A Low-Cost Approach to Fabricating Thin-Film Solar Cells: From Nanocrystals To Thin-Films

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PURDUE CHEMICAL ENGINEERING

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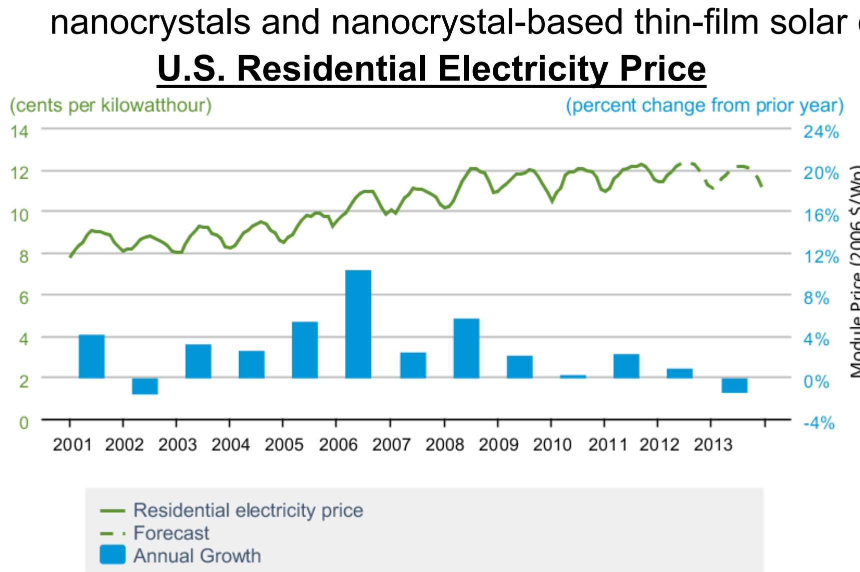
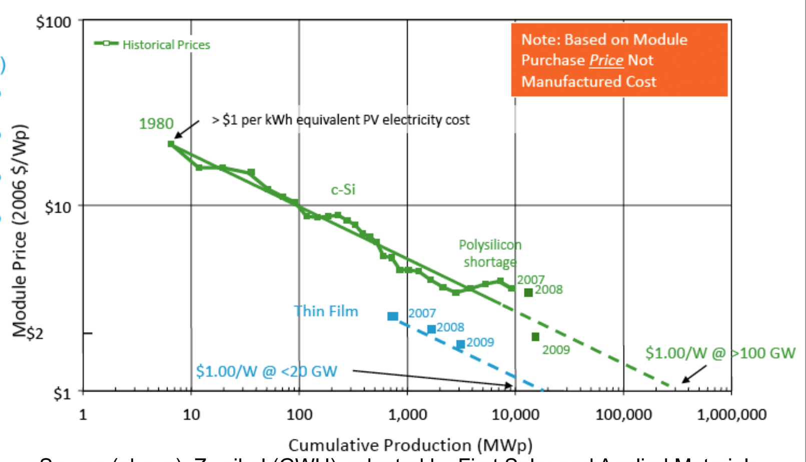
Within the Solar Economy IGERT (SEIGERT), a group of researchers develop and optimize a scalable process to fabricate low-cost thin-film solar cells that harvest clean and inexpensive energy from sunlight. Utilizing the nanocrystal-based process developed in-house, the $Cu_2ZnSn(S_{1-y}Se_y)_4$ (CZTSSe) thin-film solar cells demonstrate their potential by achieving total area 8.5% power conversion efficiency (PCE) under AM1.5 illumination. In this method, the multinary chalcogenide nanocrystals are first synthesized and later selenized into a dense CZTSSe layer, which is a promising absorber material consisting of earth-abundant elements.

