Incorporation of Novel Nanostructured Materials into Solar Cells and Nanoelectronic Devices

Presented by

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Idaho DOE EPSCoR Program

Overview

- Co-PIs
- Capabilities
- Research Groups
- Basic Scientific Studies
- Applications/Devices

Co-Principal Investigators

Prof. Chien Wai
Univ. of Idaho
Dept. of Chemistry

Prof. Pamela Shapiro
Univ. of Idaho
Dept. of Chemistry

Prof. Dmitri Tenne
Boise State Univ.
Dept. of Physics

Prof. Leah Bergman
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Dept. of Physics

Prof. You Qiang
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Dept. of Physics

Prof. Alan Hunt
Idaho State Univ.
Dept. of Physics

Prof. Joshua Pak
Idaho State Univ.
Dept. of Chemistry

Prof. Alex Punnoose
Boise State Univ.
Dept. of Physics

Prof. Chris Berven
Univ. of Idaho
Dept. of Physics

Geography

Vandals

University of Idaho

BOISE STATE UNIVERSITY

BENGALS IDAHO STATE

Idaho State UNIVERSITY

Capabilities

Chris Berven and Alan Hunt

Tools for electrical measurements such as low-noise/small-signal charge transport

- Keithley source measure units for measuring current-voltage characteristics, AM1.5 and LED light sources
- Digital lock-in amplifiers for differential conductivity tests and inelastic tunneling spectroscopy. These are set up to perform measurements as a function of temperature and with a back-gate (three terminal device) experiments.
- Environmental chambers for controlling the atmosphere (10e-7 torr to 3 p.s.i. over 1 atm.), temperature (110 K to 400 K) and illumination. A 6 K continuous flow cryostat for minimization of the thermal signal with an optical window for optical excitation.
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- 300 mK cryostat with an 8 T magnet for performing high magnetic field experiments at low temperatures to perform magneto-resistance measurements.

Capabilities

Joshua Pak, Pamela Shapiro, Chien Wai, Rene Rodriguez

Tools to perform chemical and nanoparticle synthesis, functionalization, and characterization

- Microwave, photochemical, and supercritical CO_2 reactors, and PECVD reactors
- Spin coater for depositing thin films
- Methodology to build dye-sensitized solar cells and composite solar cells as well.
- Spectrophotometric and spectrometric characterization instrumentation including XRD, IR microscopy, NMR, Raman microscopy, fluorimetry, UV-Vis, SEM/EDS, Mass Spectrometry
- Single Crystal X-ray Crystallography Instrument

