Incorporation of Novel Nano-structured Materials into Solar Cells and Nano-electronic Devices

Presented by
Prof. Joshua Pak
Department of Chemistry
Idaho State University

DOE EPSCoR Annual Review and Workshop 2009
Brookhaven National Laboratory
Long Island, New York
July 20-23, 2009

Idaho DOE EPSCoR Program

Overview

- History
- Current DOE Award
  - Co-PIs
  - Research Students
  - Capabilities
  - Sustaining and Leveraging the DOE EPSCoR Funding
  - Publications
- Scientific Studies

History

- Spring/summer 2003 –Ad hoc committee
  - Dr. Edwin House, ISU - ID DOE EPSCoR coordinator
  - Dr. Margrit Von Braun, UI
  - Dr. Jack Owens, BSU
  - Dr. Steve Aumeier, INL
  - Dr. Dick Jacobson, INL
- Discussed research strengths of universities, priorities of the ID Office of Science and Technology and DOE
- Two areas selected.
  - Materials/nanoscience/nanostructure
  - Environmental remediation (bio and georemediation)
- Universities named researchers to work on projects
- Two proposals submitted
- Nanotechnology proposal awarded

Synthesis & Characterization of Wide-Band-Gap Semiconductors for Optoelectronic Applications

- Award: 2004-2007
- Researchers from all three universities came together
- PI – UI, 4 UI, 2 ISU, & 1 BSU researchers
- There were three junior and four senior faculty members
- Resulted in:

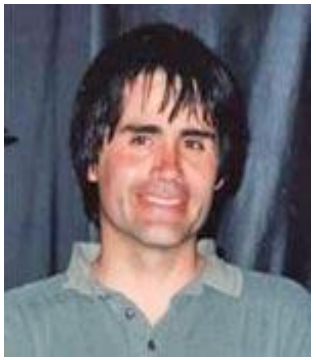
  50 publications, 4 patents, 19 graduate students, 20 undergraduates, 2 postdocs, over $2,000,000 received in grant funding related to DOE project

Renewal was submitted and awarded - $1,320,000 (*2007)*

Incorporation of Novel Nanostructured Materials into Solar Cells and Nanoelectronic Devices

- PI at ISU
- Researchers - 4 UI, 4 ISU, 2 BSU
- 6 are continuing from initial award, 4 are new - junior faculty.
- Working with INL, PNNL, AMIS, CAES

Faculty Investigators



Drs. Holland, Rodriguez, & Pak
ISU Chemistry

Dr. Bitterwolf
UI Chemistry

Dr. Hunt
ISU Physics

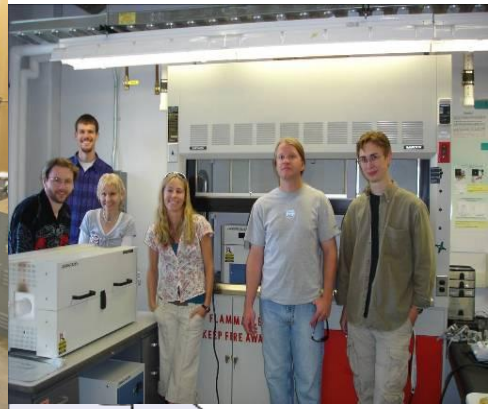
Drs. Bergman, Qiang, & Berven
UI Physics

Drs. Tenne & Punnoose
BSU Physics

Geography

Sandpoint
90
Coeur d'Alene
University of Idaho
Moscow
Orofino
Lewiston
Grangeville
Salmon R.
Salmon
Snake R.
Weiser
15
Rexburg
Boise
Ketchum
Idaho Falls
Craters of the Moon Nat'l Monument
Blackfoot
Mountain Home
Pocatello
84
86
Twin Falls
Heyburn
15
Soda Spring
Snake R.
84

Research Groups



Current DOE Award

- We have retained outstanding faculty within the scope of the implementation award.
- We have attracted and hired outstanding graduate students and postdoctoral students.
- We are developing unique infrastructure capabilities that are critical to the advancement of science and technology.
- We are making unique contributions to DOE oriented capabilities for preparing semiconductors and incorporating them into devices.
- Many of participating faculty are on track to a sustained leadership position in their disciplines.
- We are working to maximize the long-term impact of the award by training students, putting in essential infrastructure and creating new knowledge.
- We have been successful in leveraging DOE funding and capabilities with local, regional, national, and private resources.

Student Researchers

Research Asst.	Degree	Dept	Institution	Fund %
1. Gibril Omar	H. S. Student	Dept. of Chemistry	ISU	30
2. Chadd Vankomen	undergraduate	Dept. of Physics	BSU	0
3. Lydia Johnson	undergraduate	Dept. of Physics	BSU	0
4. Paul Turner	undergraduate	Dept. of Physics	BSU	50
5. Trevor Engman	undergraduate	Dept. of Physics	BSU	100
6. Joshua Anghel	undergraduate	Dept. of Physics	BSU	50
7. Zed Platt	undergraduate	Dept. of Chemistry	ISU	100
8. Michael Fernandez	undergraduate	Dept. of Chemistry	ISU	70
9. Ben Donahoo	undergraduate	Dept. of Chemistry	ISU	50
10. Jeffery Hess	undergraduate	Dept. of Chemistry	ISU	50
11. Janine Elliot	undergraduate	Dept. of Chemistry	ISU	100
12. Wyatt Thornley	undergraduate	Dept. of Chemistry	UI	50
13. Marie Young	undergraduate	Dept. of Physics	UI	0
14. Sarah Nathan	undergraduate	Dept. of Chemistry	ISU	50
15. Richard Westover	BS/MS student	Dept. of Chemistry	ISU	100
16. Jeffery Mottishaw	graduate student	Dept. of Chemistry	ISU	20
17. Cyril Bajacharya	graduate student	Dept. of Chemistry	ISU	50

Student Researchers and Associates

Research Asst.	Degree	Dept	Institution	Fund %
18. Gary Long	graduate student	Dept. of Chemistry	ISU	20
19. Anna Hoskins	graduate student	Dept. of Physics	ISU	85
20. Jesse Huso	graduate student	Dept. of Physics	UI	100
21. Eric Kangas	graduate student	Dept. of Physics	UI	100
22. Jacob Turner	graduate student	Dept. of Physics	UI	100
23. Mark Williams	graduate student	Dept. of Chemistry	UI	100
24. Justin Nairn	graduate student	Dept. of Chemistry	UI	100
25. Temple Warwick	graduate student	Dept.of Chemistry	UI	100
26. Ryan Souza	graduate student	Dept. of Physics	UI	100
27. Hui Che	graduate student	Dept. of Physics	UI	50
28. Jonathan Schmidt	graduate student	Dept. of Physics	BSU	0
29. M. R. Kongara	postdoc	Dept. of Physics	BSU	100
30. Chivin Sun	postdoc	Dept. of Chemistry	ISU	20
31. Lisa Lau	technician/R.A.	Dept. of Chemistry	ISU	30
32. Kelsey Seipel	technician/RA	Dept. of Chemistry	ISU	20
33. Aaron Thurber	technician/RA	Dept. of Physics	BSU	0
34. Dr. Joseph Gardner	Research Assoc.	Dept. of Chemistry	CSI/ISU	100

Capabilities

Chris Berven and Alan Hunt

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

- 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.
- 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, Andrew Holland, Tom Bitterwolf, Rene Rodriguez

