Efficiency Enhancement of Bulk-Heterojunction Hybrid Solar Cells

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Overview

Bulk-Heterojunction Hybrid Solar Cells

I. Device Structure and working principle

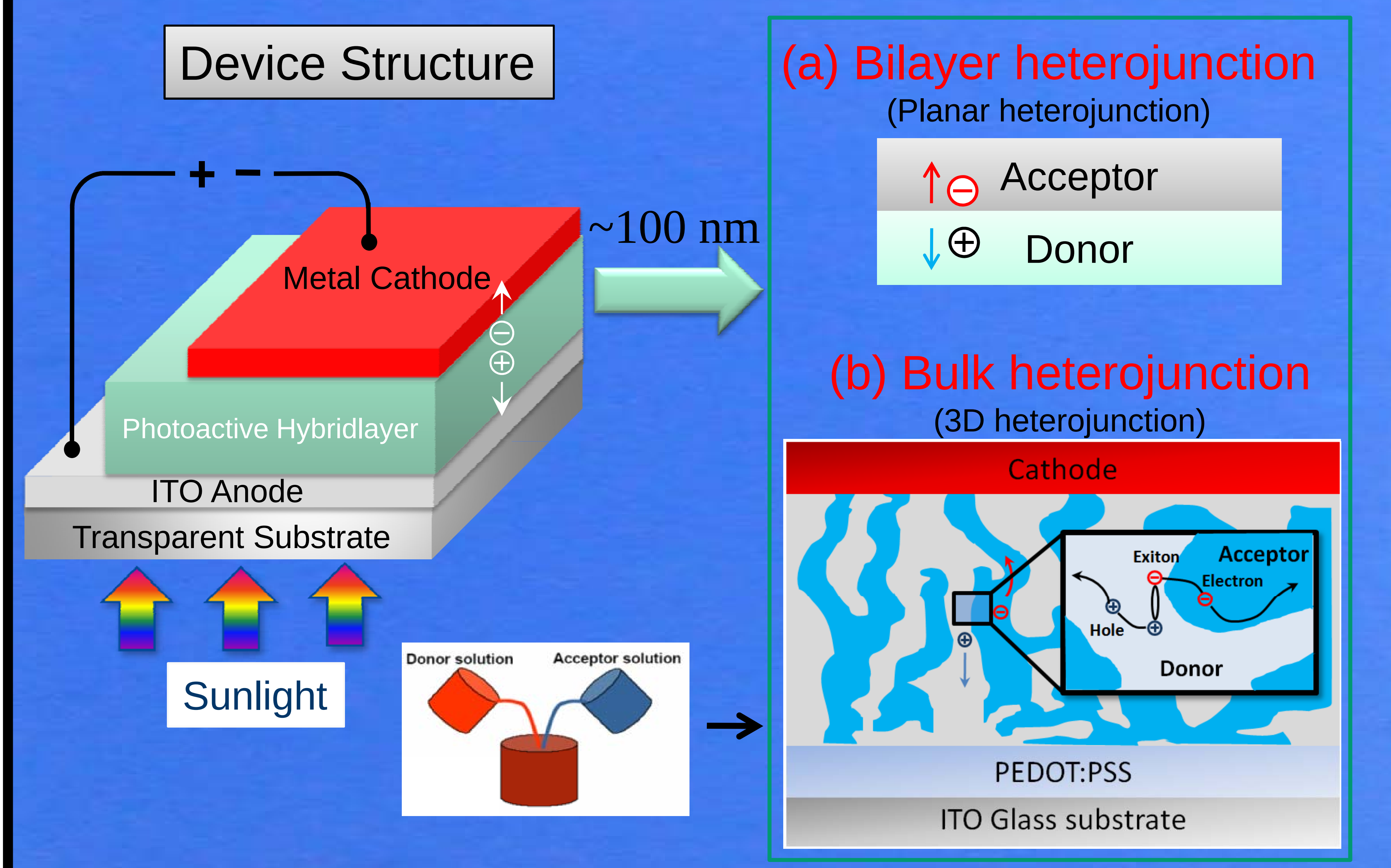
II. Materials and potential applications

III. CdSe nanocrystals based solar cells

- **a) Synthesis of quantum dots**
- **b) Photoactive hybrid films**
- **c) Solar cell performances**

IV. Outlook

Bulk-Heterojunction Hybrid Solar Cells

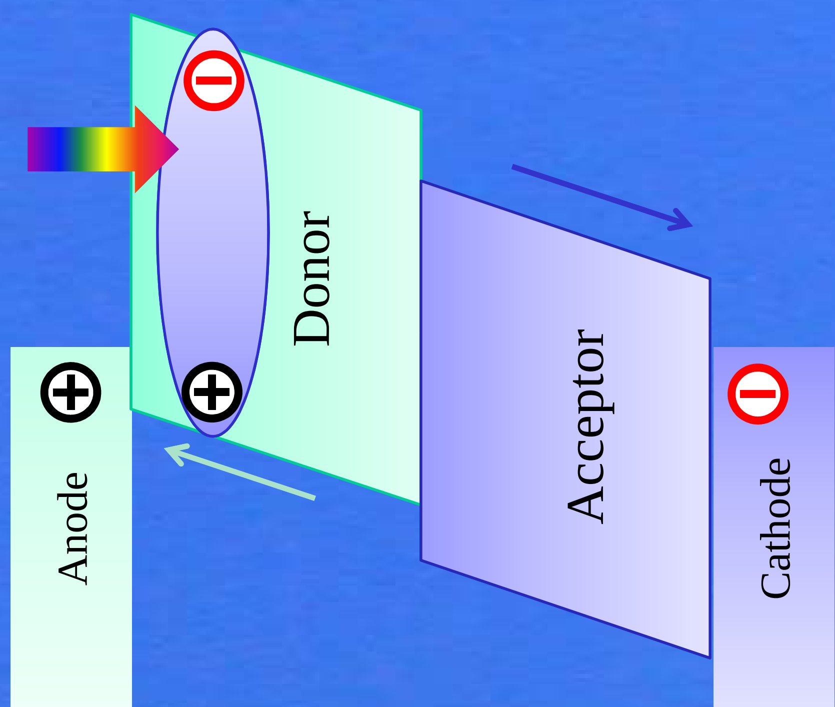


Bulk-Heterojunction Hybrid Solar Cells

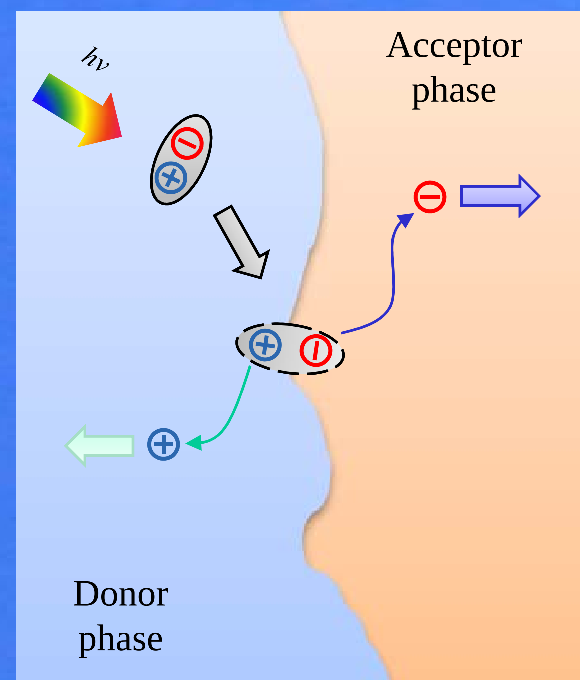
Working Principle

Review: Yunfei Zhou, Michael Eck, Michael Krüger, Energy Environ. Sci. **3**, 1851-1864, (2010)