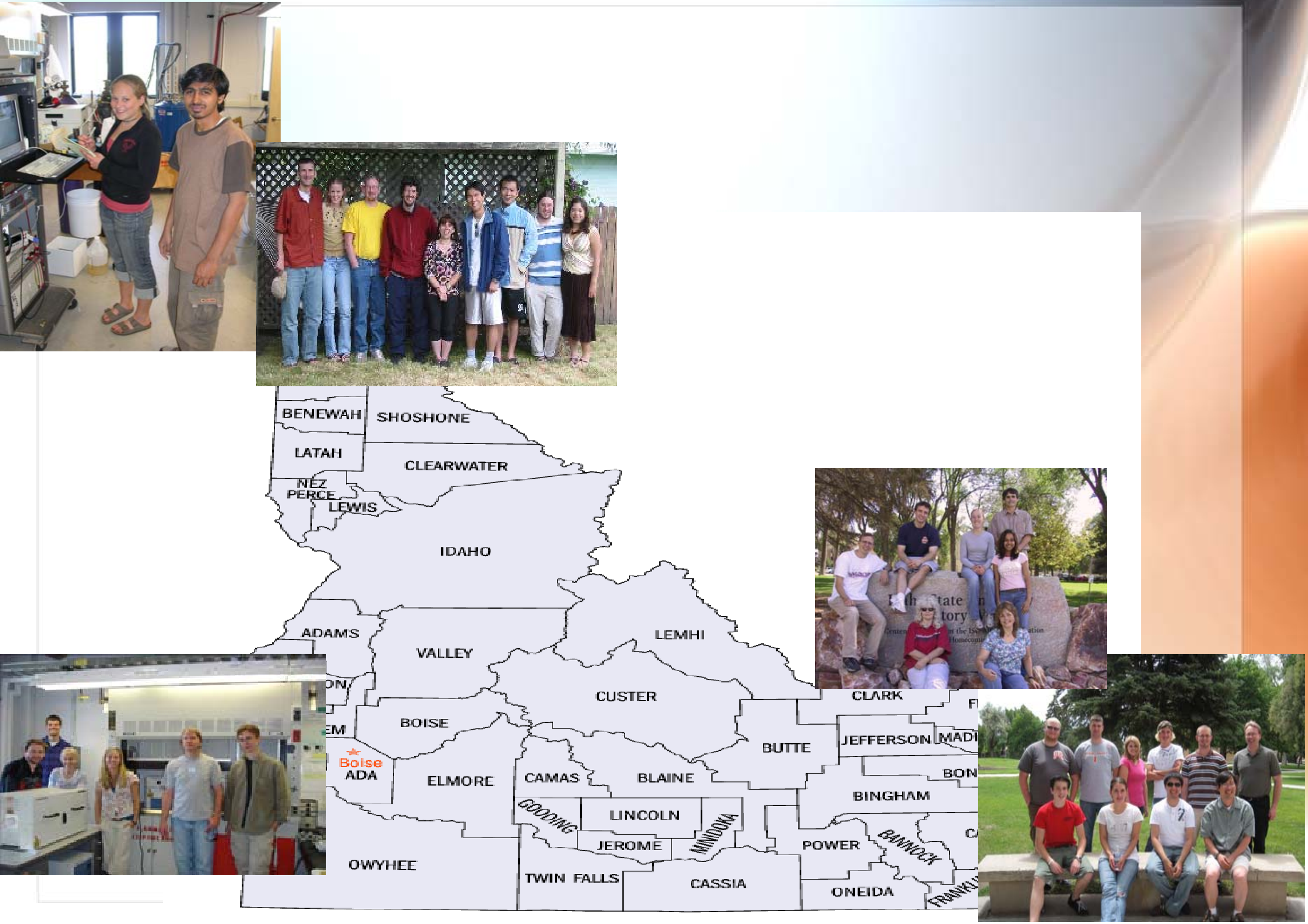
Capabilites

Alex Punnoose, You Qiang, Leah Bergman, Dmitri Tenne

<u>Thin Film and nanoparticle synthesis and magnetic and optical characterization</u>

- Nanoparticle synthesis ball milling, magnetron nanocluster deposition
- Rf and dc sputter deposition (SnO_2, ZnO, TiO_2)
- XRD and TEM, EDS/STEM, bio-TEM, electron diffraction) XPS measurements Zetapotential, nanoparticle surface charges, agglomeration behavior in different media, thermogravimetric analyzer
- Magnetic measurements (4 to 1200K), Curie temperature measurements, Quantum Design SQUID (up to 7 T field, 1.5 – 400 K), Conductivity and magneto-resistance (MR) measurements
- Spectrophotometry including high Resolution Raman w/ closed cycle He cryostat and high temperature stage, photoluminescence, transmittance, diffuse reflectance, absorbance, band gap measurements, EPR spectroscopy (transition metal dopant sites)

Research Groups



Training Future Researchers

Research Asst.	Degree	Sponsoring Dept.	
1. Anna Hoskins	Ph.D. candidate	Dept. of Physics	ISU
2. Ian Kiahara	BS/MS student	Dept. of Chemistry	ISU
3. Dominic Denty	BS/MS student	Dept. of Chemistry	ISU
4. Stephanie Pritchard	undergraduate	Dept. of Chemistry	ISU
5. Robert Barnett	undergraduate	Dept. of Chemistry	ISU
6. Richard Westover	undergraduate	Dept. of Chemistry	ISU
7. Ben Donahoo	undergraduate	Dept. of Chemistry	ISU
8. Jeffery Hess	undergraduate	Dept. of Chemistry	ISU
9. Jordan Reynolds	undergraduate	Dept. of Chemistry	ISU
10. Joshua Peterson	H. S. Student	ID Falls H.S./Chem.	ISU
11. Dr. Joseph Gardner	Postdoc.	Dept. of Chemistry	ISU
12. Ryan Souza	graduate student	Dept. of Physics	UI
13. Yufeng Tian	graduate student	Dept. of Physics	UI
14. McConnaughey	undergraduate	Dept. of Chemistry	UI
15. M. R. Kongarac	Postdoc.,	Dept. of Physics	BSU
16. Chadd Vankomen	undergraduate	Dept. of Physics	BSU
17. Paul Turner	undergraduate	Dept. of Physics	BSU
18. Joshua Anghel	undergraduate	Dept. of Physics	BSU

Training Researchers (cont.)