<u>Tools to perform chemical and nanoparticle synthesis, functionalization, and characterization</u>

- 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)

Sustaining & Leveraging EPSCoR Funding

Prof. Pak *(Current)*

1. "Development of Dye Sensitized Solar Cells (DSSCs) Incorporating Novel Synthetic and Natural Dyes" Idaho State Board of Educ., $85,000, (PI) – (Overlap 30%)

2. "ACS Project SEED at ISU Department of Chemistry for High School Students for Summer 2009" American Chemical Society, $24,500 – (Overlap 10%)

3. "NSF MRI: Proposal to Purchase an ESEM with CL, STEM, and EDX, at Idaho State University" NSF, $37,5000, co-PI with Prof. Maschner 2008 (Overlap: will use instrument for characterization)

4. "Improved Fabrication Methods and Materials for Advanced Photovoltaic and Semiconductor Devices" Precision Nanoparticles Inc. (PI, in collaboration with INL, total budget $3 M) $1.35 M. (Overlap: similar work on chalcogenide nanomaterials)

Prof. Qiang *(Current)*

1. "Integrated Passive Electronic Components", Co-PI of DOD-AFRL grant, $2.56M, 06/2007-06/2010. PI: G. Donohoe, $405K.

2. "Magnetic and Optical Properties of Ferromagnetic ZnO Nanoclusters", Co-PI of DOE grant, $372,948, 06/30/07 to 05/30/10. PI: M. McCluskey, WSU, $113K

3. "Development of Dye sensitized solar cells (DSSCs) incorporated novel synthetic and natural dyes", Co-PI for Idaho-SBOE grant, PI: J. Pak, ISY, $75K, $13K, Jan. 22, 2008 to June 30, 2009.

4. "Conjugates of Actinide Chelator-Magnetic Nanoparticles for Used Fuel Separation Technology", PI of DOE-AFCI grant, $735K, 10/01/2008 – 6/30/2010.

University of Idaho

EPSCoR Experimental Program to Stimulate Competitive Research

Prof Holland *(Current)*

1. "Demystifying Microwave Assistance in Homogeneous Catalysis – Chemical Kinetics of Microwave-Heated Palladium Reactions"ACS Petroleum Research Fund #49399-UR, (PI) $65,000, 06/09-08/11.

Prof. Hunt *(Current)*

1. "Support of Large Standoff Fissionable Material Detection for DTRA," FY09 (PI)

Department of Defense through Idaho National Laboratory, $100,256 12/2008 through 12/2009

"High-Energy Prompt Neutrons for the Detection of Fissionable Materials at Long Range" (PI) Idaho National Laboratory, $49,503, 11/2008 through 9/2009

2. "High Repetition Rate, Linac based Nuclear Resonance Fluorescence (NRF) for FY09 NA-22
3. "Life Cycle Plan" (PI) National Nuclear Security Administration through Idaho National Laboratory, $598,450, 11/2008 through 10/2009

4. "Development of Dye Sensitized Solar Cells (DSSCs) Incorporating Novel Synthetic and Natural Dyes" (Co-PI) Idaho State Board of Education, $75,000, 12/2007 through 5/2009

5. "Basic Research in High Sensitivity SNM Forensics via Correlated Photo Induced Emission Signatures for Topic B: Advanced Radiological Detection and Forensics" (PI)

Department of Defense, $1,112,741, 11/2007 through 12/2010 *Pending*

6. "09-093: Near real-time nondestructive active inspection technologies utilizing delayed □-rays for advanced safeguards," Department of Energy through BEA, $466,233, 7/2009 through 6/2011

7. "Brems-Based Photonuclear Long Range, Standoff Detection of SNM," Department of Defense, subcontractor to L-3 communications, $1,059,023, 7/2009 through 12/2012

Boise State University

Bengals Idaho State

Prof. Punnoose *(Current)*

1. "A study of the wet chemical synthesis of N-doped ZnO, Co- and Mn-doped ZnO, and (N,Mn)- and (N,Co)-codoped ZnO", NSF, Co-PIs; Duration: 2008 – 2011, $308,000 *(some overlap)*

2. "Semiconductor-Based Nanotechnology Applications," Army Research Office (ARO):, PI, Duration: 10.2008-10.2010, $770,000, (*some overlap*).

Prof. Bergman *Current*

1. "Magnetic and Optical Properties of Ferromagnetic ZnO Nanoclusters" DOE-Office of Science 6/2007- 5/2010. Co-PI with Matt McCluskey (PI) at Washington State University, ~$370,000.

Prof. Bitterwolf *(Pending)*

1. "MRI: Acquisition of a Femtosecond Mid-Infrared Spectrometer," Co-PIs: Prof. Peter Griffiths, Prof. Eric Brauns, NSF, $552,029

2. "Examination of short lived reaction intermediates using stopped flow methods coupled to an ultrafast FTIR spectrometer," Co-PI: Prof. Peter Griffiths, NSF, $564,661, 07/01/09 – 06/30/12

3. "Applications of vitrification compatible, functionalized mesoporous silica to nuclear waste management," DOE, $571,508, 09/01/09 - 08/30/12

4. "Time-resolved XAFS spectroscopic studies of B-H and N-H oxidative addition to transition metal catalysts relevant to hydrogen storage," DOE EPSCoR, $449,976, 07/01/09 - 06/30/12

Prof. Rodriguez *(Current)*

1. NASA EPSCoR Subcontract "Radiation Resistant Phase-Change Memory and Reconfigurable Electronics" co- PI, subcontract from NASA EPSCoR to Boise State Univ., 9/07-9/10, Prof. Kris Campbell, PI. (Amount to ISU, ~ $140,000)

2. "NSF MRI: Proposal to Purchase a ESEM with CL, STEM, and EDX, at Idaho State University" NSF, co-PI with Prof. Maschner 2008. (overlap: may be used to analyze samples)

3. Improved Fabrication Methods and Materials for Advanced Photovoltaic and Semiconductor Devices" Precision Nanoparticles Inc. (PI, in collaboration with INL, total budget $3 M) $1.35 M. (Overlap: working on chalcogenide nanomaterials)

Prof. Tenne *(Current)*

1. NSF DMR: "Lattice dynamics and phase transitions in nanoscale ferroelectric heterostructures" Agency: NSF; PI; Duration: 09/01/2007 – 08/31/2010; $240,000.