Motivation

Photovoltaics has shown potential to meet the renewable energy demands resulting from the rising price of electricity and limited reserves of fossil fuels. Thin-film solar cells (TFSC) incur lower module cost compared to crystalline silicon solar cells. Subsequent benefits from the use of earth abundant elements in thin-film technologies attract our attention to study Cu_2ZnSnS_4 nanocrystals and nanocrystal-based thin-film solar cells.

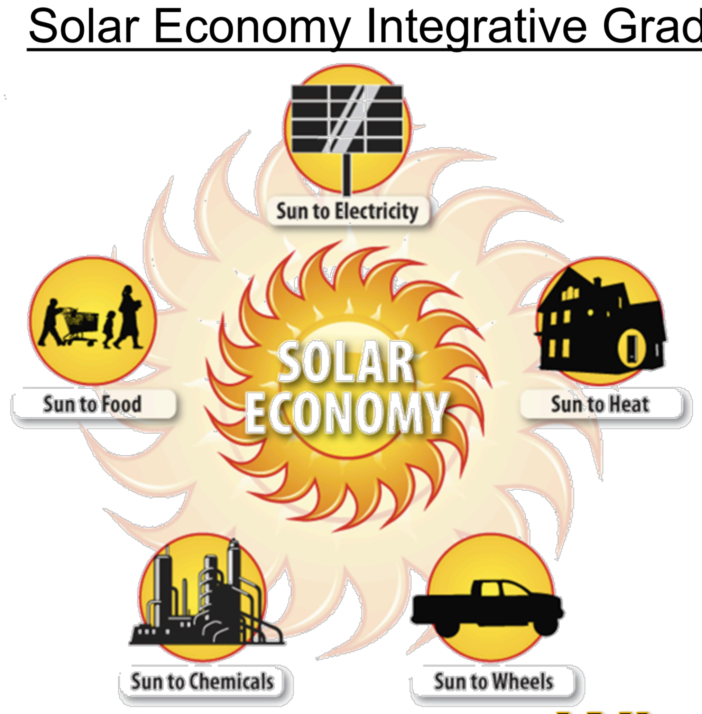




Source (above): Zweibel (GWU), adapted by First Solar and Applied Materials from NERL.
Source (Left): EIA, Short-Term Energy Outlook, April 2012

SEIGERT

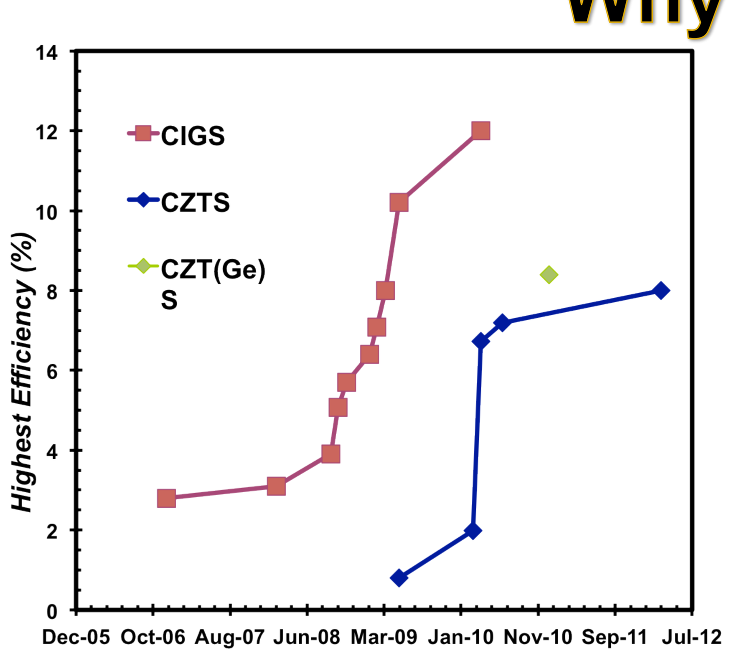
Solar Economy Integrative Graduate Education and Research Traineeship



The goals of SEIGERT are to:

- Educate and train the IGERT Fellows to become researchers, teachers, leaders, and entrepreneurs who have an interdisciplinary systems-level understanding of the complexities and constraints in our evolving energy economy.
- Educate and train IGERT Fellows in the art of generating superior integrative concepts/solutions for a future solar economy.
- Develop and deploy lectures, course modules, laboratory modules, and systems models online to enable a broad impact of the new educational paradigm and tools developed by the program.