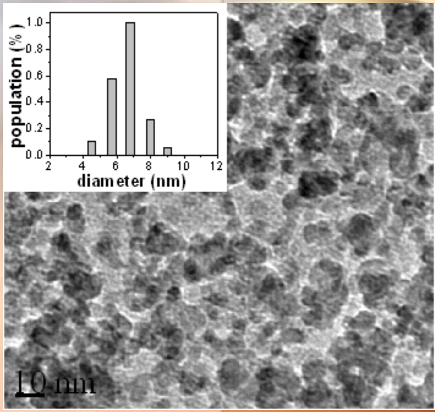
Research Asst.	Degree	Sponsoring Dept.	
19 Aaron Thurber	graduate student	Dept. of Physics	BSU
20. Jesse Huso	graduate student	Dept. of Physics	UI
21. Sirisha Chava	graduate student	Dept. of Physics	UI
22. Pramod Gadde	graduate student	Dept. of Physics	UI
23. Jacob Turner	graduate student	Dept. of Physics	UI
24. Sarah Levine	undergraduate/REU	Dept. of Physics	UI
25. Mark Williams	graduate student	Dept. of Chemistry	UI
26. Rawda Okasha	Postdoc.	Dept. of Chemistry	UI
27. Mike Fernandez	undergraduate	Dept.of Chemistry	ISU
28. Cyril Bajacharya	undergraduate	Dept. of Chemisty	ISU
29. Lisa Lau	technician/R.A.	Dept. of Chemistry	ISU
30. Jeff Mottishaw	graduate student	Dept. of Chemistry	ISU
31. Paul Turner	undergraduate	Dept. of Physics	BSU
32. Jonathan Schmidt	graduate student	Dept. of Physics	BSU
33. Trevor Engman	undergraduate	Dept. of Physics	BSU
34. Carlos Fernandez	Ph.D. thesis (2007)	Dept. of Chemistry	UI
35. Horng-bin Pan	graduate student	Dept. of Chemistry	UI

Project Focus

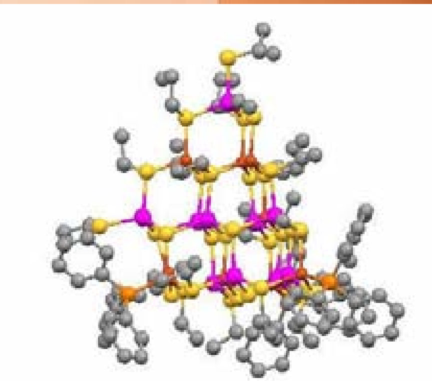
The Project, “Incorporation of Novel Nanostructured Materials into Solar Cells and Nanoelectronic Devices,”

Basic scientific research efforts have been focused in two main areas:

1. The formation and characterization of doped and un-doped transition metal oxide semiconductor nanoparticles, and studies of their interesting magnetic and optical properties including the effect of size and packing on these properties



2. The formation and characterization of tunable bandgap metal sulfide semiconductor nanoparticles, and studies of the formation of these semiconductor nanoparticles from small molecular clusters.



<u>Alex Punnoose and Dmitri Tenne</u>

Magnetic and optical properties of doped Transition Metal oxides

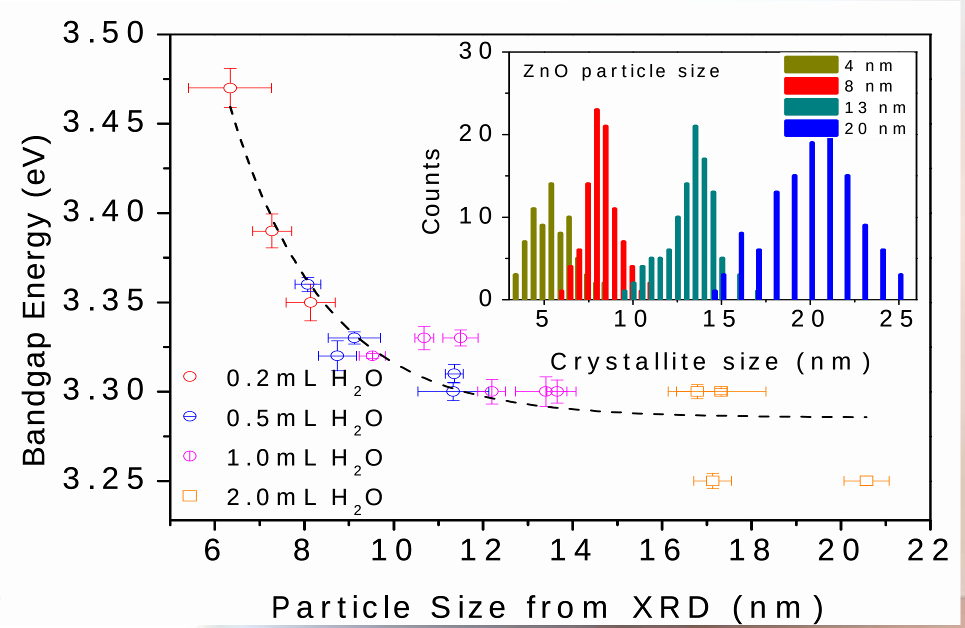
Size control for synthesis of ZnO nanoparticles

