2132-14

Winter College on Optics and Energy

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Organic/Inorganic hybrid solar cells

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Organic/Inorganic hybrid solar cells

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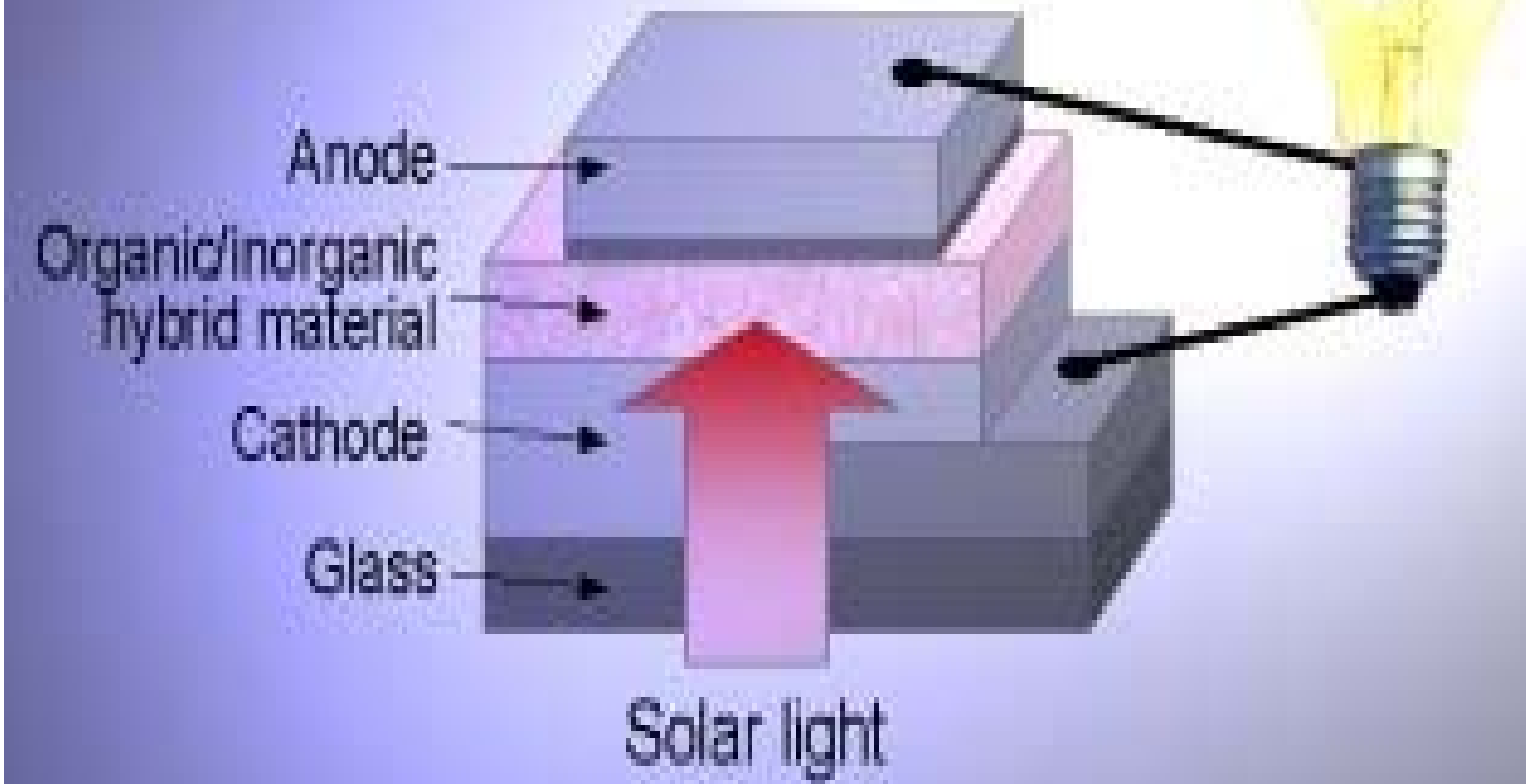


Contents

- New generation Solar cells
- Inorganic Semiconductor Nanocrystals
- Device structure, working mechanisms
- Some examples
- Strategies for improving the performance

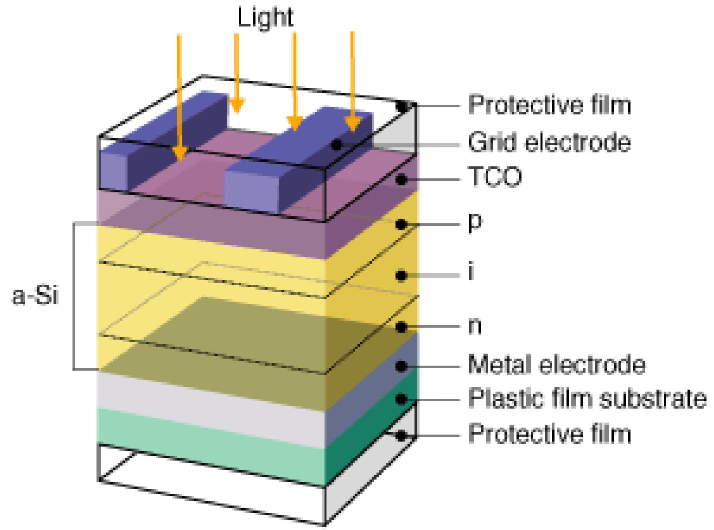
Silicon Solar Cells

Well established and robust technology

Long life time (>20years)

Expensive technology (3-6€/Wp)

Silicon availability?



Amorphous film configuration

Power conversion effciency

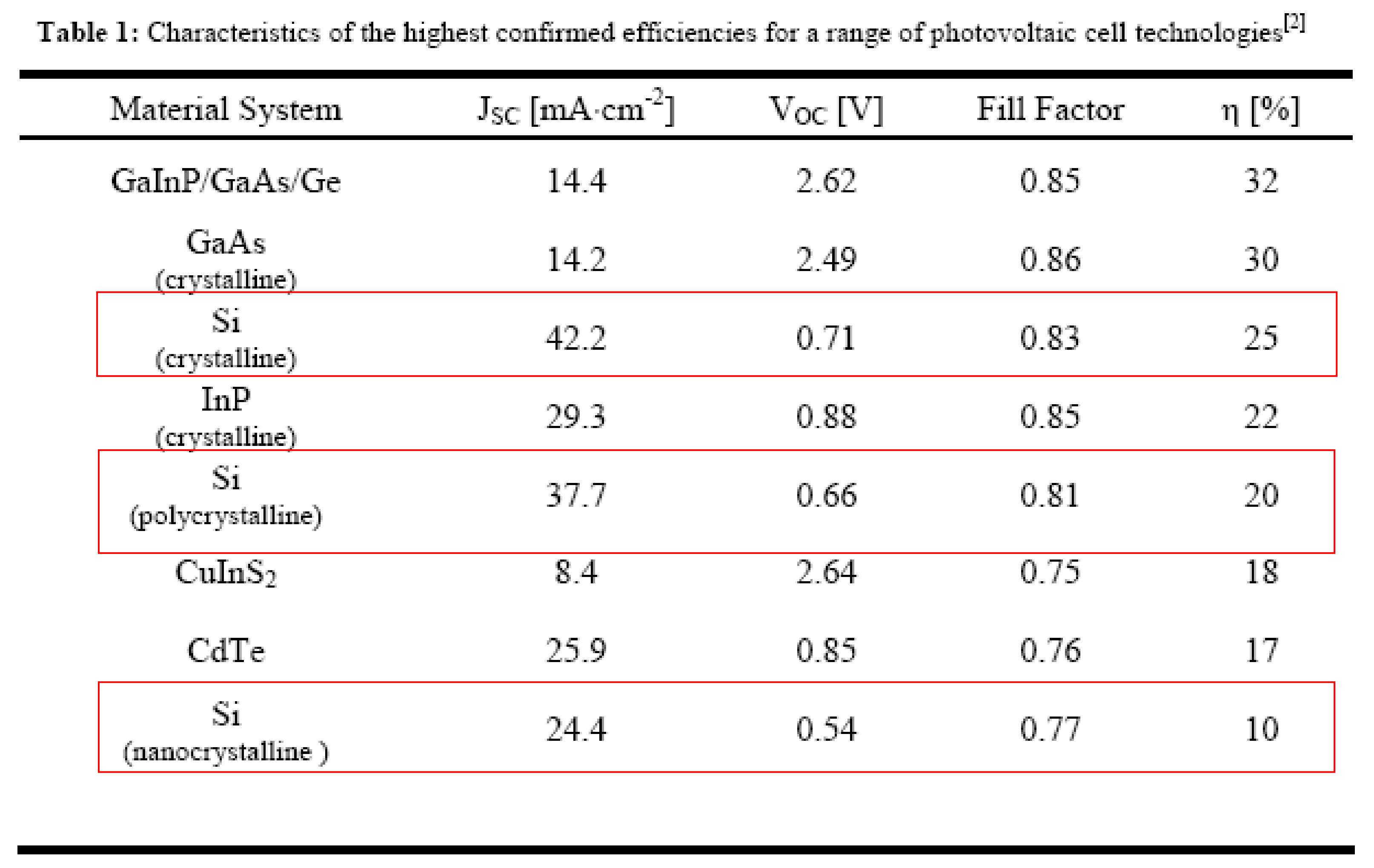
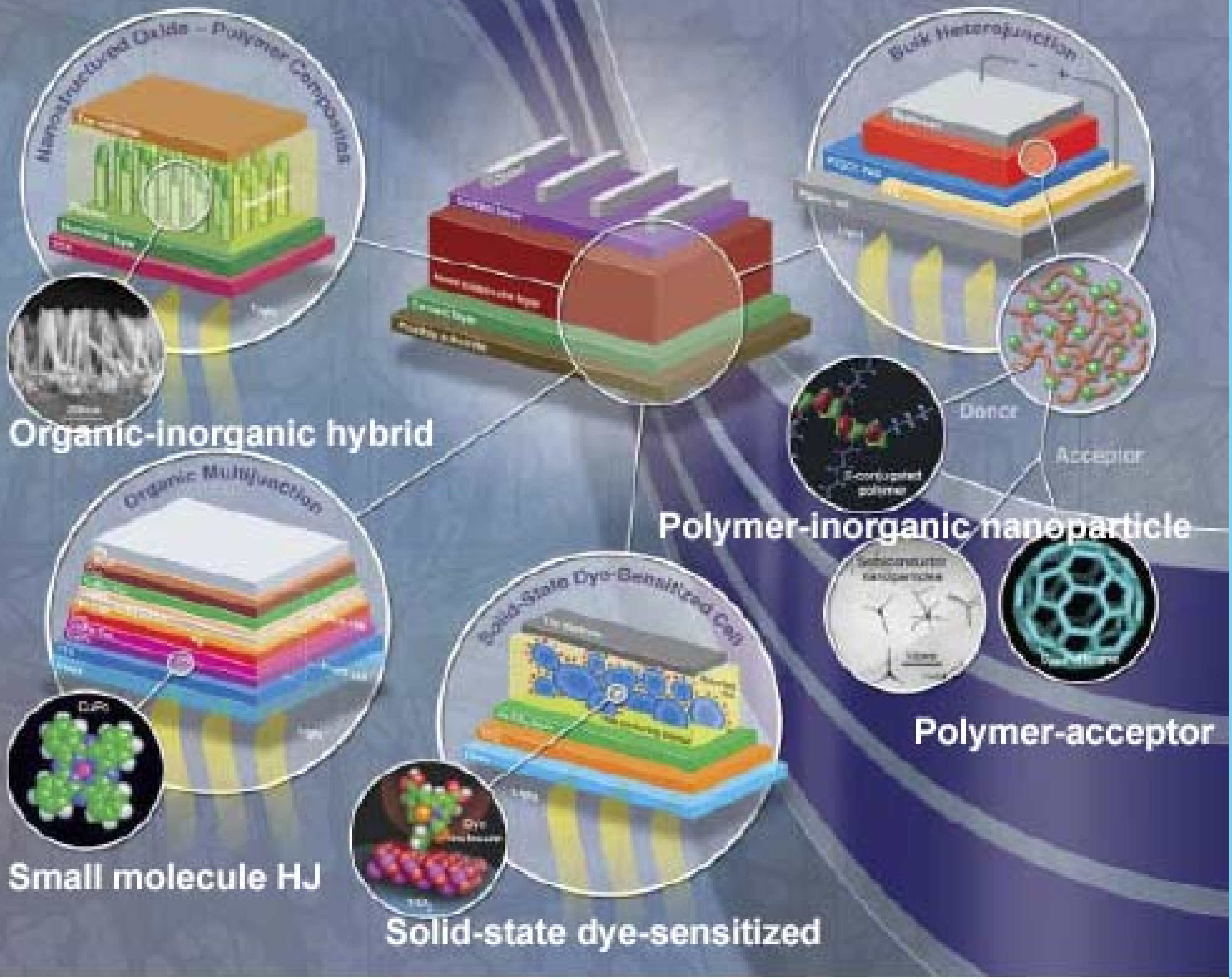


Table 1: Characteristics of the highest confirmed efficiencies for a range of photovoltaic cell technologies[2]

Material System	J_{SC} [mA·cm^{-2}]	V_{OC} [V]	Fill Factor	η [%]
GaInP/GaAs/Ge	14.4	2.62	0.85	32
GaAs (crystalline)	14.2	2.49	0.86	30
Si (crystalline)	42.2	0.71	0.83	25
InP (crystalline)	29.3	0.88	0.85	22
Si (polycrystalline)	37.7	0.66	0.81	20
$CuInS_2$	8.4	2.64	0.75	18
CdTe	25.9	0.85	0.76	17
Si (nanocrystalline)	24.4	0.54	0.77	10

Organic (Excitonic) Solar Cells: 5 Types



Organic-inorganic hybrid

Polymer-inorganic nanoparticle

Polymer-acceptor

Small molecule HJ

Solid-state dye-sensitized

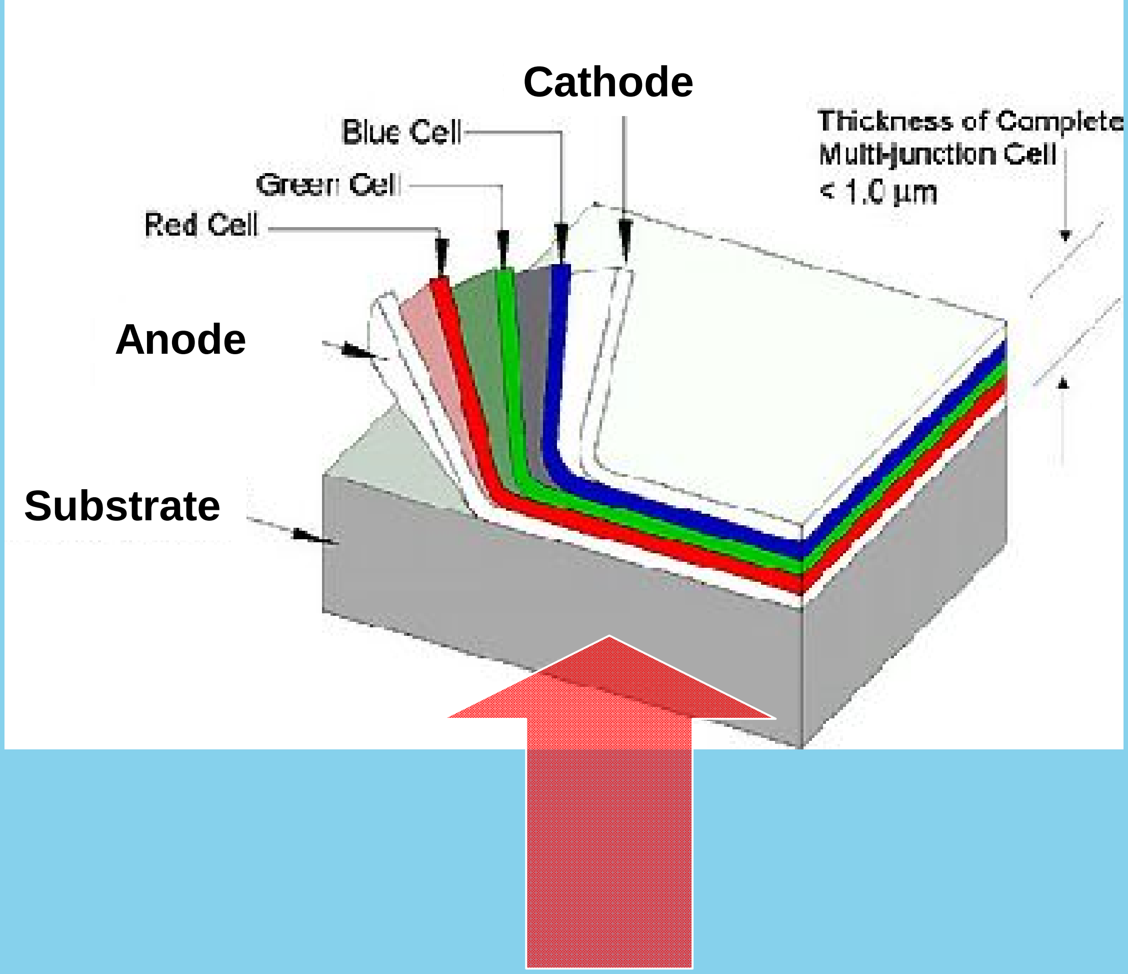
Small molecular weight Solar cells (PCE ~5%)

Advantages:

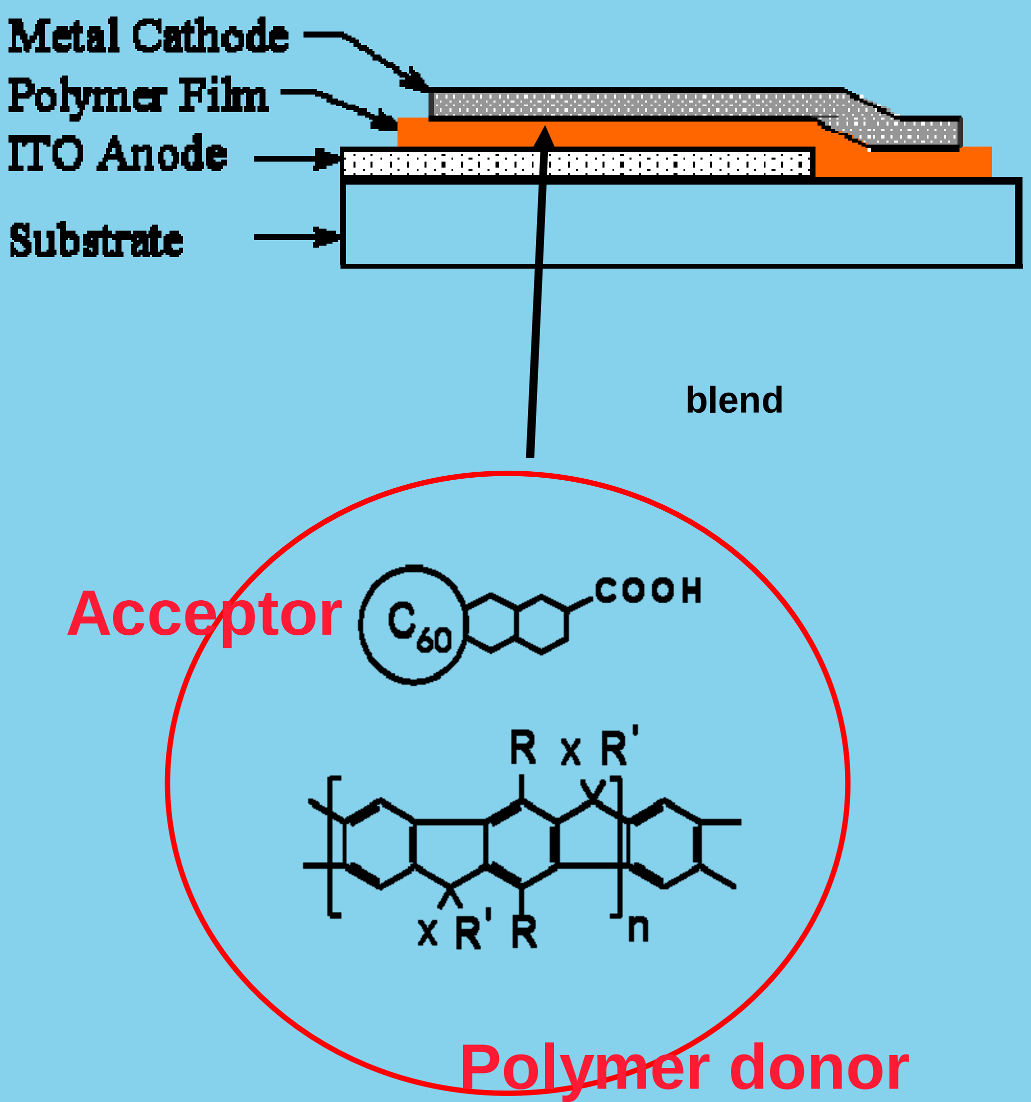
- Can Fabricate complex multilayer devices→ performances
- Relatively easy to model
- No need to make molecule soluble→performance
- Materials can be purified at high degree prior to use

Disadvantages:

- Formation of thermodinamically stable phases is kinetically limited



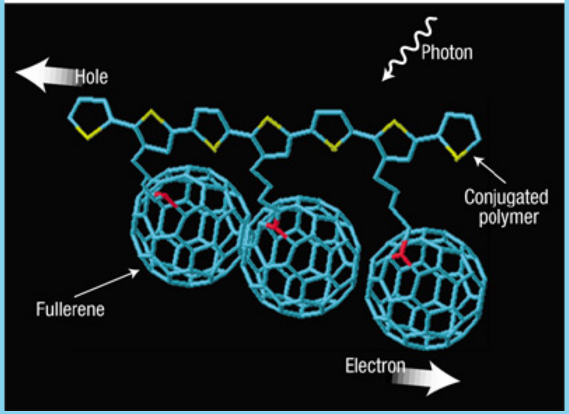
Polymer-Acceptor Solar Cells (PCE ~5%)



blend

Acceptor

Polymer donor



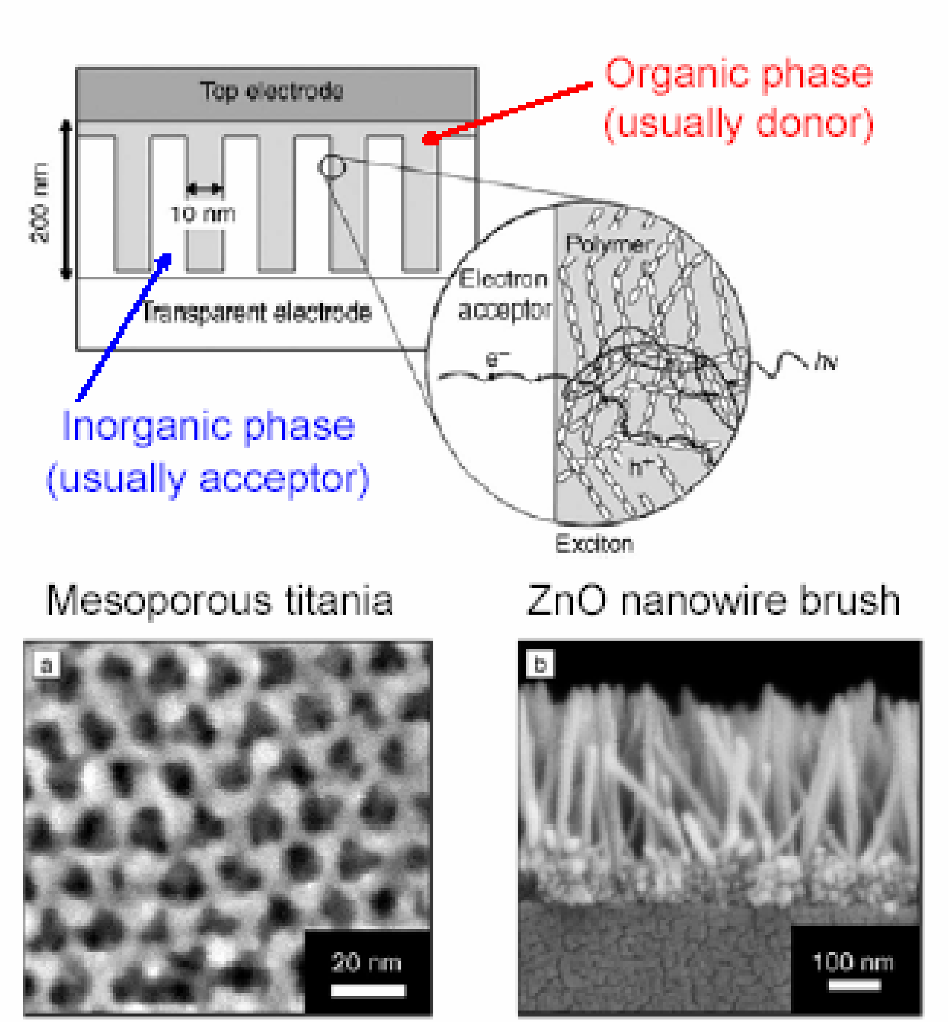
Advantages:

- Very low cost processing (roll to roll, screen printing, doctor blading, etc.)
- Morphology control by solvent choice, drying time, etc

Disadvantages:

- Materials must be designed with solubility in mind (performances degrade)

Organic-Inorganic Hybrid Solar cells



Fabrication:

- Prestructure inorganic phase using self assembly, templated growth, nanopatterning.
- Fillin with polymer

•Advantages:

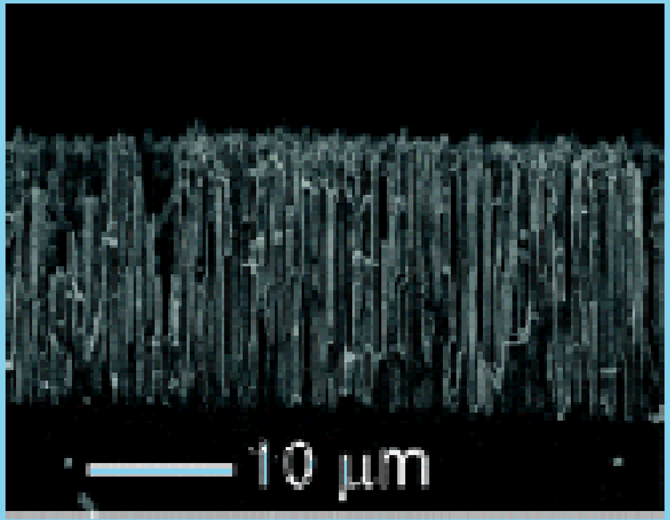
- You can lock-in geometry and design polymer without worring about morphology→optimal ordered path for carrier collection, efficient exciton diffusion
- Efficient polymer alignment→ mobility enhancement

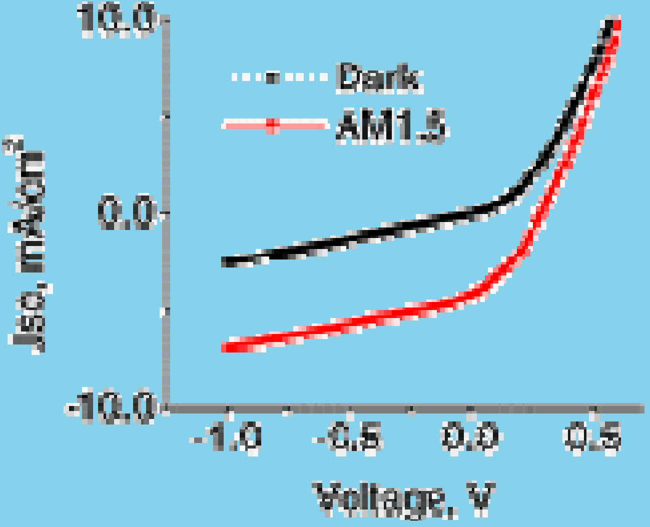
Modelling

Disadvantages:

- Hard to make precise nanostructures

Silicon Nanowire Radial p−n Junction Solar Cells





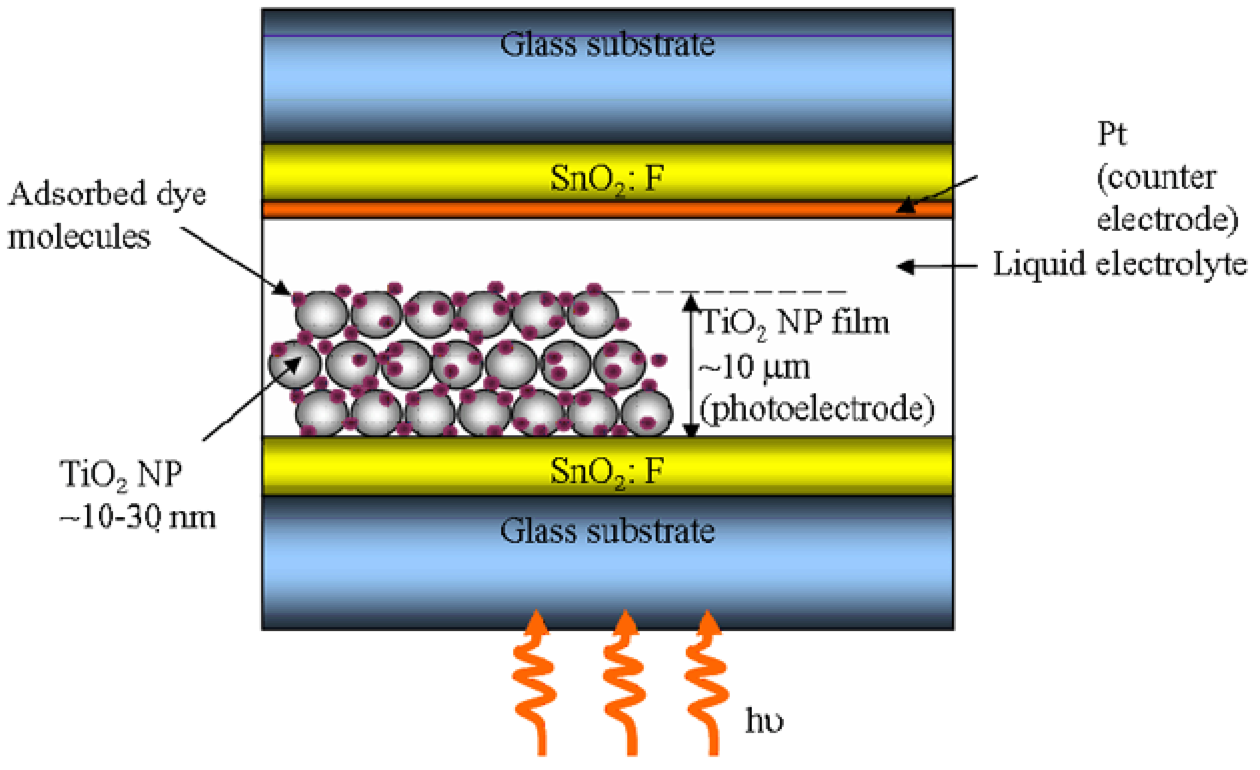
a low-temperature wafer-scale etching and thin film deposition method were demonstrated for fabricating silicon n−p core−shell nanowire solar cells. The devices showed efficiencies up to nearly **0.5%.**

J. AM. CHEM. SOC. 2008, 130, 9224-9225

Solid State Dye Sensitised (PCE ~4%)

Fabrication:

Dye on nanoporous inorganic acceptor. Hole conducting polymer replaces electrolyte



Advantages:

- High EA material (TiO_2)→ better carrier separation

Disadvantages:

- Thick devices needed→ need high carrier mobility

Polymer-Inorganic Nanocrystal Solar cells

Fabrication:

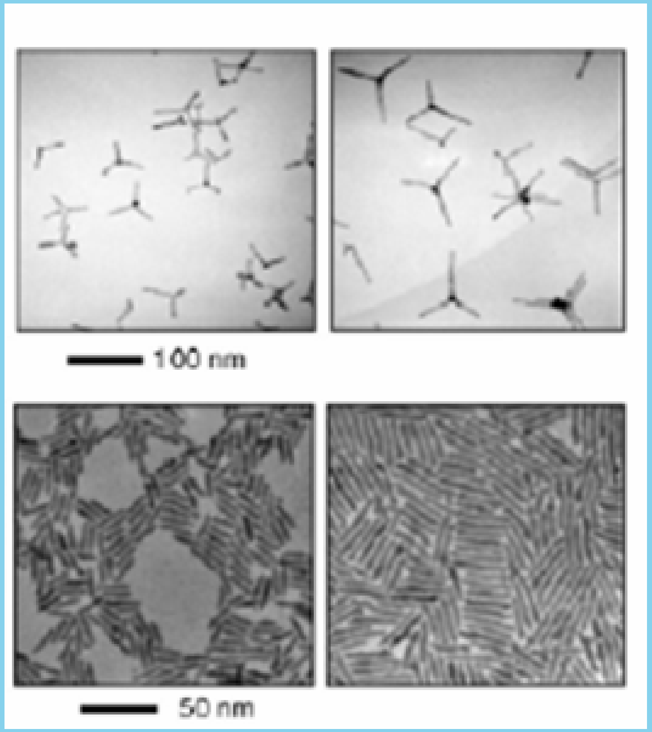
- Blend of polimer (organic) with inorganic semiconducting nanocrystal

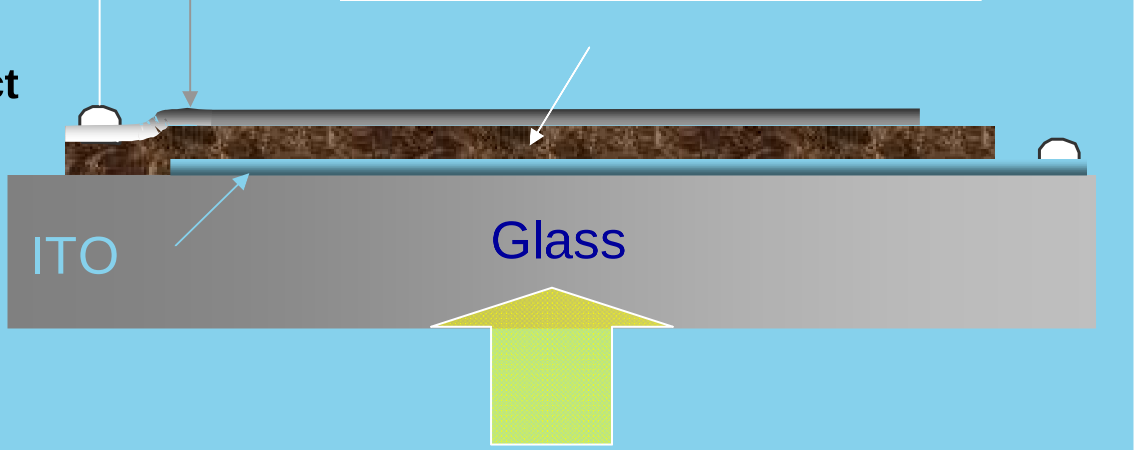
•Advantages:

- Shape control over nanoparticles
- Energy gap control
- Can cover IR wavelength
- Solution processing (cheap, flexible substrates)

Disadvantages:

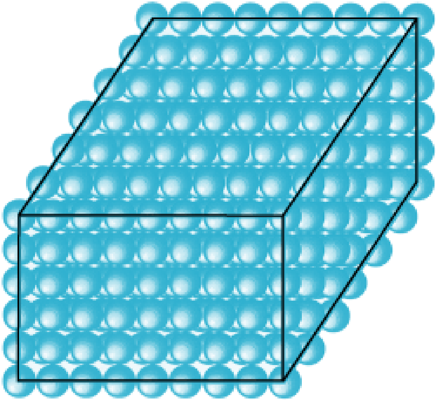
- Hard to control nanoscale morphology
- Hard to assure good Np-Np contact





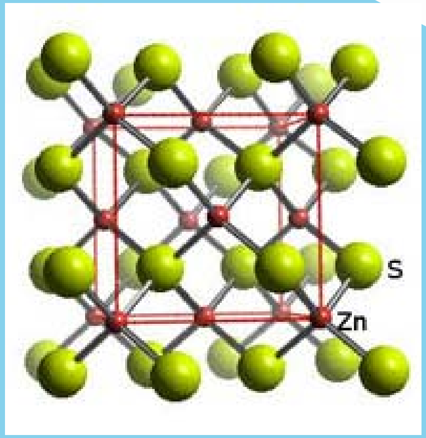
What are Nanocrystals?

BIG



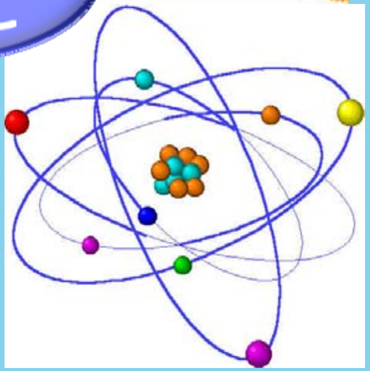
Bulk materials

SMALL



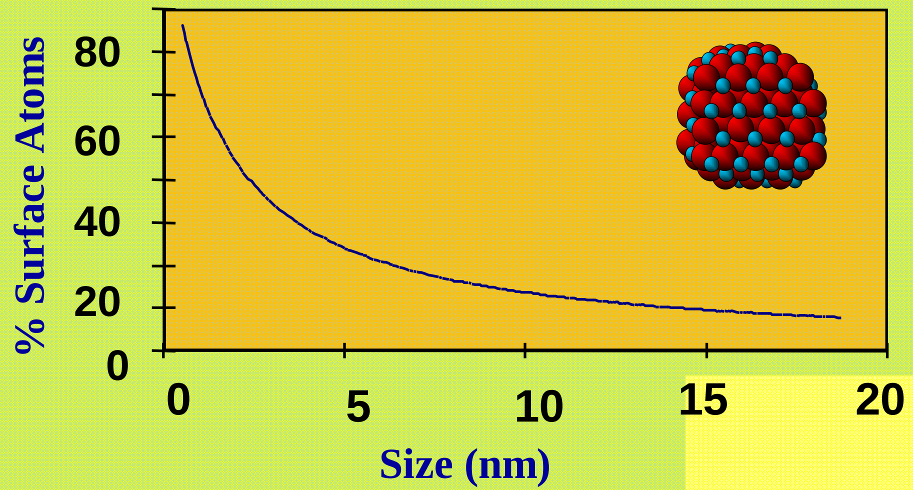
Nanocrystals

VERY SMALL

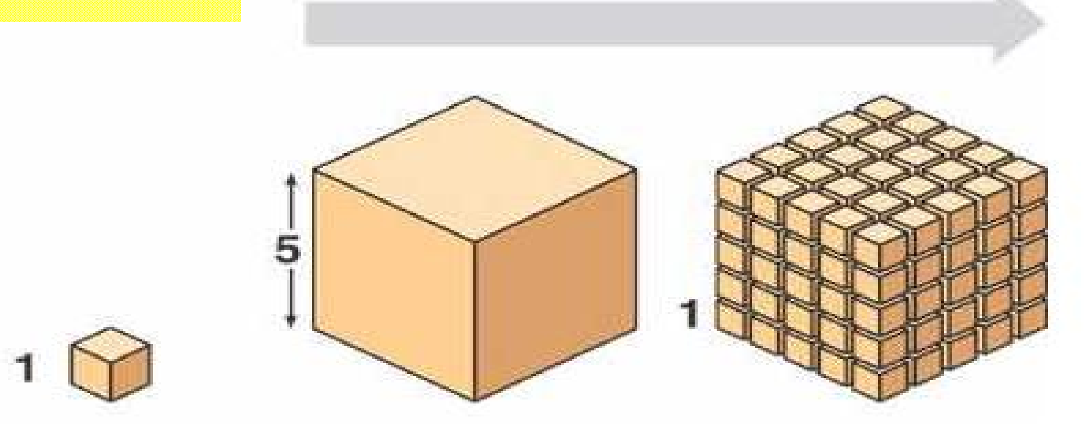


Atom

Surface/Volume Ratio



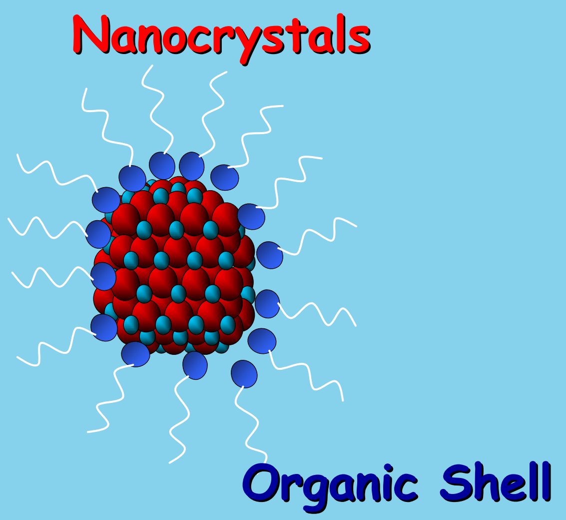
Surface area increases while total volume remains constant



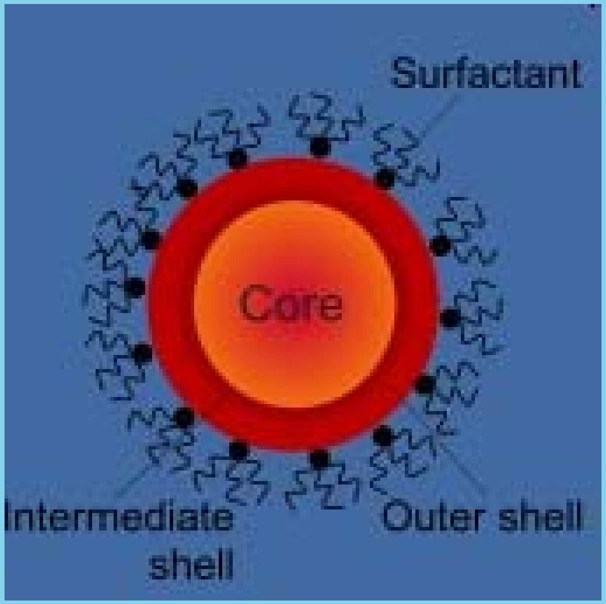
It is better to have more small objects that only a big one