Why Purdue?



Highest efficiencies in nanocrystal based solar cells

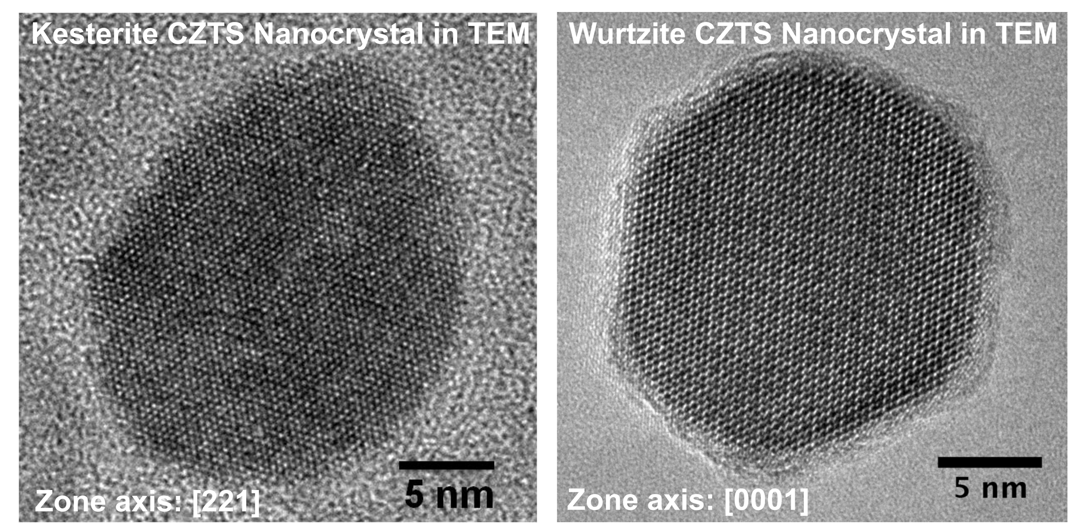
- ✧ For CIGS (>12%)
- ✧ For CZTS (>8%)
- ✧ For CZTGeS (>8.4%)

- Patented techniques
- Strong connections to industry, academia, national labs, and worldwide
- PSEUL (Purdue Solar Energy Utilization Laboratory)
- Birck Nanotechnology Center
- SEIGERT