2. Cottrell College Science Award: "Ultraviolet Raman spectroscopy of ferroelectric and multiferroic nanostructures" Agency: Res. Corp; PI; Duration: 07/07 – 06/09; $40,968 (some overlap)

Publications

1. C. Van Komen, A. Punnoose and M. S. Seehra, “Transition from n-type to p-type destroys ferromagnetism in semi-conducting Sn1-xCoxO2 and Sn1-xCrxO2 nanoparticles,” Solid State Comm. (submitted, 2009).
2. A. Punnoose, K. M. Reddy, J. Hays, A. Thurber, S. Andronenko and S. K. Misra, “Dopant Spin States and Magnetic Interactions in Transition Metal Doped Semiconductor Nanoparticles”, Appl. Magn. Reson. (in press, 2009).
3. A. Thurber, K. M. Reddy and A. Punnoose, “Influence of oxygen level on structure and ferromagnetism in Sn0.95Fe0.05O2 nanoparticles,” J. Appl. Phys. (in press, 2009).
4. H. Wang, D. Wingett, M. H. Engelhard, K. Feris, K. M. Reddy, P. Turner, J. Layne, C. Hanley, J. Bell, D. Tenne, C. Wang and A. Punnoose, “Fluorescent dye encapsulated ZnO particles with cell-specific toxicity for potential use in biomedical applications,” J. Mater. Sci.: Mater. Med. 20, 11-22 (2009).
5. C. Hanley, J. Layne, A. Punnoose, K. M. Reddy, I. Coombs, A. Coombs, K. Feris and D. Wingett, “Preferential killing of cancer cells and activated human T cells using ZnO nanoparticles”, Nanotechnology 19, 295103 (2008).
6. S. K. Misra, S. I. Andronenko, M. H. Engelhard, A. Thurber, K. M. Reddy and A. Punnoose, “Role of dopant incorporation on the magnetic properties of Ce1-xNixO2 nanoparticles: An electron paramagnetic resonance study” J. Appl. Phys. 103, 07D122 (2008).
7. C. Van Komen, A. Thurber, K. M. Reddy, J. Hays and A. Punnoose, “Structure-magnetic property relationship in transition metal (M = V, Cr, Mn, Fe, Co, Ni) doped SnO2 nanoparticles”, J. Appl. Phys. 103, 07D141 (2008).

8. D. A. Tenne, H. N. Lee, R. S. Katiyar, and X. X. Xi, “Ferroelectric phase transitions in three-component short-period superlattices studied by ultraviolet Raman spectroscopy”, J. Appl. Phys. 105, 054106 (2009).
9. Y. Sakaguchi, D. A. Tenne, and M. Mitkova, “Structural development in Ge-rich Ge-S glasses,” Journal of Non-Crystalline Solids,2009, accepted for publication.
10. Y. Sakaguchi, D. A. Tenne, and M. Mitkova, “Oxygen-assisted photoinduced structural transition in amorphous Ge-S films,” Physica Status Solidi (a), submitted. Jiji Antony, You Qiang, Faheem Muhammad, Daniel Meyer, David E. McCready, Mark H. Engelhard “Ferromagnetic semiconduc. nanoclusters: Co-doped Cu_2O”, Appl. Phys. Lett., 90, (2007) 013106
11. Jiji Antony, You Qiang, Faheem Muhammad, Daniel Meyer, David E. McCready, Mark H. Engelhard “Ferromagnetic semiconduc. nanoclusters: Co-doped Cu_2O”, Appl. Phys. Lett., 90, (2007) 013106
12. Jiji Antony, You Qiang, “Cathodoluminescence from a device of carbon nanotube-field emission display with ZnO nanocluster phosphor”, Nanotechnology 18 (2007) 295703.
13. Y.F. Tian, J. Antony, R. Souza, Y. Qiang, S.S. Yan and L.M. Mei, “Giant positive magnetoresistance in Co-doped ZnO nanocluster films”, Applied Physics Letters 92 (2008) 192109
14. C. M. Wang, L. V. Saraf, and Y. Qiang, “Microstructures of ZnO films deposited on (0001) and r-cut α-Al2O3 using MOCVD”, Thin Solid Films 516 (2008) 8337-42

15. John L. Morrison, Jesse Huso, Heather Hoeck, Erin Casey, James Mitchell, Grant Norton, and Leah Bergman, “Optical properties of ZnO and MgZnO nanocrystals below and at the phase separation range”, J. of Appl. Phys. 104, 123519 (2008).
16. Jesse Huso, John L. Morrison, James Mitchell, Erin Casey, Heather Hoeck, Chris Walker, W. M. Hlaing Oo, and M. D. McCluskey, and Leah Bergman, “Optical Transitions and Multiphonon Raman Scattering of Cu Doped ZnO and MgZnO Ceramics” Appl. Phys. Lett. 94, 61919 (2009).
17. K. K. Zhuravlev, W. M. Hlaing Oo, M. D. McCluskey, J. Huso, J.L. Morrison and L. Bergman, “MgxZn1-xO and ZnO nanocrystals under high pressure”. Submitted J. Appl. Phys. (2009).
18. Joseph Gardner, Endrit Shurdha, Lisa Lau, Chivin Sun, Gary Long, Chongmin Wang, Rene G. Rodriguez, and Joshua J. Pak,“Size-Selective Synthesis of Ternary Chalcopyrite CuInS2 and CuInxGa1-xS2 Nanoparticles via Microwave Irradiation.” Chem. Comm. 2009, Submitted.
19. Jeffery Mottishaw, Lisa Lau, Caryn Evilia, Ryan Patterson, Miglena Manadahar, Liang Yan, Richard Holsten, and R. Rodriguez, “Incorporation of Bacteriorhodpsin in a Dye Sensitized Solar Cell”, submitted, Journal of Photochemistry and Photobiology Dec. 2008 (under revision).
20. Lisa D. Lau, Ebner Manuel, Anna Hoskins, A. W. Hunt, Joshua J. Pak, and R. Rodriguez, “Comparison of the Conversion Efficiency in Dye Sensitized Solar Cells made from Mangosteen Fruit and α-Mangostin.” In revision, Journal of Photochemistry and Photobiology (2009).

Incorporation of Novel Nano-structured Materials into Solar Cells and Nano-electronic Devices

- Current Award: 2007-2010
- Researchers from all three universities came together
- PI – UI, 4 UI, 4 ISU, & 2 BSU researchers
- There are four junior and six senior faculty members
- Resulted in (so far):

  20 publications, 1 patent, 3 HS students, 13 graduate students, 14 undergraduates, 2 postdocs, 3 research associates, 1 community college faculty, over $4.6 M received in grant funding related to DOE project

Acknowledgements

- DOE EPSCoR Grant Application

DE-FG02-04ER46142

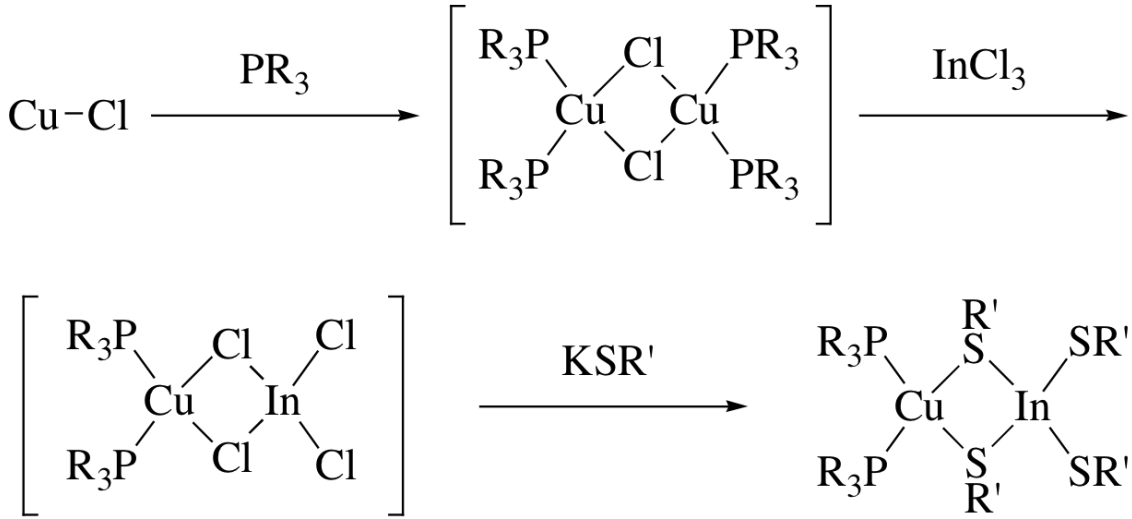
- State of Idaho
- UI, BSU, & ISU
- Many collaborators and supporting institutions