Colloidal Nanocrystals

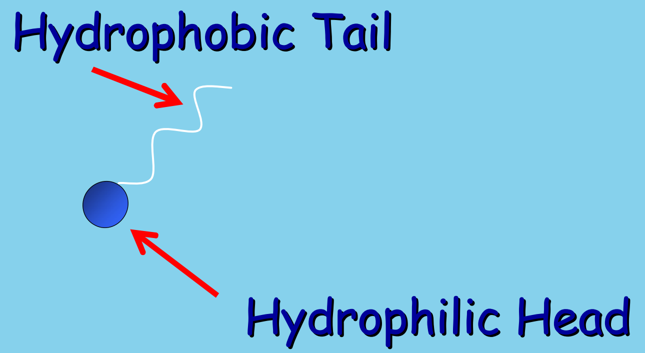
Surfactants control the size and shape of nanocrystals and allow their solubilization in organic solvents



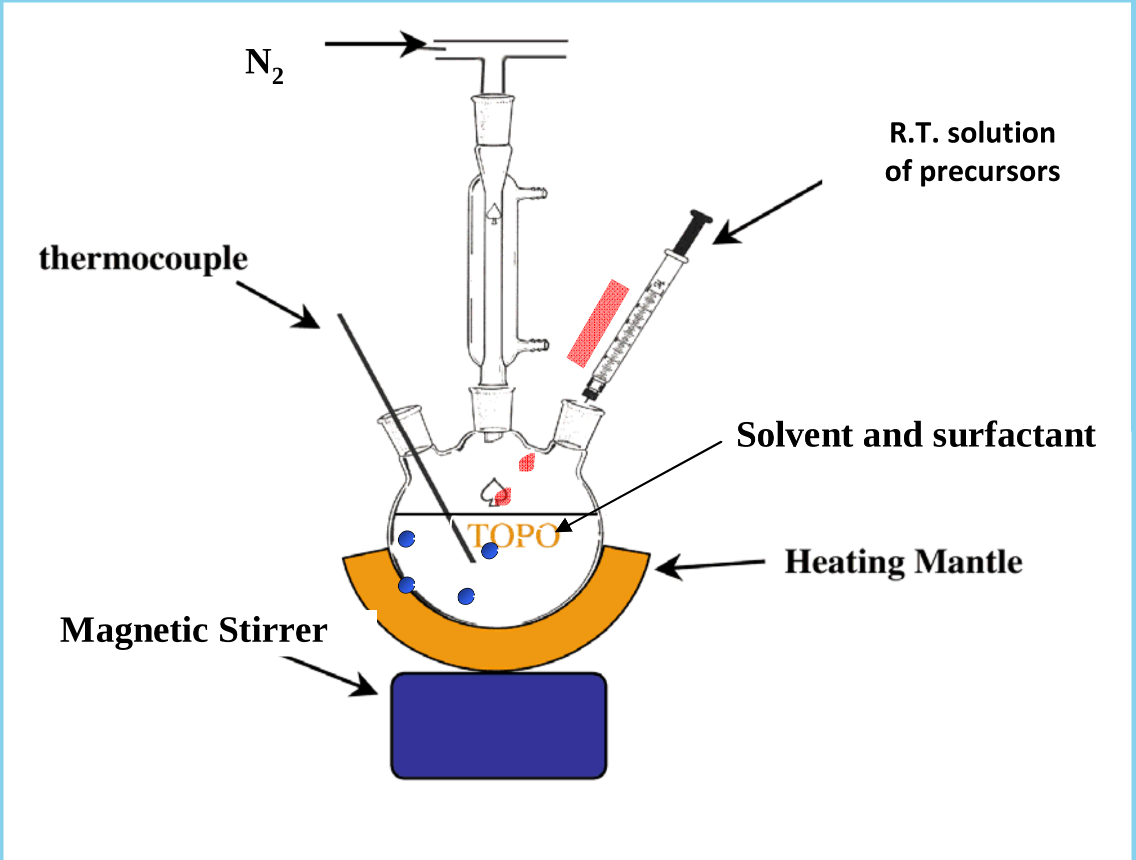
CdSe/ZnS



Surfactants

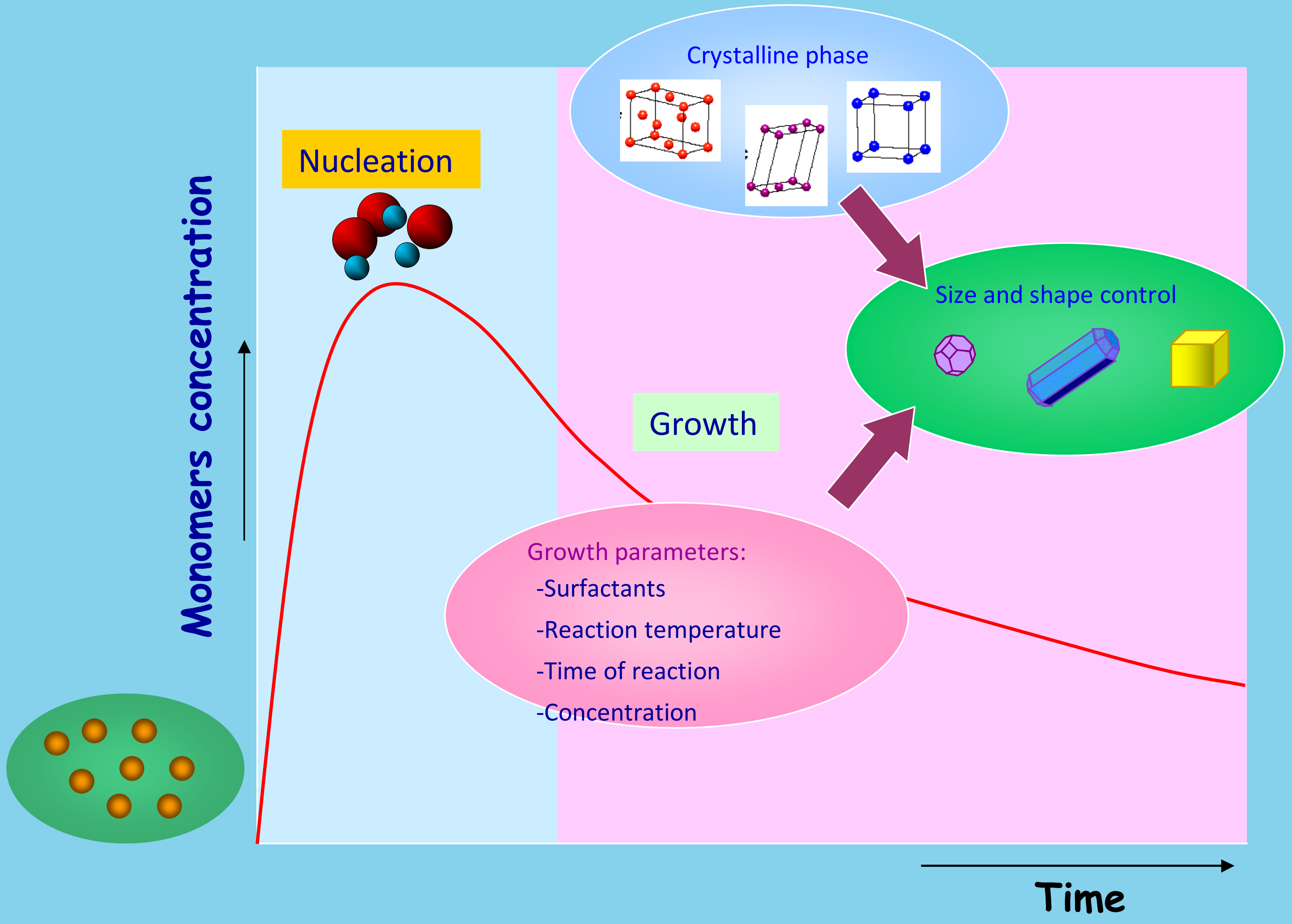


Synthesis of Colloidal Nanocrystals



The nanocrystals are synthetized by the
"HOT-INJIECTION" TECHNIQUE
that is based on the high temperature reaction of molecular precursor in the presence of coordinating organic molecules as dynamic templates for nanocrystal growth.

Synthesis of Colloidal Nanocrystals



Crystalline phase

Nucleation

Size and shape control

Growth

Growth parameters:

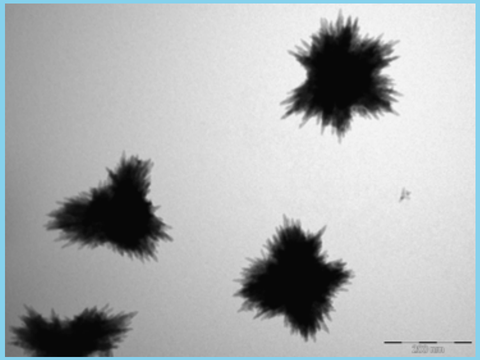
- -Surfactants
- -Reaction temperature
- -Time of reaction
- -Concentration

Growth mechanism

The Shape of Nanocrystals

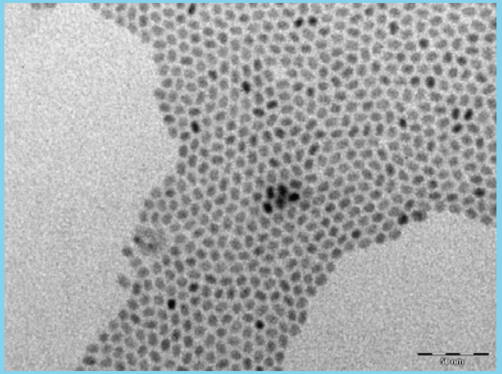
CdSe Nanocrystals

Hyperbranched

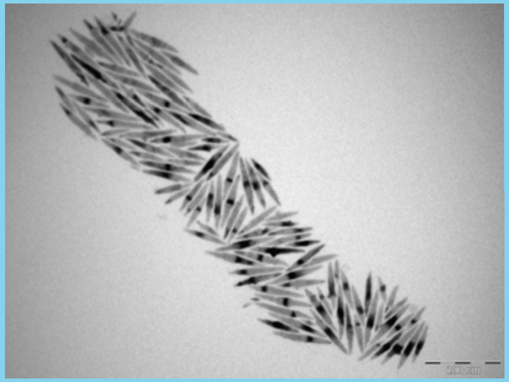


Same
materials
but
different
shapes

Dots



Rods



Synthesis of Colloidal Nanocrystals

Seeded Growth Approach

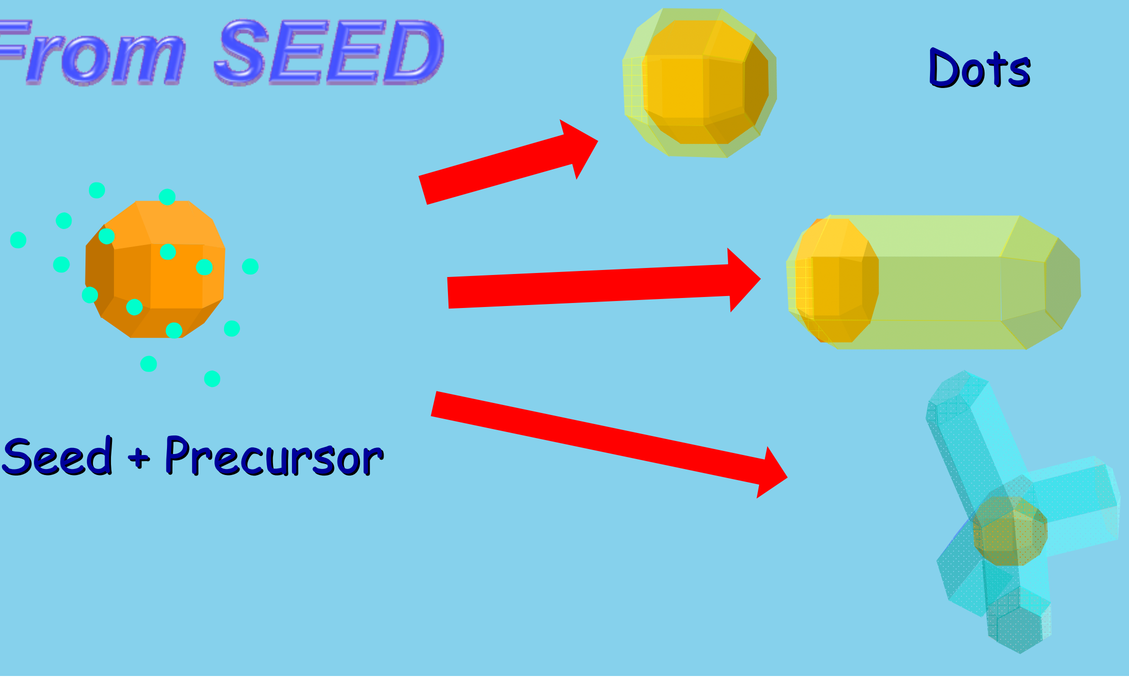
Separation of nucleation and growth

Advantages:

- Different shape
- Different combination of material (Heterostructure)
- Narrow distribution of length and diameter

To HETEROSTRUCTURE

From SEED



Dots

Rods

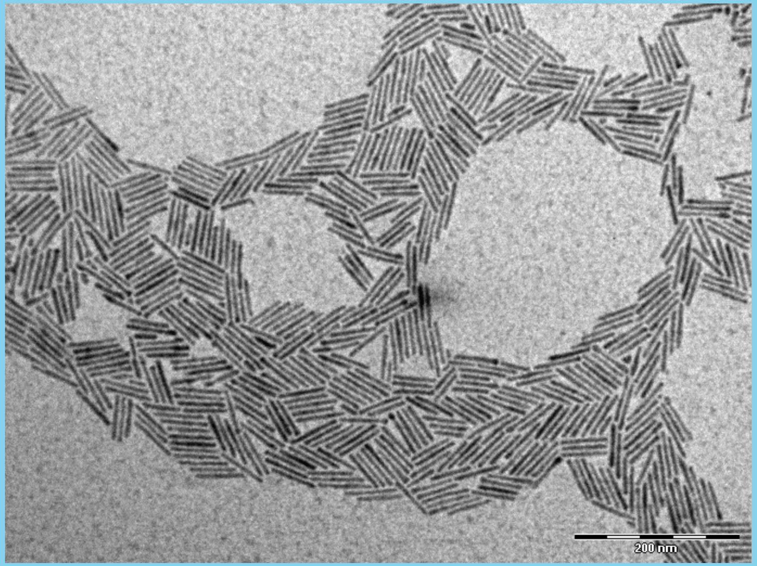
Tetrapods

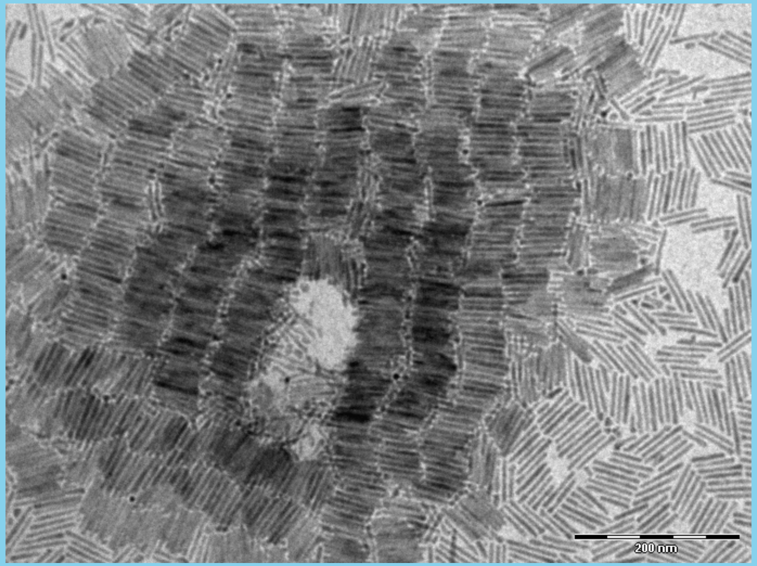
Seed + Precursor

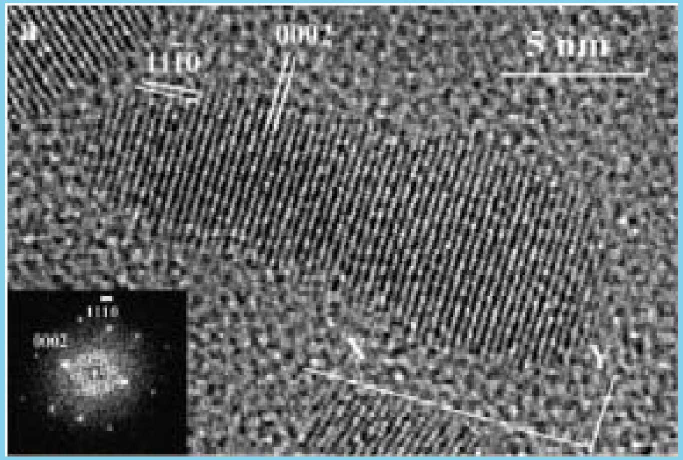
CdSe/CdS heterostructures

Tem Image

CdSe/CdS Rods

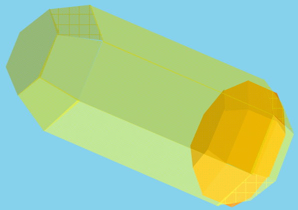


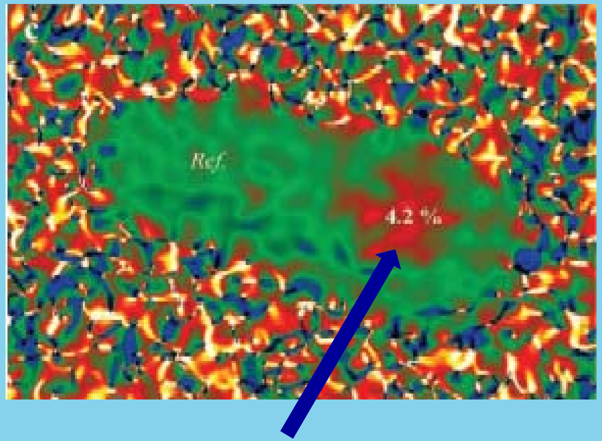




Carbone et al. Nanoletters, 2007

HRTEM

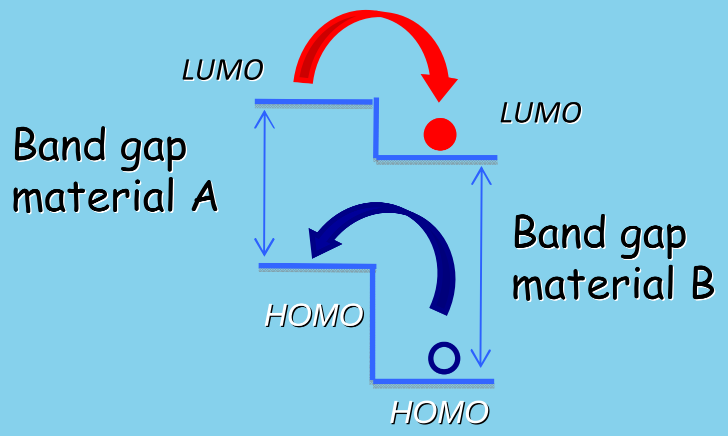




Altered lattice parameters

New type II heterostructures

A type II colloidal heterostructure consists of semiconductor materials where both the valence and conduction Band in the core are lower (or Higher) than in the shell



● ELECTRON

○ HOLE

Charge separation can occur at the interface between the two semiconductor materials

