2008 Solar Annual Review Meeting

Session: OPV, Sensitized, Seed Funds
Company or Organization: NREL
Funding Opportunity: PV Conversion Technologies

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Budget and Solar America Initiative Alignment

NREL / SNL			
Project Beginning Date	**FY07 Budget**	**FY08 Budget**	**Total Budget**
October, 2007	405,000	1,271,000	

- This project supports the Solar America Initiative by:
  - Effort partner and CRADA with Konarka on their SAI program
  - Effort 2 CRADA with Plextronics on their SAI incubator program
  - Effort 3 CRADA with TDA

Konarka

PLEXTRONICS Light. Power. Circuitry.™

TDA Research

OPV Milestones/Summary Overview

Table 1. Multiyear Plan for OPV

FY	Milestone	Budget ($K/yr)
2008	4% OPV device with 1 cm^2 area and 2,000 hour stability*	2100

* Stability for OPV devices is currently being defined

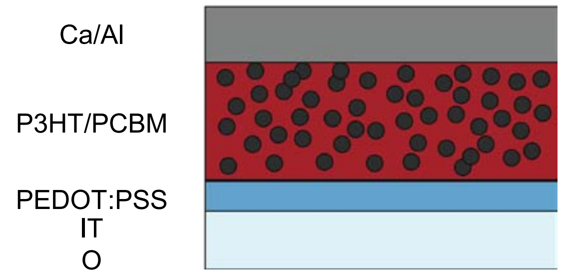
Table 3. Summary of FY2008 Milestones for OPV

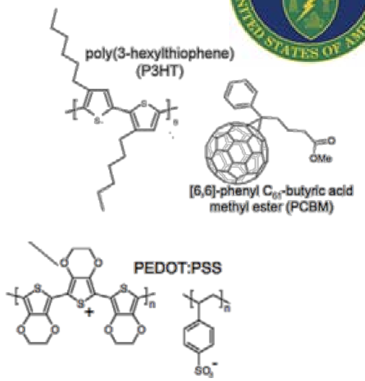
#	FY2008 Milestones	Milestone Importance	Status
1	Development of a 4% efficient OPV device with 1 cm^2 area and <10% loss over 2,000 hours	3	~ 4% device efficiency, scaling up to 1 cm^2, stability studies underway
2	Synthesis of a light absorbing dendrimer with optical band gap approaching 1.6 eV.	4	Achieved
3	Optimization of top and bottom electrode interfaces.	4	Underway, initial study and paper complete
5	Demonstration of printing/processing of device with ~25 cm^2 area and >3% efficiency.	5	Scalable technology developed for HIL and absorber – system under construction in glove box
6	Development of Monte Carlo simulation for excitonic devices.	4	Staffing up

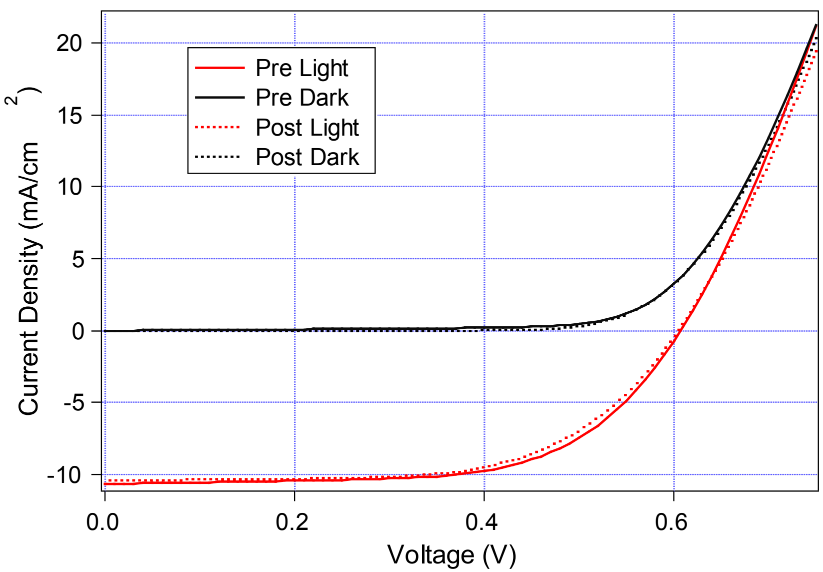
David Ginley, Garry Rumbles, Nikos Kopidakis, Dana Olson, Joe Berry, Matthew Reese, Ben Rupert, Matthew White, Erkan Kose