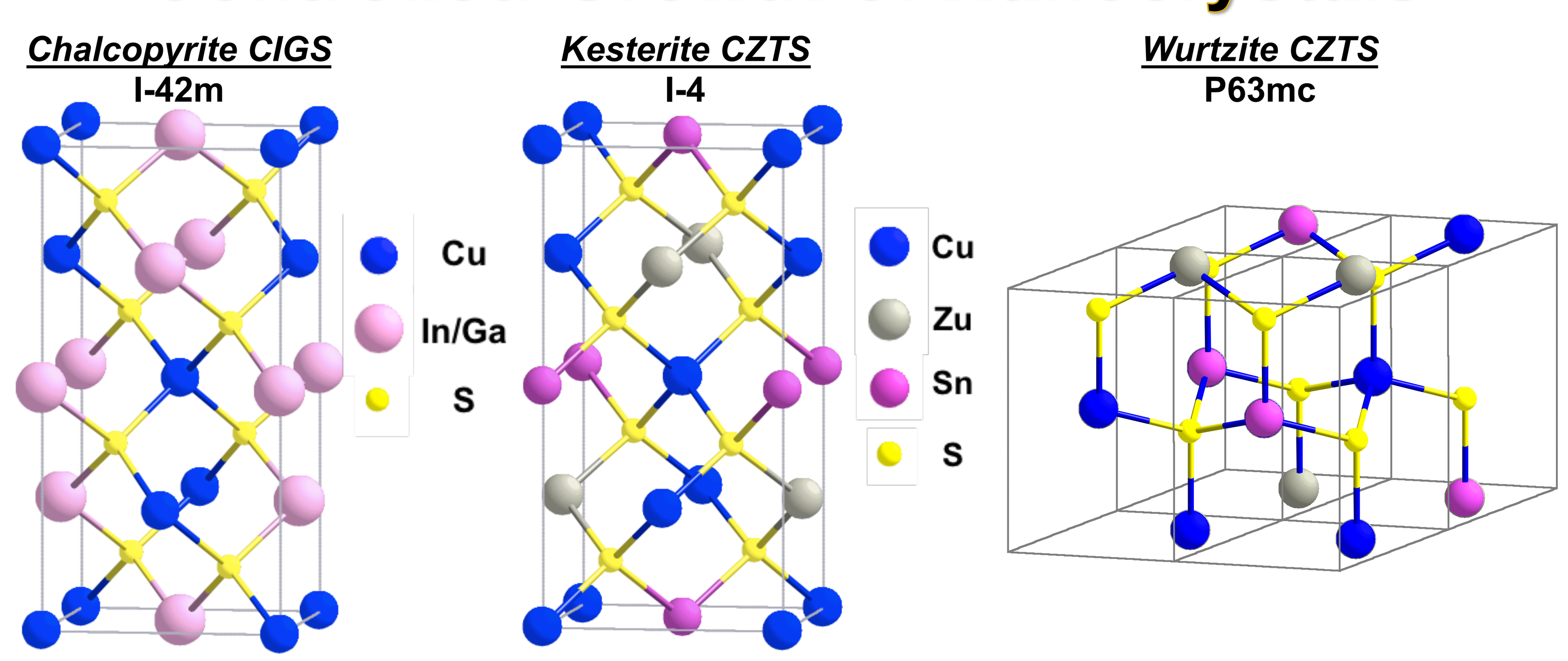
Nanocrystal-Based Processing

The fabrication of thin-film solar cells becomes more affordable and scalable using nanocrystal-based process.

- Better homogeneity control
  - ✧ Composition
  - ✧ Crystal structure
- Solution based processes
- Low processing temperatures
- Roll-to-roll manufacturing
- Flexibility in substrate choice

