CONTACT Program
Rice University

March 10, 2011

APEC 2011
Fort Worth, TX
AGENDA

- CONTACT Program
- Supercapacitors .................................................. UT Dallas
- Hybrid Tandem Solar Cells with Carbon Nanotube Interlayers .................................................. UT Dallas
- Organic-Inorganic Hybrid Materials for Solar Cells ............................................................... UT Austin
- Armchair Quantum Wire ................................. Rice University
**What is CONTACT?**

**Consortium for Nanomaterials for Aerospace Commerce and Technology**

- Partnership of the following institutions:
  - U.S. Air Force Research Laboratory
  - University of Texas at: Arlington, Austin, Brownsville, Dallas, and Pan American
  - Rice University
  - University of Houston

- Basis for cooperative nanotech research in Texas to provide breakthrough technological solutions

- Strengthened by cross-cutting intellectual collaborations and the availability of state-of-the-art equipment

- Focused on tech transfer to aerospace, commercial, and defense sectors
CONTACT Project Descriptions

CONTACT is focused on the following areas of interest to the Air Force and aerospace industry:

1. Adaptive Coatings and Surface Engineering
   - Nano coatings (reduce drag, corrosion, repair cracks)
   - Thermal control, space environment resistant satellites
   - Nanoparticle enhanced composites – structures

2. Nano Energetics
   - High energy propellants and explosives
   - Use nanoparticles to control the burn rate

3. Electromagnetic Sensors
   - Devices for optical sensing, communications
   - Ultraviolet, visible, infra-red, terahertz frequencies

4. Power Generation and Storage
   - Solar cells, magnets, next generation batteries, capacitors
   - Enable directed energy weapons, compact power generators
Research in power generation and storage for the Air Force

Novel Composite Carbon Nanofibers for Supercapacitor Electrodes

John P. Ferraris\textsuperscript{1,2,3}

\textit{The University of Texas at Dallas}

\textsuperscript{1}Department of Chemistry
\textsuperscript{2}The Alan G. MacDiarmid NanoTech Institute
\textsuperscript{3}Solarno, Inc.
Supercapacitors

John Ferraris - University of Texas at Dallas

- Energy storage devices
- Strategies to increase energy and power densities in supercapacitors; electrodes and electrolytes
- Electrospinning of nanofibrous polymers
- Adding templated carbon precursor: metal-organic framework-5 containing furfurol
Energy density by mass (Wh/kg)

Power density by mass (W/kg)

- Fuel cells
- Conventional batteries
- Lithium ion capacitor
- Supercapacitors
- Conventional capacitors
Strategies for increasing energy and power densities in supercapacitors

Electrode:
- increase effective surface area: mesopores >> micropores
- Increase conductivity
- decrease contact resistance

Electrolyte:
- highly conducting
- wider electrochemical window
- (>3V)
Electrostatic Deposition (Electrospinning) of Nanofibrous Polymers
RESEARCH RATIONALE

E-spun composite polymer fiber containing dispersed templated carbon precursor

Stabilization

Carbonization

Carbon fiber matrix incorporating high surface area carbon (No binders required)
Templated Carbon Precursor: Metal-organic framework-5 (MOF-5) containing Furfural

doi:10.1038/nature01650
Carbonized Furfural (filtered)/MOF-5/PAN

Carbonized Furfural (Vapor deposited)/MOF-5/PAN
Charge/discharge for Furfural(filtered)/MOF-5/PAN in EMITFSI
Energy density by mass (Wh/kg)

Power density by mass (W/kg)

- Fuel cells
- Conventional batteries
- Solarno Phase I
- Lithium ion capacitor
- Supercapacitors
- Conventional capacitors
The Supercapacitor Group @ UTD

Funding

• CONTACT

• NSF STTR to SOLARNO/UTD
Research in power generation and storage for the Air Force

Hybrid Tandem Solar Cells with Carbon Nanotube Interlayers: DSC/OPV Parallel Tandems

Anvar Zakhidov$^{1,2,3}$

The University of Texas at Dallas
1 Nanotech Institute
2 Department of Physics
3 SOLARNO Inc.
Hybrid Tandem Solar Cells with Carbon Nanotube Interlayers

Anvar Zakhidov - University of Texas at Dallas

- Schematic of a thin film hybrid tandem solar cell
- Newest results for organic photovoltaic (OPV)-dye sensitized solar cells (DSC) tandem including efficiency and absorption profile
- Future plans
A flexible hybrid tandem solar cell based on transparent carbon nanotube networks as interlayers between DSC, CIGS and OPV for maximal collection and recombination of charges.