New type II heterostructures

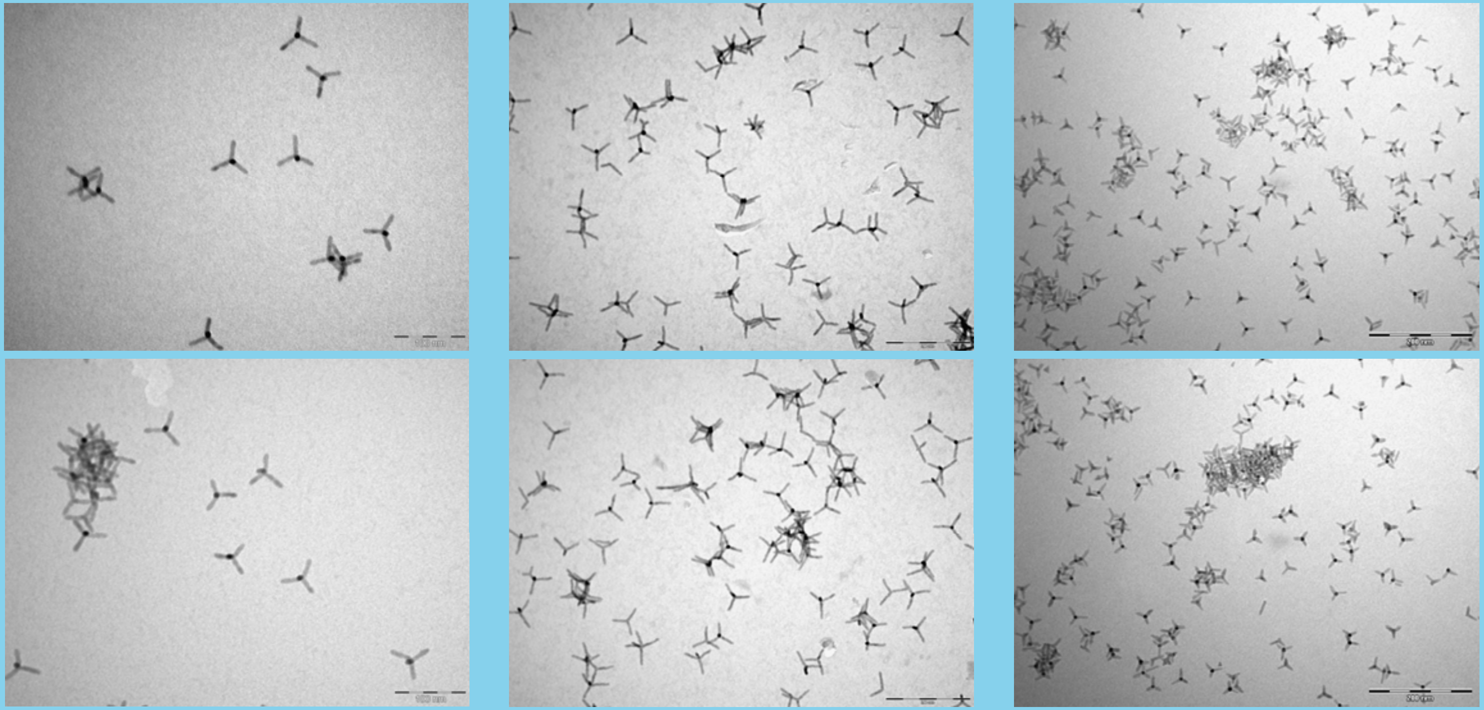
Tem Image

Tetrapods

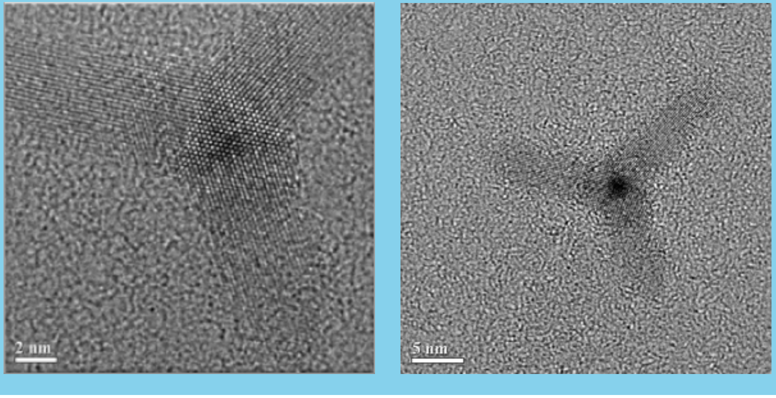
CdSe/CdTe

ZnTe/CdTe

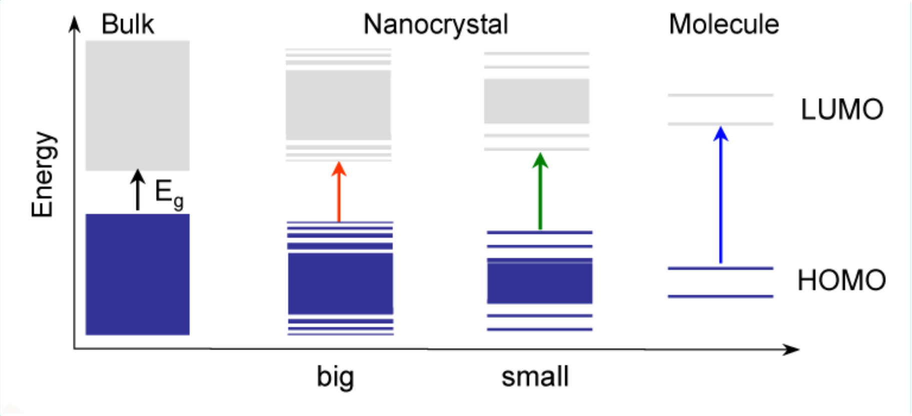
ZnTe/CdS



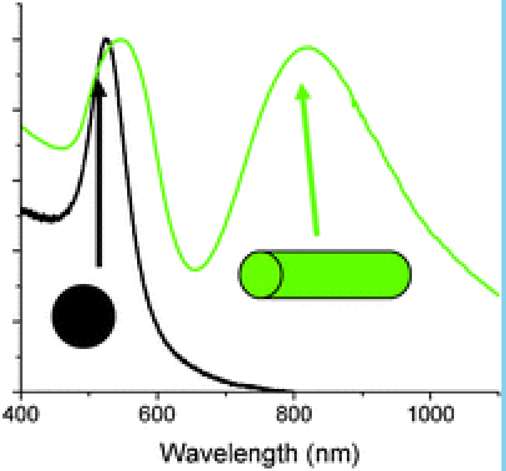
HRTEM



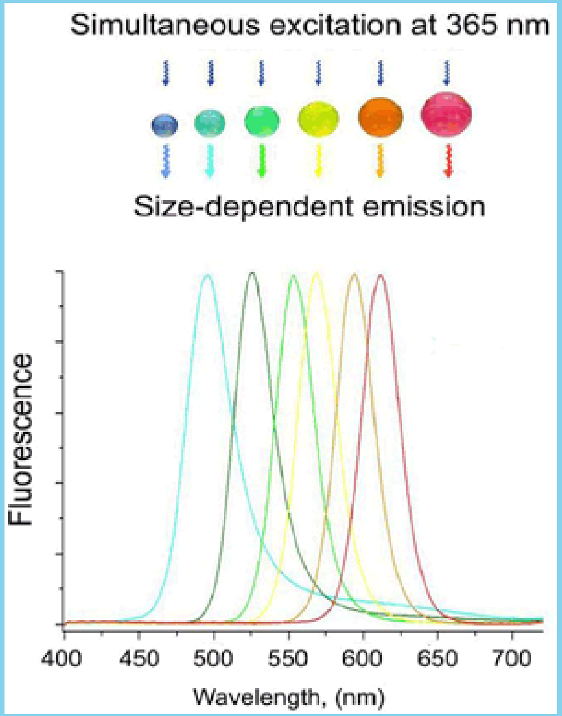
Optical Properties tuning

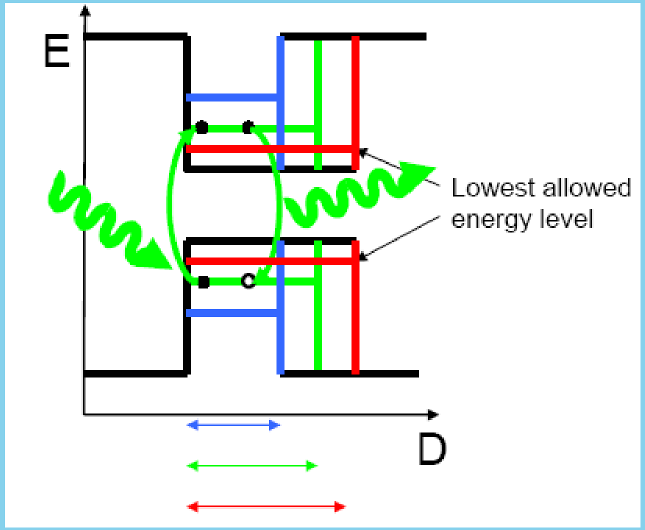


Size dependent band gap



Shape dependent band gap



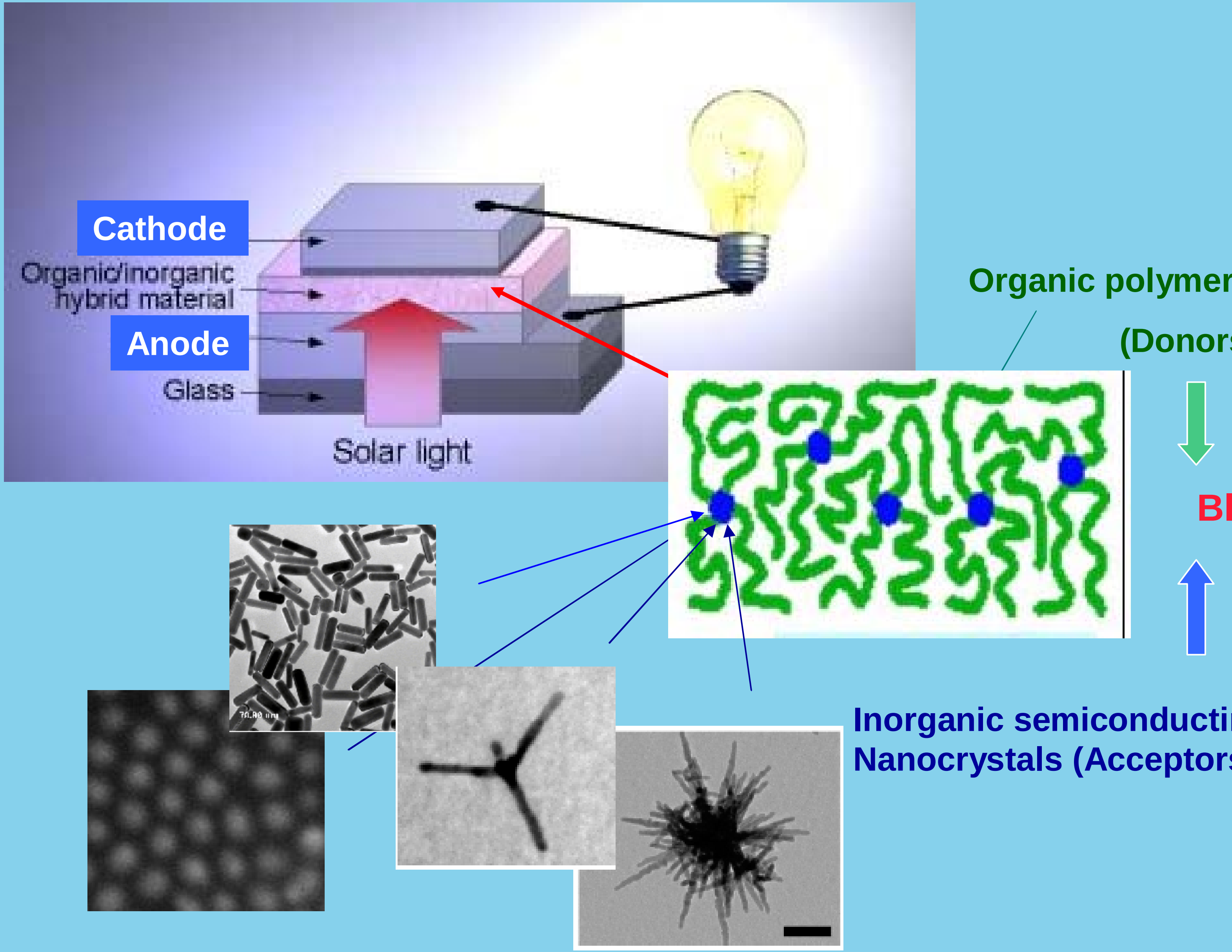


Quantum Dots size

$$E_g(R) = E_g^b + \frac{\hbar^2 \pi^2}{2\mu R^2}$$

$$E_{l,n}^{e,h} = \frac{\hbar^2 \rho_{n,l}^2}{2m_{e,h}^* R^2}$$

Organic-inorganic semiconducting NCs Hybrid SCs



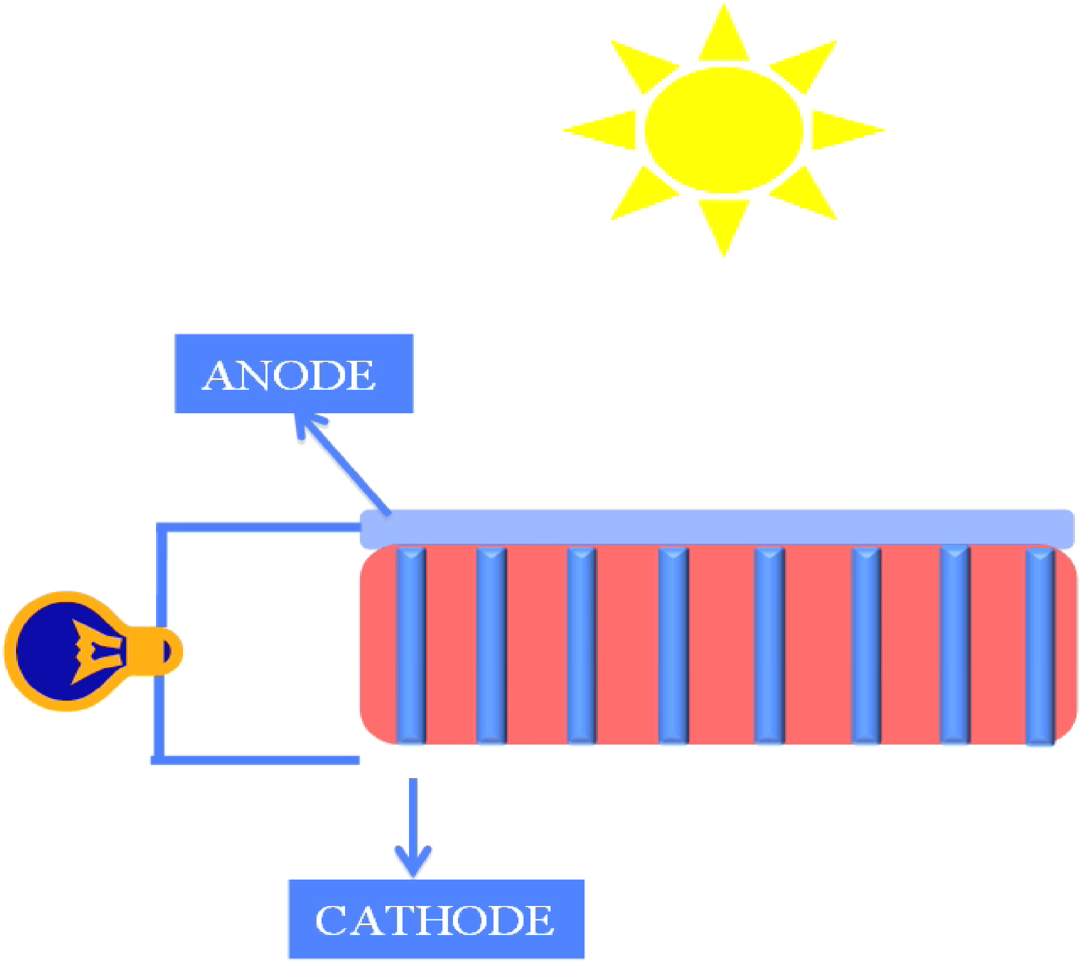
Organic polymers

(Donors)

Blend

Inorganic semiconducting Nanocrystals (Acceptors)

How an Hybrid Solar Cell Works



Process

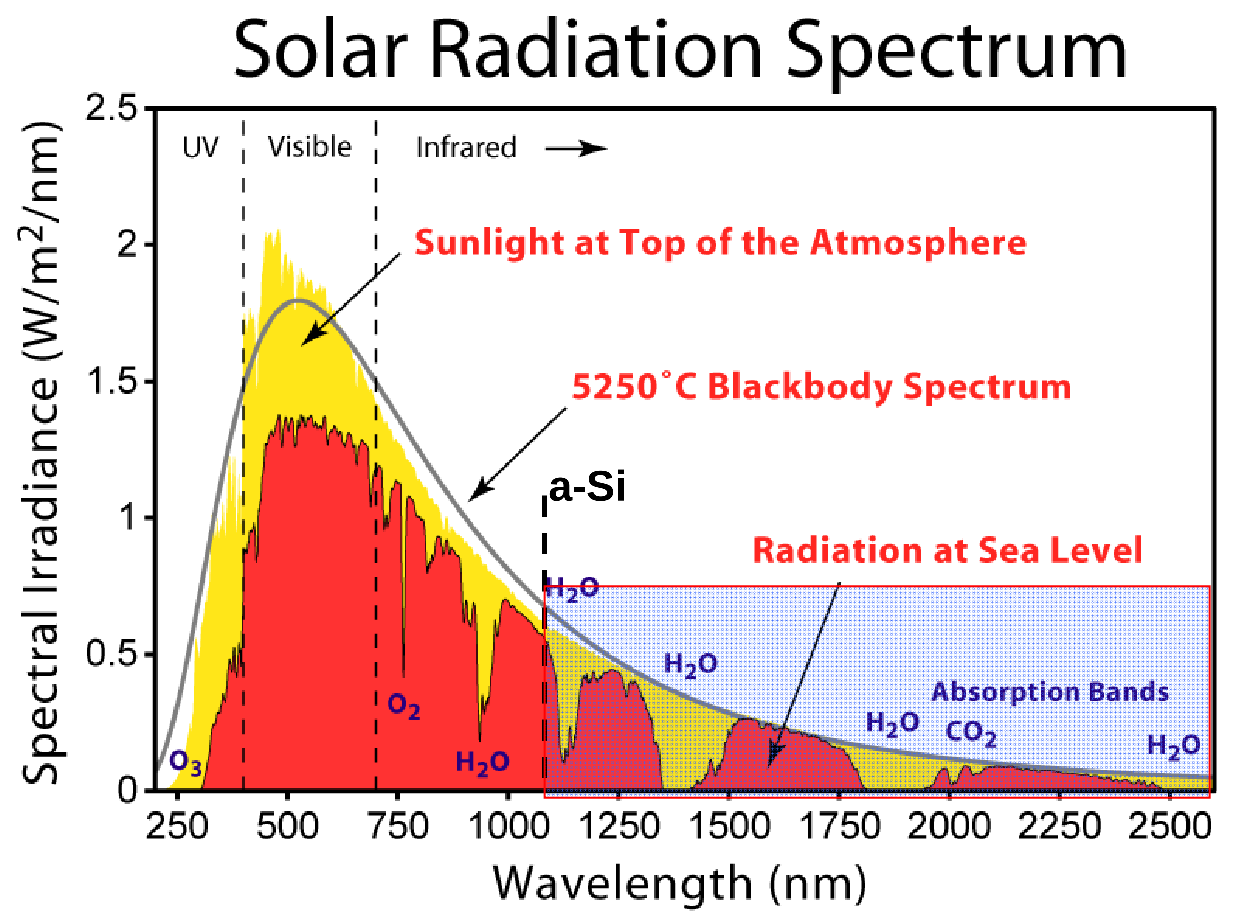
Absorption

Exciton Diffusion

Exciton Dissociation

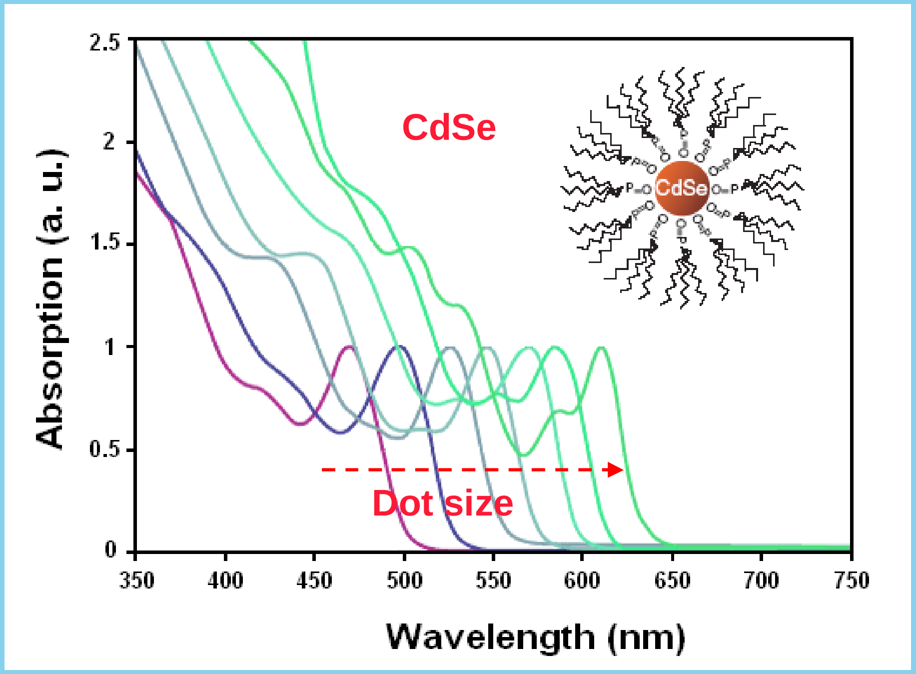
Charge Transport

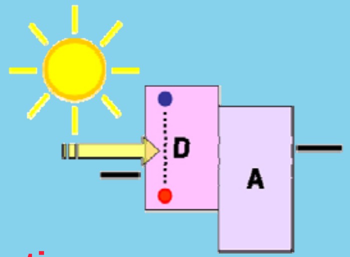
Charge collection



TOA irradiance: amount of global horizontal radiation that a location would receive if there was no atmosphere or clouds. It resembles closely that of a black body at 5250°. SL irradiance: TOA attenuated by scattering from molecules, aereosol, dust particles as well as absorption .PV