Bilayer Heterojunction



Bulk Heterojunction



Photon absorption → Exciton diffusion → Charge transfer → Carriers transport & collection

Bulk-Heterojunction Hybrid Solar Cells

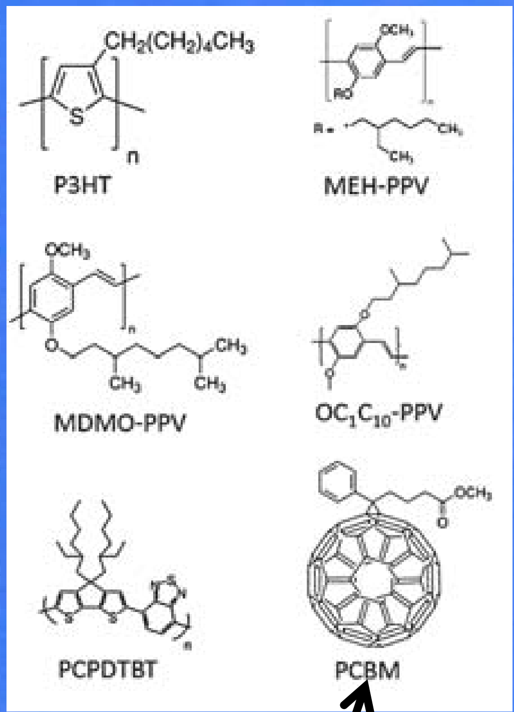
Donor Acceptor Materials

Review: Yunfei Zhou, Michael Eck, Michael Krüger, Energy Environ. Sci. **3**, 1851-1864, (2010)

Donor	Acceptor	PCE
Polymer	C_{60} derivative	~8%[1]
Polymer	Nanocrystals (e.g. CdSe)	~3%[2]
Polymer	Polymer	~2%[3]

Small molecules / small molecules ~ 8~%[4]

Conjugated Polymers



Buckyball Derivative

[1] www.konarka.com, accessed on December 3, 2010.

[2] Dayal et al. Nano Lett. 10, 239-242 (2010).

[3] He et al. Nano Lett. 10, 1302 (2010).

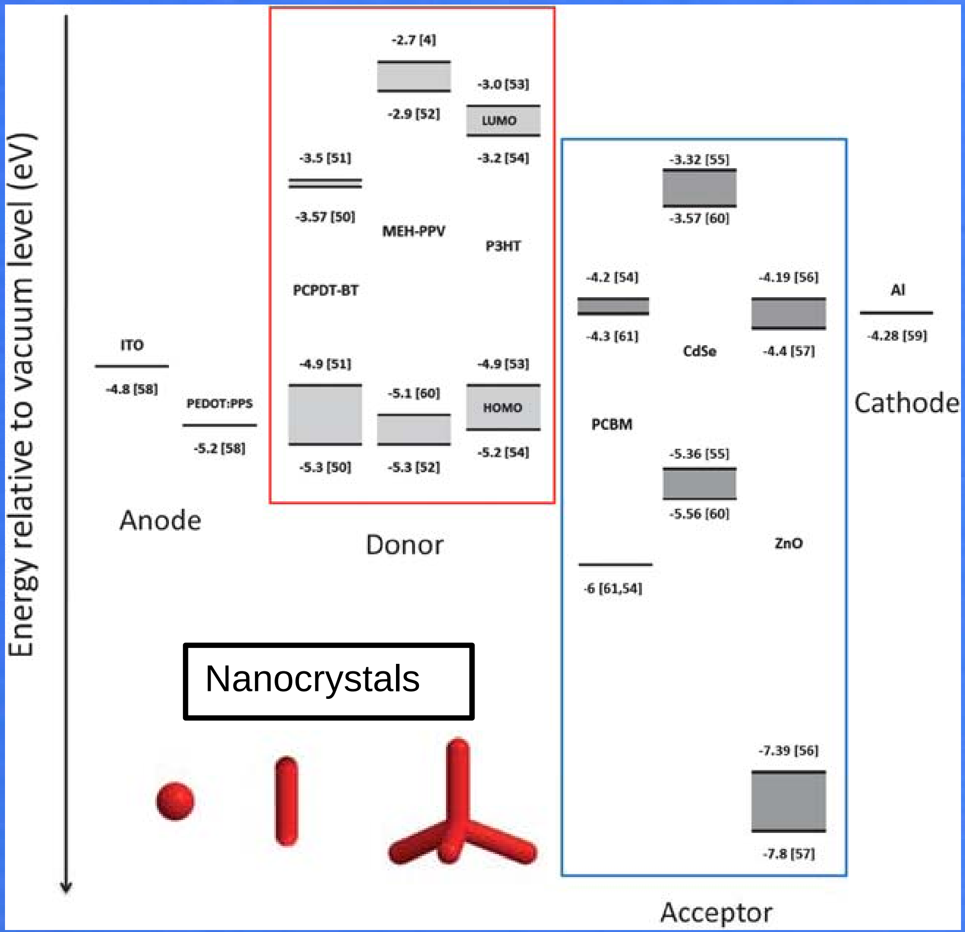
[4] Heliatek (2010)