Preparation and Study of Single Source Precursors (SSPs) for the formation of $CuInS_2$ Nanoparticles and Related Materials

Joshua J. Pak

Idaho State University

Department of Chemistry


Cu−Cl
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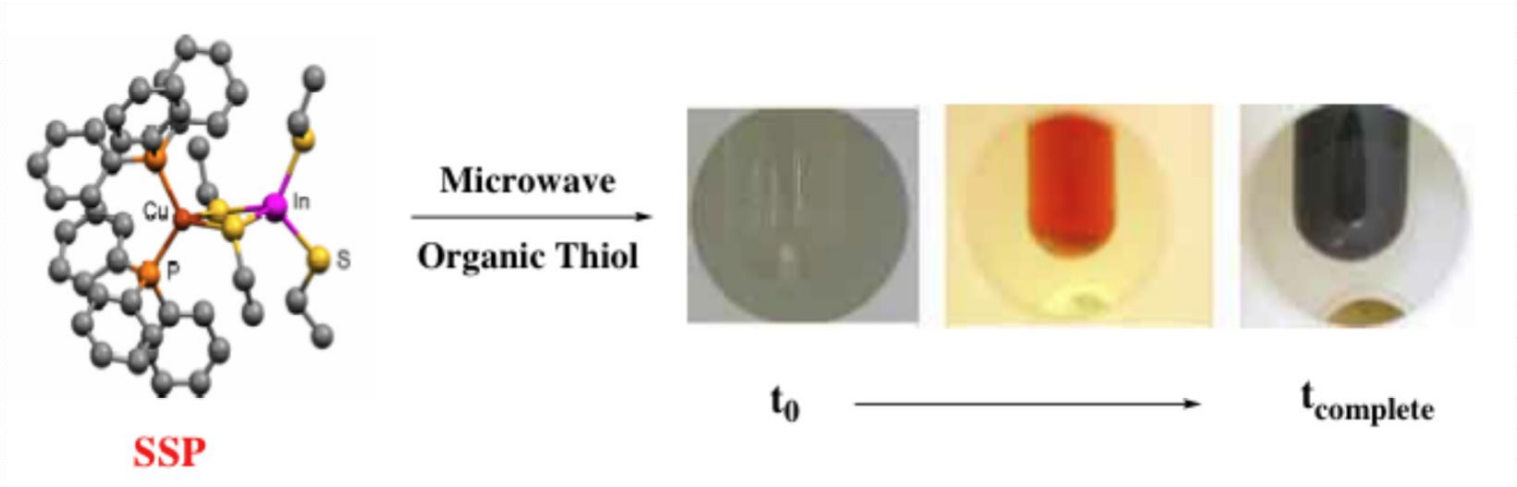
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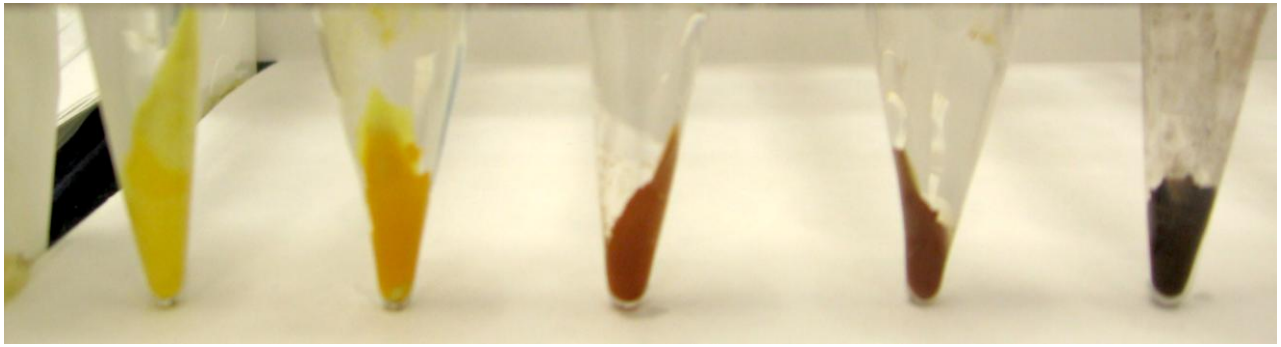
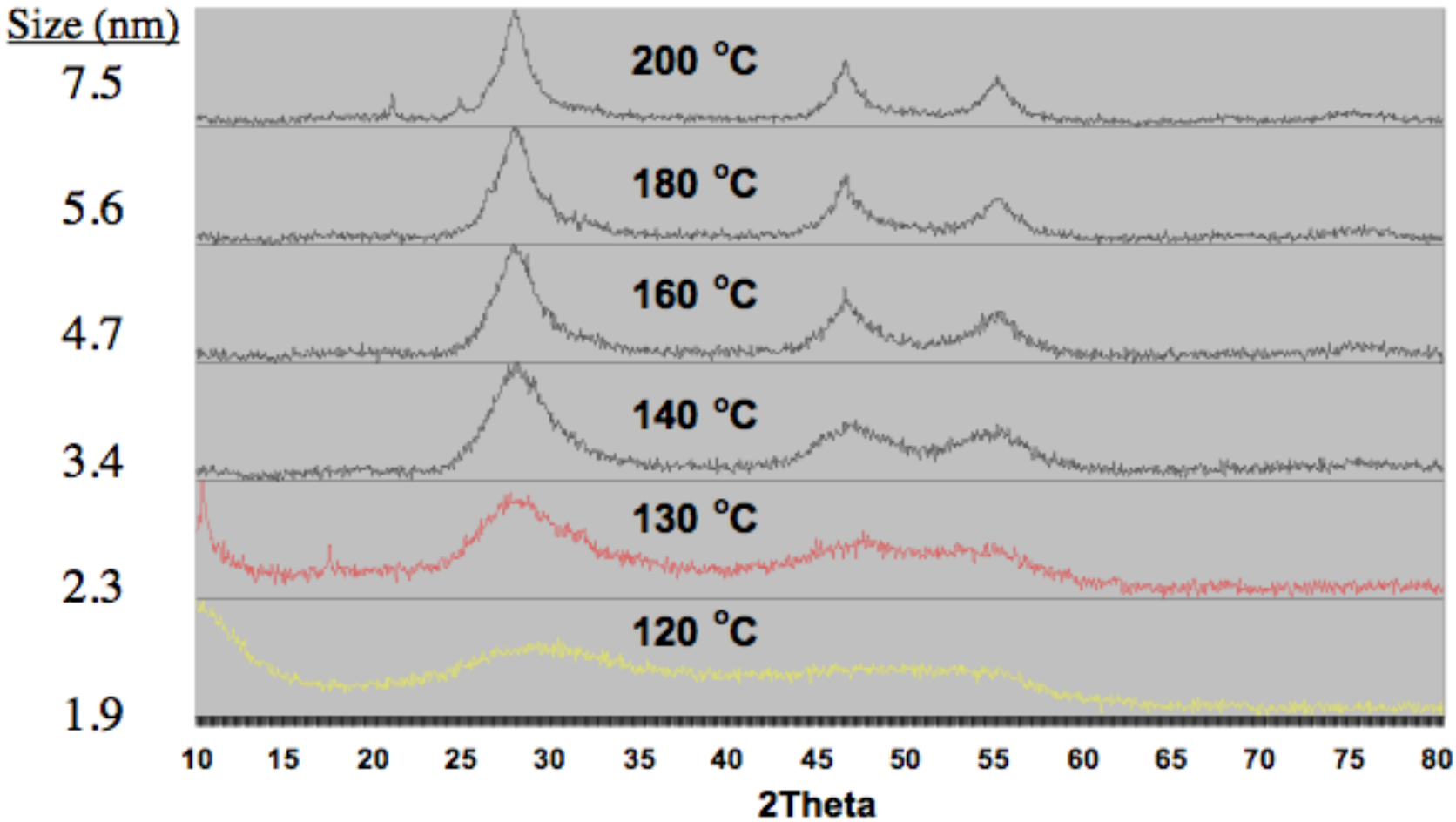
Size-Selective Synthesis of NPs