Improving Devices OPV Bulk Heterojunction Devices

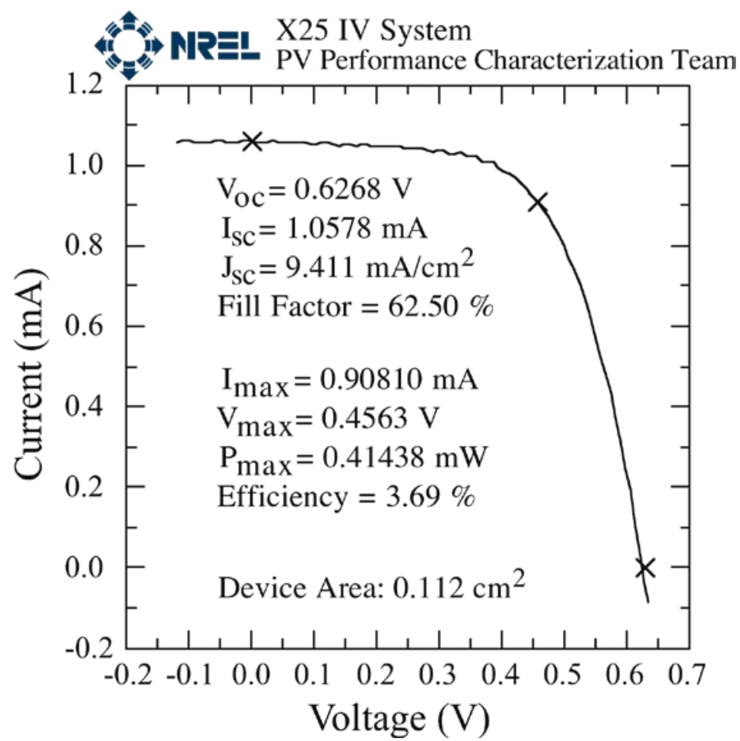
- Objective: Development of 4% OPV device with 1 cm^2 area







	V_{OC} (mV)	J_{SC} (mA/cm²)	FF (%)	Eff. (%)
Pre-	609±1	10.89±0.19	63.0±0.4	4.18±0.09
Post-	603±2	10.54±0.18	61.3±0.3	3.85±0.08

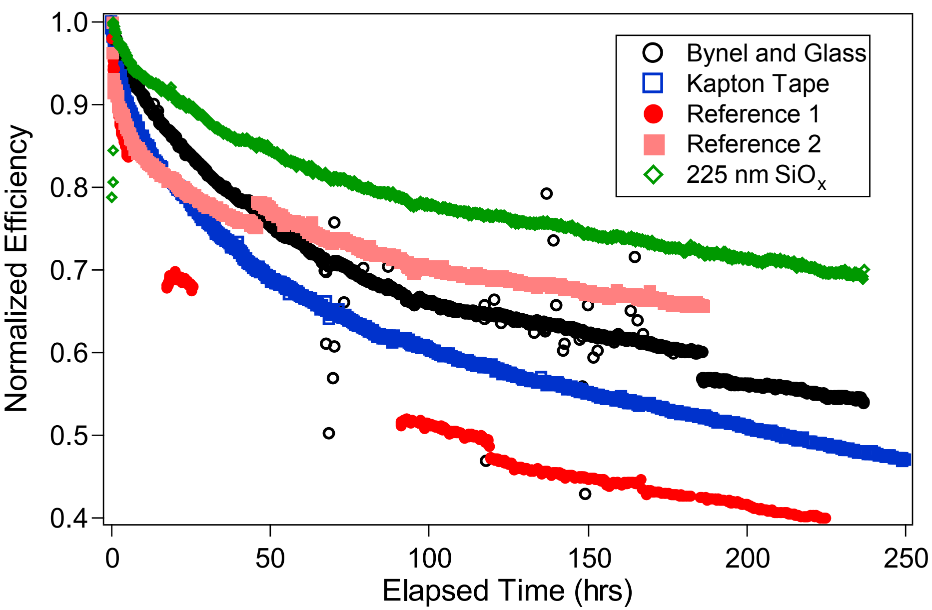


M.O. Reese, M.S. White, G. Rumbles, D.S. Ginley, S.E. Shaheen, *Appl. Phys. Lett.* **92**, 053307 (2008).

Initial Reliability Studies

- Objective: determine if degradation is intrinsic or extrinsic and mechanism
  - Developing parallel combinatorial degradation setups (glove box & air)
- Working with Plextronics to standardize methodology for measurements
- Organizing Lifetime summit with Plextronics on degradation
  - July 14-16, 2008
- Working with Konarka on device encapsulation materials & methods

Initial data indicates that there are a number of mechanisms including a fast and a slow one.

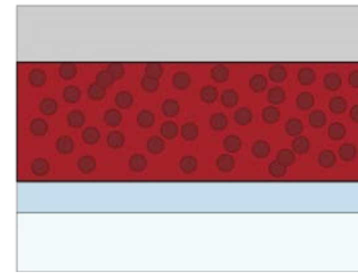


M. Reese, A. Morfa, M. White

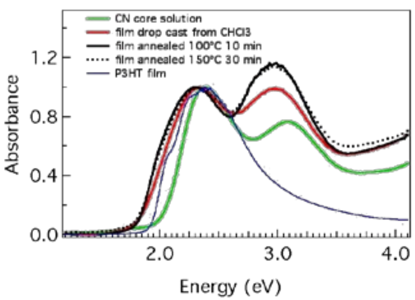
M.O. Reese, A.J. Morfa, M.S. White, N. Kopidakis, S.E. Shaheen, G. Rumbles, D.S. Ginley, *Sol. Energy Mater. Sol. Cells* (2008), *in press* **(Invited)**