Bulk-Heterojunction Hybrid Solar Cells

Donor Acceptor Materials

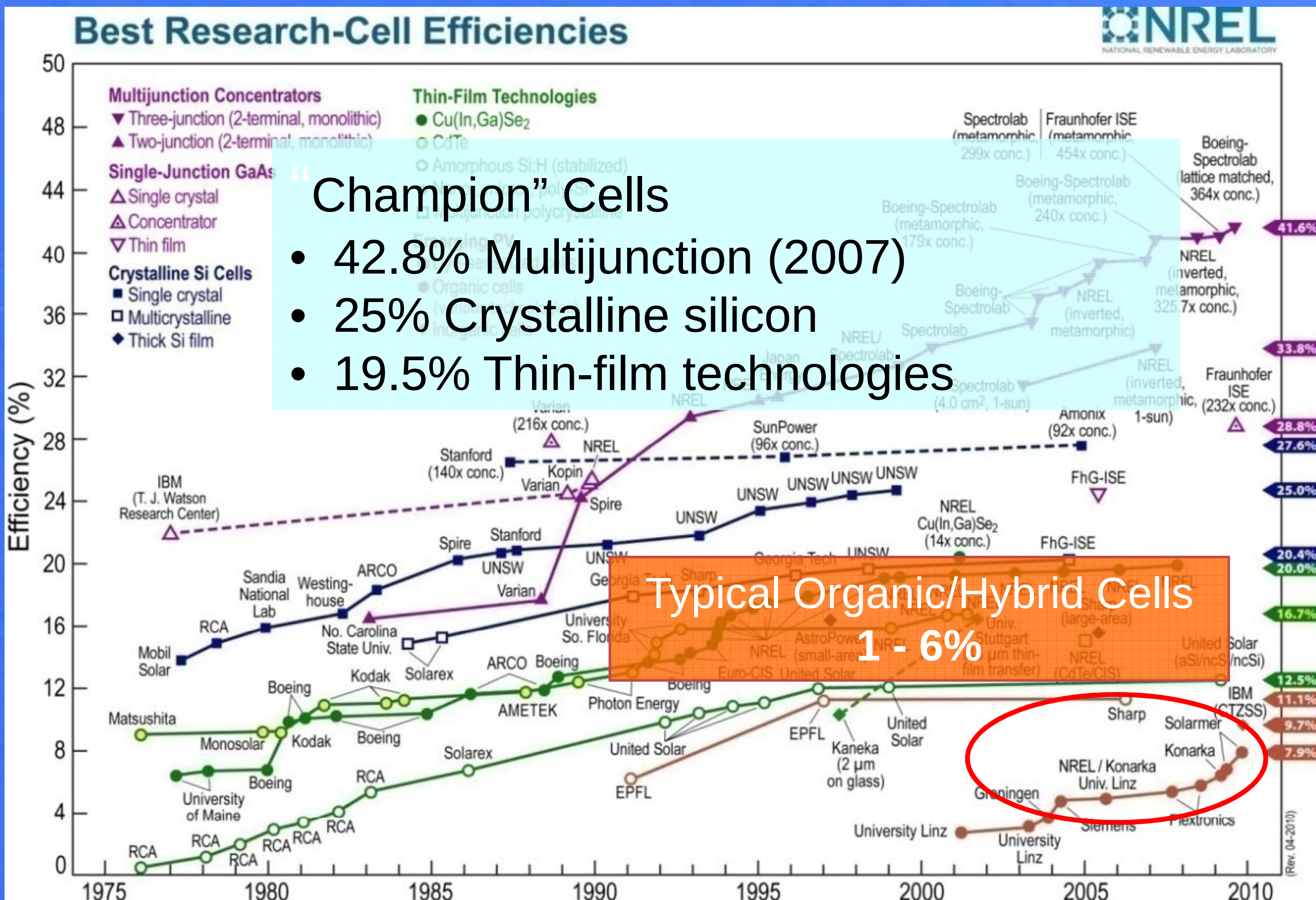
Review: Yunfei Zhou, Michael Eck, Michael Krüger, Energy Environ. Sci. **3**, 1851-1864, (2010)

Energy Levels Diagram



Applications for Nano-Hybridmaterials: Bulk-Heterojunction Hybrid Solar Cells

Development of Photovoltaic Devices and their solar power efficiencies



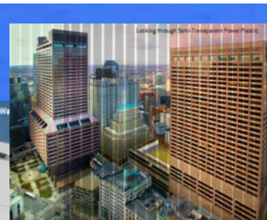
8.13% PCBM based OPV annoumved by Konarka Inc. December 2010 (www.konarka.com)

Source: National Renewable Energy Laboratory 2010, USA

Motivation for Organic/Hybrid Solar Cells

Advantages of Organic / Hybrid Solar Cells

- Processed easily over large area
- Low weight (~100 nm ultra-thin active layer)
- Low cost potential (roll-to-roll fabrication possible)
- Mechanical flexibility (wearable solar power module)



[Konarka Technologies]

Public installations

[Konarka Technologies]

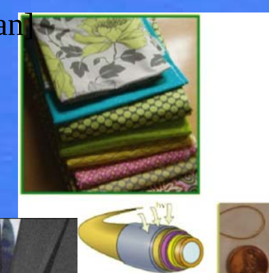
buildings

organic solar cells

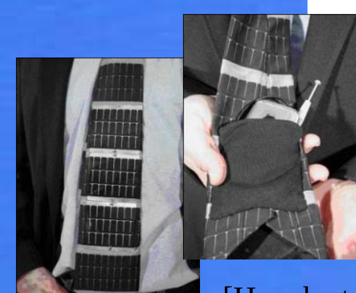
consumer electronics

clothing

[M. Shtein, Univ. of Michigan]

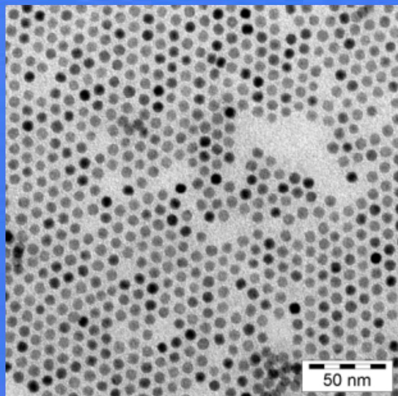


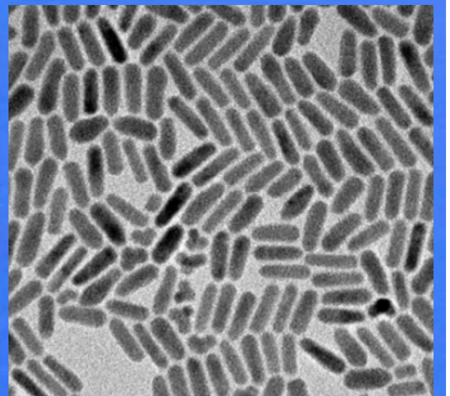
[Konarka Technologies]

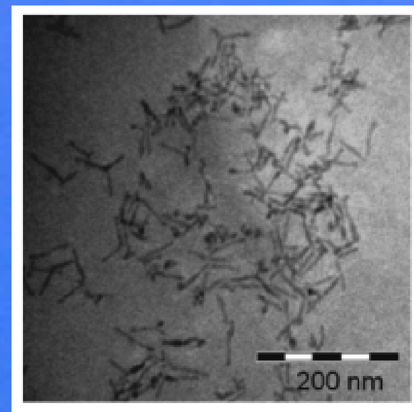


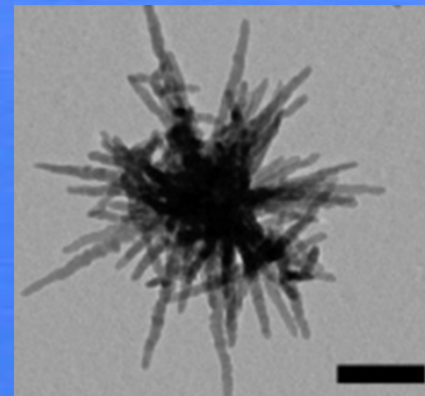
[Hynek et al., Iowa State Univ.]