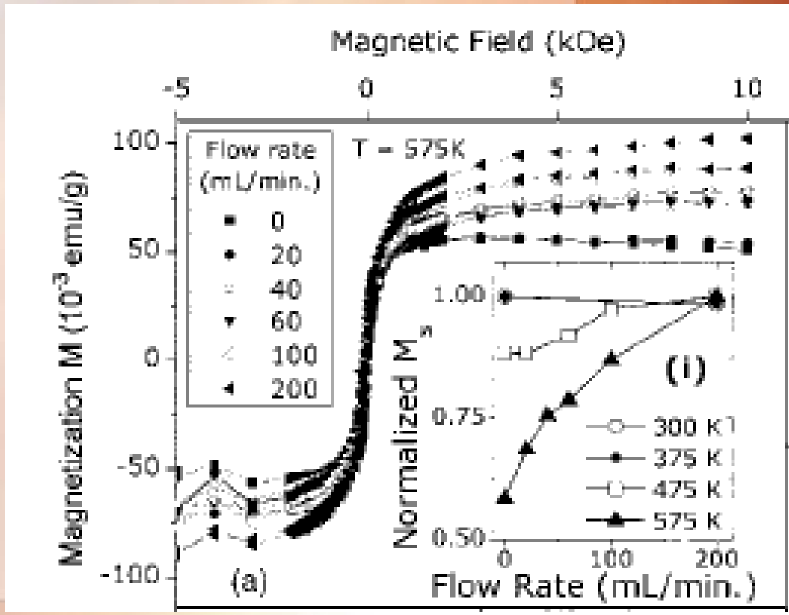
Prepared 4-20nm particles

Bandgap varies with size

Can encapsulate with fluorescent dye

Preparation of Co doped SnO_2 thin films that may show strongest ferromagnetic behavior





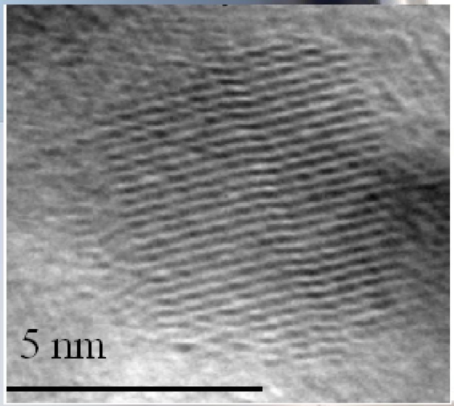
You Qiang, Leah Bergman, Chris Berven

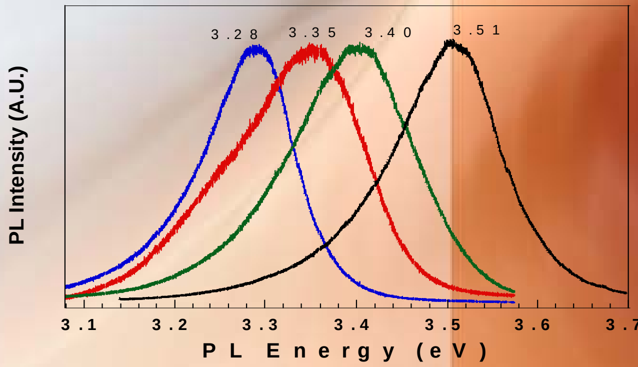
Magnetic and optical properties of doped Transition Metal oxides

Ferromagnetic doped ZnO and Cu_2O
- Conc. Range 0.2% to 30% Cobalt
  - Optical & Magnetic properties change
- Giant Magnetoresistance effect found

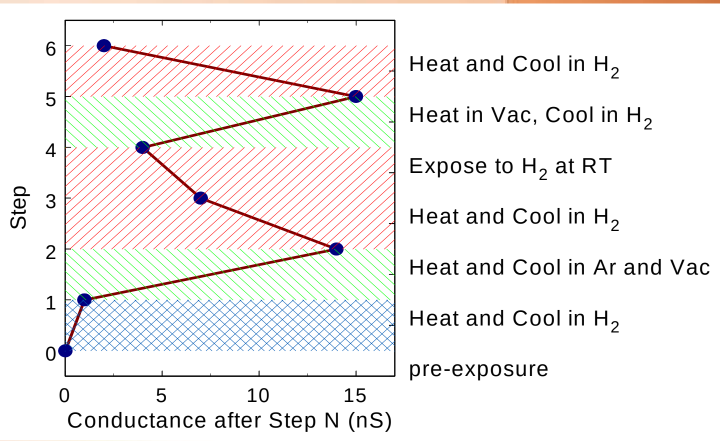
Core shell ZnO/Zn nanoclusters study
- Red shift in photoluminescence

Synthesis of $Mg_xZn_{1-x}O$ nanoalloy system
- Studied photoluminescence 0 to 30% Mg
- Phase segregation occurs at ~40%
- Anti-doping effect, lowering of
  - electrical conductivity results when $Mg_xZn_{1-x}O$ is exposed to H_2 gas