Blend Polymer+NCs

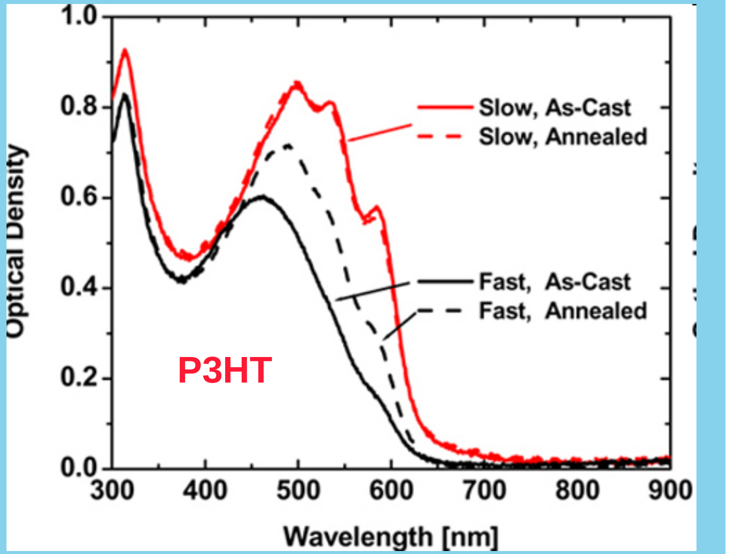




Polymer:

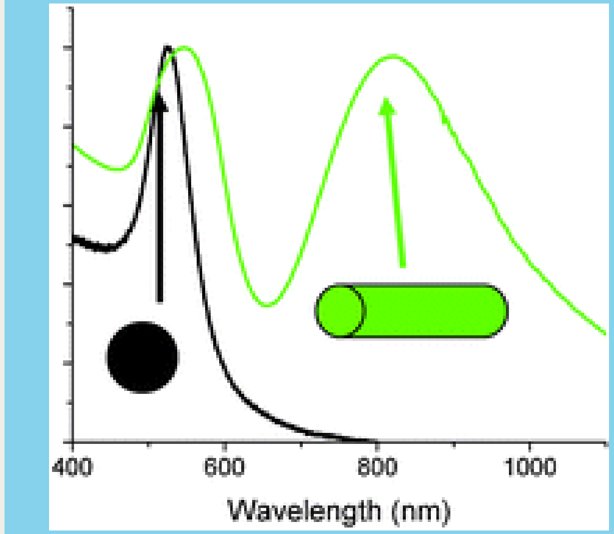
UV–Visible Absorption

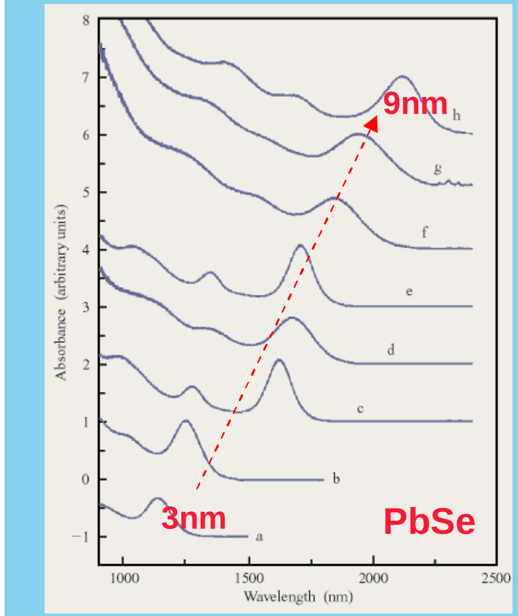
High extinction coefficient → thin films (80-200nm)



Inorganic Sem.Nanocrystals:

Energy band gap tuning by changing material, size and shape → IR absorption

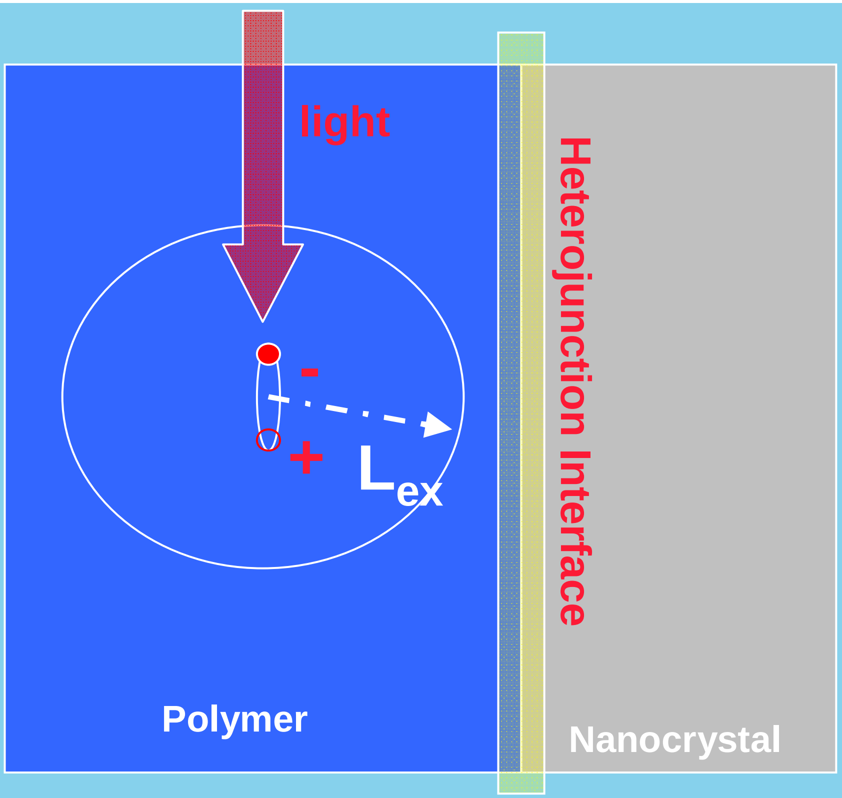




η_A= Photon Absorption Yield (optical absorption coeff and Thickness)

Process

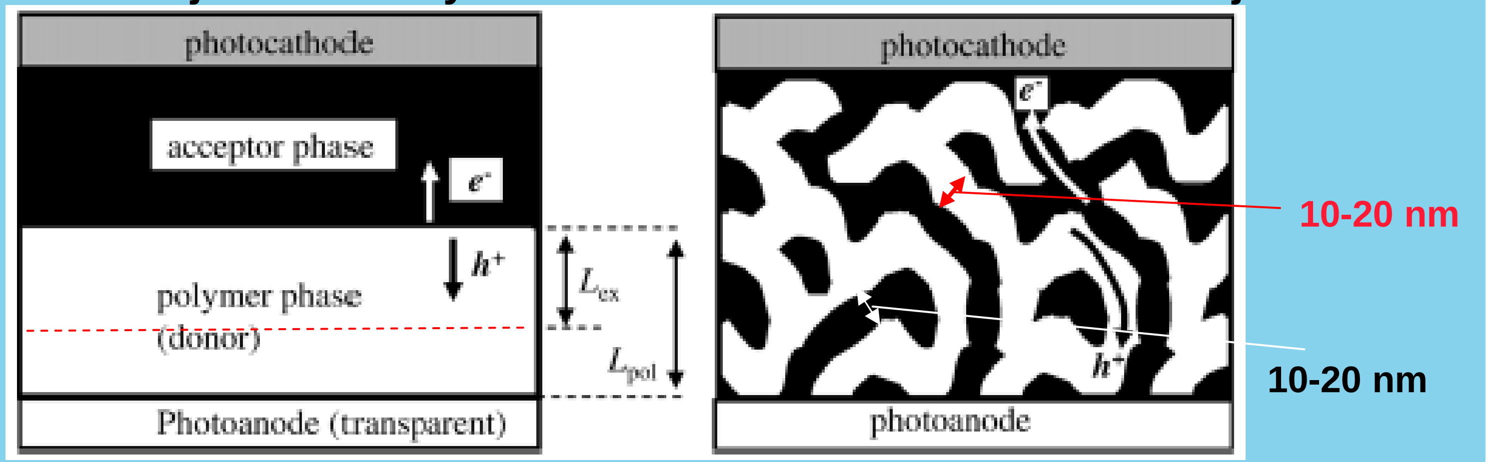
- Absorption
- Exciton Diffusion
- Exciton Dissociation
- Charge Transport
- Charge collection



L_{ex}= Exciton diffusion length (typical in polymer 10-20 nm)

Excitons generated at a distance more than L_{ex} away from the interface tend to radiatively recombine before dissociation

If $L_{ex} > L_{pol}$ (average polymer phase domain size) exciton can reach the interface

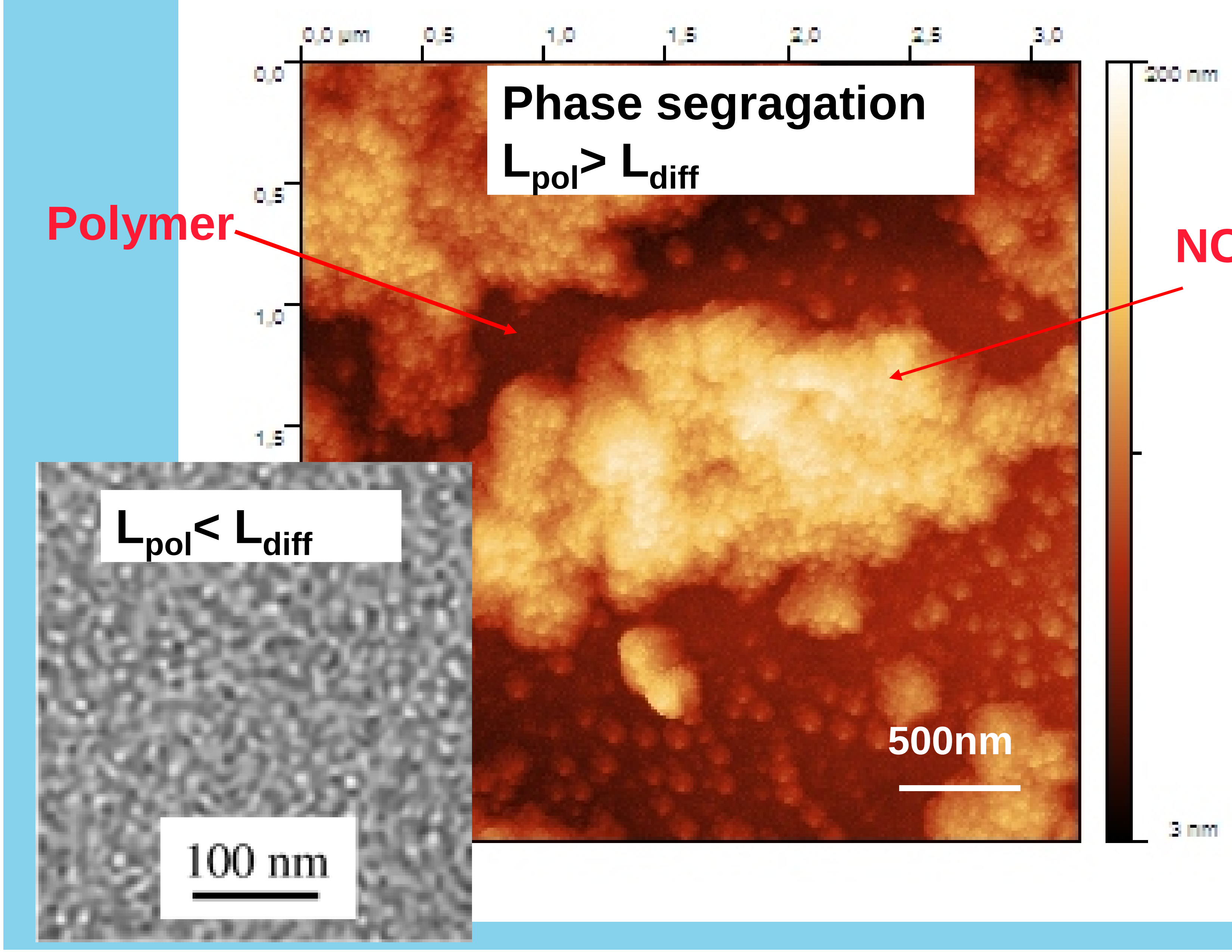

Heterojunction bilayer

Nanometric Bulk heterojunction

η_{diff}= **Exciton diffusion Yield**

(ability of exciton to diffuse through the polymer without recombination (loss)

Bulk Heterojunction



Phase segragation

$L_{pol} > L_{diff}$

Polymer

NCs

$L_{pol} < L_{diff}$

Process

Absorption

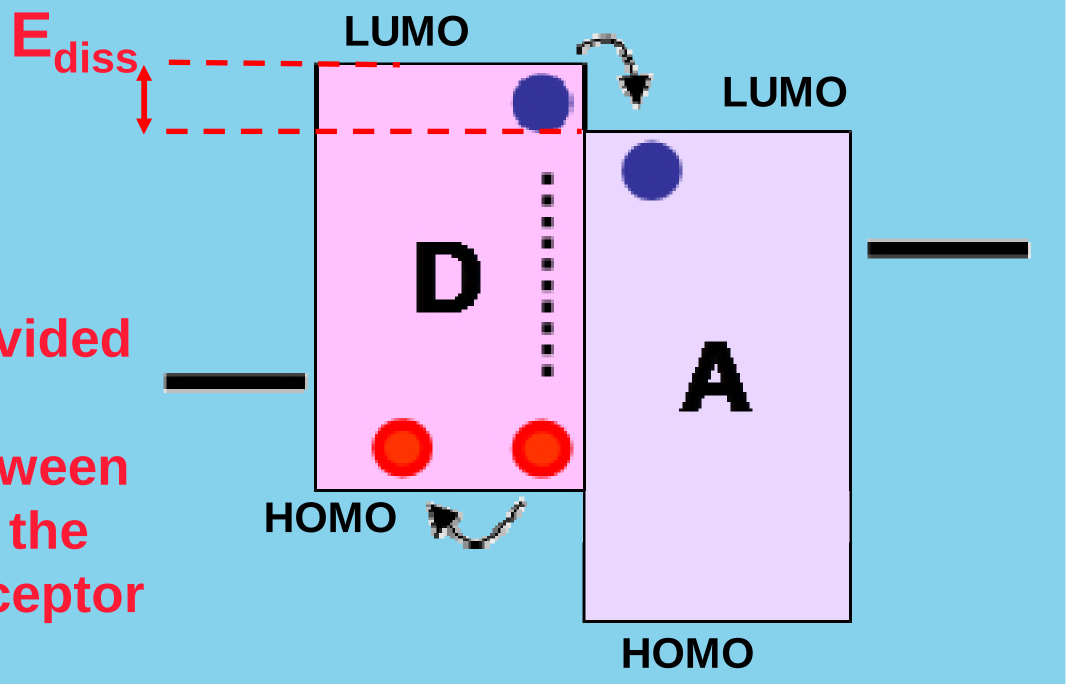
Exciton Diffusion

Exciton Dissociation

Charge Transport

Charge collection

(Frenkel) Exciton Binding Energy in Organics (0.4-0.6eV) are much higher than Wannier-Mott Exciton BE in inorganic bulk semiconductors (~meV). Thermal energy is not sufficient for Energy dissociation

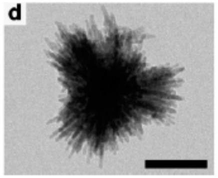


The energy required to separate the exciton is provided by the energy difference between the LUMOs of the donor and acceptor

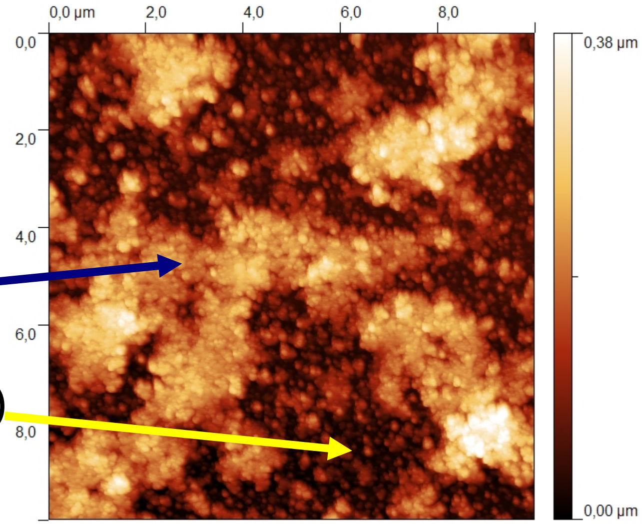
η_{diss} = Exciton dissociation Yield

Probability that the hole and the electron will be separated by the internal electric field at the interface

Scanning Kelvin Force Microscopy (SKFM) on hybrid solar cells: P3HT-CdSe hyperbranched nanocrystal

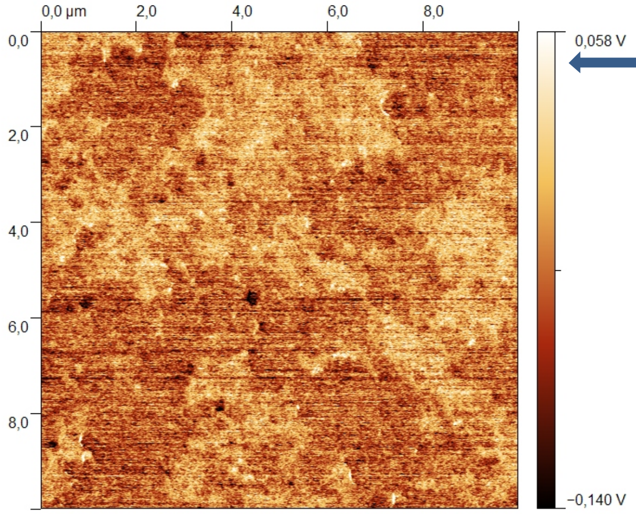


Topography of P3HT-CdSe nanocrystals: it revelas nanocrystal aggregates of the electron acceptor (A; CdSe) embedded into a matrix of the electron donor (D; P3HT)



The Skfm technique allows the determination of the local surface potential of nanostructured materials in a non invasive way detecting the electrostatic-force interaction between the tip and the sample

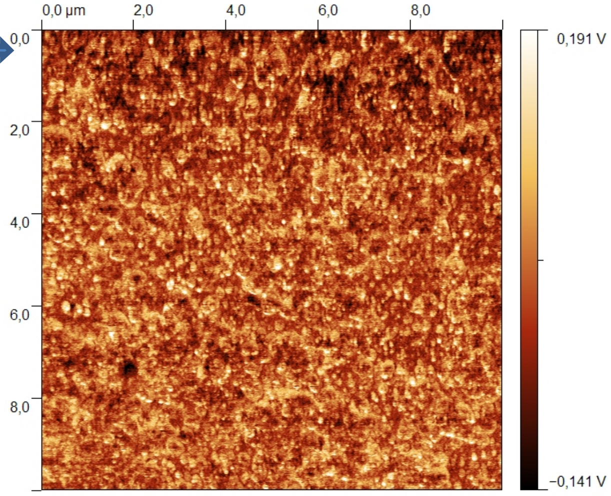
Light on



Surface potential

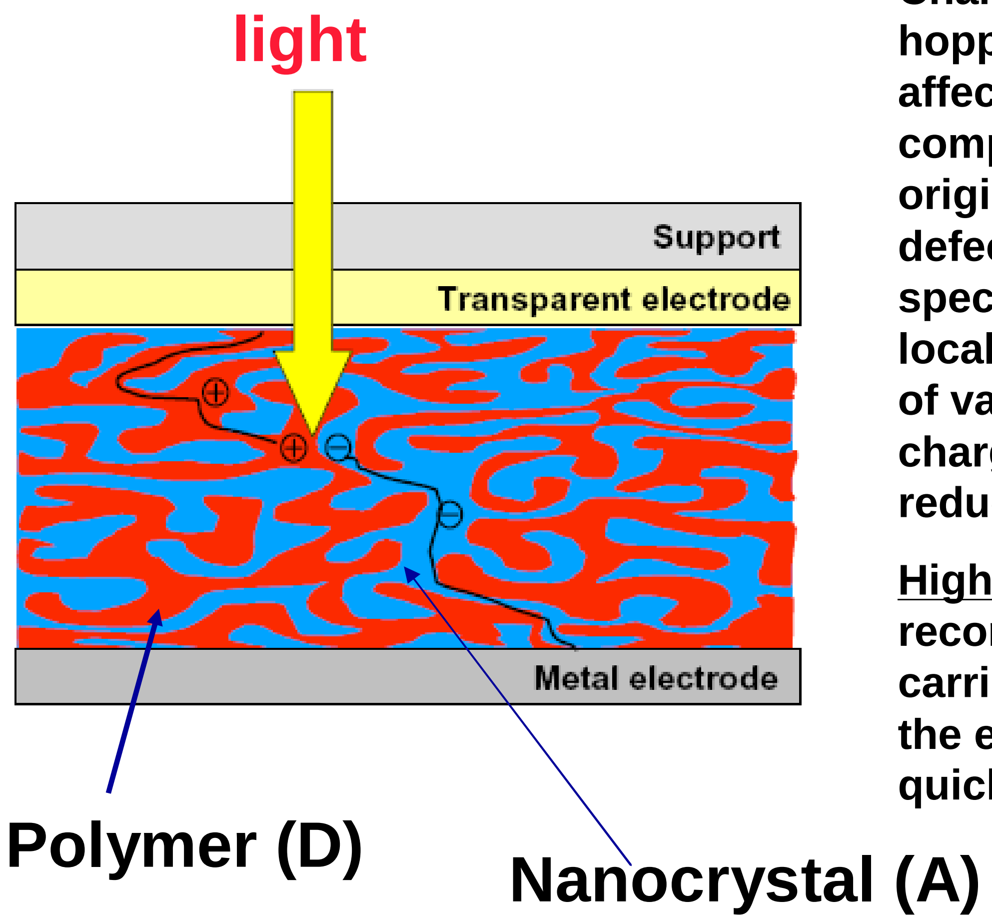
The contrast enhancement demonstrates that photogenerated excitons are split at the interface between the two materials, leading to the accumulation of the electrons in CdSe nanocrystals and holes in the P3HT polymer matrix

Light off



Process

- Absorption
- Exciton Diffusion
- Exciton Dissociation
- Charge Transport
- Charge collection



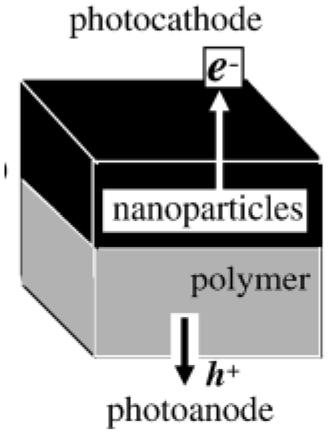
Charge transport involves hopping processes and is affected by traps in the composite film. Traps originate from structural defects or impurity species, They provide localised energy minima of variable depth for charge transport which reduce mobility.