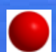
Nanocrystals as electron acceptor material









 Quantum Dots

(1) 0.1 % (1996) (MEH-PPV)

(2) 1.1% (2006) (P3HT)

(3) 1.7-1.8% (2009) (P3HT)

(4) 2.0-2.1% (2010) (P3HT)

(5) 2.7% (2010) (PCPDTBT)

 Nanorods

(6) 1.7% (2002) (P3HT)

(7) 2.6% (2006) (P3HT)

 Tetrapods

(8) 2.1-2.8% (2005)(P3HT)

(9) 3.19% (2010) (PCPDTBT)

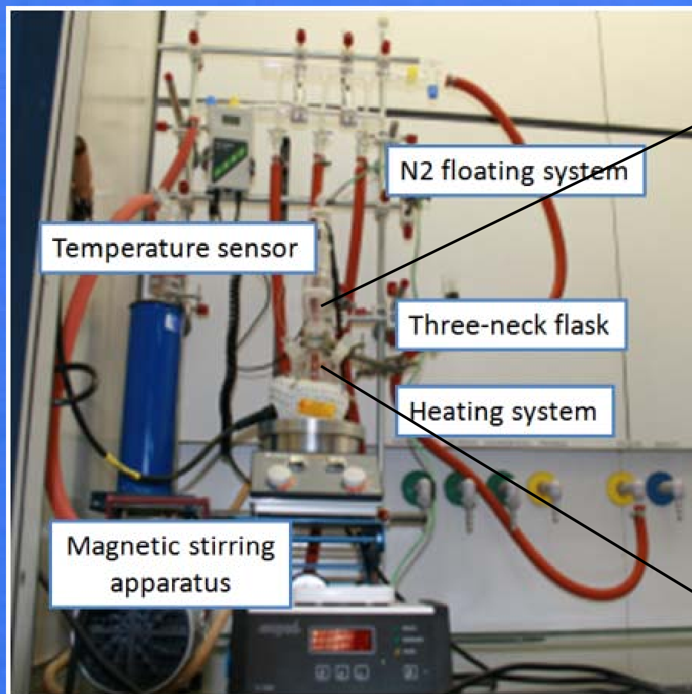
 Hyperbranched

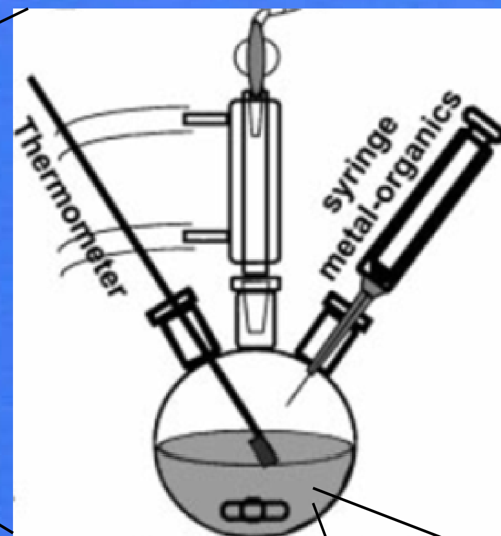
(10) 2.2% (2007) (P3HT)

Hybrid Solar Cells with CdSe NCs
- Additional absorption
- Bandgap & energy levels fitting
- Elongated/branched structure
- Well-established synthesis methods
- Theoretically: better electron transport

(1) Greenham et al. Phys. Rev. B 54, 17628 (1996).
(2) Han et al. Nanotechnology 17, 4736-4742 (2006).
(3) Olson et. al, Solar Energy Mater. & Solar Cells 93, 519 (2009).
(4) Zhou et al. Appl. Phys. Lett. 96 0133014 (2010).
(5) Zhou et al. Sol. Energy Mater. Sol. Cells (2011).
(6) Huyhn et l. Science 295, 2425 (2002).
(7) Sun et. al, Phys. Chem. Chem. Phys. 8, 3557 (2006)
(8) Sun et. al, J. Appl. Phys. 97, 014914 (2005).
(9) Dayal et al. Nano Lett. 10, 239-242 (2010).
(10) Gur et al. Nano Lett 7 (2), 409-414 (2007).

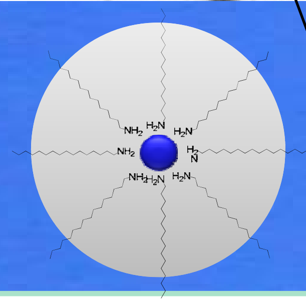
Quantum Dot Synthesis: Hot Injection Method



