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***Nano-Oxide Photocatalysis for Solar Energy Conversion***

**DE-FG02-07ER46418**

**Frederick Seitz Materials Research Laboratory**

**University of Illinois at Urbana-Champaign**

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**Cluster Participants:**

James N. Eckstein  
Kenneth S. Suslick (Cluster Leader)

**Primary National Laboratory Collaborators:**

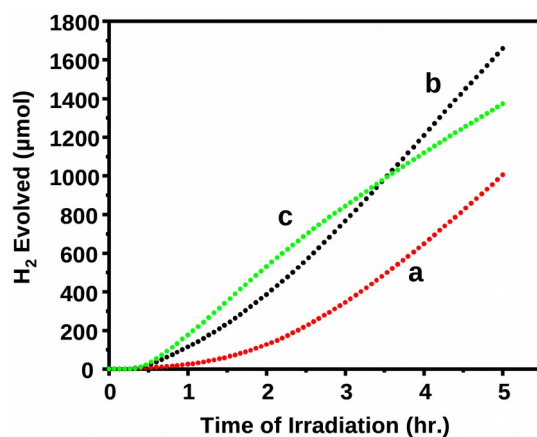
Anand Bhattacharya (ANL)  
Ivan Bozovic (BNL)

**Graduate Student Researchers:**

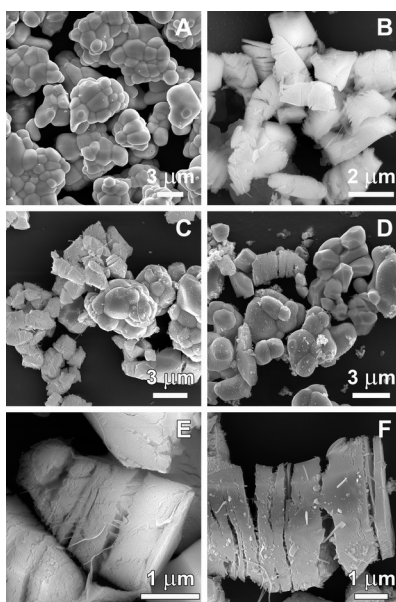
Maria Fortunato (25%)  
Richard Helmich (50%)  
Brian Mulcahy (50%)

## RESEARCH ACCOMPLISHMENTS

- We have very recently discovered a new hydrogen-producing photocatalyst is  $\text{BiNbO}_4$  (Figure 1).  $\text{BiNbO}_4$  powders prepared by solid state reaction were tested for photocatalytic activity in methanol solutions under UV irradiation. When the material is tested without the presence of a Pt co-catalyst, photocatalytic activity for  $\text{H}_2$  evolution is superior to that of  $\text{TiO}_2$ . It was also found that  $\text{BiNbO}_4$  photodegrades into metallic Bi and reduced Nb oxides after use; materials were characterized by SEM, XRD, and XPS. Adding Pt to the surface of the photocatalyst increases photocatalytic activity and importantly, helps to prevent photodegradation of the oxide material. With 1 wt. % Pt loading, photodegradation is essentially absent.  $\text{BiNbO}_4$  photodegrades into metallic Bi and reduced Nb oxides after use; materials were characterized by SEM, XRD, and XPS. Adding Pt to the surface of the photocatalyst increases photocatalytic activity and importantly, helps to prevent photodegradation of the oxide material. With 1 wt. % Pt loading, photodegradation is essentially absent.



**Figure 1.** The amount of  $\text{H}_2$  evolved over time for  $\text{BiNbO}_4$  (a) without a co-catalyst, (b) with 0.2 wt.% Pt nanoparticles, and (c) with 1.0 wt.% Pt.



**Figure 2.** SEM micrographs of BiNbO<sub>4</sub> photocatalysts (A) before use, (B) after use without a co-catalyst, (C) with 0.2 wt.% Pt, and (D) with 1.0 wt.% Pt. Higher magnification images of delaminated particles found in samples after use (E) without a co-catalyst and (F) with 0.2 wt.% Pt.