Super Critical CO_2 Products

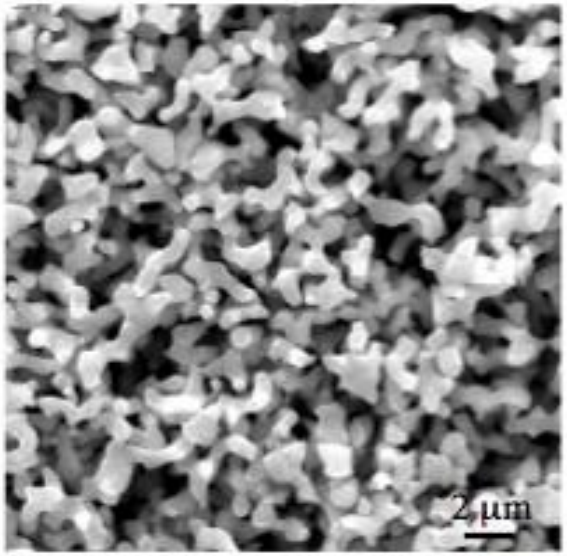


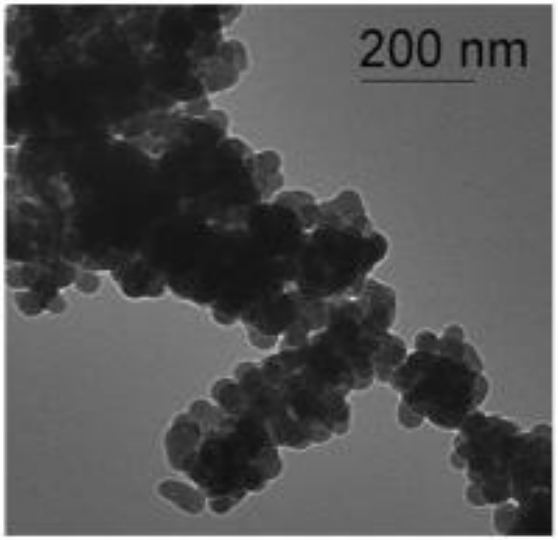
Microwave Products

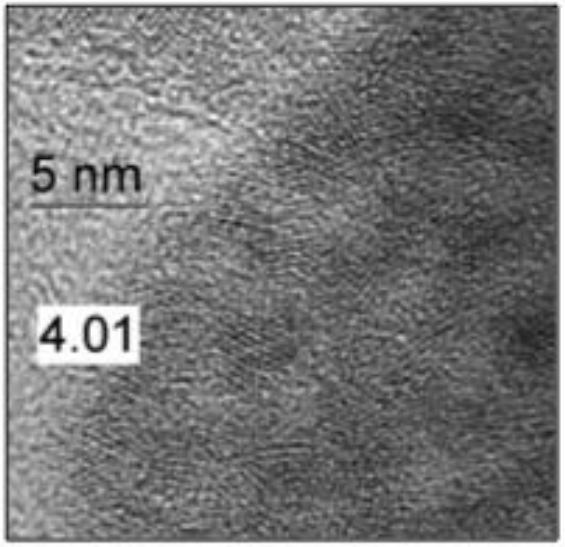
- $CuInS_2$ Nanoparticles ranging from ~ 2 nm (yellow) up to ~ 20 nm (dark red/black) in size.
- >10 g scale reactions with ~70-98% NP Yield

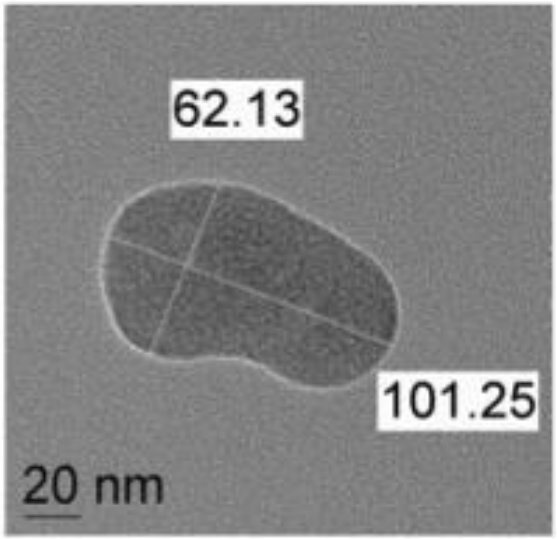


❖ Higher reaction temperature produces larager $CuInS_2$ nanoparticles.

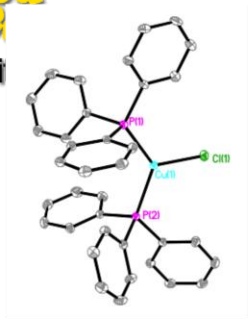






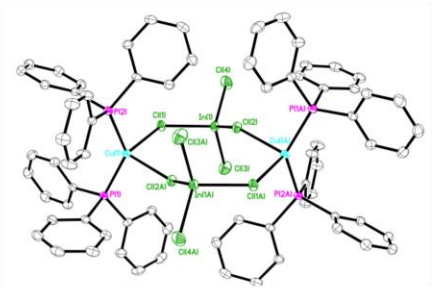


Clusters (Orange powder) are composed of ~4 nm particles



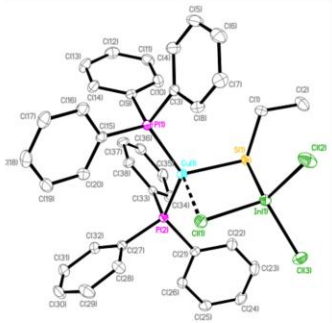
$(Ph_3P)_2CuCl$

$InCl_3$ →



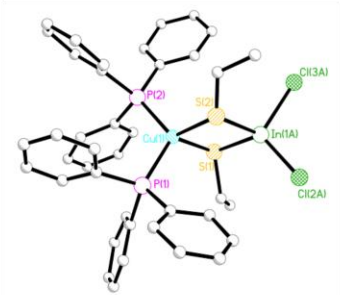
$\{(Ph_3P)_2Cu(\mu\text{-}Cl)_2InCl_2\}_2$