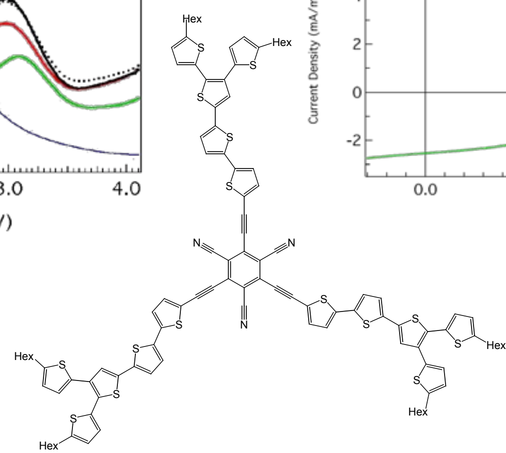
Decreasing the Band Gap

- Synthesis of light absorbing dendrimer with optical band gap of 1.8 eV.
  - Increased V_{OC} compared to P3HT with decreased band gap
- Synthesis of conjugated polymer with band gap of 1.5 eV.
  - Similar V_{OC} to P3HT despite being significantly lower band gap

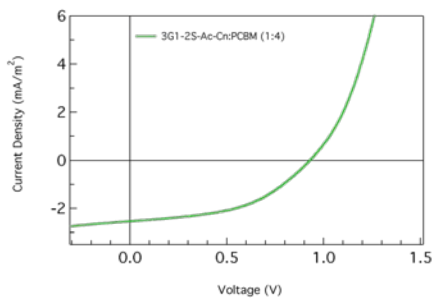


UV-Vis of 3G1-2S-CN solution and films

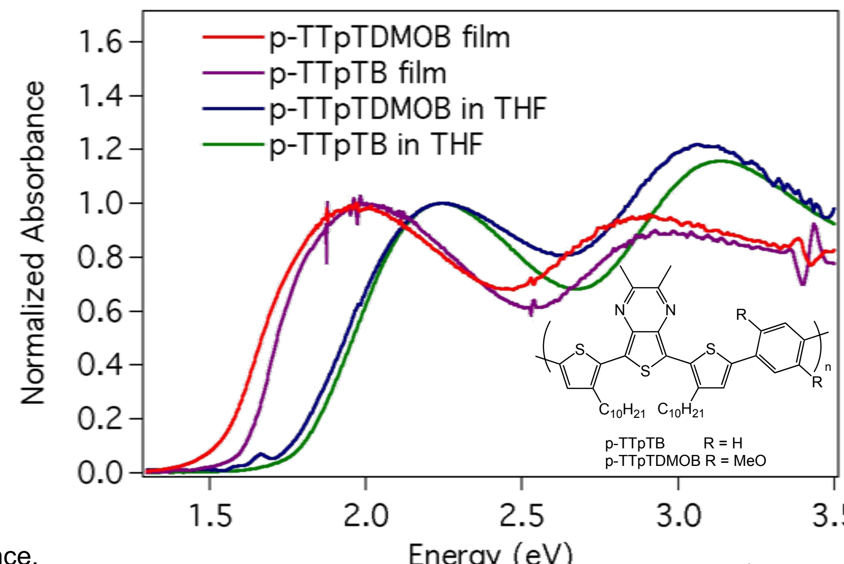




Current-Voltage curve of 3G1-2S-CN:PCBM



Polymer	Optical Band Gap (eV) Solution (THF)	Film
p-TTpTB	1.79	1.62
p-TTpTDMOB	1.77	1.52



Optical and device data of 3G1-2S-CN

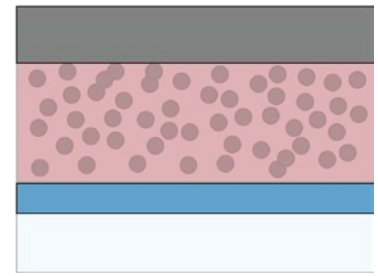
Dendrimer	Optical Band Gap eV (λ/nm) CHCl$_3$ Solution	Film	Film, 110° C Anneal	Film, 130° C Anneal
3G1-2S-CN	2.02 (613)	1.83 (677)	1.81 (683)	1.80 (688)

Active layer (weight ratio 1:4)	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	η (%)
3G1-2S-CN:PCBM	2.540	931	47	1.12

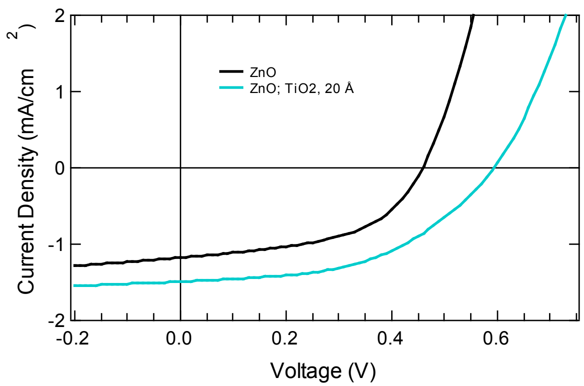
B. Rupert, W. Rance, W. Mitchell

Modifying interfaces for improved device performance

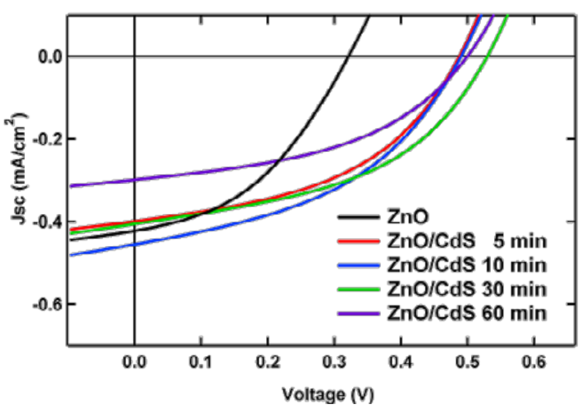
- Interface Modification dramatically affects device performance
  - Conformal coating of electron acceptors on ZnO to enhance device performance
    - TiO_2 via ALD and solution deposition
    - CdS vis solution deposition
  - Effect of cathode materials on device performance