- **We have investigated BiVO<sub>4</sub> as a new visible-light photocatalyst for O<sub>2</sub> evolution**, the other half of the photocatalytic splitting of water. We have prepared BiVO<sub>4</sub> powders with unique particle architectures using USP. Gases created from the evaporation of solvent and the decomposition of precursor materials shape the morphology of the particles as the solids are formed in the heated aerosol. The BiVO<sub>4</sub> powder was tested as an oxygen evolving photocatalyst by monitoring the kinetics of O<sub>2</sub> formation from an aqueous AgNO<sub>3</sub> solution irradiated with  $\lambda > 400$  nm light. USP prepared BiVO<sub>4</sub> was found to have significantly superior photocatalytic activity compared to commercial BiVO<sub>4</sub> and WO<sub>3</sub> (which is the standard O<sub>2</sub> generating photocatalyst in the field), likely due to differences in particle morphology.
- **We also discovered a very simple route to nanostructured carbon materials**, produced from simple precursors such as sucrose and sodium carbonate or bicarbonate using a facile, one-step USP process without the need for sacrificial templates. The high surface areas and unique hierarchical pore structures of these materials suggest that they may find use as adsorbents and catalyst supports. The hollow interior (Figure 3) provides a low-density, free-flowing microsphere morphology that may prove especially useful for any applications requiring a fluidized bed reactor or packed chromatographic column.

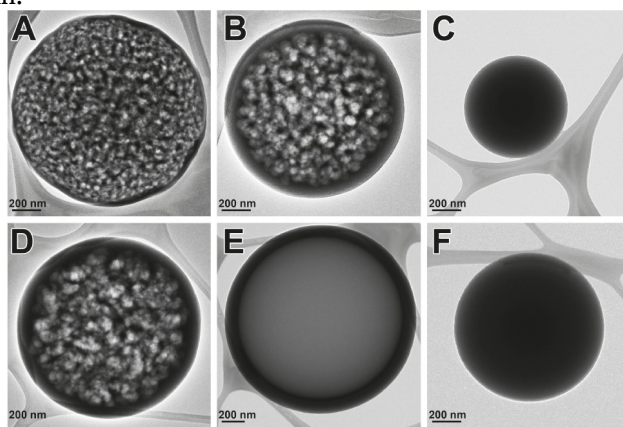
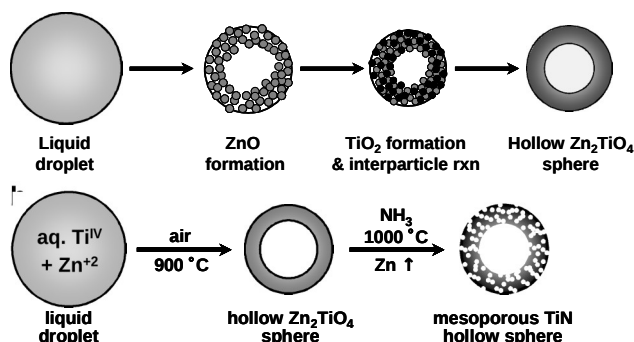
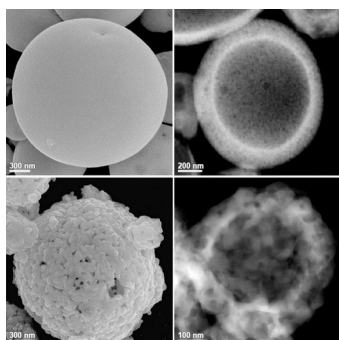


Figure 3. TEM images of carbons prepared by ultrasonic spray pyrolysis from 0.5M sucrose and (A) 1.0M Na<sub>2</sub>CO<sub>3</sub>, (B) 0.5M Na<sub>2</sub>CO<sub>3</sub>, (C) 0.1M Na<sub>2</sub>CO<sub>3</sub>, (D) 1.0 M NaHCO<sub>3</sub>, (E) 0.5 M NaHCO<sub>3</sub>, and (F) 0.1 M NaHCO<sub>3</sub>. Furnace residence time is 9 s at 800 °C.