NaSEt →



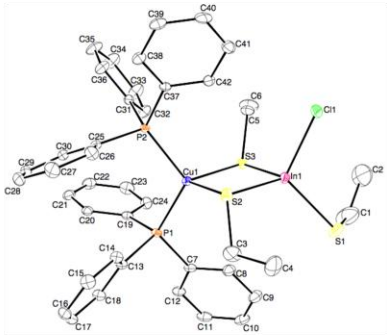
$(Ph_3P)_2Cu(\mu\text{-}SEt)(\mu\text{-}Cl)InCl_2$

NaSEt →



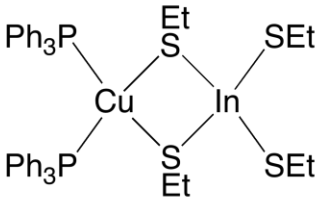
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2InCl_2$

NaSEt →



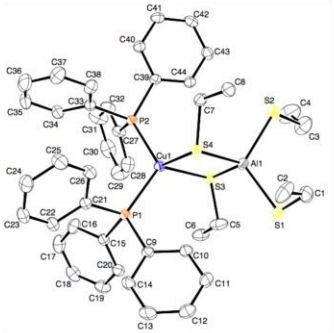
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2In(SEt)Cl$

NaSEt →

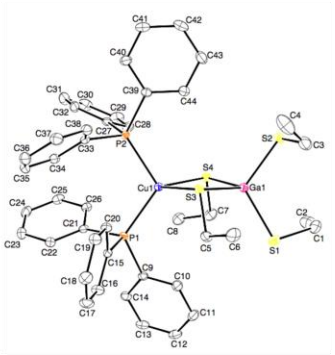


SSP

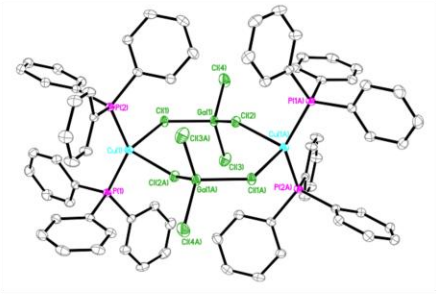
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2In(SEt)_2$



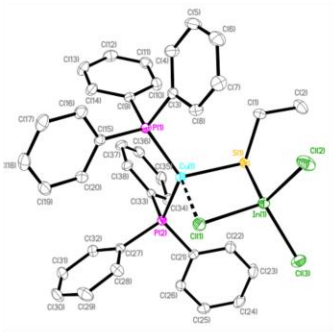
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2Al(SEt)_2$



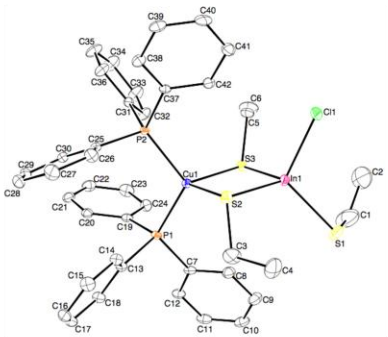
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2Ga(SEt)_2$



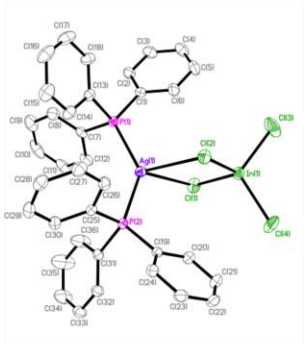
$\{(Ph_3P)_2Cu(\mu\text{-}Cl)_2GaCl_2\}_2$



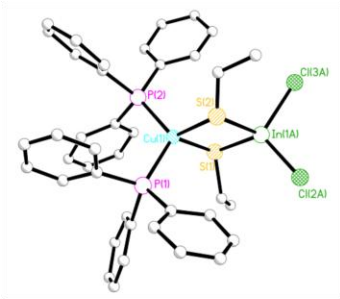
$(Ph_3P)_2Cu(\mu\text{-}SEt)(\mu\text{-}Cl)InCl_2$



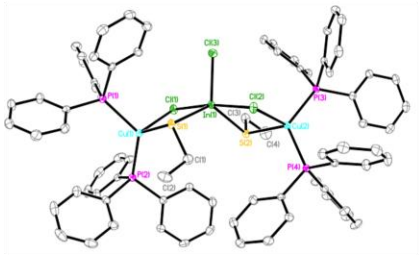
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2In(SEt)Cl$