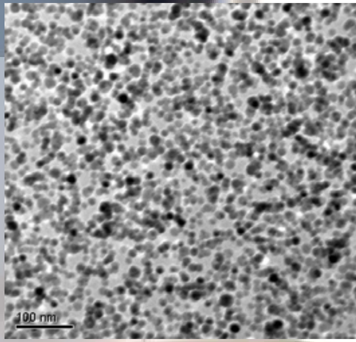


Composition ranging from pure ZnO to 30% Mg



Joshua Pak, You Qiang, Alan Hunt

Formation of doped and undoped TiO_2 nanoparticles of a specific size and packing

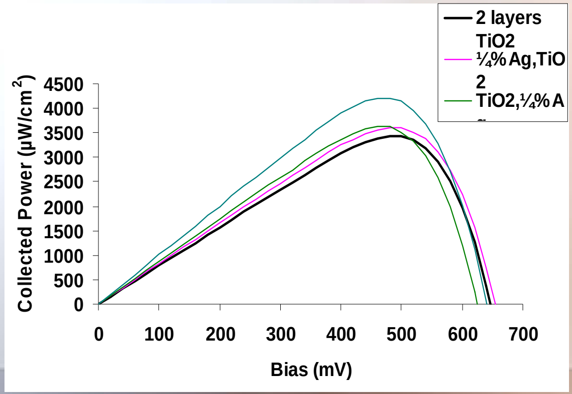


Deposit TiO_2 nanoparticles of a specified size using magnetron sputtering system:

- Low Temp. Yields TiO
- Anneal at 450^{o}C yields TiO_2

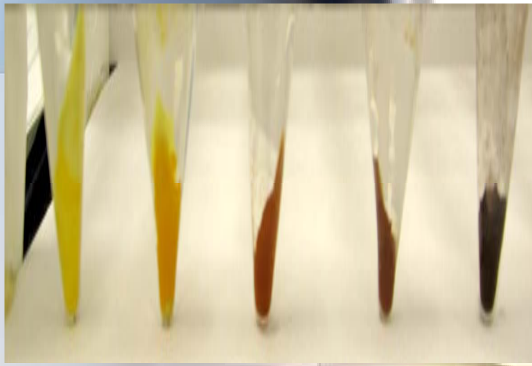
Metal Doped TiO_2

- 0.25% Silver gives increase in efficiency
- Study surface plasmon vs increase in conductivity



Prof. Pak, Prof. Shapiro, Prof. Wai, Prof. Rodriguez

Formation and Study of the production of $CuInS_2$ and PbS semiconductor nanoparticles



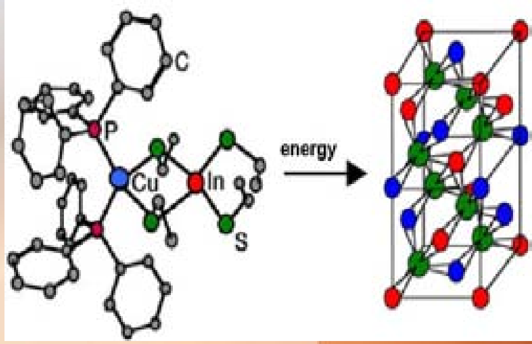
Nanoparticle size increases w/Temp.

For $CuInS_2$, single source precursors, $(PPh_3)_2Cu(SEt)_2In(SEt)_2$

Decompose using heat, light, microwave, rf-plasma

Study decomposition in supercritical CO_2, SCC

Use light decomposition to study the mechanism, molecular clusters

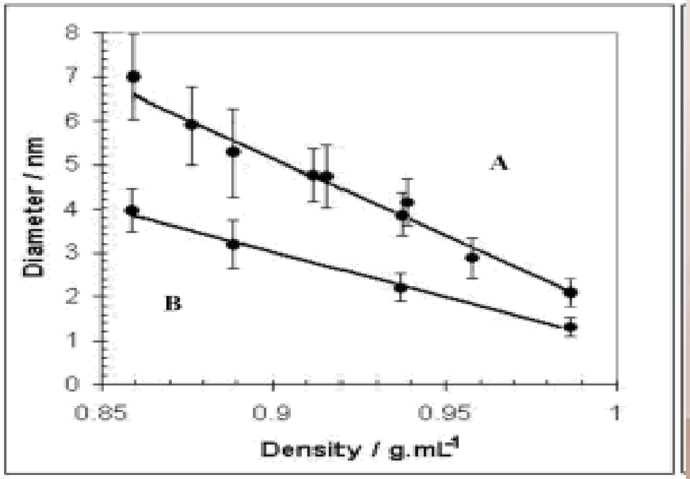


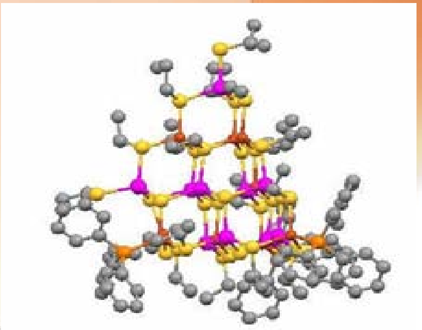
For PbS, use microemulsions in SCC to control nanoparticle formation