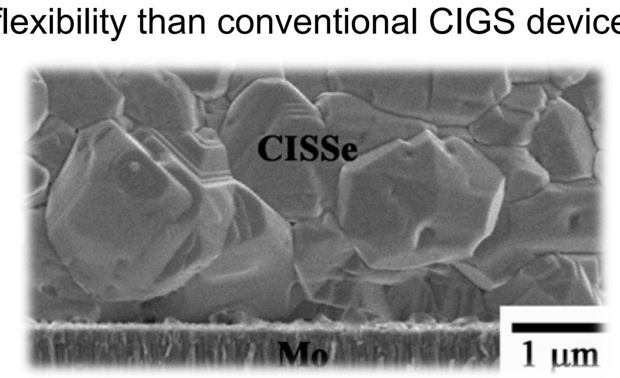


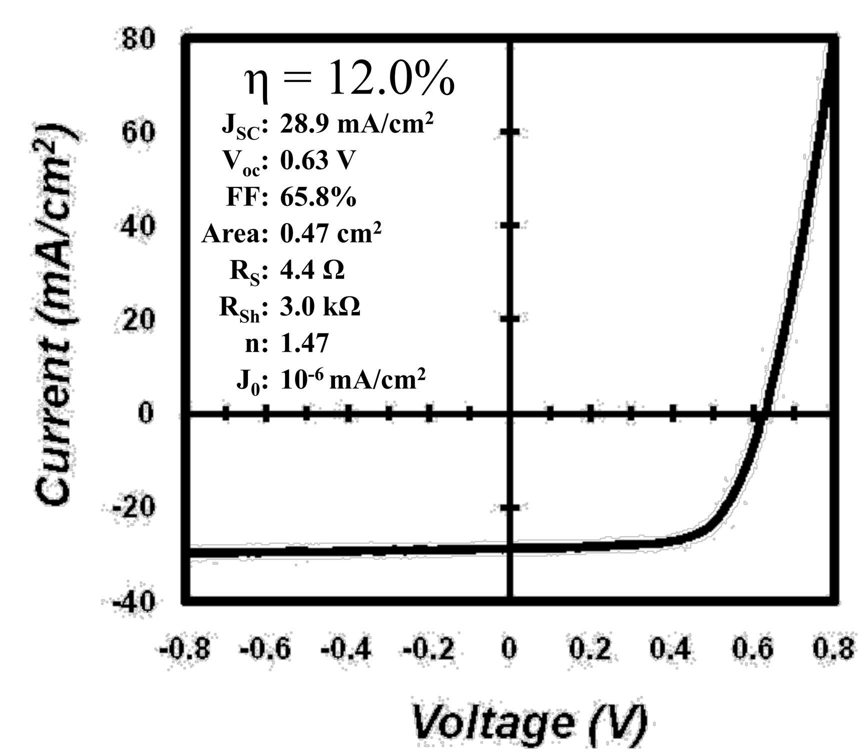
Controlled-Growth of Nanocrystals



CIGS Thin-film Solar Cells

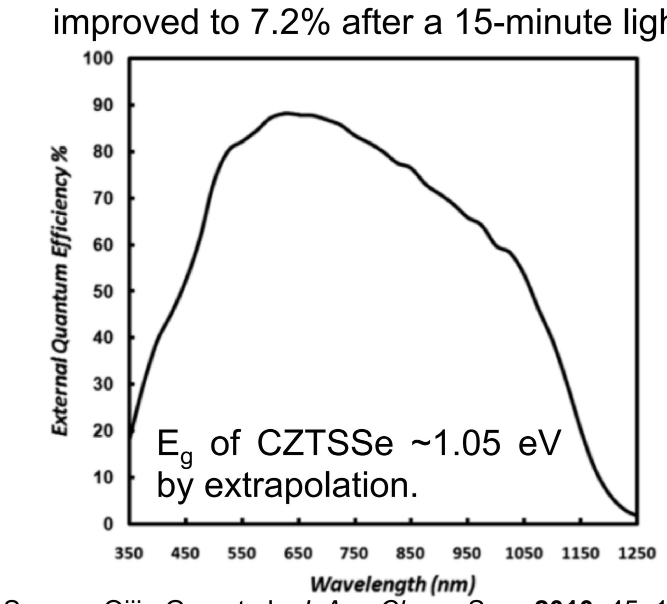
- Copper Indium Gallium diSelenide is a thin film technology with demonstrated 20% efficiency using thermal evaporation.
- **$Cu(In,Ga)(S,Se)_2$** at Purdue leads the way in performance from nanocrystal based ink of CIGS at > 12%.
- Our process results in cheaper cells, faster deposition rates, and greater flexibility than conventional CIGS devices.