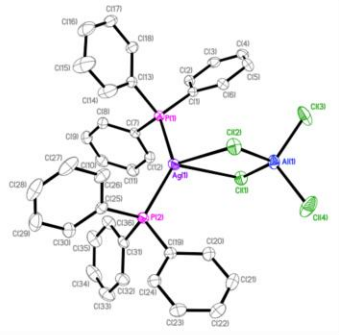
$(Ph_3P)_2Ag(\mu\text{-}Cl)_2InCl_2$



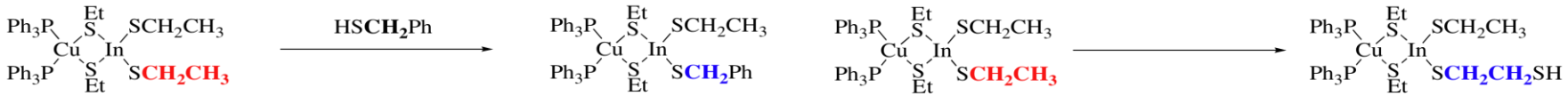
$(Ph_3P)_2Cu(\mu\text{-}SEt)_2InCl_2$

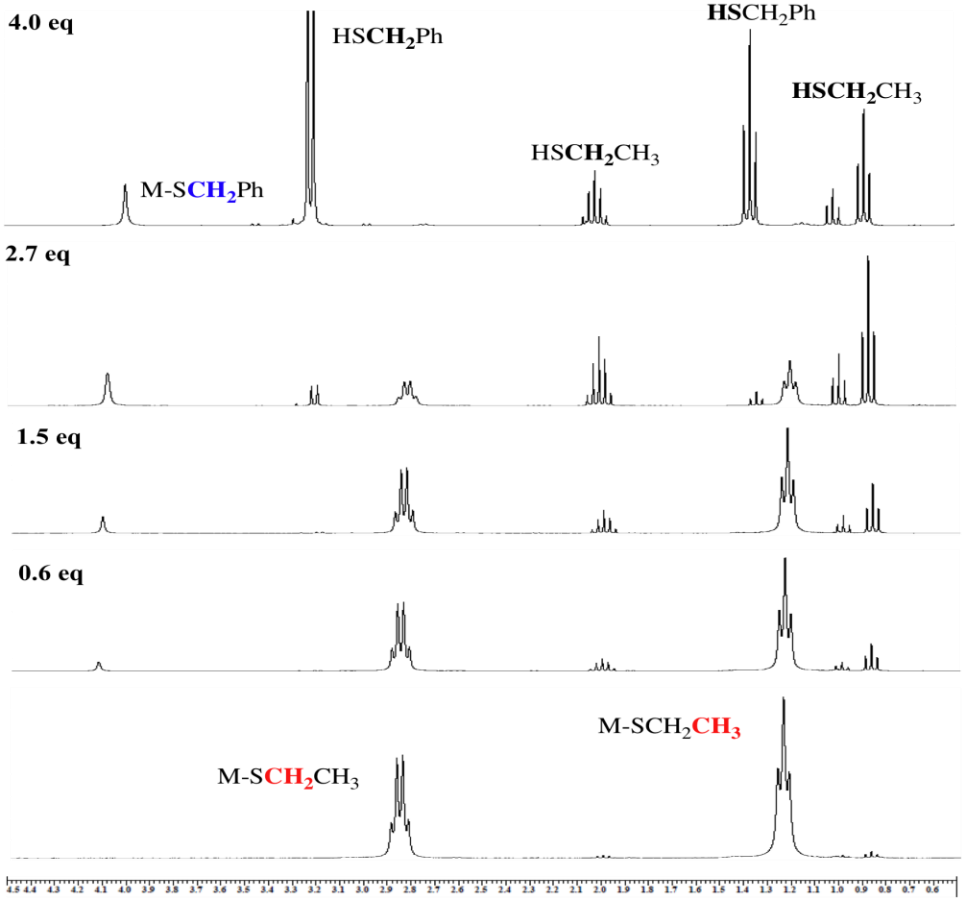


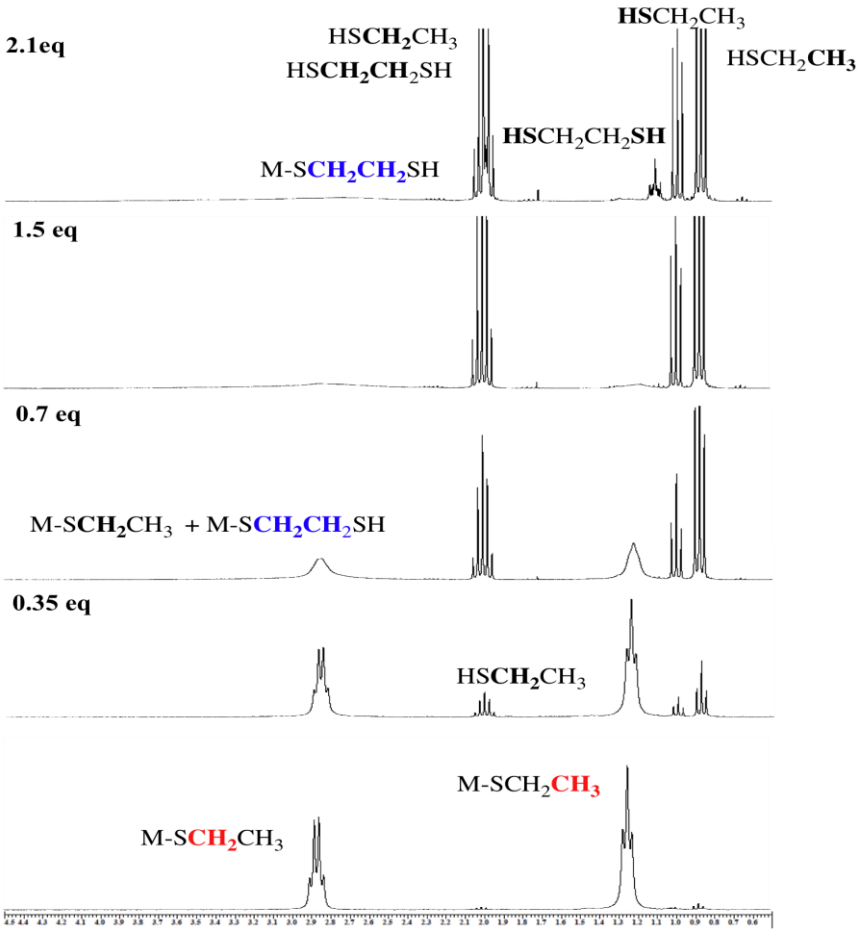
$\{(Ph_3P)_2Cu(\mu\text{-}SEt)(\mu\text{-}Cl)\}_2InCl$

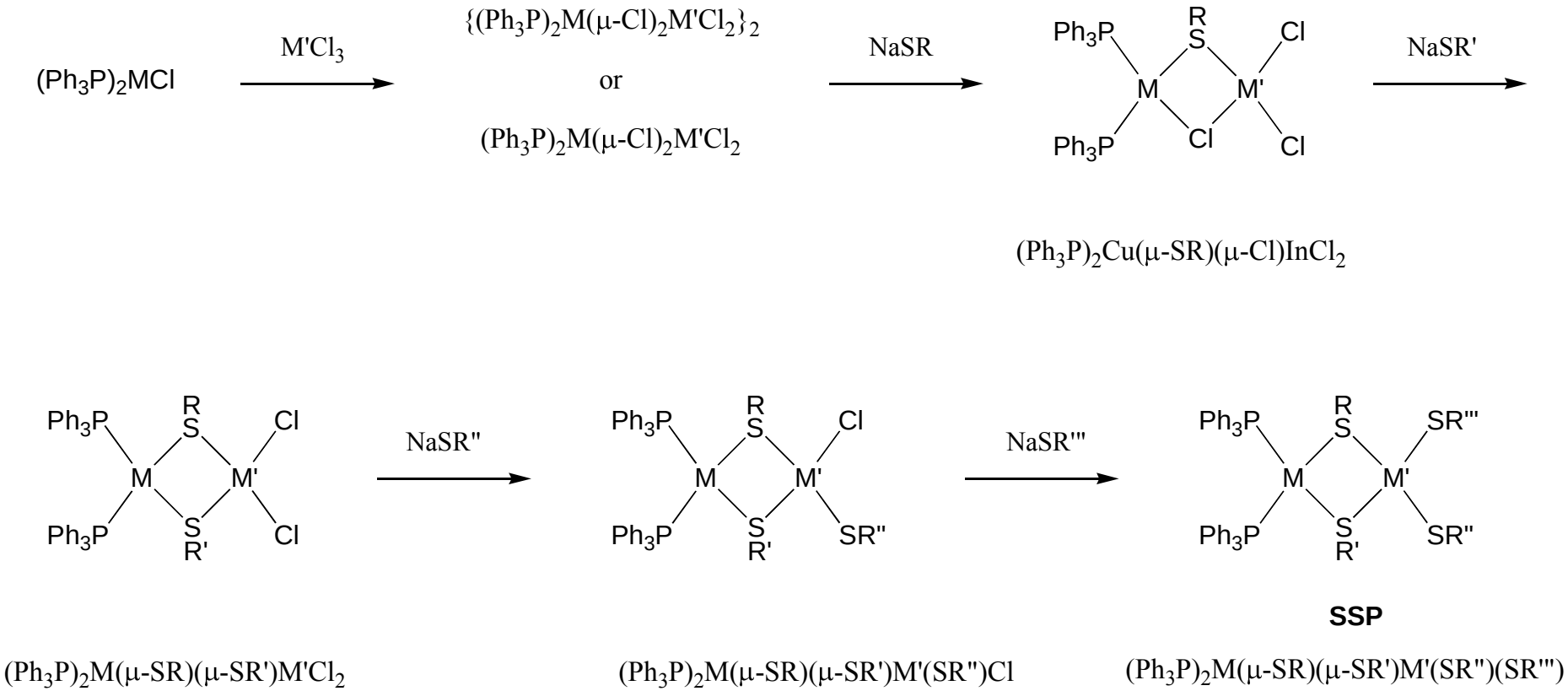


$(Ph_3P)_2Ag(\mu\text{-}Cl)_2AlCl_2$


HSCH2Ph
HSCH2CH3
HSCH2CH2SH


4.0 eq
HSCH2Ph
HSCH2Ph
HSCH2CH3
HSCH2CH3
M-SCH2Ph
2.7 eq
1.5 eq
0.6 eq
M-SCH2CH3
M-SCH2CH3