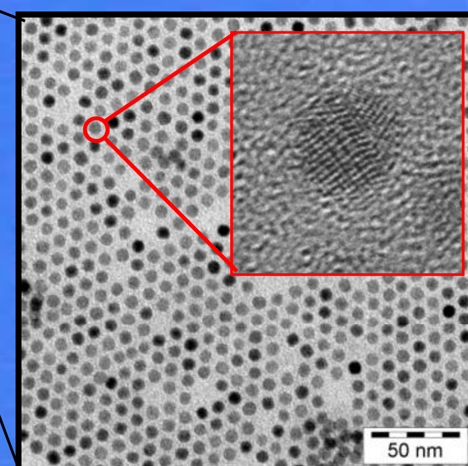


Precursors: Cd-Stearat, Se-TOP
Ligands: HDA/TOPO
Temperature: 300 ^{o}C

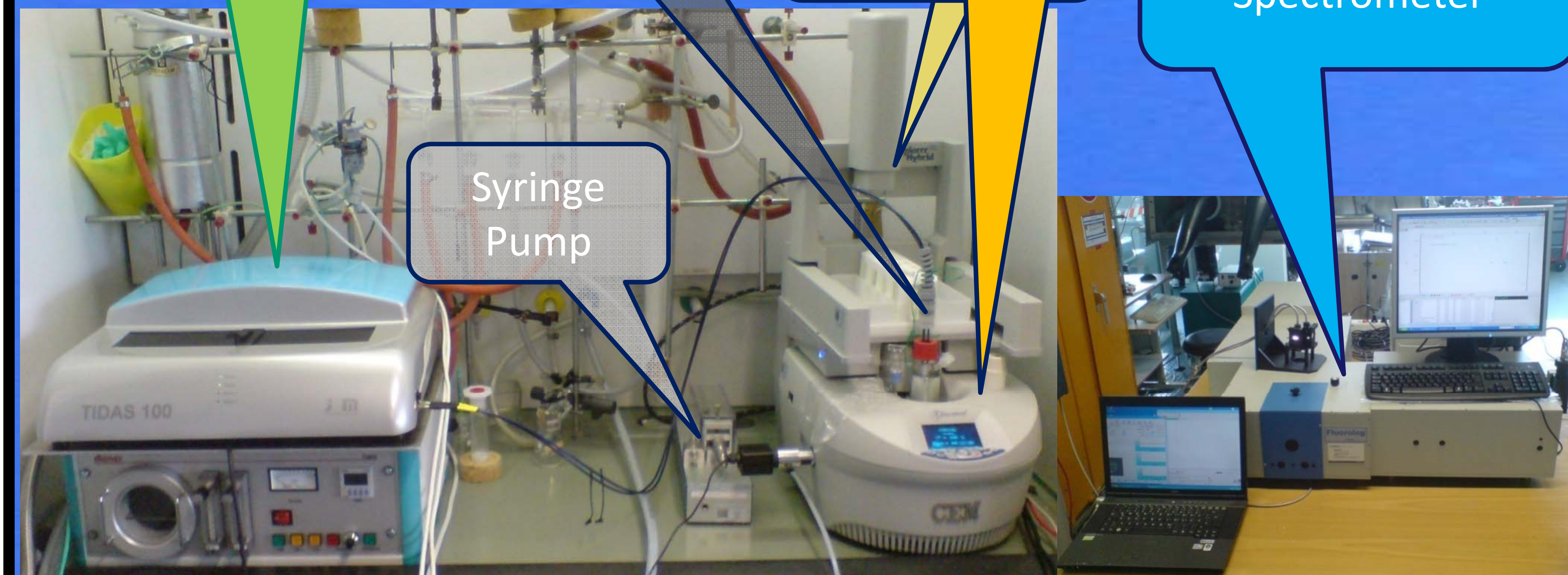
CdSe Core
- Diameter: 2-10 nm
- Size dependent physical properties
- Quantum confinement effect



Ligand Shell
- Colloidal stabilization
- Prevent aggregation
- Maintain optical properties