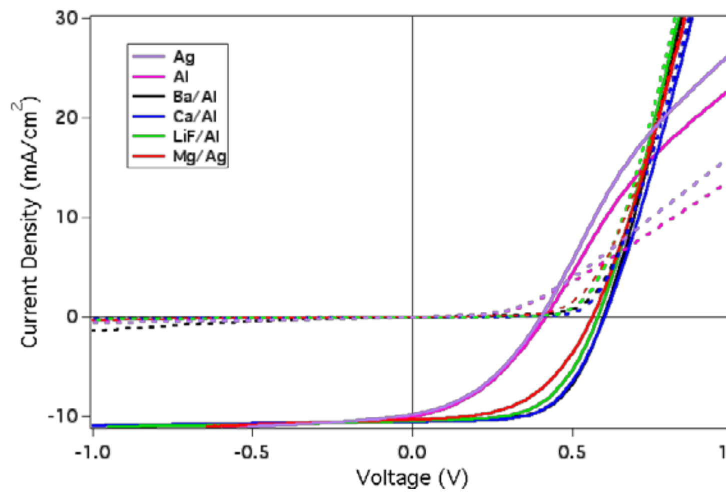
TiO_2 on ZnO dramatically improves V_{oc} and J_{sc}



CdS deposition on ZnO has a similar effect



Sandia: J.A. Voigt, J.W.P. Hsu, E.D. Spoerke, Y.-J. Lee, M.T. Lloyd

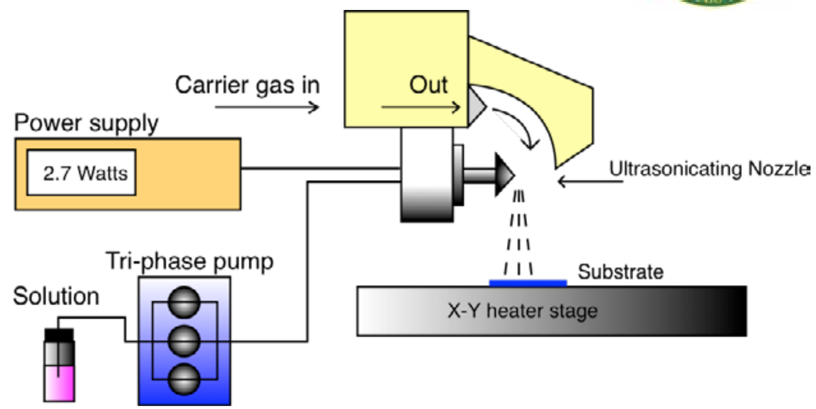


Cathode metal choice significantly affects device performance and stability

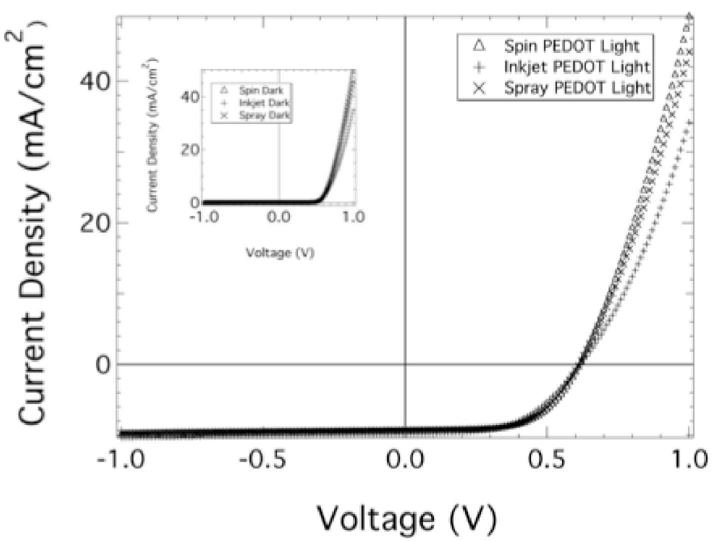
M.O. Reese, M.S. White, G. Rumbles, D.S. Ginley, S.E. Shaheen, *Appl. Phys. Lett.* **92**, 053307 (2008).

Process Scalability

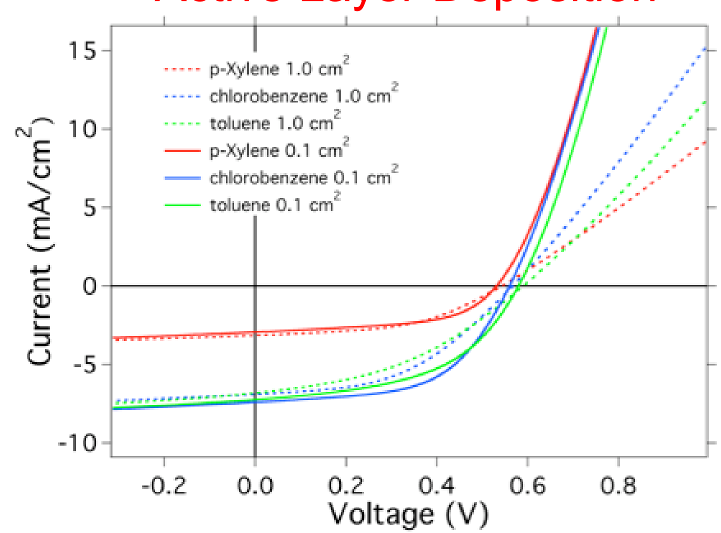
- Inkjet and ultrasonic / airbrush spray produce devices comparable to spin coated for both the HIL and the absorber.
- Devices scale up in air to 1 cm^2 with efficiency greater than >2%
  - Setting up deposition system in glove box for increased device performance