Today OPV-DSC tandem will be described for the CONTACT program.
1) We demonstrated a parallel tandem of DSC/OPV: “Dye sensitized - Organic photovoltaic cell with:
- Increase of photocurrent, and enhanced power efficiency (~7 % presently and 13-14 % predicted for optimized)
- Enhanced spectral sensitivity
- Semi-Monolithic design incorporating a MWCNT interlayer and Inverted OPV with SWCNT cathode
- Filled 2 patents (by Solarno/UTD) and awarded Phase II STTR program by DOE on development of Hybrid tandems

2) From our model we demonstrated advantages of parallel architecture and need to improve conductivity of both MWCNT interlayer and inverted SWCNT cathodes; In order to achieve 14-16 % in DSC/OPV tandem

3) Future Plans: to create Inorganic/Organic Parallel tandem of Si-OPV and Si-DSC type (partnership with Euro-Asia Center for Advanced Technologies). Total efficiency predicted ~ 20-25 %
“Science is People!”
Alan MacDiarmid, 2000 Nobel Laureate in Chemistry

UTD Nanotubes Team:
Ali Aliev, Sergey Lee, Anvar Zakhidov, Mei Zhang, Ray Baughman, Shaoli Feng

UTD Nano Energy and Nanophotonics:
Yuen Jung, Chao Chen, Alex Cook, Raquel Ovalle, Anvar Zakhidov, Alex Kuznetsov, Josef Velten, Dean Hsu, Brian Wang, Kamil Mielczarek

Funding
- CONTACT (AFRL/Rice Strategic Partnership for Commercialization of Nanotechnology)
- Texas Advanced Technology Program,
- STTR by DOE and NSF to SOLARNO/UTD
- Robert A. Welch Foundation
Synthesis and characterization of Cu(In,Ga)Se₂ and creating a stable photovoltaic material
- Schematic of a thin film solar cell
- Lowering the cost of solar energy
- Spray-on CuInSe₂ inks and its challenges
- Si nanowires
How does thin-film solar work?

2. Electrons gain energy.
3. A high-energy electron drifts into another semiconductor layer, leaving behind an electron vacancy.
4. The electron is collected by a transparent top electrode.
5. The energy from the electron is used to power a fluorescent light.
6. The ‘used’ electron transfers to the bottom metal contact layer (Molybdenum or stainless steel metal foil).
7. The electron travels to combine with an electron vacancy, completing the circuit.

Drawings are schematic/not to scale
Sources: Brian Korgel, UT

Metal
n-type semiconductor
Nanocrystal ink
Metal
Glass or plastic support
To Lower the Cost of Solar Energy...
Change the way solar cells are made

Slow, high temperature vacuum processes

Print like newspaper

Photovoltaic Paints...?
Armchair Quantum Wire

Wade Adams
-Rice University

- Potential and challenges of solar energy
- Revolutionizing power grid technology
- Characteristics and synthesis of single-wall carbon nanotube (SWCNT) quantum wire
- Strategies for developing large quantities of Armchair SWCNT
Solar energy could power the country

Nathan S. Lewis, California Institute of Technology
Or the world – except for two problems:

6 Boxes at 3.3 TW Each = 20 TW
And distance:

Transmission lines lose approximately 8% of electricity every 200 miles.
Wind is important, but...

...it’s also a long way from the market.
SWCNT* Quantum Wire

• **Expected Features**
  – 1-10x Copper Conductivity
  – 6x Less Mass
  – Stronger Than Steel
  – Zero Thermal Expansion

• **SWCNT Technology Benefits**
  – Type & Class Specific
  – Higher Purity
  – Lower Cost
  – Polymer Dispersible

*Single-Wall Carbon Nanotube*
Making the AQW

• What needs to be done:
  • Go from single SWCNT
    • to macroscopic material
  • All-armchair SWCNTs
    • preferably all same diameter
  • Large quantity
  • Align and transform into fiber
3 Routes to Large Quantities of Armchair SWCNT

• Sort Large Quantities of SWCNTs

• Sort Small Quantities of SWCNTs

• Amplify

• Grow Only Armchair SWCNTs (catalyst tuning)