



Inorganic Nanocomposite Solar Cells: Materials Studies

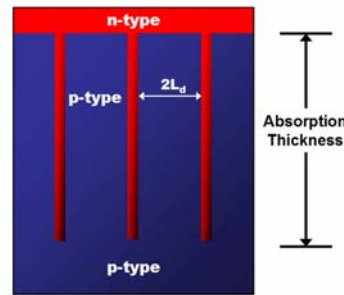
Jeffrey S. King, David B. Jackrel, Evan Pickett, James S. Harris, Michael McGehee, and Stacey Bent

Stanford University



Motivation

- Solar energy is a strong candidate for meeting future energy needs, but **costs are still too high**.
- Cost can be decreased by either increasing cell efficiency, or decreasing production costs.
- Poor quality materials (cheaper) yield low efficiencies in typical planar configurations**, since impurities, crystallographic defects, and grain boundaries severely limit performance.
- These performance limitations can be overcome by nanostructured interpenetrated pn junctions.**
- Maximization of photon absorption and minimization of required diffusion length** – layers are thinner than minority carrier diffusion length, so full collection of photogenerated carriers is possible, and the interpenetrated architecture insures full absorption of incident photons.
- Nanoscale junction formation requires well controlled, conformal deposition methods – atomic layer deposition (ALD) and chemical bath deposition (CBD), for example.



Nano-interpenetrated p/n junction solar cell geometry; L_d – minority carrier diffusion length

Materials and Nanostructuring

- Nanostructuring accomplished by nanosphere lithography (See Jackrel, et. al.)
- The opposite polarity material will be deposited by both ALD and CBD.
- CdS is a commonly used heterojunction material for thin film solar cells (CIGS, CdTe), and zinc compounds (ZnSe, ZnTe and ZnS) are possible alternative window materials ($E_g > 2.0$ eV)
- II-VI-like compounds of Cd, Zn and Pb, with Se, Te and S, cover the whole solar spectrum, and are readily depositable by ALD and CBD.
- Some materials under investigation: c-Si/CdS (test structures), a-Si:H, nano-TiO₂/CIGS.
- Recombination at the nanostructured, high interfacial area p/n junction is a major challenge, mitigation of which will be studied by use of a thin interfacial layer (ALD) at the junction.

Windows/buffers/junctions
CdS, ZnO, ZnS, ZnSe

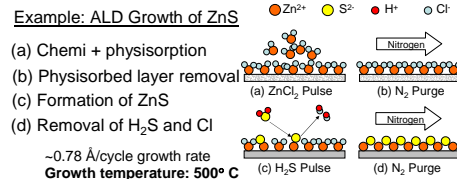
Absorbers
c-Si, poly-Si, a-Si:H, CdTe/Se
CuInGaSe₂ (CIGS)

Atomic Layer Deposition (ALD)

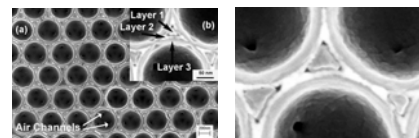
- ALD is a chemical vapor deposition variation that utilizes sequential *self-limiting* precursor pulses.
- Surface-limited instead of source-limited growth.
- Growth of sulfides, selenides, nitrides, oxides, metals, and pure elements (e.g. Si) possible.

Advantages

- Highly conformal film growth on nanostructured substrates
- Digital nature - sub-monolayer control of film thickness.
- Abrupt interfaces and sequential deposition of materials.
- Atomic level control over composition.



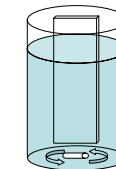
Example: ZnS/TiO₂ photonic crystal



King, et. al, *App. Phys. Lett.* 2006

Chemical Bath Deposition (CBD)

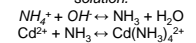
- Solution-based deposition technique used for rapid, economical growth of thin films on a variety of substrates.
- Well-established technique for growth of CdS films in solar cell applications, and our first test structures are being fabricated using this method.
- Conformal – good for nanostructures.**
- Substances are deposited by preparation of a solution containing both components of a solid that is insoluble under the bath conditions. For example, presence of both metal ions and sulfur ions in a bath will result in the precipitation of metal sulfide under the right conditions.
- Applicable to a wide range of materials.



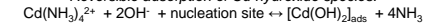
Constant Temperature Bath
 $T = 50 - 80^\circ \text{C}$

Growth of CdS

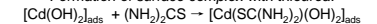
Cadmium – ammonia complex formation: enables slow release of Cd^{2+} ions during film growth, and limits precipitation of $\text{Cd}(\text{OH})_2$ in solution.



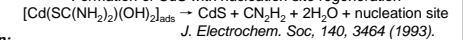
Reversible adsorption of Cd-hydroxide species:



Formation of surface complex with thiourea:



Formation of CdS with nucleation site regeneration



J. Electrochem. Soc., 140, 3464 (1993).

Growth of ZnS is similar - replace CdSO₄ with ZnSO₄

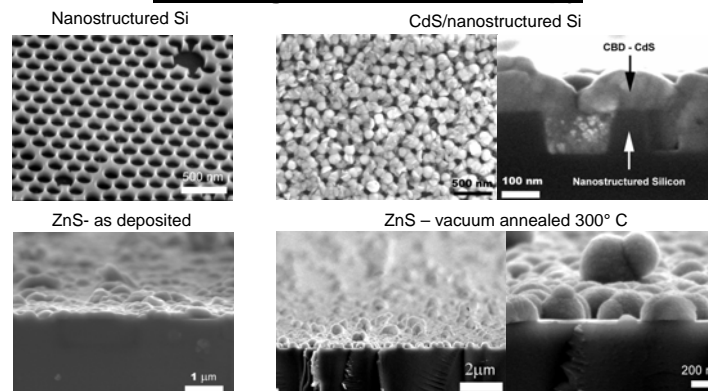
- More difficult to prevent hydroxide precipitation
- Much slower growth rate

Bath composition:
Metal salt - (Zn/CdSO_4)
 NH_4OH
Ammonium salt (buffer) - $(\text{NH}_3)_2\text{SO}_4$
Thiourea $(\text{NH}_2)_2\text{CS}$
DI water
Resulting pH = 9-10

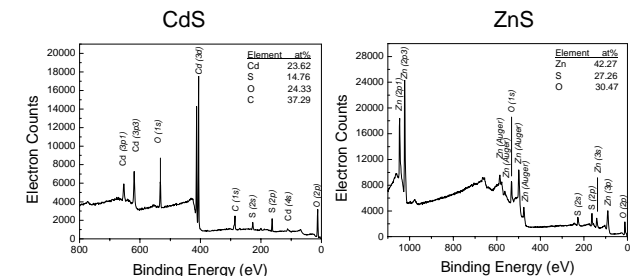
Results

- Successful growth of both CdS and ZnS films by CBD on both glass and silicon substrates.
- For test structures: CdS (n-type heterostructure)
ZnS (potential window)
- Successful growth of CdS on nanostructured silicon.
- In process of design and purchase of new ALD reactor.

Scanning Electron Microscopy



X-ray Photoelectron Spectroscopy



- Confirmation of presence of Zn/Cd and S in films
- Similar stoichiometry for ZnS film ($\text{Zn}_{1.55}\text{S}$) and CdS ($\text{Cd}_{1.6}\text{S}$)
- Both have significant oxygen incorporated in film
- Carbon from surface contamination in CdS disappears upon sputtering

Acknowledgements: This work is funded by The Global Climate Energy Project (GCEP)