Tuning density allows tuning of nanoparticle size

Adjustment of the water/surfactant ratio, also affects size

S. L. Castro, S. G. Bailey, R. P. Raffaelle, K. K. Banger, A. F. Hepp, *Chem. Mater,* **15**, 3142-3247 (2003).





Devices

Hydrogen Gas Sensor

Cathodoluminescent Cell

Nanoparticle Photovoltaic Cell

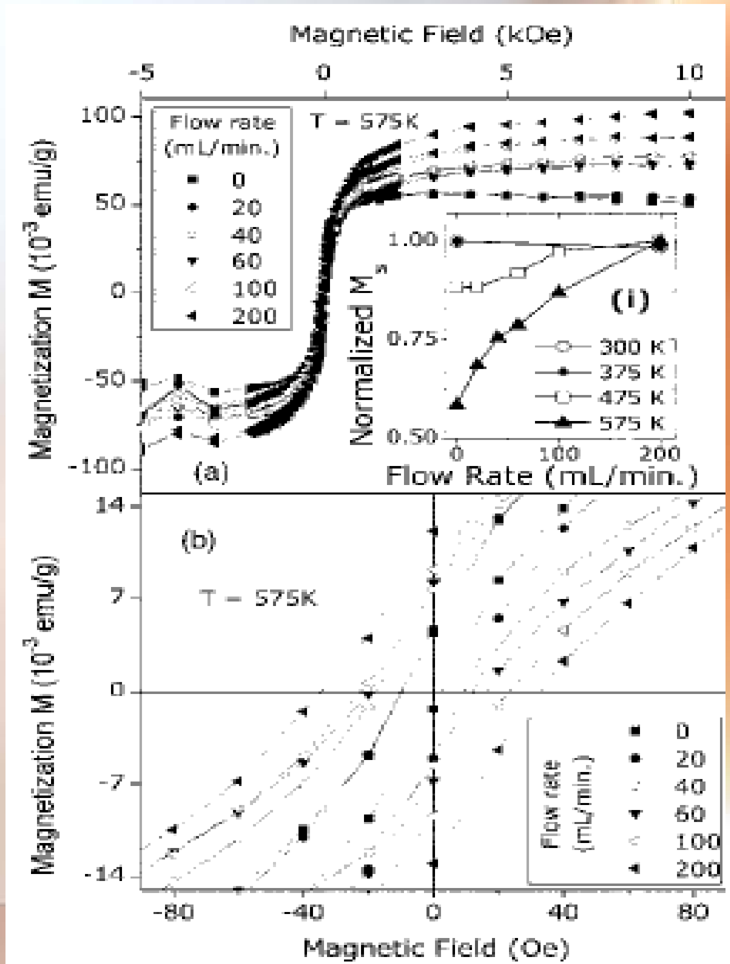
Hydrogen Sensor

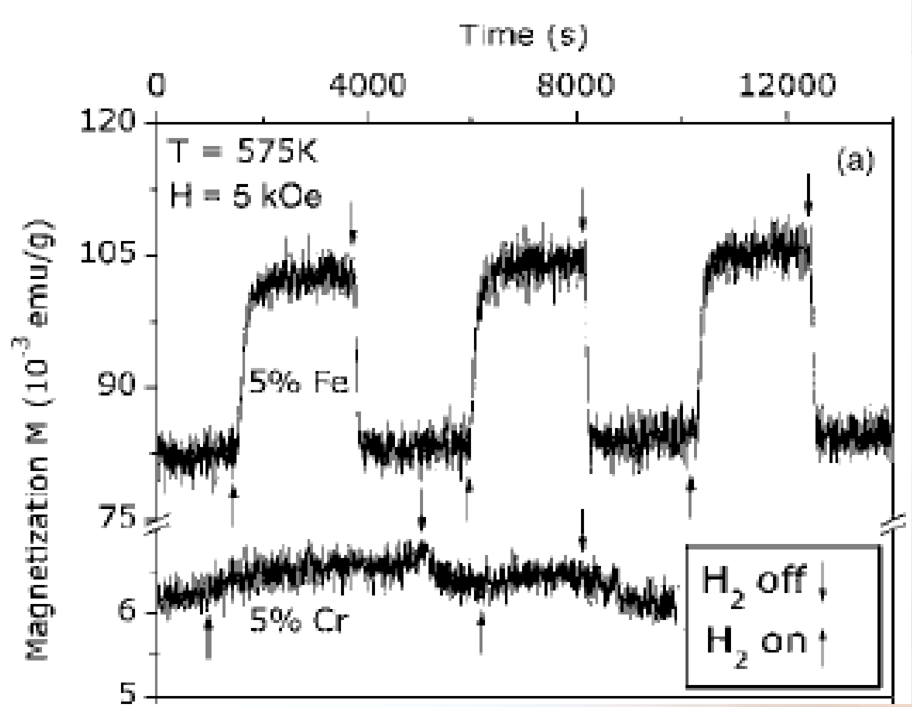
Ferromagnetism (FM) is produced in some semiconductor materials at room temp. through transition metal doping.