- **A novel and facile synthetic approach to prepare hierarchically nanostructured titanium nitride via an in situ dual templating** was developed using USP. No pre-structured templates are necessary to produce the hierarchical nanostructures; instead, a template is generated in situ during the synthesis from a liquid core and the resulting spherical shell, and the template is removed in the final heating without any additional chemical etching.



# • **Interfaces between two band insulators.**

Work continued on how to make two dimensional electron systems in oxides. Last year we began a systematic study of inverted LaAlO<sub>3</sub> (LAO) to SrTiO<sub>3</sub> (STO) interfaces. Instead of preparing a Ti terminated STO substrate and then growing an LAO film on top, our idea was to grow STO on top of LAO. This would effectively solve the problem of contacting the 2DEG which is difficult in the case of LAO on STO since LAO is much more insulating than STO. The charge transfer discontinuity that is thought to give rise to the 2DEG has to be explicitly grown in this case. The architectures grown are shown schematically in Figure 4. On top of a substrate, typically STO, we grow a layer of LAO. In Figure 4 this is shown to be only 2 unit cells thick, but often it was substantially thicker. Then to transition to the STO something else must be done. In order to get an electron gas it is necessary to have the same atomic oxide layer structure sequence that is in the “normal” layer. Since layers grown always terminate in the transition metal oxide, to get the same atomic oxide layering it is necessary to grow an interfacial layer of LaTiO<sub>3</sub>. This requires a very different oxygen environment than either STO or LAO do.

The layers grown typically showed good crystalline order during growth as evidenced by strong specular RHEED reflections and layer by layer growth as evidenced by spontaneous and self generated oscillations of the RHEED specular intensity. These are shown in Figure 5. Figure 6 shows a cross sectional TEM lattice image taken by students of J-M Zuo in which good crystalline order of the heterostructure can be seen. In transport we continued to observe low temperature anomalies similar to those reported last year. With improved epitaxy we are able to report improved magneto

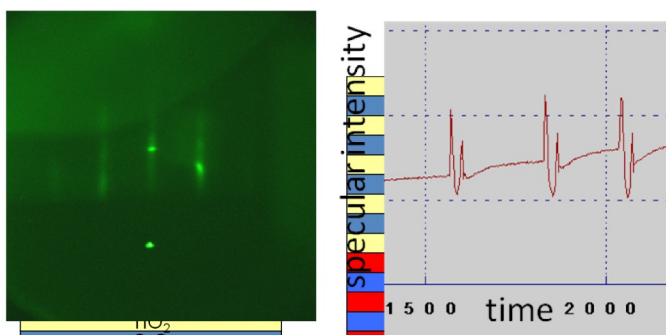


Figure 5. RHEED pattern observed during the growth of STO and oscillations of specular spot showing layer by layer growth.

as the inverted LAO-STO heterointerface.

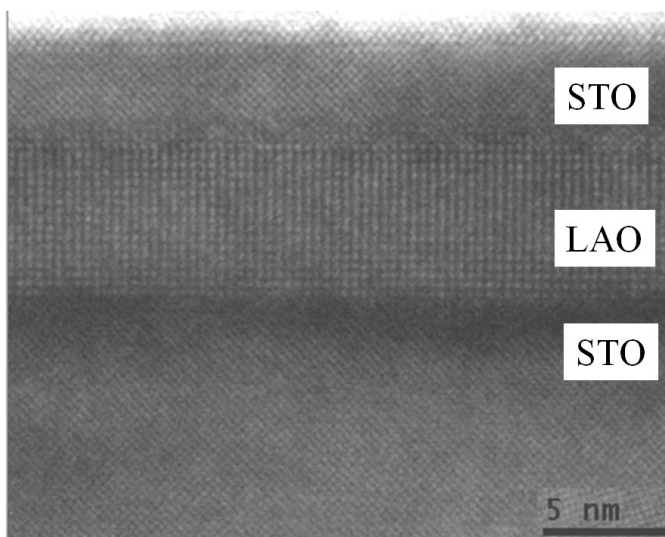


Figure 6. Cross sectional TEM showing the well ordered LAO layer grown on top of the etched STO substrate.

transport results. We obtained a room temperature mobility of  $3.7 \text{ cm}^2/\text{Vsec}$  and a sheet carrier density of  $5.3 \times 10^{14} \text{ cm}^{-2}$ . The later number is very close to the value expected for doping via the polarization catastrophe that was originally proposed, but hardly ever reported. Coupled with the good mobility number (good for STO) this may indicate we are producing more ideal 2DEGs. We are interested in continuing this work to determine the properties exhibited by these new materials.