High mobilities minimise recombination losses, carriers are trasported to the electrodes more quickley

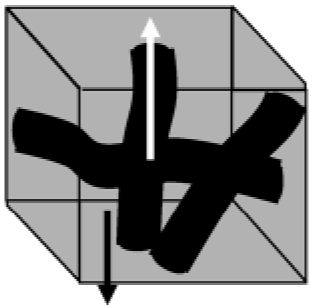
Needs: Percolation network, High mobilities

η_{ct} = **Charge Carrier transport Yield**

Carrier transport in bulk heterojunction structures

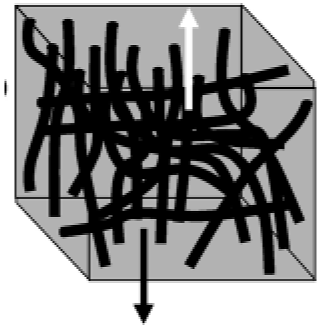


$L_{pol} >> L_{ex}$



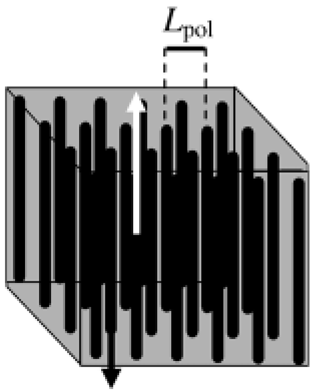
$L_{pol} > L_{ex}$

Interconnected with sustantial aggregation

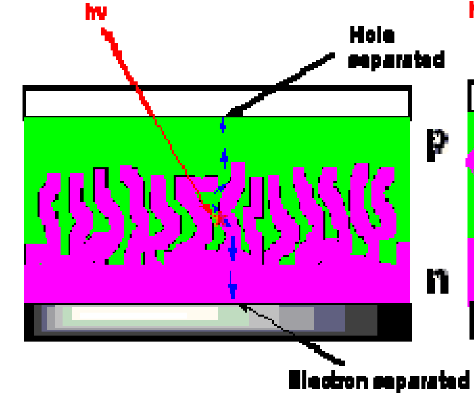


$L_{pol} < L_{ex}$

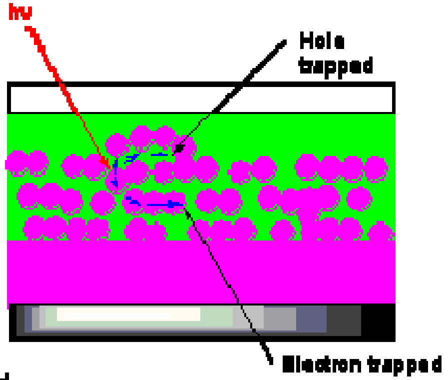
Interconnected with minimal aggregation



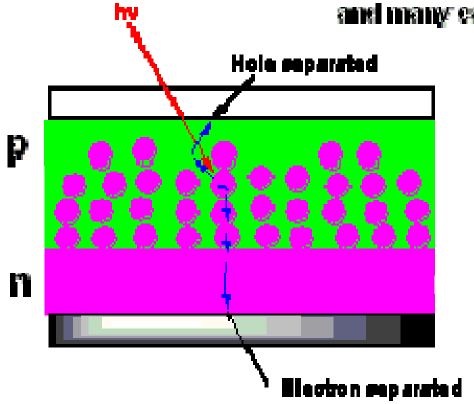
$L_{pol} < L_{ex}$



Segregated interpenetrating network



Interpenetrating network with no percolating paths
and many carrier traps



Interpenetrating network with percolating paths

Loss mechanism: Charge Recombination
Solution: Interpenetrating network and good Percolating paths

Process

Absorption

↓

Exciton Diffusion

↓

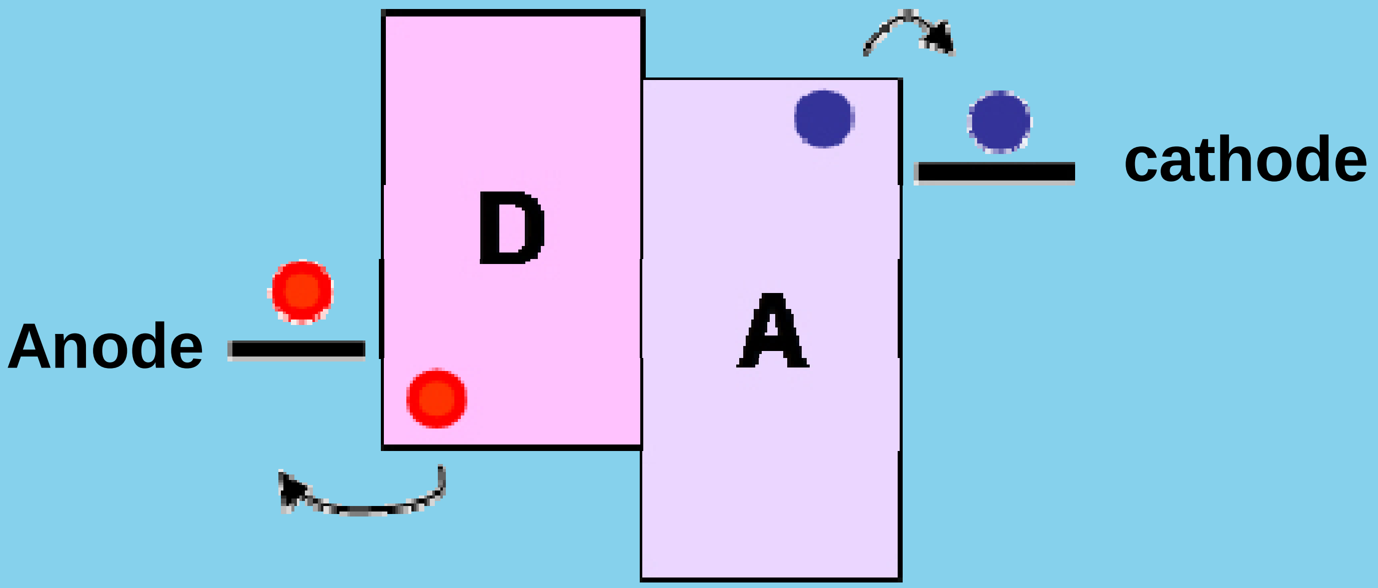
Exciton Dissociation

↓

Charge Transport

↓

Charge collection



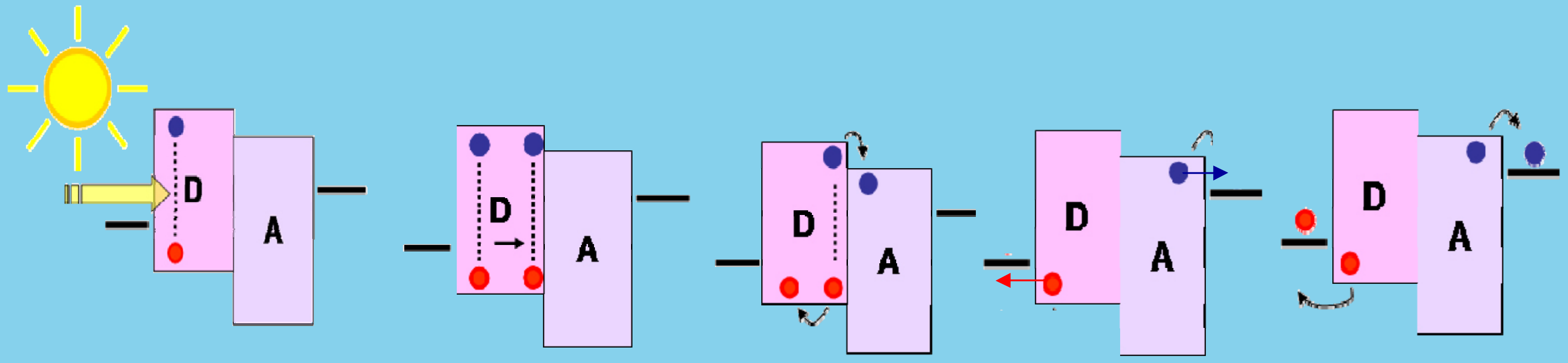
High η_{cc} can occur when a) the Fermi level of the anode is higher then the Donor HOMO energy; b) the acceptor LUMO energy is higher than the Fermi level of the cathode

η_{cc} = Charge collection Yield

Ability of the charges to be trasferred from the photoactive layer to the electrodes

The external quantum efficiency EQE

It's defined as the number of the electrons flowing in the external circuit per photon incident on the PV cell.



Light Absorption

Exciton Diffusion

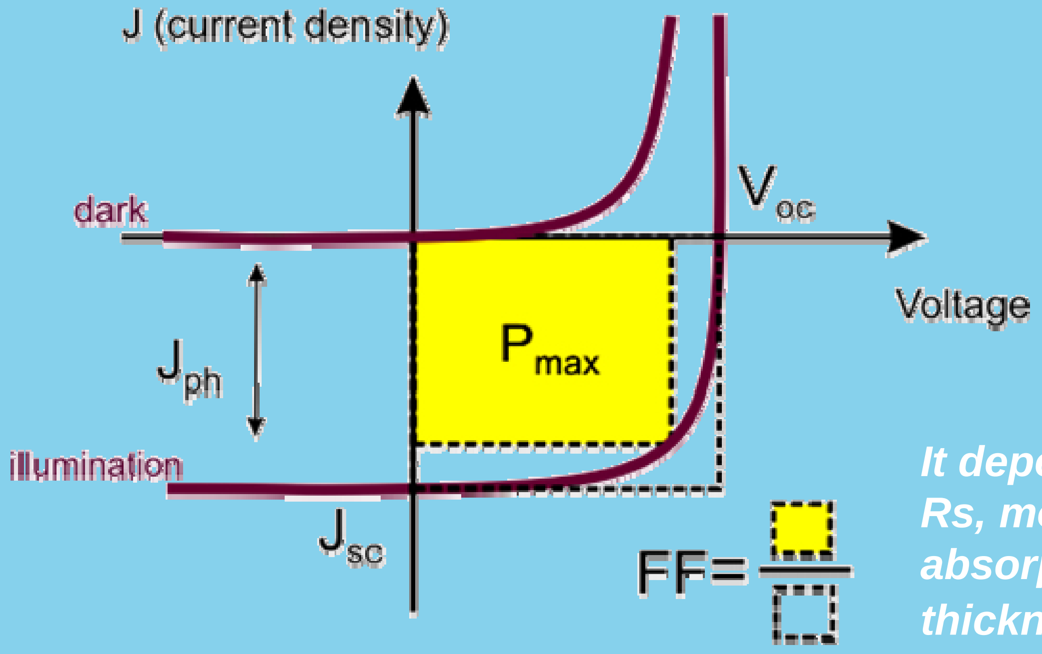
Exciton dissociation

Charge transfer

Charge Collection

$$\eta_{EQE}(\lambda,V)=\eta_A(\lambda)\cdot\eta_{diff}\cdot\eta_{diss}(V)\cdot\eta_{ct}(V)\cdot\eta_{cc}(V)$$

Solar cell efficiency and its light power dependence



It depends on *the difference between worfunction of electrodes (pedot and Al), as well as on the difference between NCs LUMO and Polymer HOMO*

It depends on the Rs, mobility, absorption, thickness

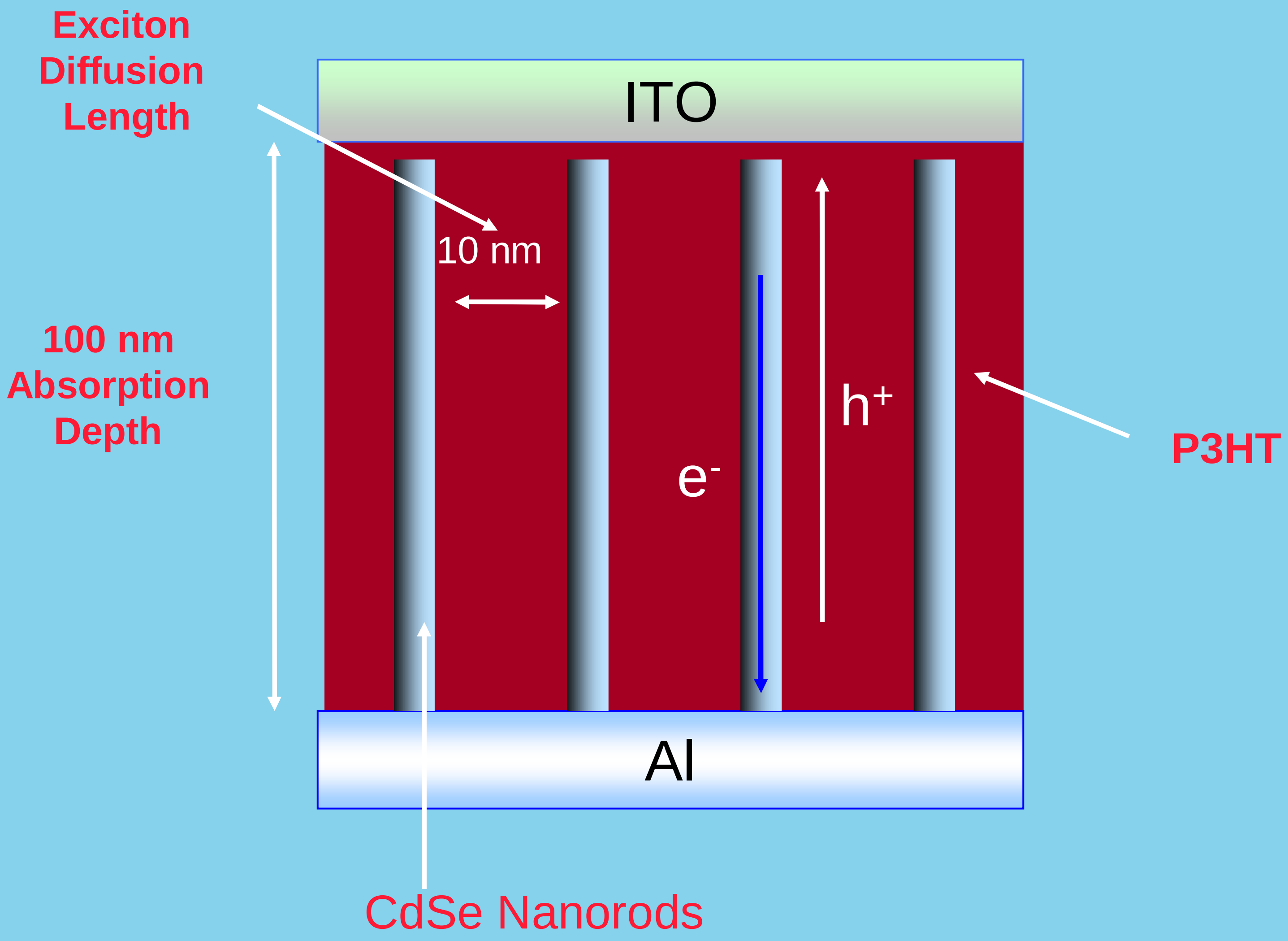
It depends by *Rs* and *Rp* *(mobility, ITO)*

$$\eta_P = \frac{J_{SC} \cdot V_{OC} \cdot FF}{P_0}$$

$$V_{OC} = \frac{nkT}{q} \ln\left[\frac{-J_{Ph}(V_{OC})}{J_S} + 1\right] \approx \frac{nkT}{q} \ln\left(\frac{J_{SC}}{J_S} + 1\right)$$

$$J(V) = J_s\left\{\exp\left[\frac{q(V - JR_S)}{nkT}\right] - 1\right\} + P_O R_0 \eta_{CC}(V),$$

Ideal nanocrystal-polymer solar cells



How to improve efficiency of hybrid solar cells

some general rules for preparing efficient hybrid solar cells

I. **High electron and hole mobilities for NCs and polymers, respectively.**

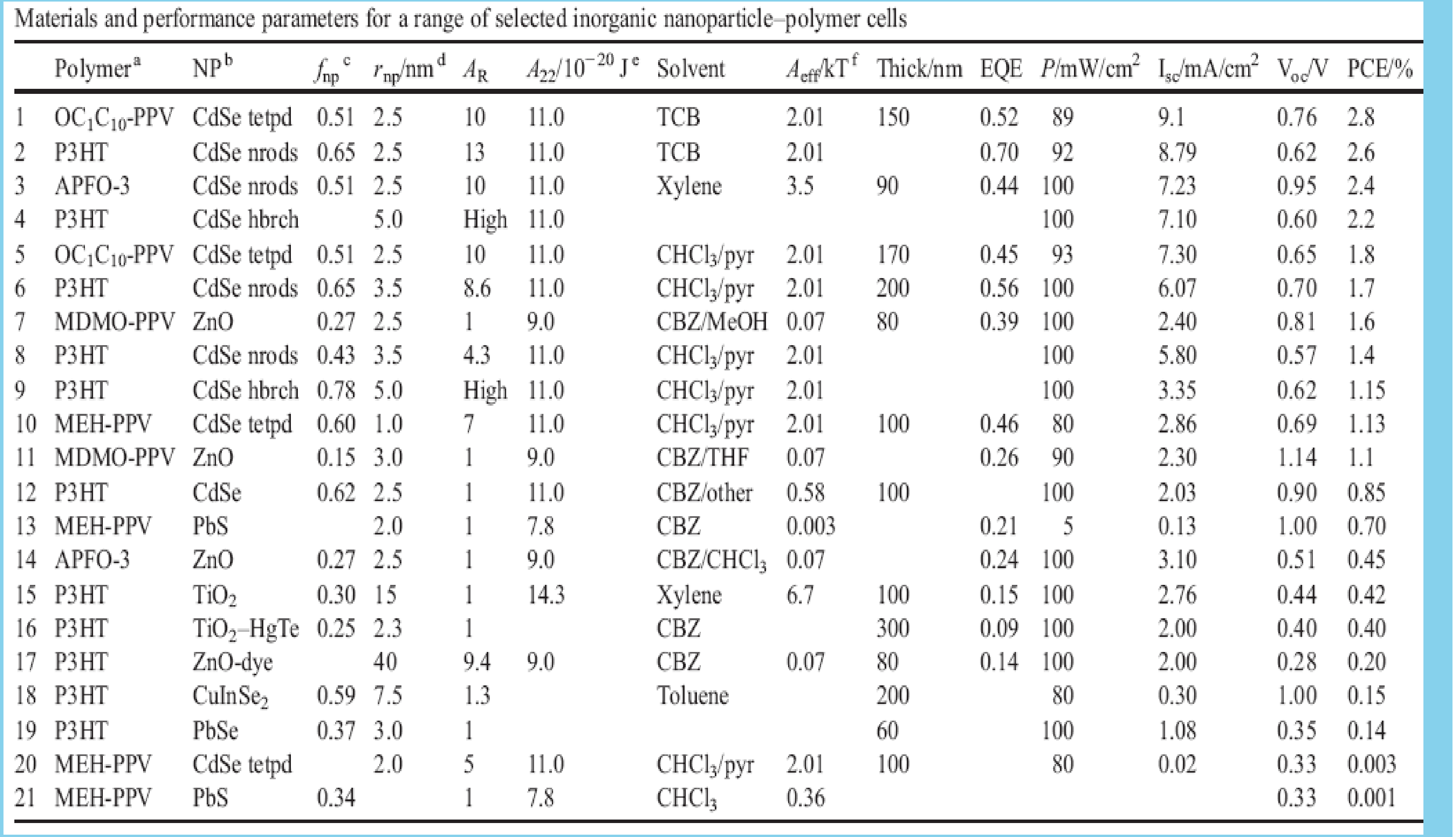
II. **High interfacial area of the bulk heterojunction structure.**