PEDOT:PSS Deposition



Active Layer Deposition

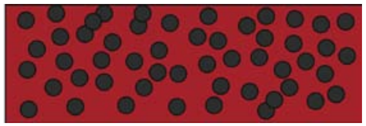


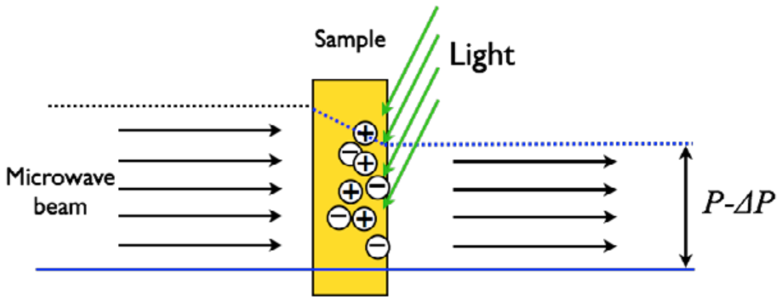
K. X. Streirer

R. Green, A. Morfa, A.J. Ferguson, N. Kopidakis, G. Rumbles, S.E. Shaheen, *Appl. Phys. Lett.* **92**, 033301 (2008).

Developing OPV specific characterization

- Characterization of donor – acceptor blends
  - Time Resolved Microwave Conductivity (TRMC)



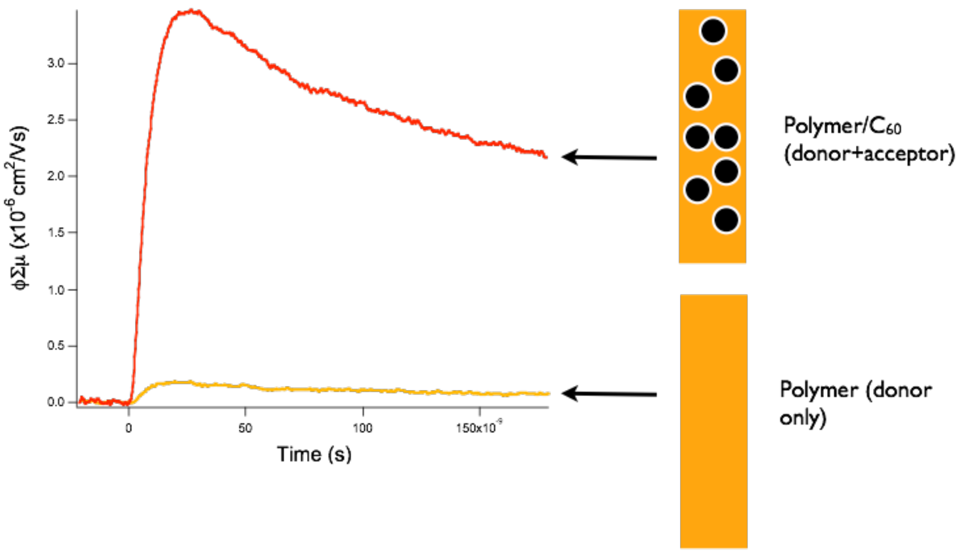


$$\frac{\Delta P}{P} = K\Delta G$$

Photoconductance

$$\Delta G = \beta q_e (n\mu_e + p\mu_h)$$

$$n = p = I_0 F_A \phi$$



J. Piris, N. Kopidakis, D.C. Olson, S.E. Shaheen, D.S. Ginley, G. Rumbles, *Adv. Funct. Mater.* **17**, 3849 (2008).

Project Alignment with Technology Roadmap

What needs in the Technology Roadmap are your project responding to?

Need	Significance
Fundamental understanding/device physics—excitons, charge transport, recombination, band structure, and interfaces.	Place constraints on what fundamental properties are required and what performance goals may be achieved.
Interfacial adhesion and electrical coherence of interfaces. Somewhat analogous to the lattice-mismatch problem in multilayers of inorganic solar cells.	These properties strongly influence both efficiency and stability.
Discovery of new donor and acceptor materials with optimized light absorption, band structure, and transport properties.	Develop/identify molecules and materials that implement the fundamental concepts to enable high efficiency.
Control of donor-acceptor morphology and new ideas for active-layer geometry.	Find optimized morphologies in which to arrange the donor and acceptor materials.
Optimization of complete device architecture, including active layer, buffer layers, and electrode and transparent conducting oxide materials.	Develop a complete device geometry that harnesses the power captured in the active layer.
High-throughput fabrication techniques for scale-up to larger-area devices and atmospheric processing.	Develop large-area, high-speed fabrication techniques that retain the efficiency of laboratory-scale cells.
Studies of reliability and long-term degradation mechanisms.	Identify degradation pathways and use to improve molecule and device design.