2.1eq
HSCH2CH3
HSCH2CH2SH
HSCH2CH3
HSCH2CH3
HSCH2CH2SH
M-SCH2CH2SH
1.5 eq
0.7 eq
M-SCH2CH3 + M-SCH2CH2SH
0.35 eq
HSCH2CH3
M-SCH2CH3
M-SCH2CH3



Our synthetic method allows us to:

- Control physical properties of SSPs
- Control stabilities of SSPs
- Control reactivity of SSPs
- Control composition and phases of NPs (i.e. $CuInS_2$)

Various I-III-VI_2 Band-Gap Materials

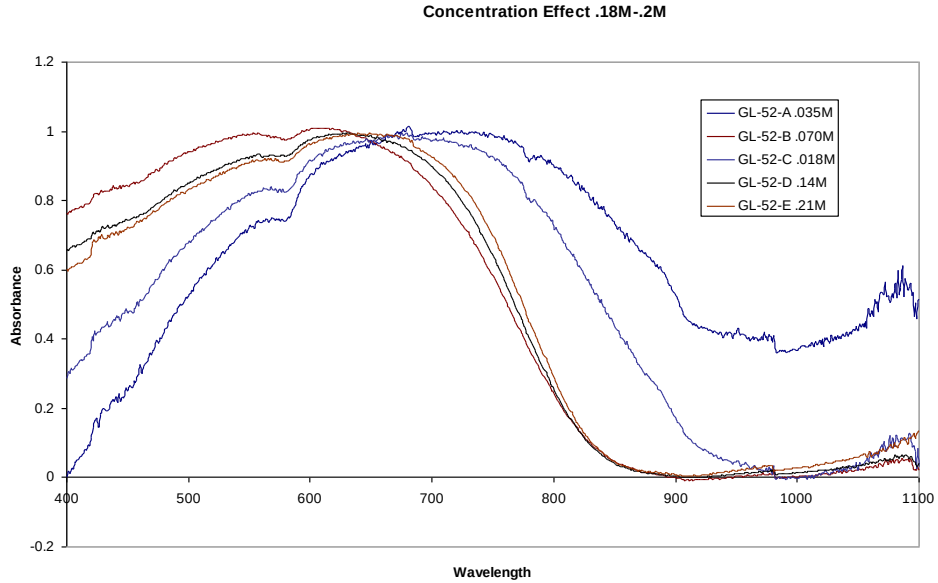
General Forumula of SSP = $(PR_3)_2CuM(SR')_4$

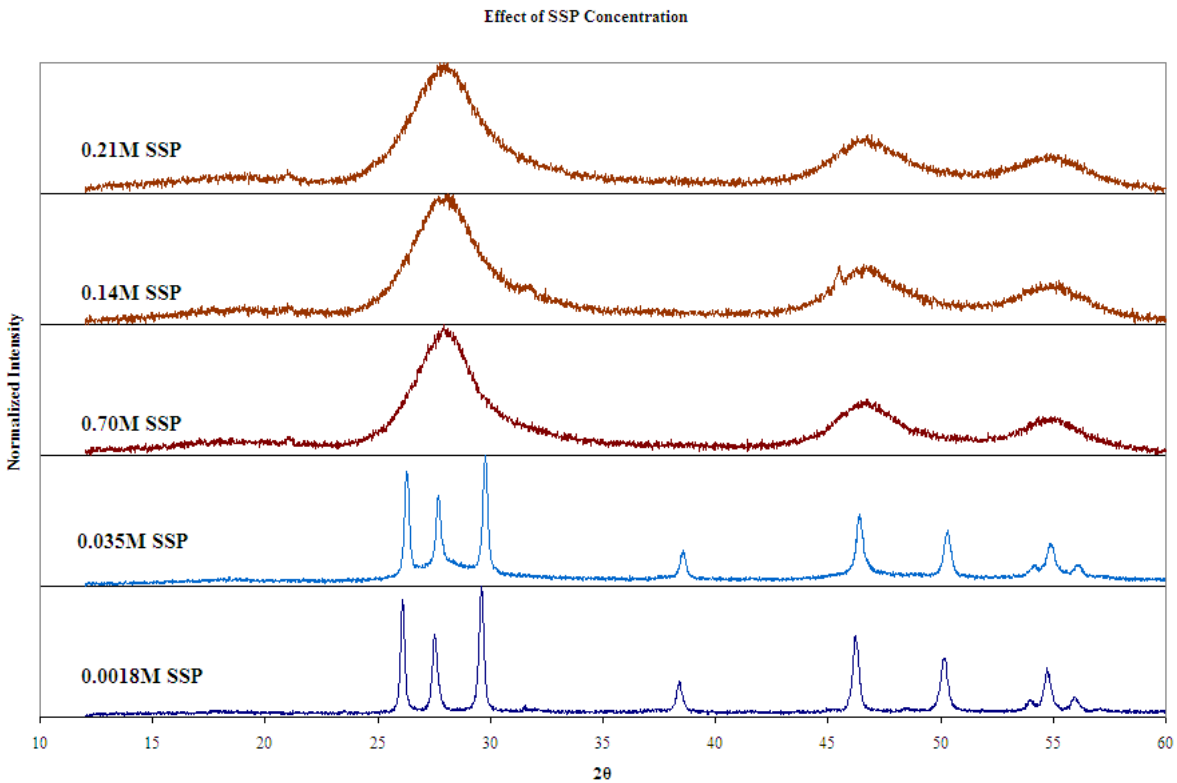
M = In, Ga, Al ⟹ $CuInS_2$, $CuGaS_2$, $CuAlS_2$

$(PR_3)_2CuIn(SR')_4$
$(PR_3)_2CuGa(SR')_4$ ⟹ $CuIn_{(1-x)}Ga_xS_2$

$(PR_3)_2CuIn(SR')_4$
$(PR_3)_2CuAl(SR')_4$ ⟹ $CuIn_{(1-x)}Al_xS_2$

$(PR_3)_2CuIn(SR')_4$
$(PR_3)_2CuGa(SR')_4$
$(PR_3)_2CuAl(SR')_4$ ⟹ $CuIn_{(1-x-y)}Ga_xAl_yS_2$


Concentration Effect .18M-.2M
GL-52-A .035M
GL-52-B .070M
GL-52-C .018M
GL-52-D .14M
GL-52-E .21M
Absorbance
Wavelength
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
400
500
600
700
800
900
1000
1100


Effect of SSP Concentration
0.21M SSP
0.14M SSP
0.70M SSP
0.035M SSP
0.0018M SSP
Normalized Intensity
2θ
10
15
20
25
30
35
40
45
50
55
60

Take Home Messages

- We have prepared $CuInS_2$ nanoparticles from SSPs with excellent size-control.
- Understanding how SSPs are formed and manipulating their chemistry is very important.
- Various I-III metal containing SSPs can be prepared with ease.
- Corresponding multinary NPs car be prepared.
- Both high temperature phases of CuInS2, Chalcopyrite and Wultzite phases, can be accessed by varying reaction conditions.

Acknowledgements

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- Gary Long (MS) & Richard Westover (BS/MS)