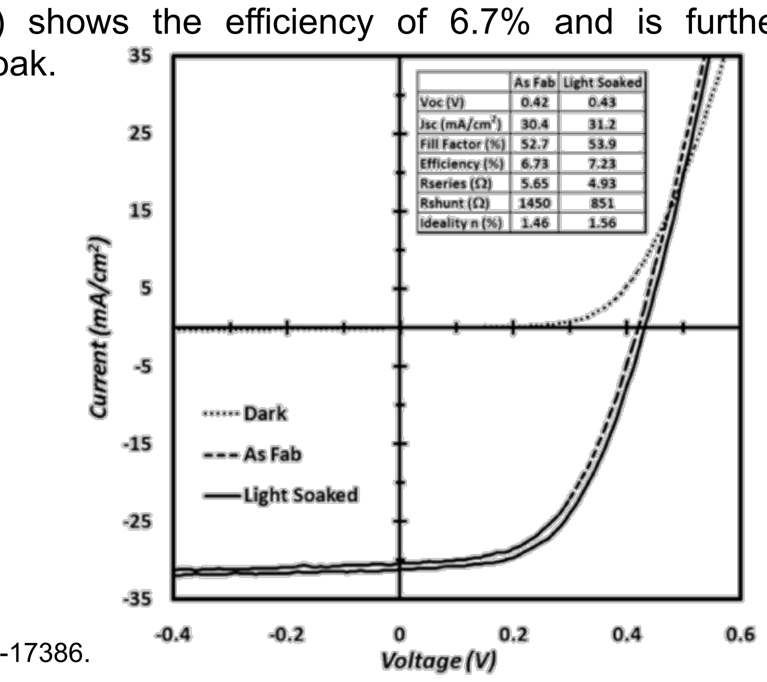




CZTS Thin-Film Solar cells

- **$Cu_2ZnSn(S,Se)_4$** - Copper Zinc Tin Sulfide/Selenide is a absorber material based off of ***earth abundant materials***.
- Sulfur atoms at the tetrahedral sites of kesterite are partially substituted with selenium.
- World-record efficiency of 10.1% has been accomplished using toxic hydrazine.
- Work at Purdue leads in performance from nanocrystal based ink of CZTS at > **7.2%**.
- As-fabricated solar cells (dashed curve) shows the efficiency of 6.7% and is further improved to 7.2% after a 15-minute light-soak.