- What approaches are you using to address those needs?

→ TRMC studies on donor / acceptor pairs, TOF studies on charge transport properties

→ Study of cathode materials as well as interface modification at polymer / metal oxide interface

→ Synthesis of lower band gap dendrimers and polymers

→ Coating of ZnO nanorod arrays with different acceptor materials, novel deposition techniques for active layer gradients

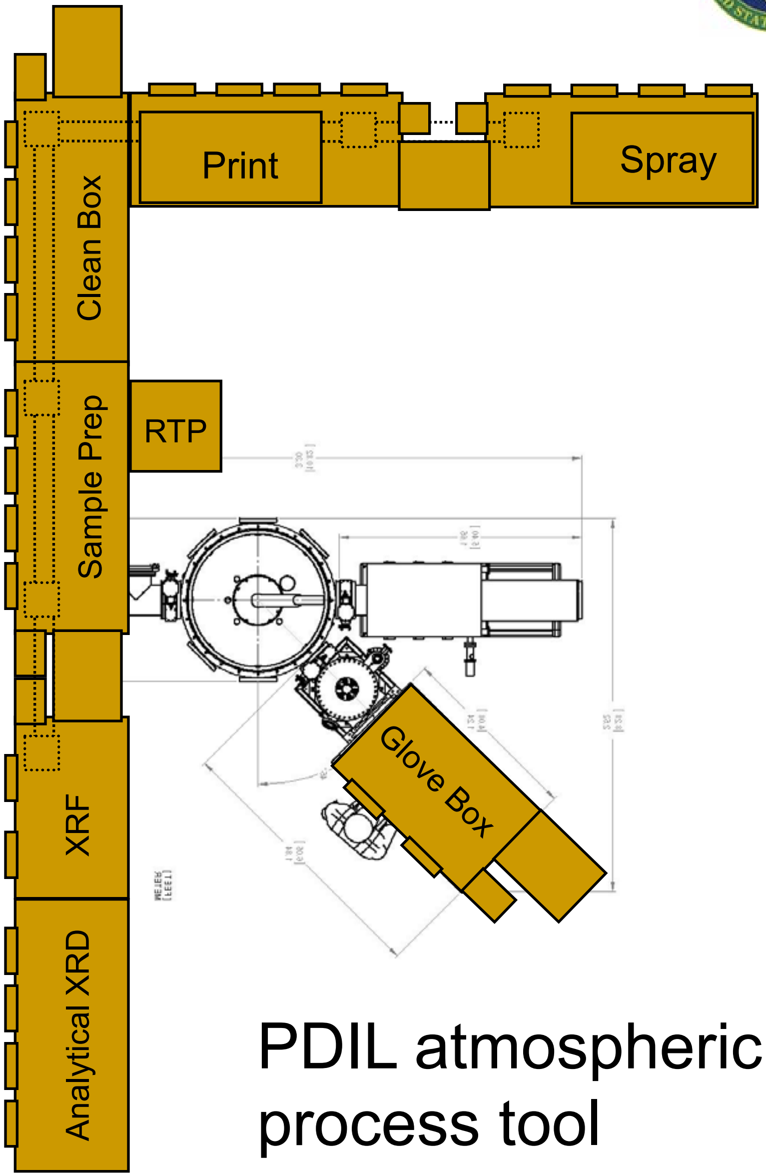
→ Optimization of anode and cathode materials

→ Spray and inkjet printing of large area devices

→ Device degradation studies

Obstacle Discussion

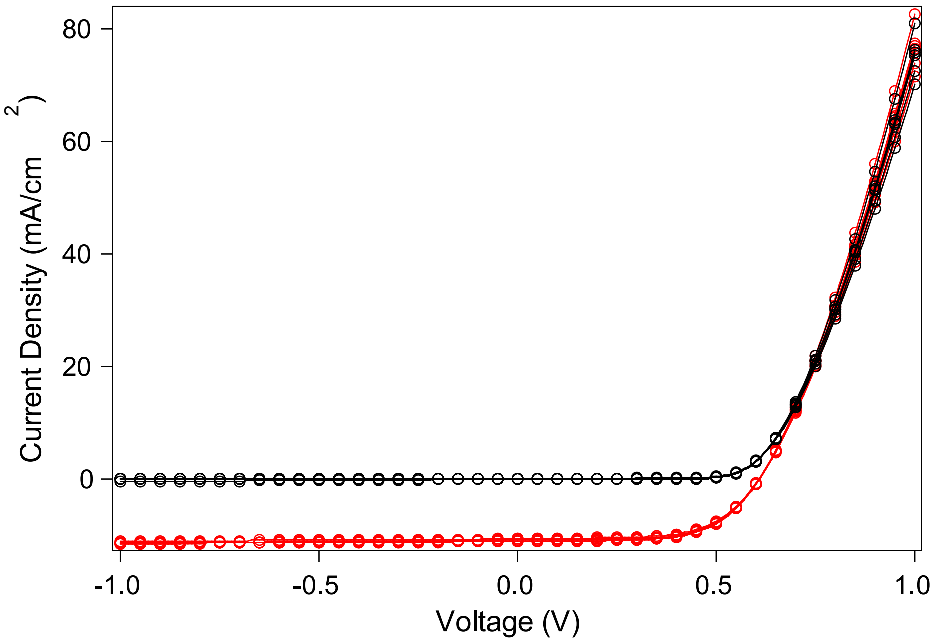
- Barriers encountered or anticipated that may inhibit success of programs
  - Scalability of devices needs to be demonstrated – new infrastructure needs to be developed
  - Lifetime issues are critical
  - Significant polymer synthesis effort is needed
  - Interfacial analysis in hybrid systems is complex and not well understood.