III. **High extinction coefficients for NCs and polymers.**

IV. **Optimum values of energy levels for NCs and polymers should be chosen so that they promote charge separation and transfer.**

V. **Interpenetrating networks and good percolating paths.**

Best results reported so far……



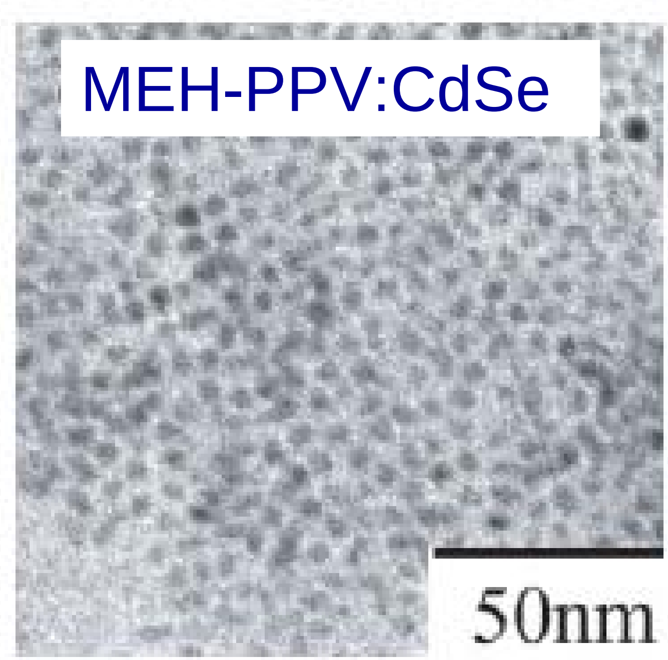
Materials and performance parameters for a range of selected inorganic nanoparticle–polymer cells

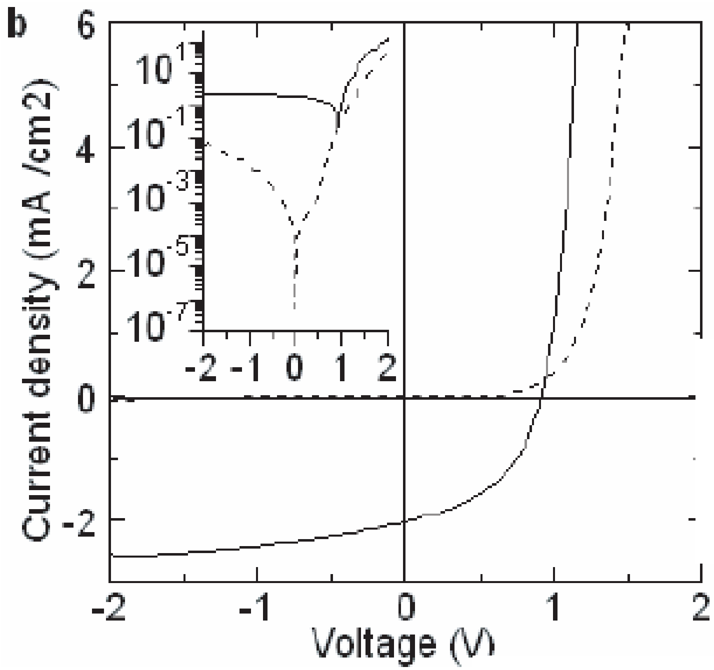
	Polymer[a]	NP[b]	f_{np}[c]	r_{np}/nm[d]	A_R	$A_{22}/10^{-20}$ J[e]	Solvent	A_{eff}/kT[f]	Thick/nm	EQE	P/mW/cm^2	I_{sc}/mA/cm^2	V_{oc}/V	PCE/%
1	OC_1C_{10}-PPV	CdSe tetpd	0.51	2.5	10	11.0	TCB	2.01	150	0.52	89	9.1	0.76	2.8
2	P3HT	CdSe nrods	0.65	2.5	13	11.0	TCB	2.01		0.70	92	8.79	0.62	2.6
3	APFO-3	CdSe nrods	0.51	2.5	10	11.0	Xylene	3.5	90	0.44	100	7.23	0.95	2.4
4	P3HT	CdSe hbrch		5.0	High	11.0					100	7.10	0.60	2.2
5	OC_1C_{10}-PPV	CdSe tetpd	0.51	2.5	10	11.0	$CHCl_3$/pyr	2.01	170	0.45	93	7.30	0.65	1.8
6	P3HT	CdSe nrods	0.65	3.5	8.6	11.0	$CHCl_3$/pyr	2.01	200	0.56	100	6.07	0.70	1.7
7	MDMO-PPV	ZnO	0.27	2.5	1	9.0	CBZ/MeOH	0.07	80	0.39	100	2.40	0.81	1.6
8	P3HT	CdSe nrods	0.43	3.5	4.3	11.0	$CHCl_3$/pyr	2.01			100	5.80	0.57	1.4
9	P3HT	CdSe hbrch	0.78	5.0	High	11.0	$CHCl_3$/pyr	2.01			100	3.35	0.62	1.15
10	MEH-PPV	CdSe tetpd	0.60	1.0	7	11.0	$CHCl_3$/pyr	2.01	100	0.46	80	2.86	0.69	1.13
11	MDMO-PPV	ZnO	0.15	3.0	1	9.0	CBZ/THF	0.07		0.26	90	2.30	1.14	1.1
12	P3HT	CdSe	0.62	2.5	1	11.0	CBZ/other	0.58	100		100	2.03	0.90	0.85
13	MEH-PPV	PbS		2.0	1	7.8	CBZ	0.003		0.21	5	0.13	1.00	0.70
14	APFO-3	ZnO	0.27	2.5	1	9.0	CBZ/$CHCl_3$	0.07		0.24	100	3.10	0.51	0.45
15	P3HT	TiO_2	0.30	15	1	14.3	Xylene	6.7	100	0.15	100	2.76	0.44	0.42
16	P3HT	TiO_2–HgTe	0.25	2.3	1		CBZ		300	0.09	100	2.00	0.40	0.40
17	P3HT	ZnO-dye		40	9.4	9.0	CBZ	0.07	80	0.14	100	2.00	0.28	0.20
18	P3HT	$CuInSe_2$	0.59	7.5	1.3		Toluene		200		80	0.30	1.00	0.15
19	P3HT	PbSe	0.37	3.0	1				60		100	1.08	0.35	0.14
20	MEH-PPV	CdSe tetpd		2.0	5	11.0	$CHCl_3$/pyr	2.01	100		80	0.02	0.33	0.003
21	MEH-PPV	PbS	0.34		1	7.8	$CHCl_3$	0.36					0.33	0.001

Some examples

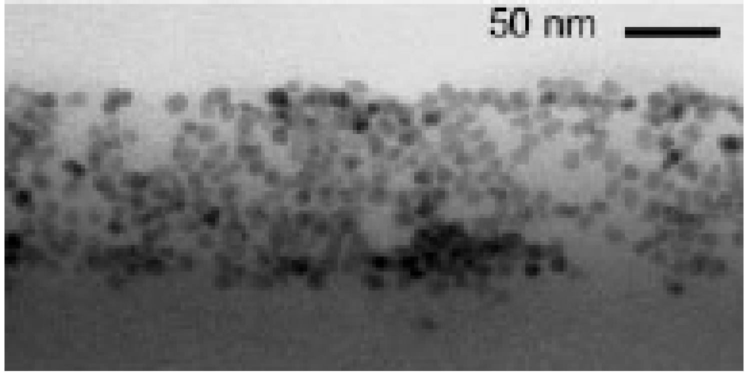
…..From Dots to hyperbranched NCs based solar cells….

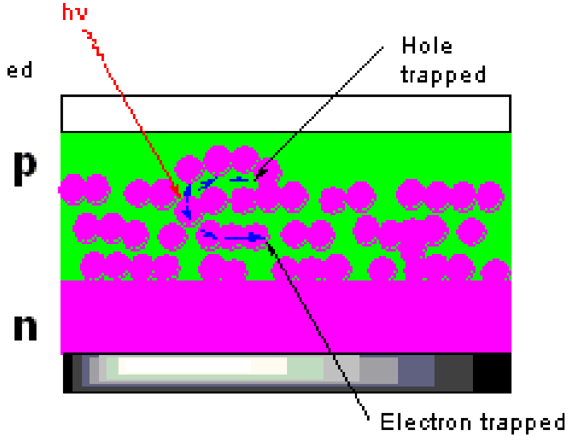
Hybrid *Spherical NCs (Dots)*-Polymer SC





Isc=2.03mA/cm2
Voc=0.9V
FF=0.47
PCE=0.85%



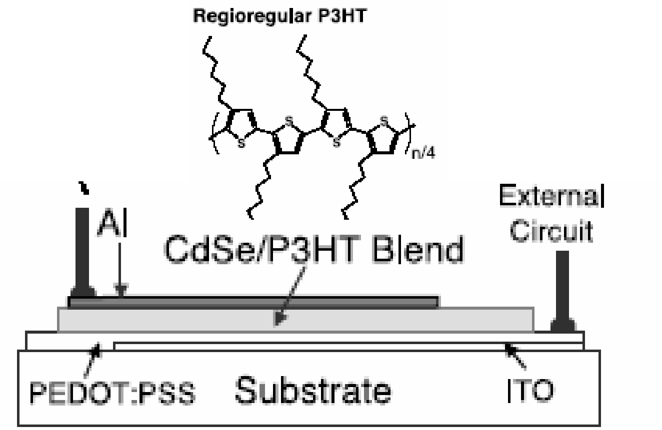


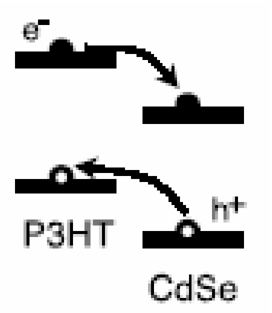
Interpenetrating network with no percolating paths and many carrier traps

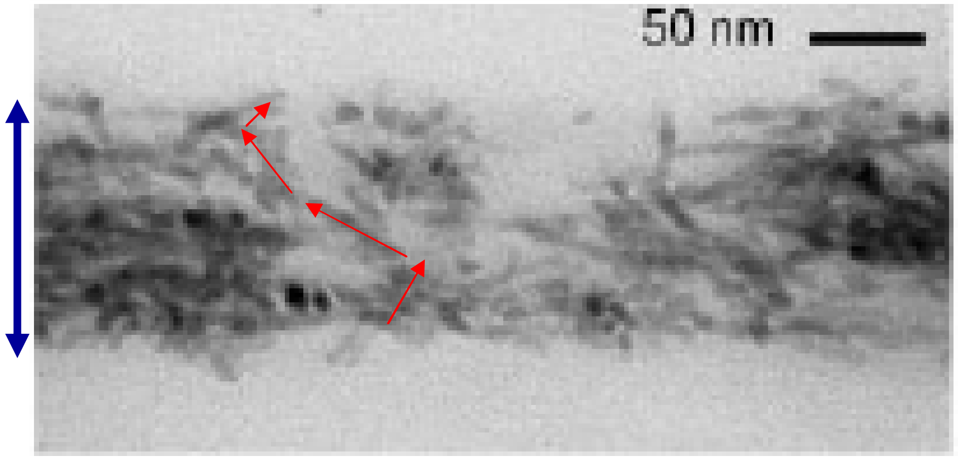
Nanotechnology 17, 4736-4742, 2006

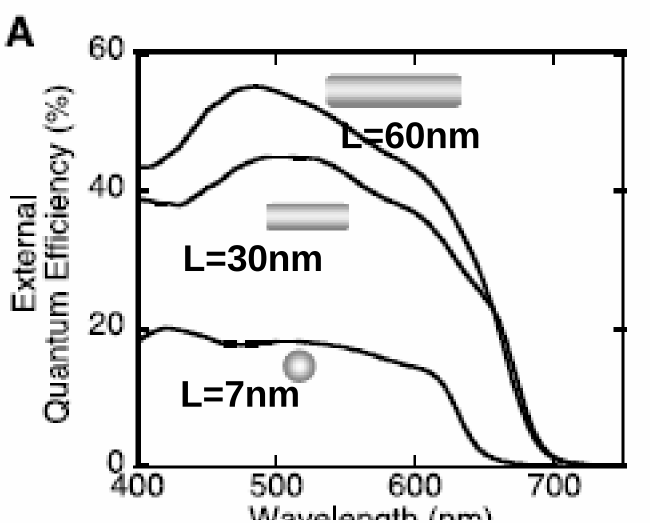
Hybrid *Nanorod*-Polymer SC

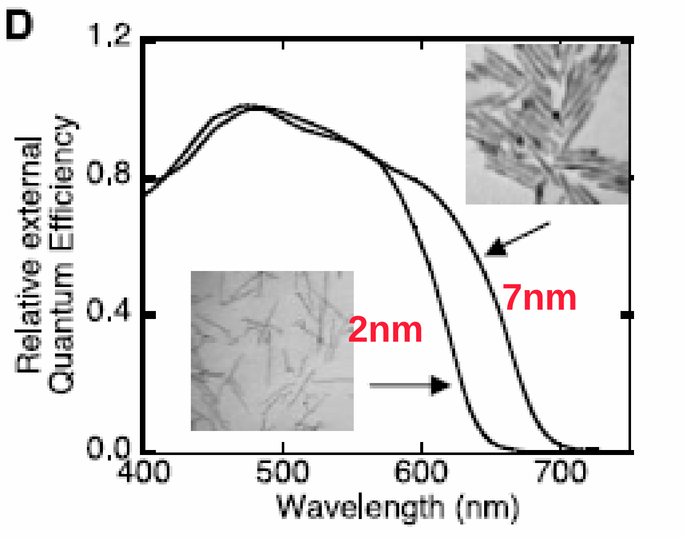
PCE=1.7%











Science, vol 295, 2425, 2002

Rods naturally provide a direct path for electrical trasport. Long nanorods oriented in the Electric field (elctron trasport) direction can penetrate through a large portion of the device

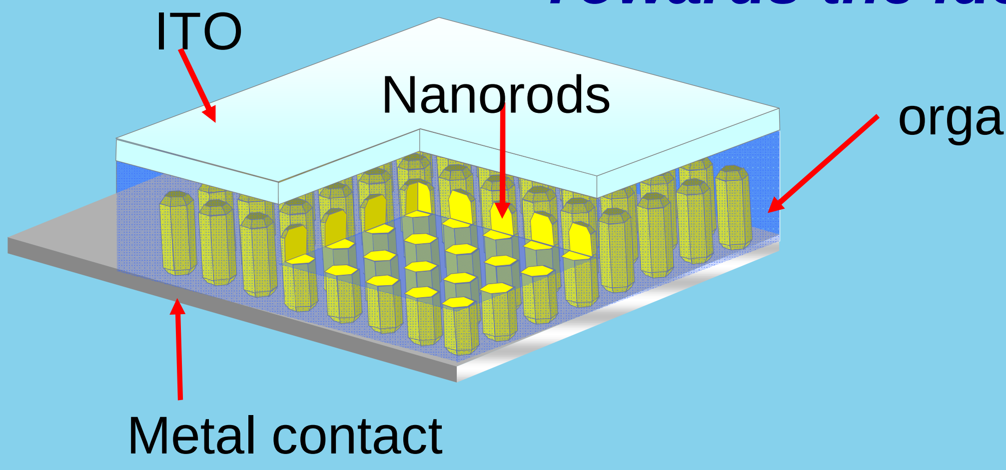
Rod size can be adjusted to the device thickness required for optimal adsorption

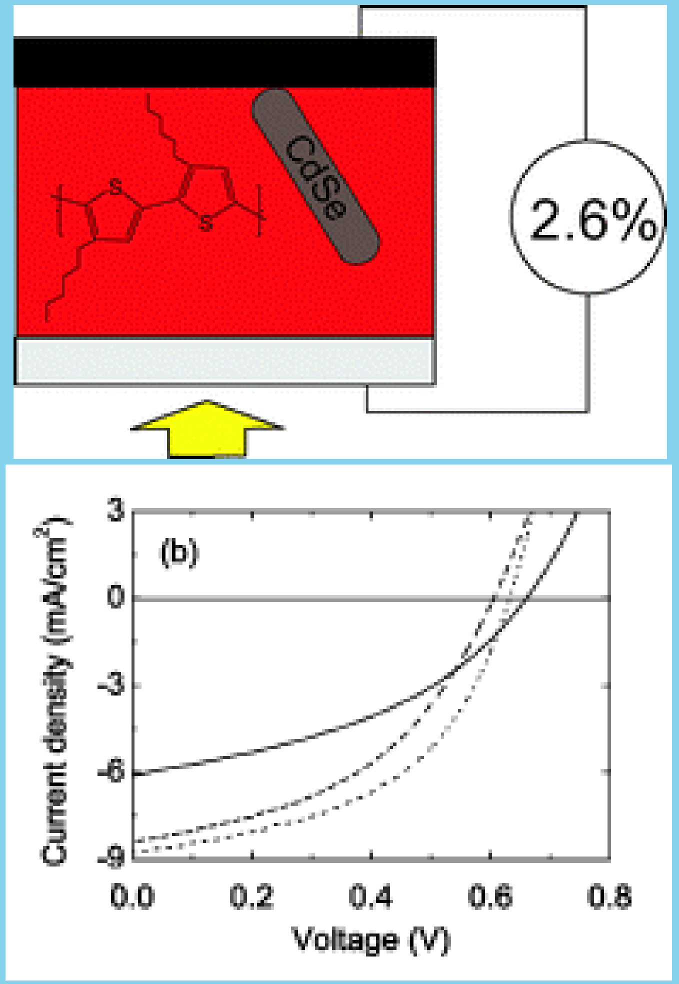
In long NCs electron trasport is dominated by band conduction (in short NCs by hopping (traps).

Problem of solubility when length is increased

CdSe nanorods and poly(3-hexylthiophene) based SC

Towards the ideal structure

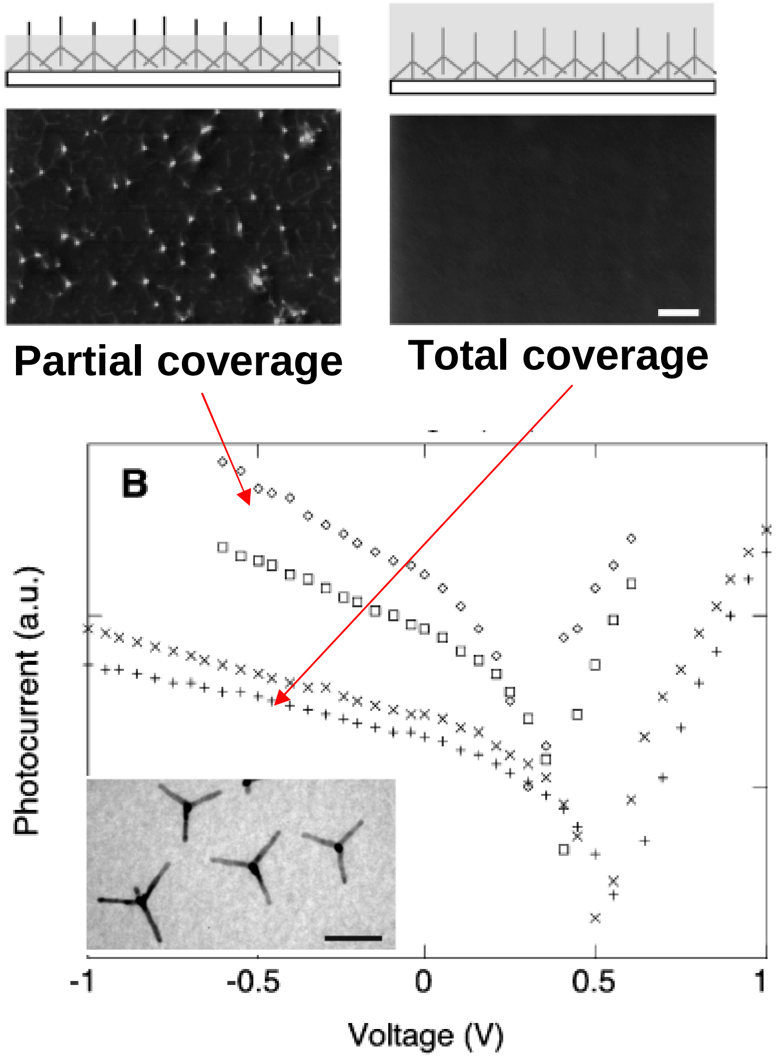




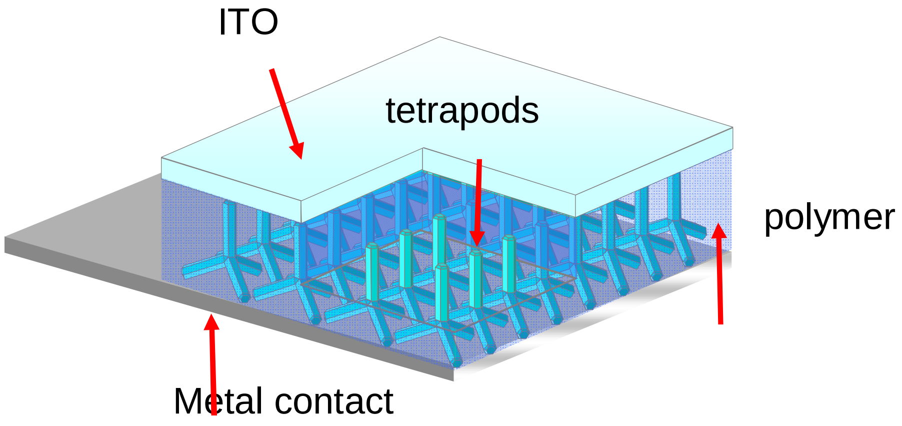
The efficiency of P3HT/CdSe nanorods can be improved by using a high boiling point solvent TCB for film deposition. The increased drying time allows larger-scale self-organized features to form in the P3HT, improving hole transport within the device. PCE is **2.6%.**