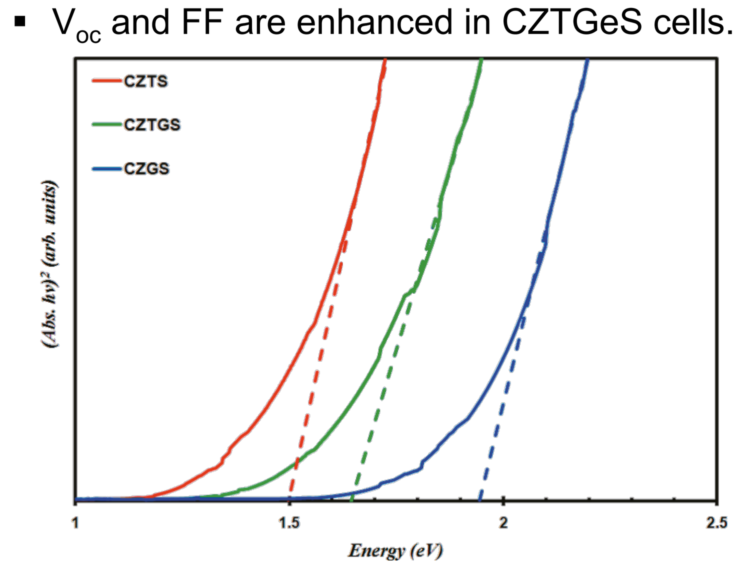


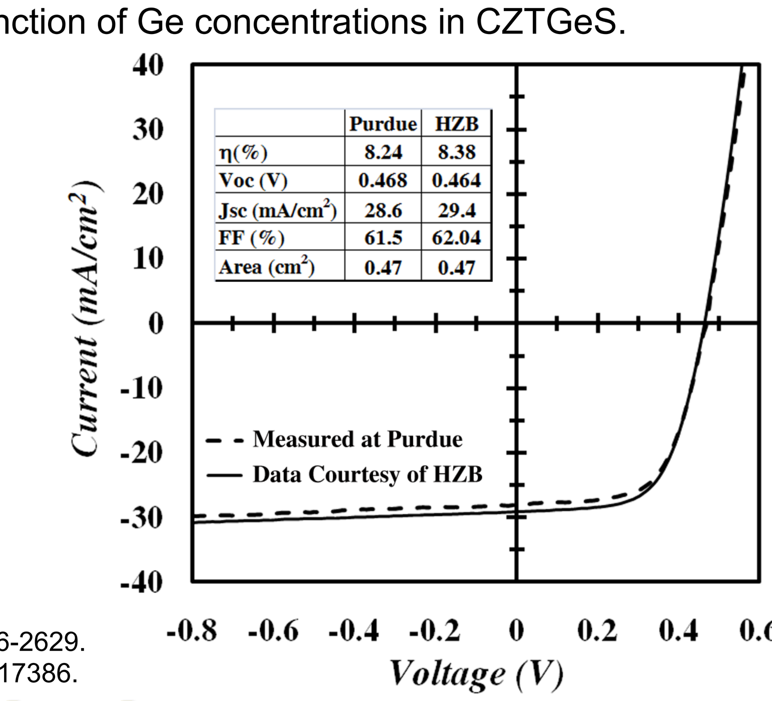


Source: Qijie Guo et al., *J. Am. Chem. Soc.*, **2010**, 45, 17384-17386.

CZTGeS Thin-Film Solar cells

- Current research includes the incorporation of Ge to form **$Cu_2Zn(Sn,Ge)(S,Se)_4$** with a tunable band gap (E_g).
- CZTGeS at Purdue has achieved efficiency of **8.4%**.
- UV-Vis shows the tunable band gap as a function of Ge concentrations in CZTGeS.
- V_{oc} and FF are enhanced in CZTGeS cells.





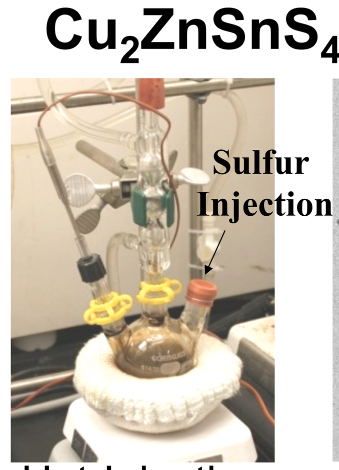
	Purdue	HZB
η(%)	8.24	8.38
Voc (V)	0.468	0.464
Jsc (mA/cm²)	28.6	29.4
FF (%)	61.5	62.04
Area (cm²)	0.47	0.47

Source: Grayson .M. Ford et al., *Chem. Mater.*, **2011**, 23, 2626-2629.
Qijie Guo et al., *J. Am. Chem. Soc.*, **2010**, 45, 17384-17386.

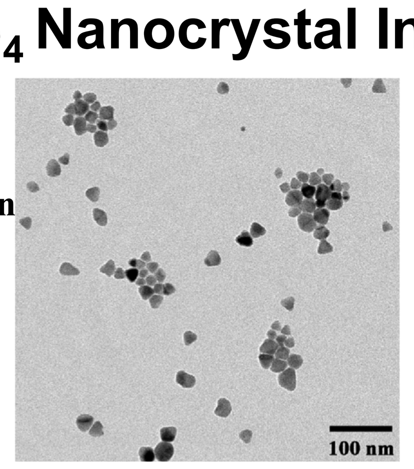
Conclusion

Future progress towards the solar energy economy requires interdisciplinary research to solve the challenges of renewable energy harvesting; SEIGERT provides this research environment to tackle the photovoltaic challenge at Purdue. Many graduate researchers from fields of chemical engineering, electrical and computer engineering, and materials science work in coordination toward this goal.