#### **PUBLICATIONS - 2009-Present (Cluster PI)**

1. J.H. Bang, S.H. Lim, E. Park, and **K.S. Suslick**, “Dual Templating Synthesis of Mesoporous Titanium Nitride Microspheres”, *Advanced Materials*, **21**, 1-5 (2009).
2. S.S. Dunkle and **K.S. Suslick**, “Photodegradation of BiNbO<sub>4</sub> Powder during Photocatalytic Reactions”, *J. Phys. Chem. C*, **113**, 10341-10345 (2009).
3. S.S. Dunkle, R.J. Helmich, and **K.S. Suslick**, “BiVO<sub>4</sub> as a Visible-Light Photocatalyst Prepared by Ultrasonic Spray Pyrolysis”, *J. Phys. Chem. C*, **113**, 11980-11983 (2009).
4. J.H. Bang and **K.S. Suslick**, “Applications of Ultrasound to the Synthesis of Nanostructured Materials”, *Advanced Materials*, **22**, 1039–1059 (2010).
5. H.X. Xu and **K.S. Suslick**, “Water-Soluble Fluorescent Silver Nanoclusters”, *Advanced Materials*, **22**, 1078-1082 (2010).
6. M.E. Fortunato, M. Rostam-Abadi, and **K.S. Suslick**, “Nanostructured Carbons Prepared by Ultrasonic Spray Pyrolysis”, *Chem. Matl.*, **22**, 1610–1612 (2010).
7. X. Zhai, C.S. Mohapatra, A.B. Shah, J.-M. Zuo, and **J.N. Eckstein**, “New optical absorption bands in atomic-layer superlattices”, *Advanced Materials*, **22**, 1136-1139 (2010).

#### **PATENTS - 2009-Present (filed)**

**James Eckstein**

None

**Kenneth Suslick**

None

#### **AWARDS – 2009-Present**

**James Eckstein**

None

**Kenneth Suslick**

- Materials Research Society Fellow (2009)
- Acoustic Society of America Mentor Award (2009)
- 3ème Cycle Lectureship, Switzerland (2010)
- Fellow, Guggenheim Memorial Foundation (2011)
- Fellow, American Chemical Society (2010)

#### **INVITED TALKS – 2009-present**

1. **J.N. Eckstein**, 2<sup>nd</sup> International Workshop, Nanoxide - Oxide Interfaces, “New phases and optical transitions at oxide heterostructures”, Valbella Grissons, Switzerland (April, 2009).
2. **J.N. Eckstein**, Novel Electronics Materials Summer School, “Electronic Oxides”, Ameland, Netherlands (June, 2009).
3. **K.S. Suslick**, California Institute of Technology, "Colorimetric Sensor Arrays: An Adventure in Molecular Recognition", Pasadena, CA (February, 2009).
4. **K.S. Suslick**, University of California, Riverside, "Colorimetric Sensor Arrays: An Adventure in Molecular Recognition", Riverside, CA (February, 2009).
5. **K.S. Suslick**, New Sensors for Environmental Monitoring, Pittsburgh Conference (PittCon), Chicago, IL (March, 2009).
6. **K.S. Suslick**, MRS National Meeting, “Photocatalysis with metal oxides”, San Francisco, CA (April, 2009).