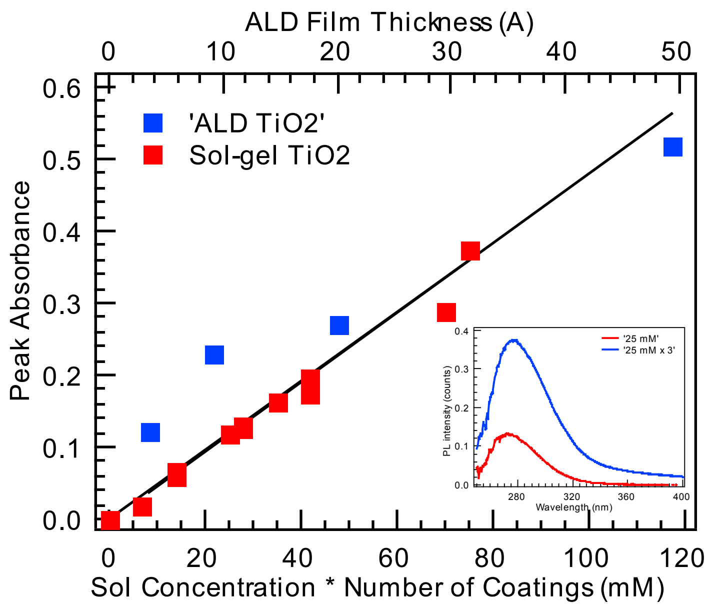
PDIL atmospheric process tool

Project Overview

- Device reproducibility is very good on each substrate



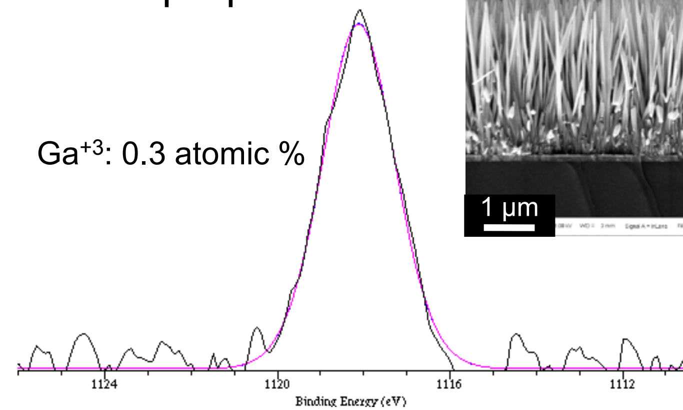
TiO_x coating and Ga:ZnO

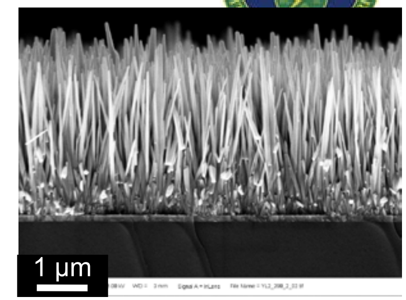


- Developed solution method to make thin TiO_x coatings similar to ALD
- Thickness of TiO_x coating linearly depends on the solution concentration & number of coatings
- Characterization by absorption, SEM, and TEM (future); Will apply to bilayer

  and nanorod PV devices

XPS:Ga 2p Spectra

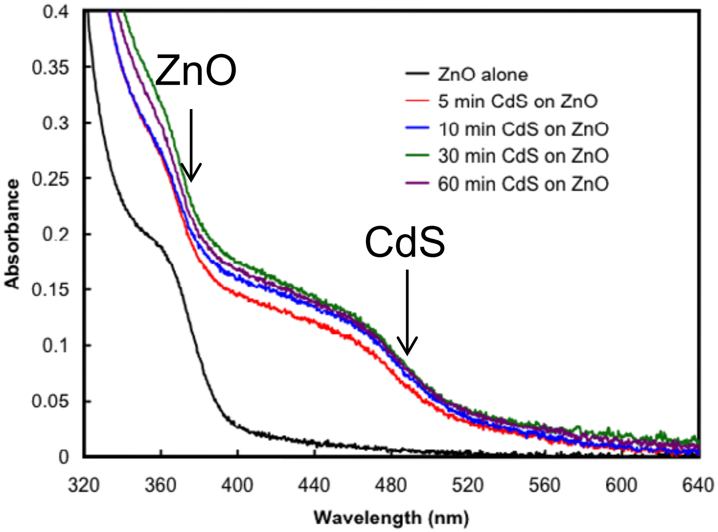


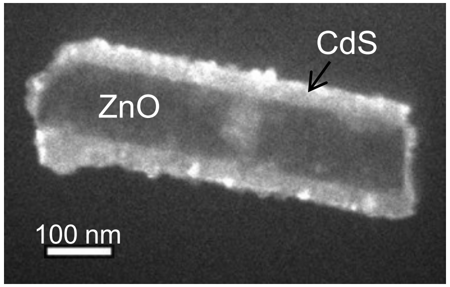


- Nanorod growth morphology retained for low concentration of $Ga(NO_3)_3$ additive in ZnO growth solution
- XPS detects 0.3 atomic % of Ga
- ac (0.1 - 50 GHz) conductivity measurements of Ga:ZnO and undoped ZnO nanorods show enhanced conductivity

