Nanotechnology Based Thin-film Photovoltaics

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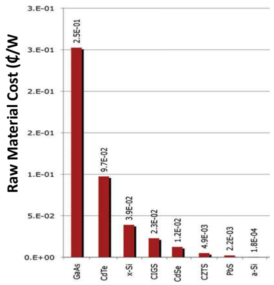
Motivation

Due to the increasing global energy demand and a paradigmatic shift towards environmental responsibility, the development of clean, sustainable energy technologies as alternatives to limited fossil fuel resources has become an imperative global challenge. Though photovoltaic technologies will contribute significantly to the alternative energy infrastructure, their widespread utilization has been hindered primarily by high module manufacturing costs. However, low cost thin film solar cells represent a scalable technology able to alleviate the economic barriers currently preventing solar cells from competing with current energy technologies. The use of nanotechnology in producing nanocrystalline solar inks via facile solution syntheses allows for roll to roll processing on an industrial scale. Meanwhile, techniques like close space sublimation allow for interfacial defect control via heterojunction engineering of nanostructured absorbers. Through device characterization we obtain crucial insight into the fundamental physics of these solar devices, allowing for a holistic approach to developing and improving these technologies.

Utilizing Nanotechnology



Cost per watt for select inorganic photovoltaic materials

Exploiting thin film nanocrystalline absorbers affords numerous advantages over energy-intensive alternative device processing and fabrication methods, including:

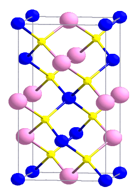
- Facile solution processing
- Scalable deposition processes
- Low processing temperatures
- Short processing times
- Roll-to-roll manufacturing
- Flexibility in substrate choice
- Less material required (< 1 µm thick coatings)
- Compositional uniformity of deposited films
- Engineering nanoscale heterostructures

Modified from Wadia et al.; *Environ. Sci. Technol.* **2009,** 43, 2072-2077.

Materials Synthesis

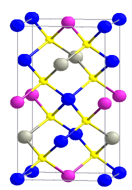
CAPABILITY	PRACTICAL RESULT
Composition control	Tunable band gap via substitution of In with Ga in CIGS and Sn with Ge in CZTS
Low reaction temperatures (< 300 °C)	Relatively low energy cost for materials production
Nanocrystalline products	Dispersion of particles in ink for scalable and uniform coating processes
Crystal size, morphology, and structure control	Affords optimization of sintered film properties
High absorption coefficient materials	Very thin films (<2 µm) needed to absorb incident radiation
Heterojunction Engineering	Reduced interfacial defects at semiconductor junction

$Cu(In_{1-x},Ga_x)(S_{1-y},Se_y)_2$
CIGS



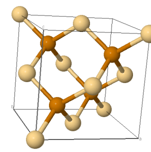
Chalcopyrite CIGS
Space group I-42m

$Cu_2ZnSn(S_{1-y},Se_y)_4$
CZTS



Kesterite CZTS
Space group I-4

$Zn_xCd_{1-x}Te$
ZnCdTe

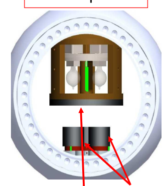


Zinc Blende
CdTe/ZnCdTe
Space group I-43m

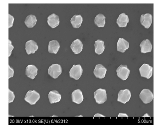
Device Fabrication:

Close Space Sublimation and Nanopatterned CdTe and Cd(x)Zn(1-x)Te Ternary Alloy Thin Film Deposition

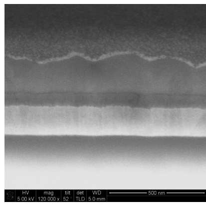
Two structure layouts designed to reduce number of defects in the CdS-CdTe interface that is inherent from using close spaced sublimation to grow the CdTe layer



- Thin CdTe is selectively grown on CdS which is nanopatterned with SiO_2 resulting in a interface between single crystals in the exposed area
- ZnTe is used has buffer layer between the two materials to reduce the strain from the varying lattice size of CdS to CdTe