7. **K.S. Suslick**, Workshop on New Sensor Technology, Solvay Corporation, Brussels, Belgium (June, 2009).
8. **K.S. Suslick**, *Plenary Lecturer*, Beijing Conference and Exhibition on Instrumental Analysis (BCEIA '09), "Colorimetric Sensor Arrays: An Adventure in Molecular Recognition", Beijing (November, 2009).
9. **K.S. Suslick**, Department of Chemistry, Peking University, "Sonochemistry", Beijing (November, 2009).
10. **K.S. Suslick**, Department of Chemistry, Tsinghua University, "The Chemical Effects of Ultrasound", Beijing (November, 2009).
11. **K.S. Suslick**, Department of Chemistry, University of North Texas, Denton "Sonochemistry", (March, 2010).
12. **K.S. Suslick**, Department of Chemistry, University of California, Davis, "Colorimetric Sensor Arrays: An Adventure in Molecular Recognition", (March, 2010).
13. **K.S. Suslick**, 3ème Cycle Lectures: Universities of Fribourg, Neuchatel, Geneva, and Bern. (April 2010)
14. **K.S. Suslick**, "Ultrasonic effects on crystallization" Invited Speaker, 2010 Association for Crystallization Technology Meeting, New Brunswick, NJ. (May 2010)
15. **K.S. Suslick**, "Conditions created during Cavitation", Plenary Lecturer, 12<sup>th</sup> Meeting of the European Sonochemistry Society, Chania, Crete. (June 2010)
16. **K.S. Suslick**, Invited Speaker, Sonochemistry Symp., Pacificchem 2010, Honolulu. (Dec. 2010)
17. **K.S. Suslick**, Schwinger Foundation Symposium on Spontaneous Energy Focusing Phenomena, NTU, Singapore. (Aug. 2010)
18. **K.S. Suslick**, "The Optoelectronic Nose", Invited Speaker, Targeting Chem. & Biol. Warfare Agents Symposium, Pacificchem 2010, Honolulu. (Dec., 2010)
19. **K.S. Suslick**, Provost's Visiting Scholars & Artists Program, Western Michigan U. (May 2011)
20. **K.S. Suslick**, Invited Speaker, Materials & Molecular Design & Discovery Initiative, Argonne National Laboratory. (June 2011)
21. **K.S. Suslick**, "Conditions during Cavitation" Invited Speaker, Nonlinear Acoustics Symposium, Acoustical Society of America National Meeting, Seattle. (Aug. 2011)
22. **K.S. Suslick**, "The Optoelectronic Nose", Invited Speaker, Gordon Research Conference on Detecting Illicit Substances, Lucca, Italy (Aug., 2011).
23. **K.S. Suslick**, Invited Speaker and symposium organizer, "The Optoelectronic Nose", Intl. Symp. on Olfaction & Electronic Noses (ISOEN-2011), NYC. (Sept 2011)

#### DOE COLLABORATORS

##### **James Eckstein**

Anand Bhattacharya, Argonne National Laboratory  
Ivan Bozovic, Brookhaven National Laboratory

##### **Kenneth Suslick**

None

#### **Nano-Oxide Photocatalysis for Solar Energy Conversion: Unexpended funds**

No unexpended funds remain.

| Current and Pending Support                                                   |                                             |                                  |                                                            |
|-------------------------------------------------------------------------------|---------------------------------------------|----------------------------------|------------------------------------------------------------|
| <b>Investigator: James N. Eckstein</b>                                        |                                             |                                  |                                                            |
| Support:                                                                      | <input checked="" type="checkbox"/> Current | <input type="checkbox"/> Pending | <input type="checkbox"/> Submission Planned in Near Future |
| Project/Proposal Title: Quantum Materials at the Nanoscale (11 Investigators) |                                             |                                  |                                                            |