Quantum Dot : automated microwave synthesis



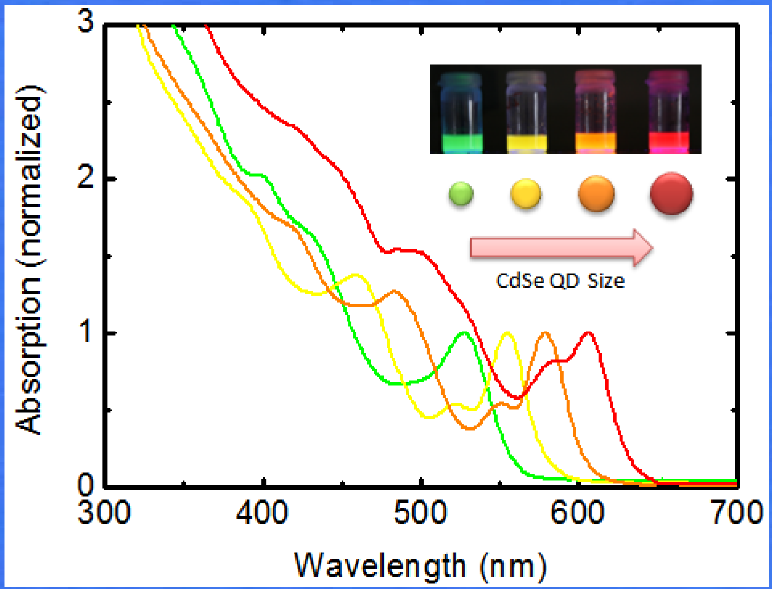
Connected via ethernet

S. Einwaechter, M. Krueger
MRS Proceedings 2010 in press

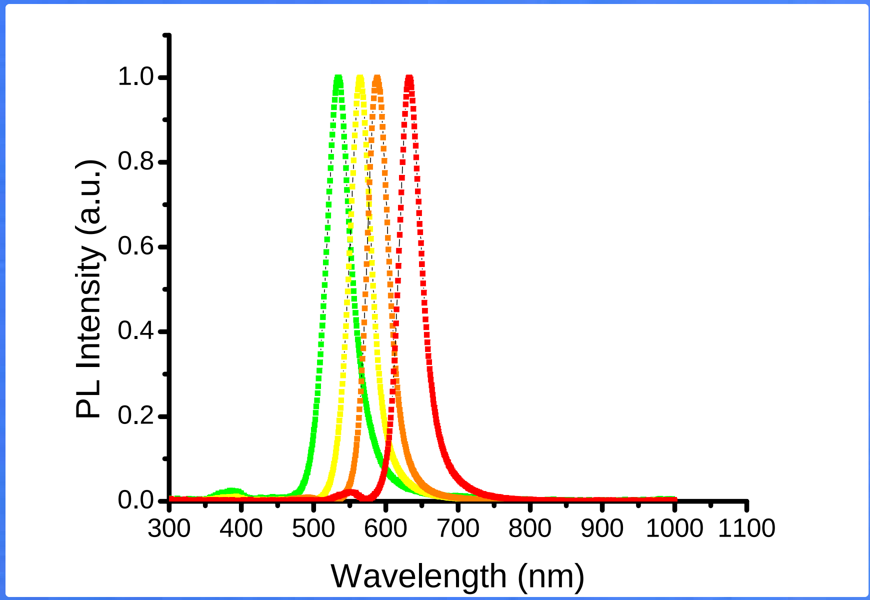
CdSe Quantum Dots: Optical Properties

Quantum confinement

UV-vis spectroscopy

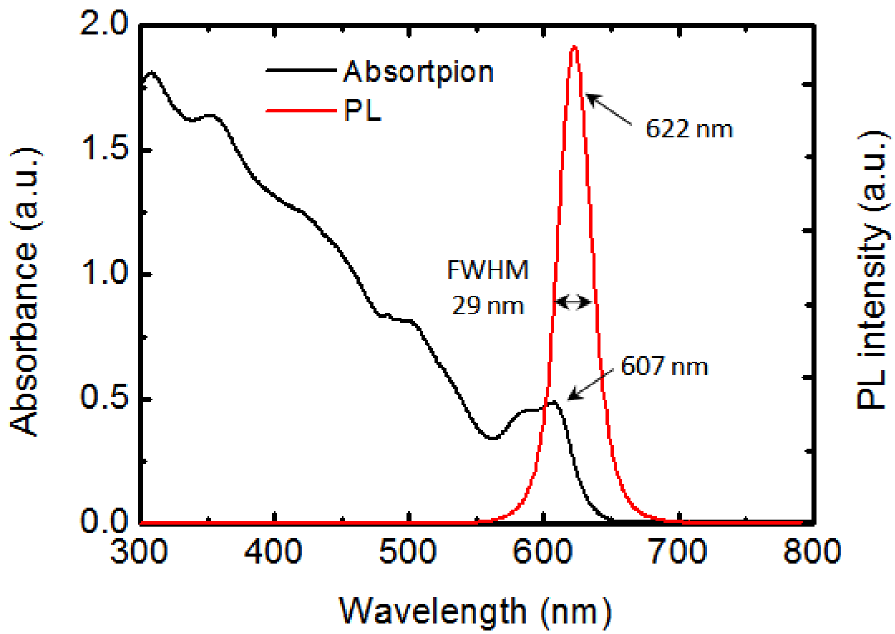


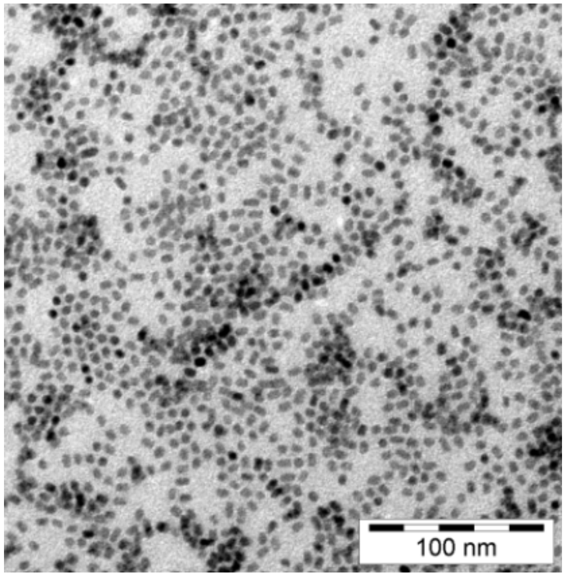
PL spectroscopy



-Broad absorption spectra
-Narrow emission spectra

Optimized CdSe QDs for Hybrid Solar Cells





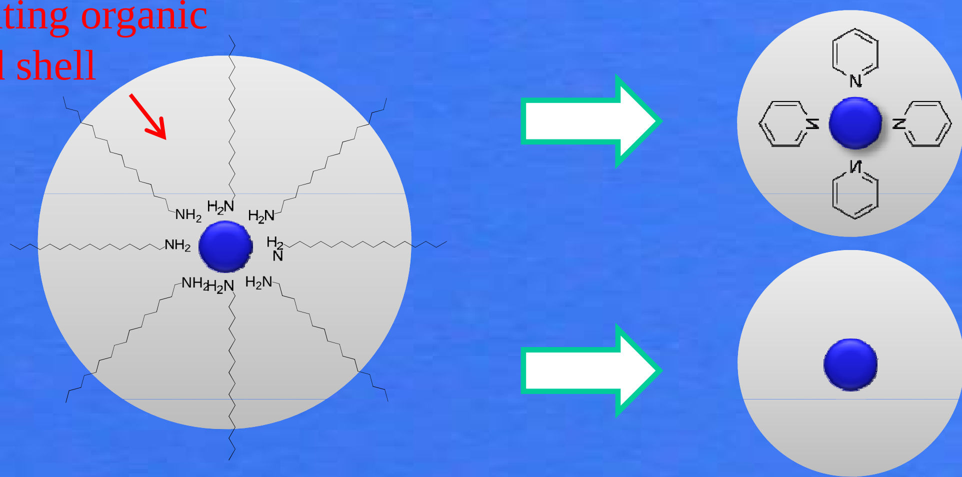
2 hours reaction @ 300^{o}C reaction temperature
→ 5.5 nm, High PL intensity and narrow PL spectrum

Bulk-Heterojunction Hybrid Solar Cells

Surface Modification of CdSe Nanocrystals

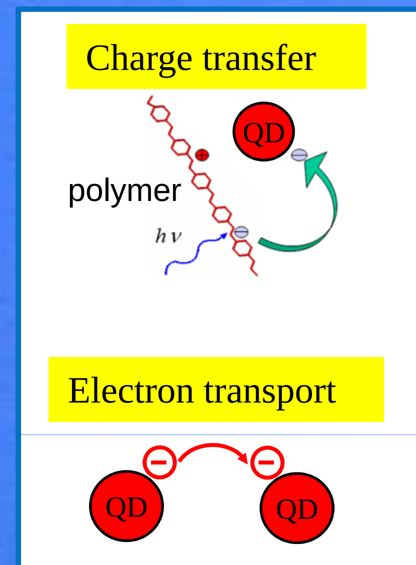
Traditional pyridine ligand exchange

Insulating organic ligand shell



Ligand shell reduction

Improving



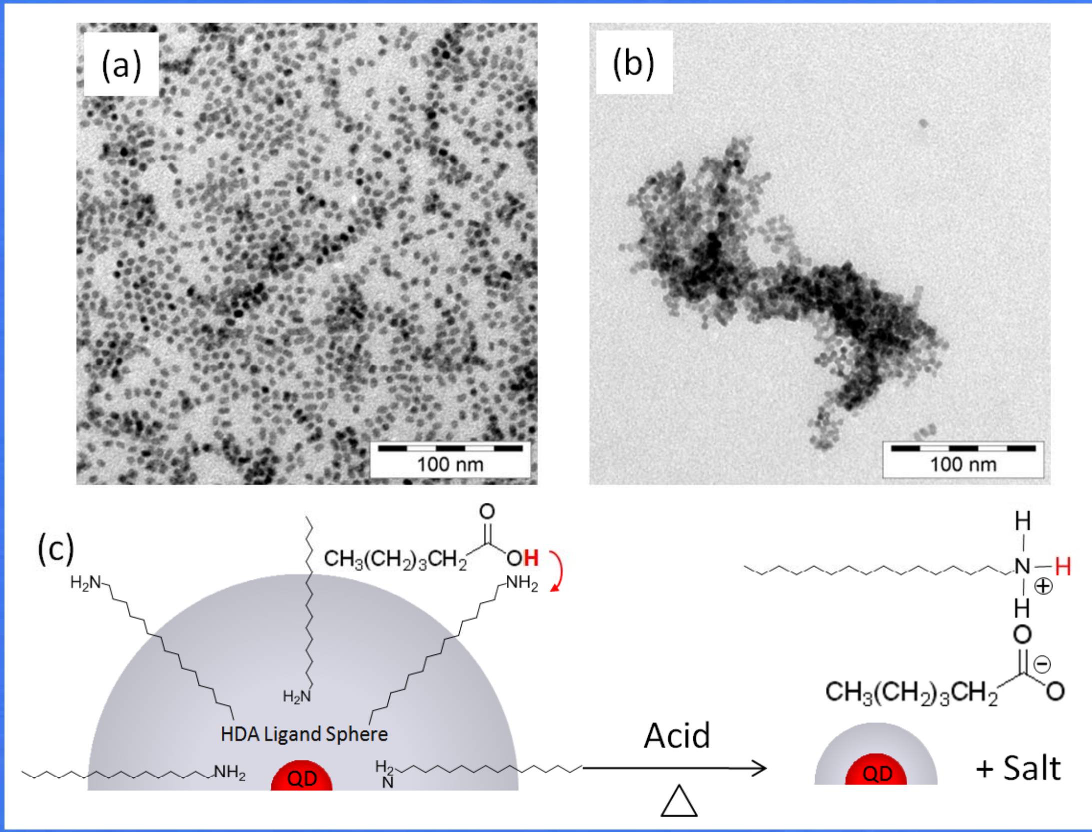
Hexanoic acid treatment

- Simple, fast, and reproducible procedure → reduce ligand shell
- Non-ligand exchange approach → good solubility in solvent
- In principle applicable to NCs with different ligands and shape