Selectively grown CdTe on CdS patterned with SiO_2

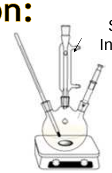


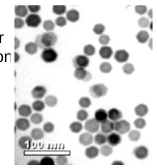
FIB cross-section of:
CdTe on ZnTe: Close Space Sublimation
CdS: Chemical Bath Deposition.
Image obtained with help of CINT-Los Alamos National Laboratory

Device Fabrication:

CIGSSe And CZTSSe Nanoparticle Based Devices

Nanocrystal Synthesis

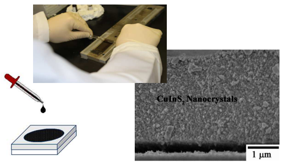




Nanocrystals

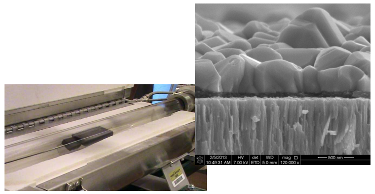
Ink

Film Formation

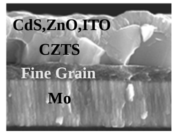


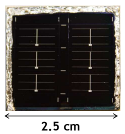
Drop-casting, doctor blade, or spray coating

Selenization



Window Layer and Grid Deposition





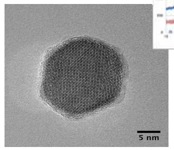
- Resistive i-ZnO layer between n-type CdS and conductive indium tin oxide (ITO) mitigates shunting
- Conductive ITO layer assists with carrier collection (sheet resistance ≤ 20 Ω/sq)
- Able to tune optical properties by varying deposition conditions

CdS: Chemical Bath Deposition (CBD)
ZnO/ITO: Physical Vapor Deposition (RF Sputtering)
Ni/Al Grid: Electron Beam Evaporation

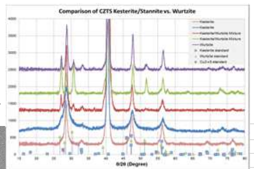
Holistic Characterization

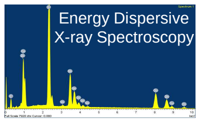
Materials

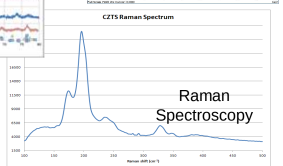
Electron Microscopy



X-ray Diffraction



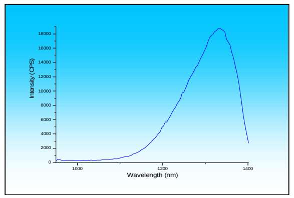




Raman Spectroscopy

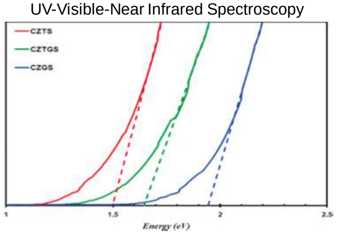
Provide information about particle size, plane spacing, crystal structure, elemental composition, chemical identity, and particle-to-particle homogeneity

Optical



Photoluminescence Spectroscopy

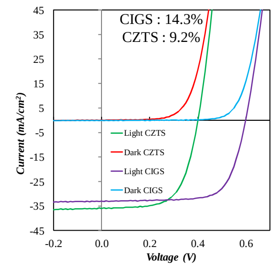
UV-Visible-Near Infrared Spectroscopy

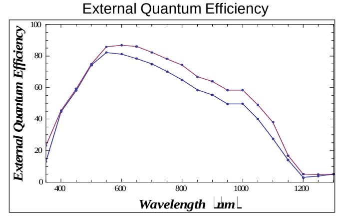


Ford, G. M.; Guo, Q.; Agrawal, R.; Hillhouse, H. W. *Chem. Mater.* **2011**, *23* (10), pp. 2626–2629.

Provide information about the optical properties of the materials, such as absorption coefficient, band gap, dominant transition energy levels, and carrier lifetimes

Electrical





Other Techniques: TRPL, Capacitance Spectroscopy, Drive Level Capacitance Profiling

Provide information about device performance (Voc, Jsc, FF, and η), fundamental device properties (Jo, Rs, and Rsh), and trap and carrier energy levels and densities