|                                                                                                                                                                      |  |                                                 |                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|-------------------------------------------------|------------------|
| Source of Support: Department of Energy                                                                                                                              |  |                                                 |                  |
| Total Award Amount (Investigator): \$307,101                                                                                                                         |  | Total Award Period Covered: 08/01/07 – 07/31/10 |                  |
| Total Award Amount: \$5,145,000                                                                                                                                      |  |                                                 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 0.50 |
| Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Nano-Oxide Photocatalysis for Solar Energy Conversion                                                                                        |  |                                                 |                  |
| No overlap with Quantum Materials at the Nanoscale Cluster.                                                                                                          |  |                                                 |                  |
| Source of Support: Department of Energy                                                                                                                              |  |                                                 |                  |
| Total Award Amount (Investigator): \$337,257                                                                                                                         |  | Total Award Period Covered: 08/01/07 – 07/31/10 |                  |
| Total Award Amount: \$750,000                                                                                                                                        |  |                                                 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 0.50 |
| Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Digital Synthesis A Novel Pathway to New Collective States in the Complex Oxides                                                             |  |                                                 |                  |
| No overlap with Quantum Materials at the Nanoscale Cluster.                                                                                                          |  |                                                 |                  |
| Source of Support: Argonne National Laboratory/Department of Energy                                                                                                  |  |                                                 |                  |
| Total Award Amount: \$423,152                                                                                                                                        |  | Total Award Period Covered: 01/01/07 – 08/31/10 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 0.50 |
| Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Center for Emergent Superconductivity (10 Illinois Investigators)                                                                            |  |                                                 |                  |
| No overlap with Quantum Materials at the Nanoscale Cluster.                                                                                                          |  |                                                 |                  |
| Source of Support: Brookhaven National Laboratory (DOE/EFRC)                                                                                                         |  |                                                 |                  |
| Total Award Amount (Investigator): \$806,450                                                                                                                         |  | Total Award Period Covered: 08/14/09 – 08/13/14 |                  |
| Total Award Amount (Illinois): \$6,216,000                                                                                                                           |  |                                                 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 0.50 |
| Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Reduction of Decoherence in Flux Qubits                                                                                                      |  |                                                 |                  |
| No overlap with Quantum Materials at the Nanoscale Cluster.                                                                                                          |  |                                                 |                  |
| Source of Support: University of California, Berkeley (USARO Prime)                                                                                                  |  |                                                 |                  |
| Total Award Amount (Investigator): \$2,000,000                                                                                                                       |  |                                                 |                  |
| Total Award Amount: \$4,001,945                                                                                                                                      |  | Total Award Period Covered: 06/15/09 – 04/30/14 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 1.00 |
| Support: <input type="checkbox"/> Current <input checked="" type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Quantum Materials at the Nanoscale (12 Investigators)                                                                                        |  |                                                 |                  |
| Source of Support: Department of Energy                                                                                                                              |  |                                                 |                  |
| Total Award Amount: \$5,400,000                                                                                                                                      |  | Total Award Period Covered: 08/01/10 – 07/31/13 |                  |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                      |  |                                                 |                  |
| Person-Months Per Year Committed to the Project.                                                                                                                     |  | Cal:                                            | Acad: Sumr: 0.50 |
| <b>Current and Pending Support</b>                                                                                                                                   |  |                                                 |                  |
| <b>Investigator: Kenneth S. Suslick</b>                                                                                                                              |  |                                                 |                  |
| Support: <input checked="" type="checkbox"/> Current <input type="checkbox"/> Pending <input type="checkbox"/> Submission Planned in Near Future                     |  |                                                 |                  |
| Project/Proposal Title: Nano-Oxide Photocatalysis for Solar Energy Conversion, (multi-PI award Seitz Materials Lab, UIUC)                                            |  |                                                 |                  |
| Project Focus: The goal of this project is to develop new hierarchical assemblies of nanostructured metal oxides for potential use in photochemical water splitting. |  |                                                 |                  |
| Source of Support: Department of Energy/BES                                                                                                                          |  |                                                 |                  |