Bulk-Heterojunction Hybrid Solar Cells

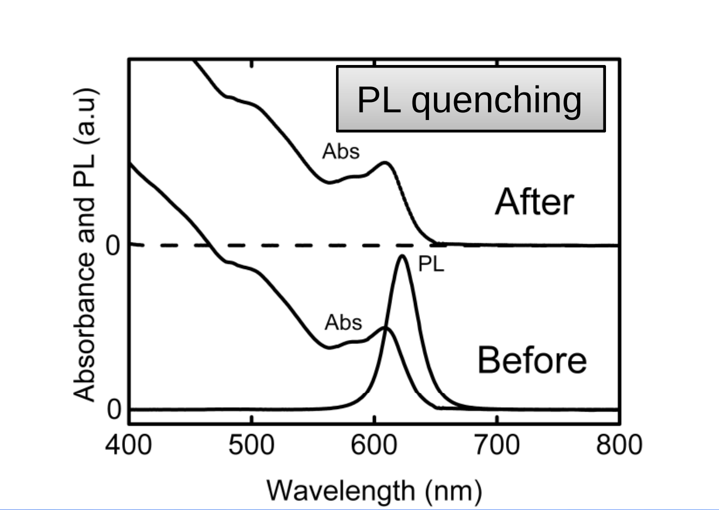
Surface Modification of CdSe Nanocrystals

Acid – treatment of Quantum Dots



Zhou et al. Appl. Phys. Lett. 96 0133014 (2010)

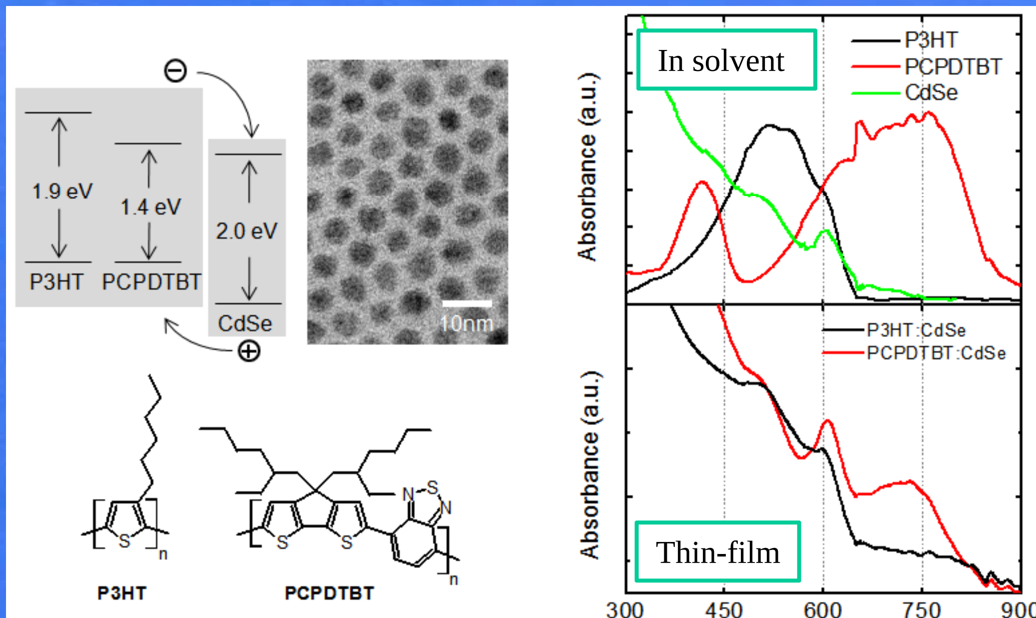
Absorption measurments



Further evidence:

-Dynamic light scattering (DLS)
-Zero loss filtered TEM
-TGA-MS (manuscript in prep)
-Significant device improvement

Comparison of CdSe QD / P3HT and CdSe QD / PCPDTBT



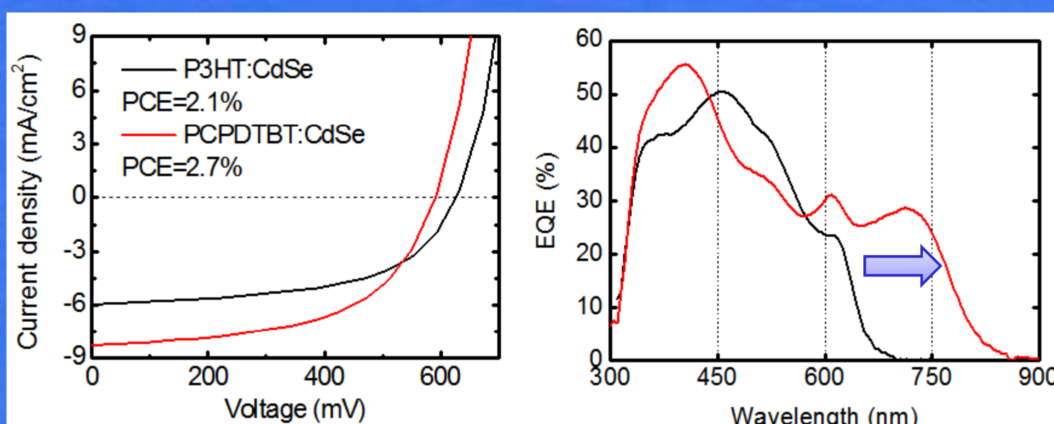
* PCPDTBT synthesized by Uni Wuppertal

PCPDTBT:

- Bandgap ~1.4 eV
- μ_e ~1.5×10^{-2} $cm^2V^{-1}s^{-1}$
- Good photon-absorbing & hole transporting material