Cu_2ZnSnS_4 Nanocrystal Ink



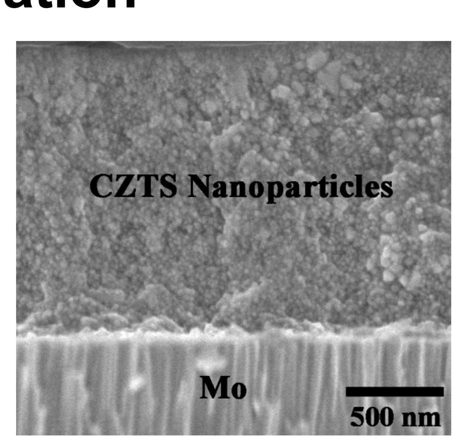
Hot-Injection Synthesis



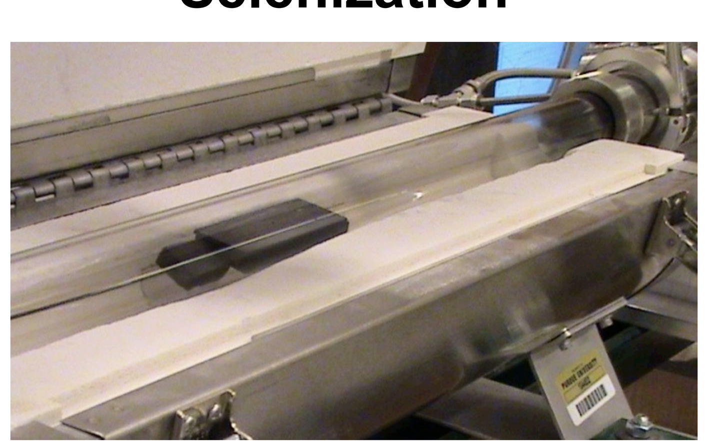
Nanocrystals

Ink

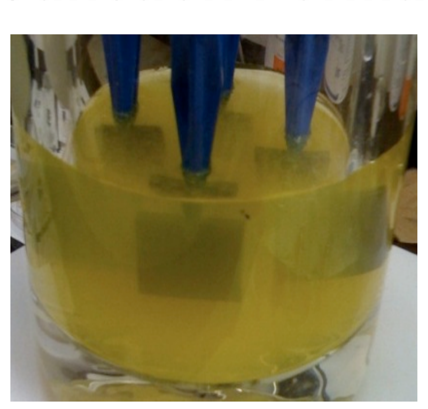
Film Formation



Selenization

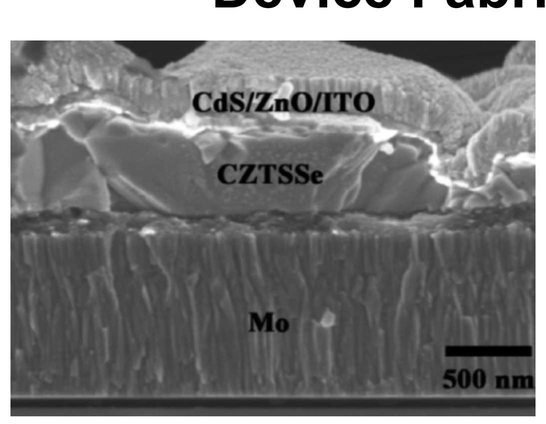


P-N Junction Formation

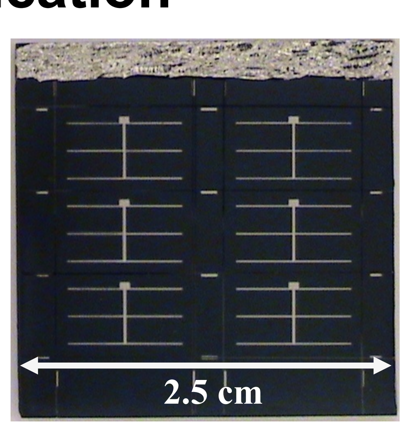


Chemical Bath Deposition (CBD)

Device Fabrication



ZnO/ITO (Sputtering)



Ni/Al Grid (Evaporator)