	Undoped ZnO	Ga:ZnO
Resistance per rod (Ω)	1500-1800	980

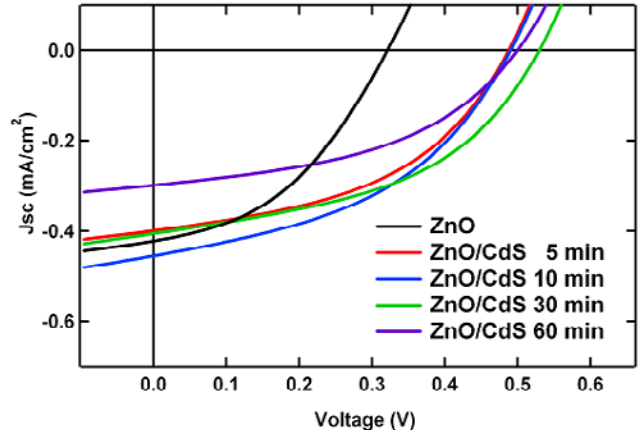
CdS modified ZnO



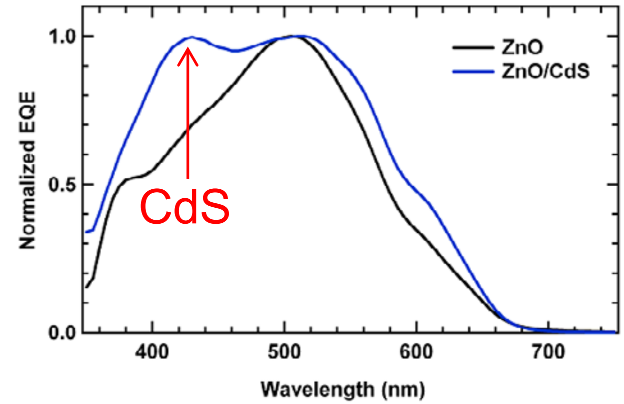


- CdS nanocrystals (~ 20 nm) selectively nucleate and grow on ZnO surface
- Amount of CdS saturated after 10 min of growth; longer growth time leads to ZnO etching

I-V under AM1.5



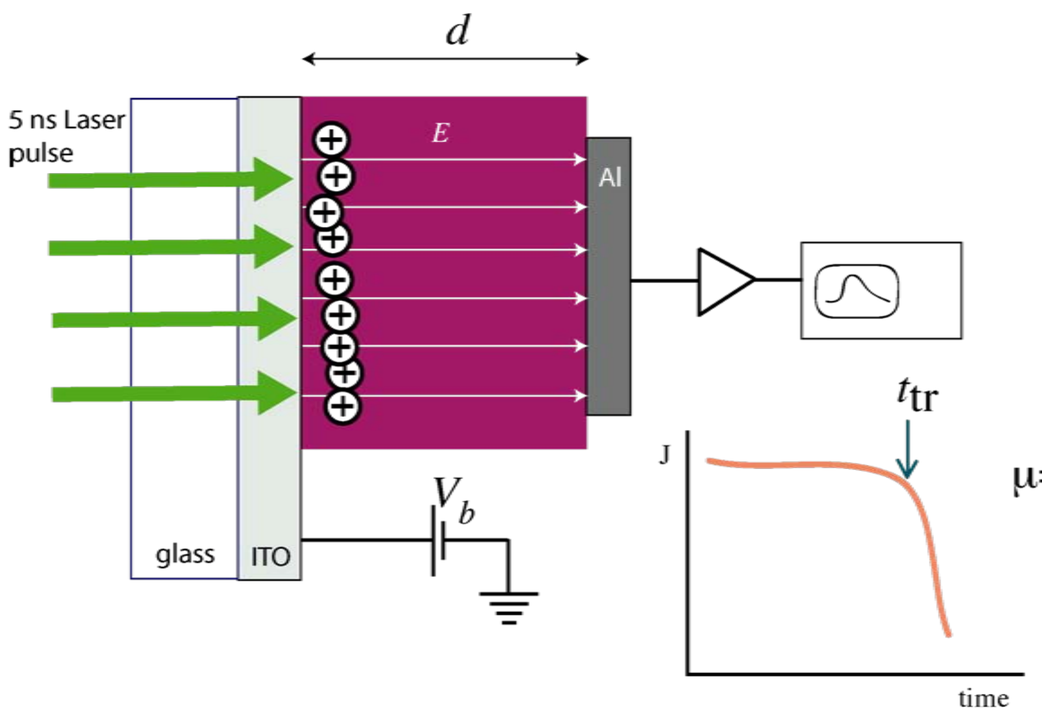
External Quantum Efficiency



- CdS increases V_{oc}
- External quantum efficiency spectra clearly shows CdS contribution

Carrier Mobility Measurments

- Characterization of donor – acceptor materials
  - Time of Flight – Mobility measurements
  - Measured polymer films deposited by ultrasonic spray
    - Equivalent to drop cast films



$$\mu = \frac{d^2}{V_b t_{tr}}$$