Proposed mechanisms for the FM ordering in dilute magnetic semiconductor oxides involve oxygen vacancies causing changes in carrier conc.

Iron doped SnO_2 nanoparticles of sizes from 20 to 70 nm show FM behavior with a Curie temperature *Tc* ≤ 850 K

The magnitudes of the FM parameters vary with oxygen stoichiometry. The presence of a reducing gas like H_2 affects the oxygen.



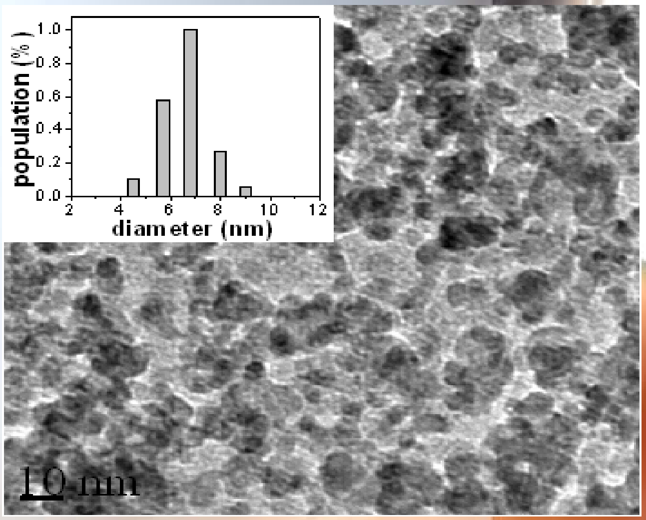


Compared to electrical-property-based gas sensors, magnetic gas sensors would be attractive

1. No electrical contacts are required allowing nanoscale powder samples for static and moving systems
2. Nanoparticle samples have a much larger surface area providing greatly improved sensitivity.

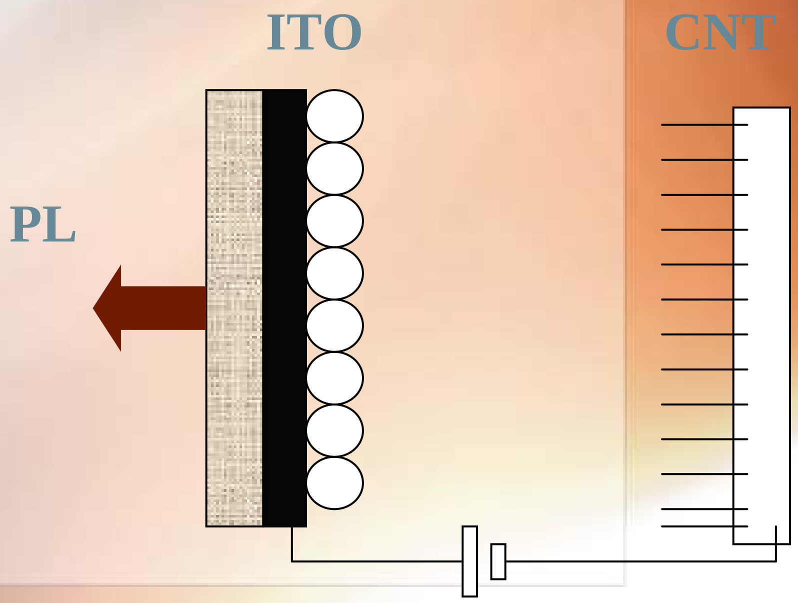
Cathodoluminescent Cell

Monodisperse pure ZnO nanoclusters can be deposited using the magnetron sputter deposition instrumentation