PCPDTBT:CdSe composite

- Wide absorption range from 300 nm to 850 nm

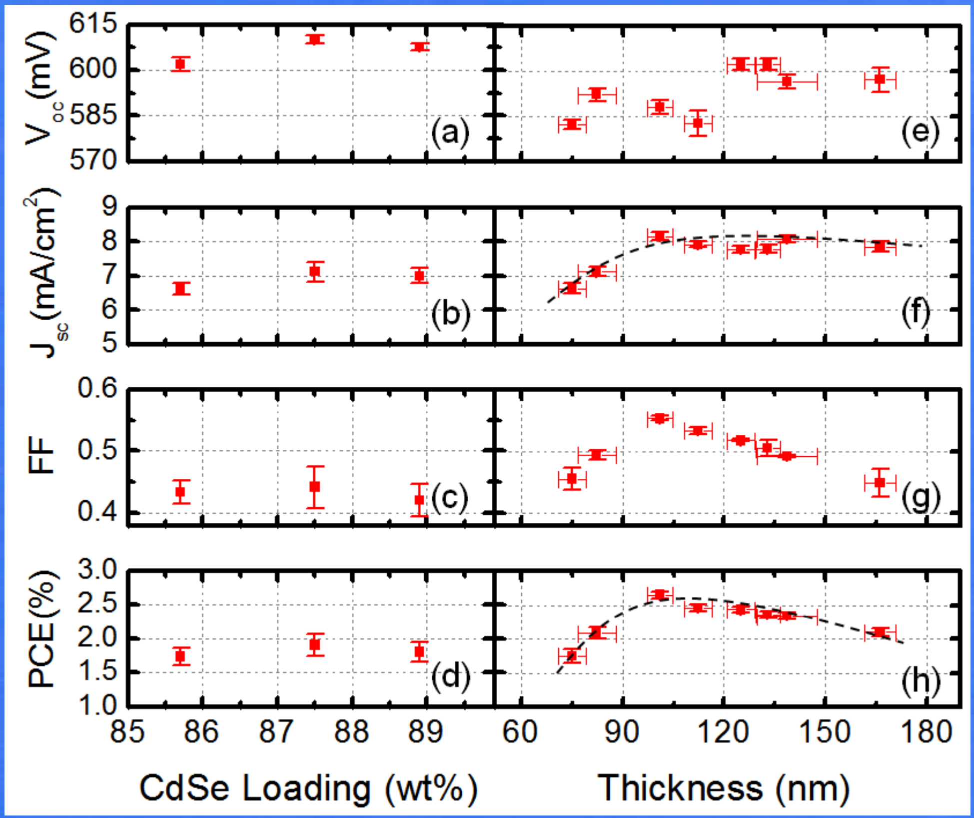


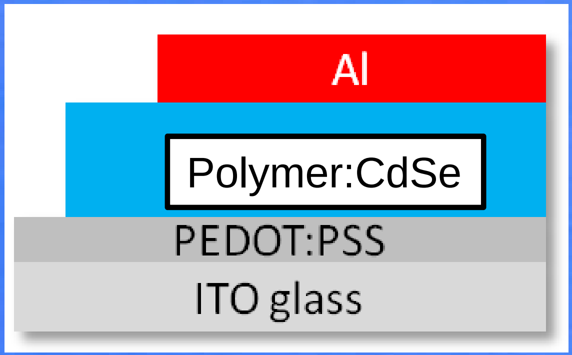
* Measured by ISE

- PCE=2.7%, best for CdSe QDs based hybrid solar cells (verified by ISE)
- Harvesting more photons compared to P3HT
- Photocurrent contribution from both QDs and Polymer

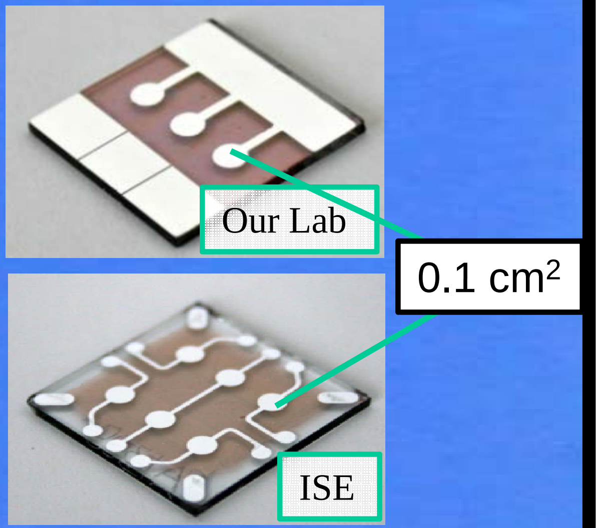
Zhou et al. Sol. Energy Mater. Sol. Cells 95 (2011), 1232-1237

Optimization of the device performance





Test devices

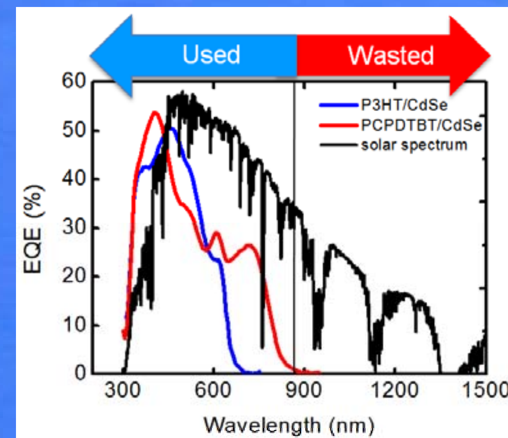


Polymer	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	PCE (%)
P3HT	616.3 ± 7.5	6.04 ± 0.10	56.2 ± 0.3	2.09 ± 0.03
PCPDTBT	588.0 ± 2.4	8.16 ± 0.12	55.3 ± 0.4	2.65 ± 0.05

Outlook: *Strategies for improving the performance of hybrid solar cells*

Photon absorption

Longer absorption wavelength materials (e.g. CdTe, CIS, low bandgap polymer)

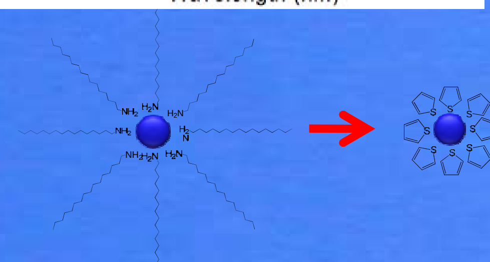


Exciton diffusion

Appropriate Donor / Acceptor interface

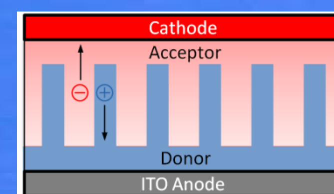
Charge transfer

Ligand exchange from synthesis ligand to more conductive ligands

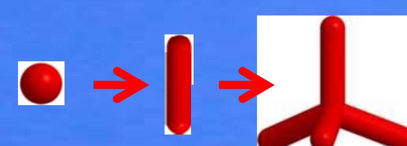


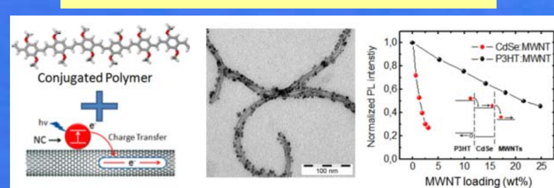
Carriers transport & collection

Nano-morphology control and device structure design



Elongated structures, novel hybrid structures





Acknowledgment

- **PV Team**
- Yunfei Zhou, Michael Eck
- **Synthesis Team, light converting films**

  Frank Riehle, Ying Yuan, Simon Einwächter (microwave synthesis)

  Partners
- FhG ISE (Freiburg): device characterization (B. Zimmermann, C. Veit))
- Bayer Technology Services, Bayer Material Science (material delivery)
- Uni Wuppertal, Germany (group of Prof. Scherf: PCPDTBT polymer)
- **Financial support from:**
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- BMBF Project “NanoPolySol” (German Ministry of Science and Education)

Thank you for your attention!