|                                                                                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|-------------------------------------------------|------------------------------------------------------------|
| Total Award Amount: \$415,000                                                                                                                                                                                                                                                                  |                                             | Total Award Period Covered: 08/01/07 – 07/31/11 |                                                            |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
| Person-Months Per Year Committed to the Project.                                                                                                                                                                                                                                               |                                             | Cal:                                            | Acad: Sumr: 1.00                                           |
| Support:                                                                                                                                                                                                                                                                                       | <input checked="" type="checkbox"/> Current | <input type="checkbox"/> Pending                | <input type="checkbox"/> Submission Planned in Near Future |
| Project/Proposal Title: A VOC Dosimeter Based On A Colorimetric Sensor Array                                                                                                                                                                                                                   |                                             |                                                 |                                                            |
| RFA-ES-06-011: U01ES16011-01                                                                                                                                                                                                                                                                   |                                             |                                                 |                                                            |
| Project Focus: Use of colorimetric sensor arrays as environmental sensors of volatile organic compounds for personal exposure assessment.                                                                                                                                                      |                                             |                                                 |                                                            |
| Source of Support: NIH                                                                                                                                                                                                                                                                         |                                             |                                                 |                                                            |
| Total Award Amount: \$2,306,718                                                                                                                                                                                                                                                                |                                             | Total Award Period Covered: 07/01/07 – 06/30/11 |                                                            |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
| Person-Months Per Year Committed to the Project.                                                                                                                                                                                                                                               |                                             | Cal:                                            | Acad: Sumr: 1                                              |
| Support:                                                                                                                                                                                                                                                                                       | <input checked="" type="checkbox"/> Current | <input type="checkbox"/> Pending                | <input type="checkbox"/> Submission Planned in Near Future |
| Project/Proposal Title: New Synthetic Methodologies for Nanostructured Materials Using Ultrasound                                                                                                                                                                                              |                                             |                                                 |                                                            |
| Project Focus: The goal of this project is the exploration of synthetic applications of sonochemistry and of ultrasonic spray pyrolysis to nanostructured inorganic materials. This proposal is strictly oriented towards the synthesis, preparation, and characterization of novel materials. |                                             |                                                 |                                                            |
| Source of Support: National Science Foundation, Division of Materials Research                                                                                                                                                                                                                 |                                             |                                                 |                                                            |
| Total Award Amount: \$340,000                                                                                                                                                                                                                                                                  |                                             | Total Award Period Covered: 09/01/09 – 8/30/12  |                                                            |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
| Person-Months Per Year Committed to the Project.                                                                                                                                                                                                                                               |                                             | Cal:                                            | Acad: Sumr: 0.75                                           |
| Support:                                                                                                                                                                                                                                                                                       | <input checked="" type="checkbox"/> Current | <input type="checkbox"/> Pending                | <input type="checkbox"/> Submission Planned in Near Future |
| Project/Proposal Title: The Chemical Effects of High Intensity Ultrasound: Sonoluminescence Competing Renewal of NSF CHE 0315494 (Suslick)                                                                                                                                                     |                                             |                                                 |                                                            |
| Project Focus: The goal of this project is to investigate sonoluminescence as a spectroscopic probe of the conditions created during acoustic cavitation in liquids.                                                                                                                           |                                             |                                                 |                                                            |
| Source of Support: National Science Foundation, Division of Chemistry                                                                                                                                                                                                                          |                                             |                                                 |                                                            |
| Total Award Amount: \$ 521,845                                                                                                                                                                                                                                                                 |                                             | Total Award Period Covered: 06/01/10 – 05/30/14 |                                                            |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
| Person-Months Per Year Committed to the Project.                                                                                                                                                                                                                                               |                                             | Cal:                                            | Acad: Sumr: 0.75                                           |
| Support:                                                                                                                                                                                                                                                                                       | <input checked="" type="checkbox"/> Current | <input type="checkbox"/> Pending                | <input type="checkbox"/> Submission Planned in Near Future |
| Project/Proposal Title: Applications of Ultrasound to Lignocellulosic Biofuel Production                                                                                                                                                                                                       |                                             |                                                 |                                                            |
| Project Focus: The goal of this project is to investigate applications of ultrasound to modification of lignocellulose.                                                                                                                                                                        |                                             |                                                 |                                                            |
| Source of Support: Energy Biosciences Institute (UC Berkeley & UIUC)                                                                                                                                                                                                                           |                                             |                                                 |                                                            |
| Total Award Amount: \$ 242,000                                                                                                                                                                                                                                                                 |                                             | Total Award Period Covered: 06/01/10 – 05/30/12 |                                                            |
| Location of Project: University of Illinois at Urbana-Champaign                                                                                                                                                                                                                                |                                             |                                                 |                                                            |
| Person-Months Per Year Committed to the Project.                                                                                                                                                                                                                                               |                                             | Cal:                                            | Acad: Sumr: 0.75                                           |