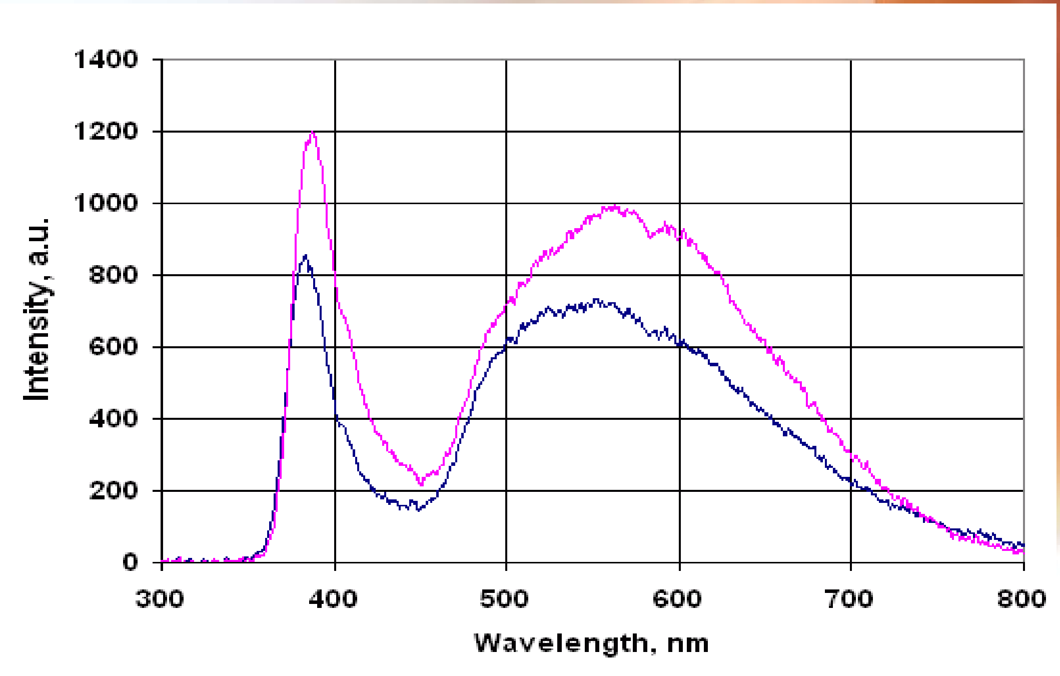
ZnO nanoclusters are deposited on indium tin oxide (ITO) coated glass substrate.

The sample is assembled with a carbon nanotube (CNT) electron emitter in a diode mode with 600 microns gap between them. The cathode cross section is ~1 cm^2.



A bias is applied between anode and cathode: a) 10 mA (1700V) current, and b) 20 mA (1800V).

Cathodoluminescence spectra of ZnO nanoclusters measured using different electron emission currents. The blue curve is from 10 mA CNT electron emission current and the red curve is from the 20 mA.

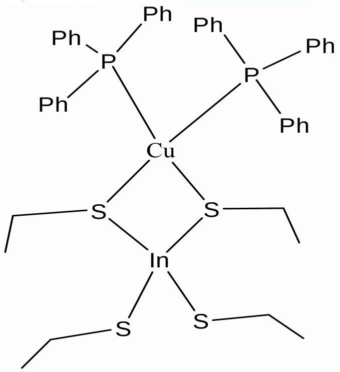


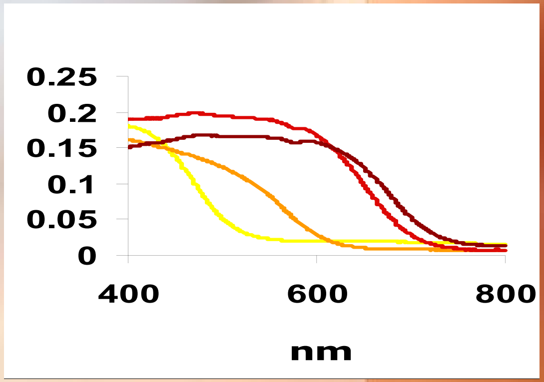
Nanoparticle Photovoltaic Cell

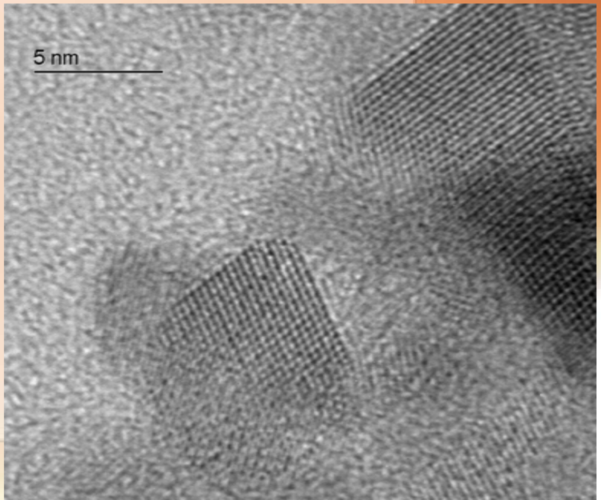
Make Chalcogenide Nanoparticles like $Cu(In,Ga)(S,Se)_2$ from single source precursors

Tunable Size

Tunable Composition







Incorporate into Nanocomposite Solar Cell/Sensor

Acknowledgements

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Pacific Northwest Lab, EMSL Facility

Universities in Idaho

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