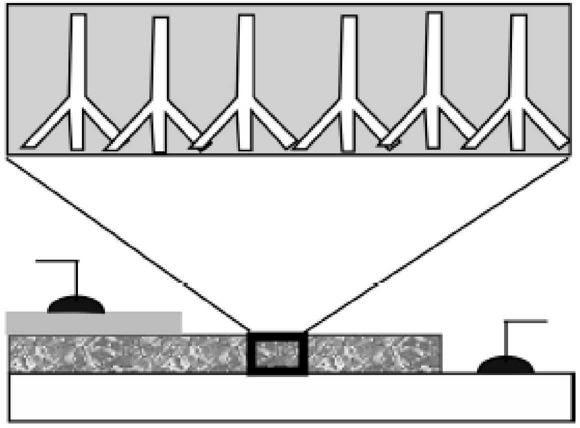
Phys. Chem. Chem. Phys., 2006, 8, 3557 - 3560

Hybrid *Tetrapod*-Polymer SC



(PCE< 1%)

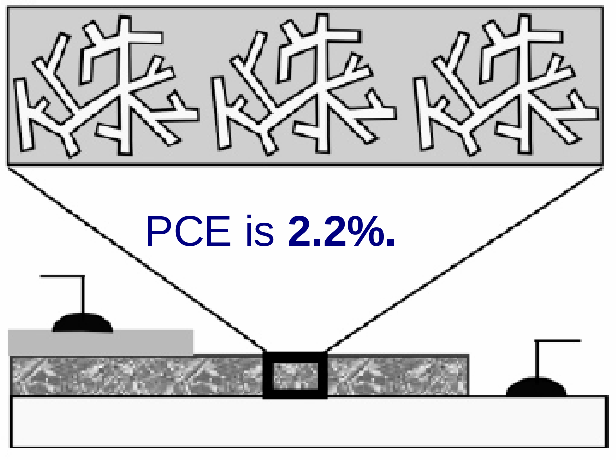




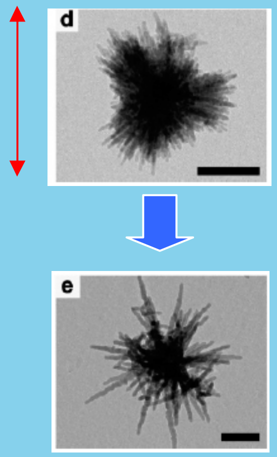
- **Morphology control**
- **Possible sequential deposition, control of polymer thickness**

J. Phys. Chem. B 2006, 110, 25543-25546

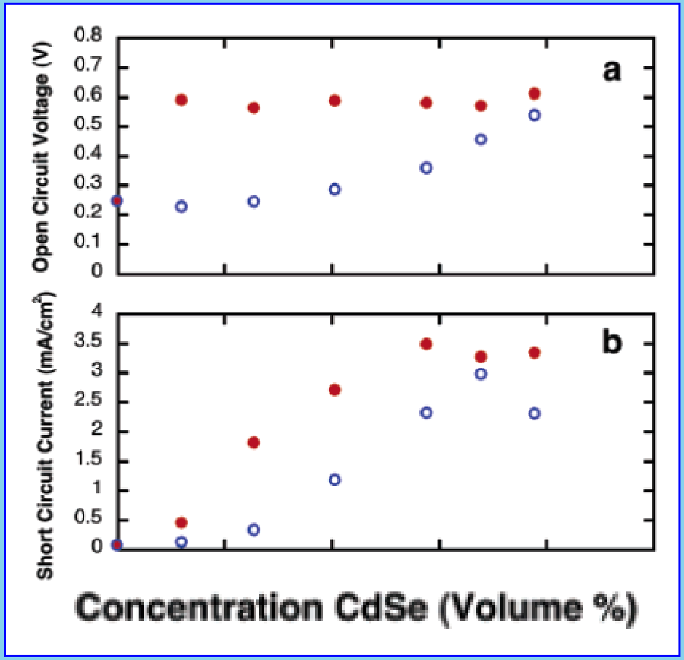
Hybrid ***Hyperbranched NCs***-Polymer SC



PCE is **2.2%.**



Nano Lett., **7** (2), 409 -414, 2007.

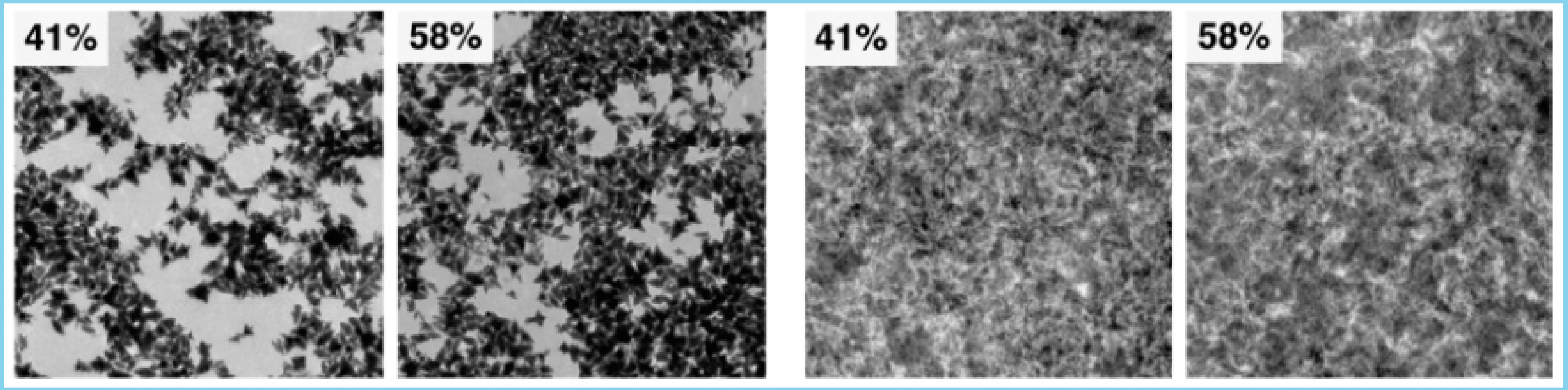


Reduced Problems of morphology control (usually stronlgy dependent on solvents, process condition (defects)on transport

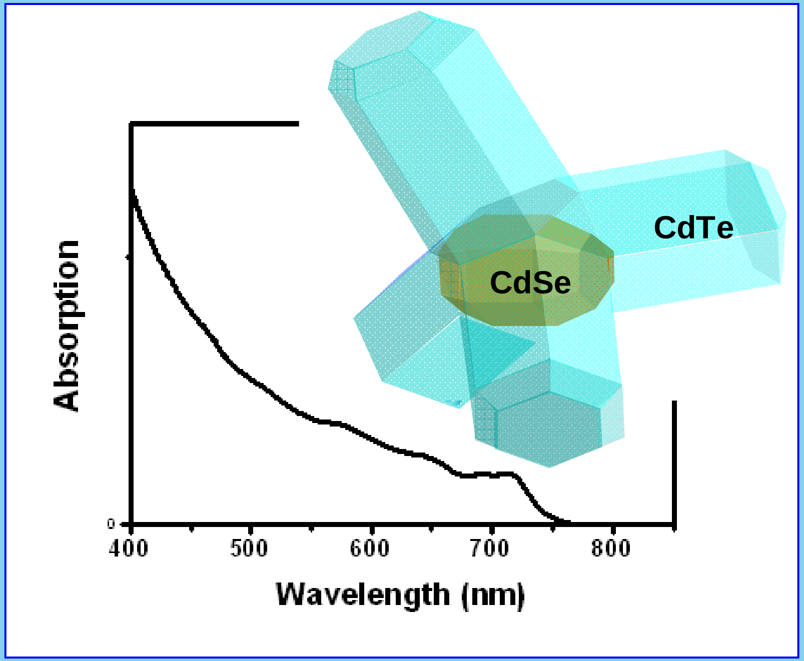
Each hyperbranced NC span the entire device thickness thus contain a built in percolation pathway for trasport of electrons to the anode (cells in parallel)

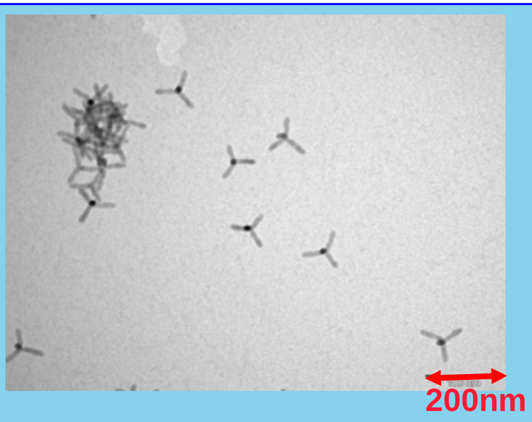
tetrapods

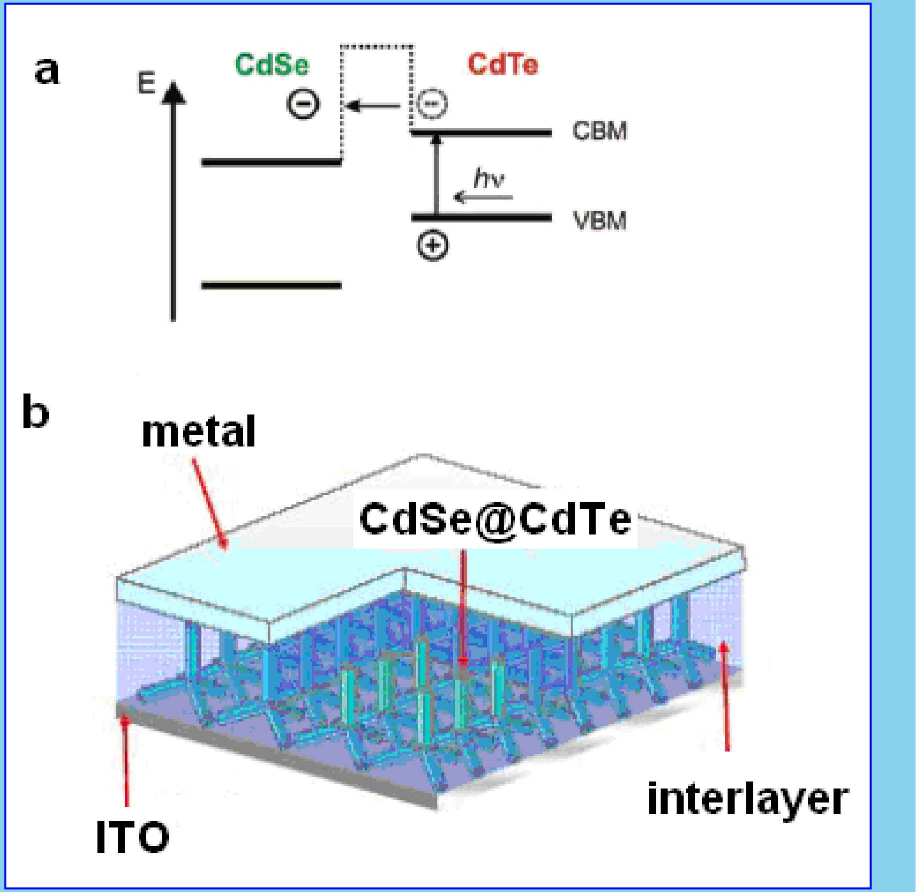
Hyperbranched



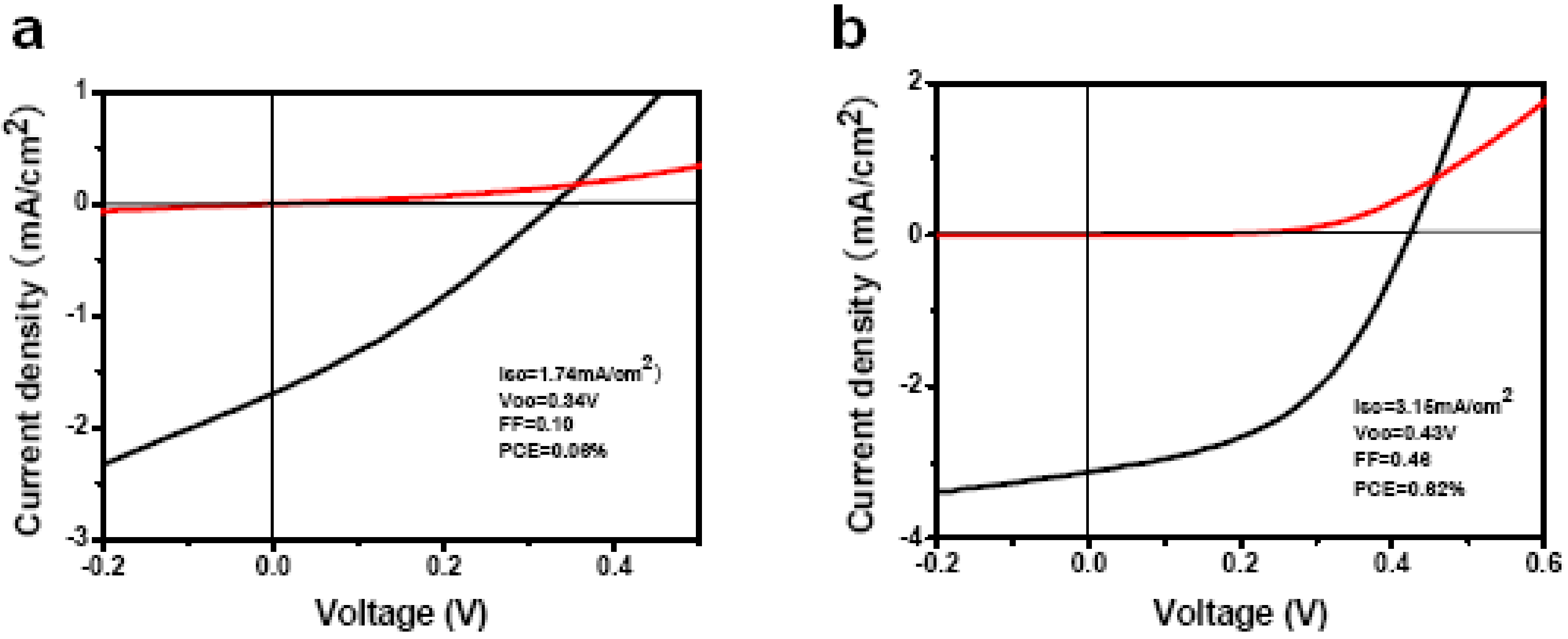
type II tetrapods CdSe@CdTe using buffer layer



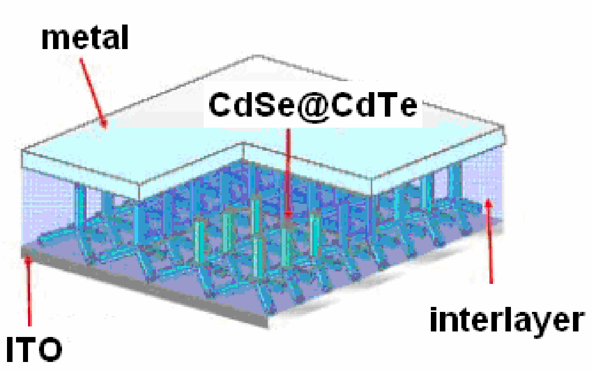




a, An energy diagram valence and conduction band levels for of type II tetrapods CdSe@CdTe, facilitating charge separation of electron and holes in CdSe cores and CdTe arms, respectively. b, Schematic drawing of the photovoltaic device structure based on CdSe@CdTe tetrapods

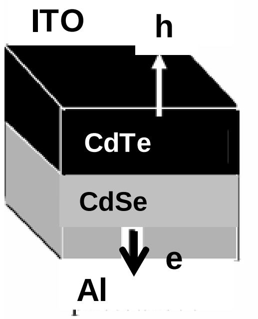


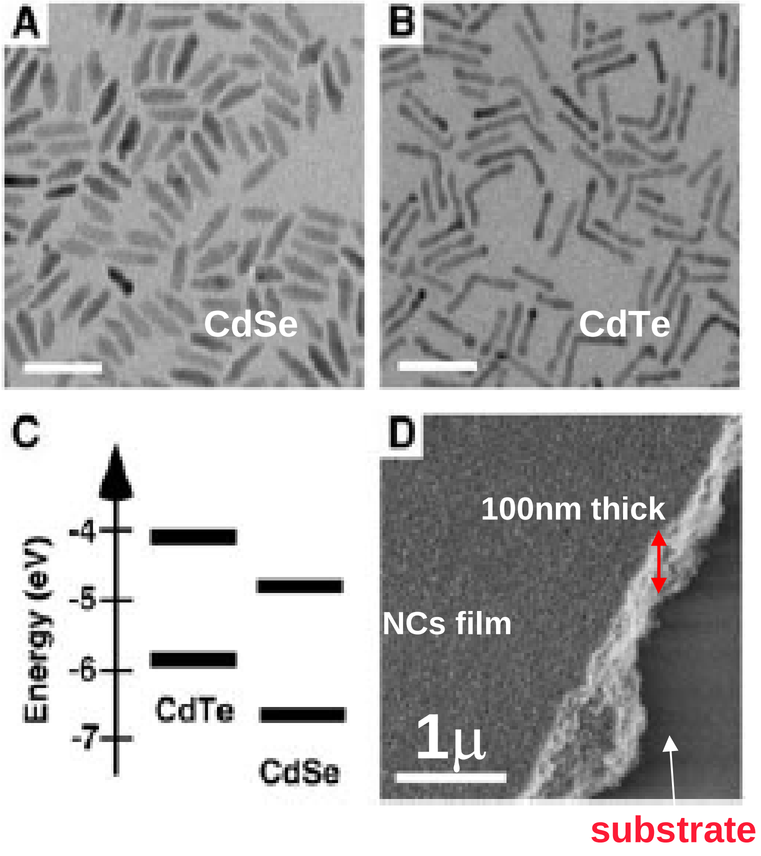
a, Current-voltage characteristics for PV cells with structure ITO/PEDOT-PSS/CdSe@CdTe/Al. b, Current-voltage characteristics for PV cells with structure ITO/PEDOT-PSS/CdSe@CdTe/C60/Al under illumination of one-sun AM 1.5G and in dark condition.

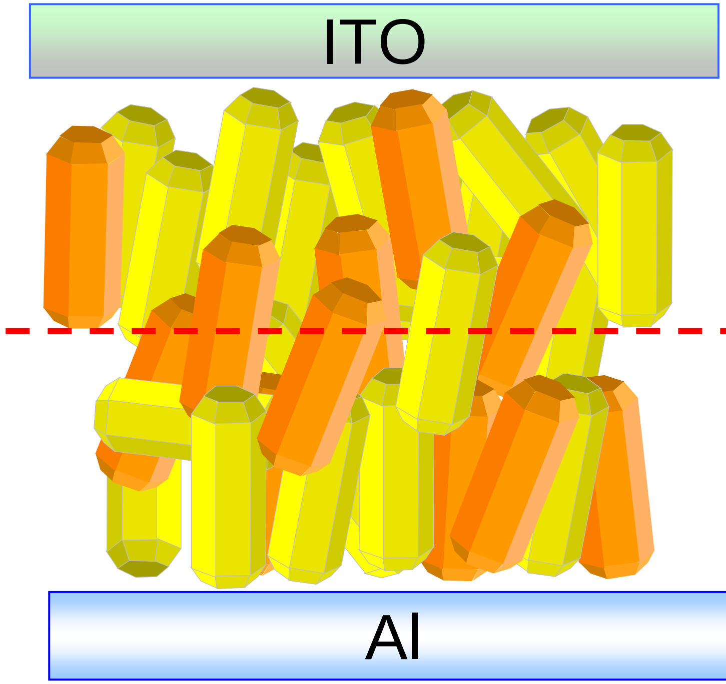


All-Inorganic Nanocrystal Solar Cells

By spin casting a bilayer and intimately mixed blends of CdTe-CdSe NCs. The devices are stable in air (no photo degradation processes) , and post-fabrication processing allows for PCE approaching **3%.**







Close packed arrays of Nanorods

No free carriers without illumination. Carrier extraction is driven not by means of a built in field created from a deplation region between pand n doped material, but by direct diffusion as dictated by type II D-A heterojunction.

free carrier thanks to interface and high rods aspect ratio (small confinement along long side) . Annealing to eliminate traps

Methods for improving perfo rmances of NCs based Solar Cells

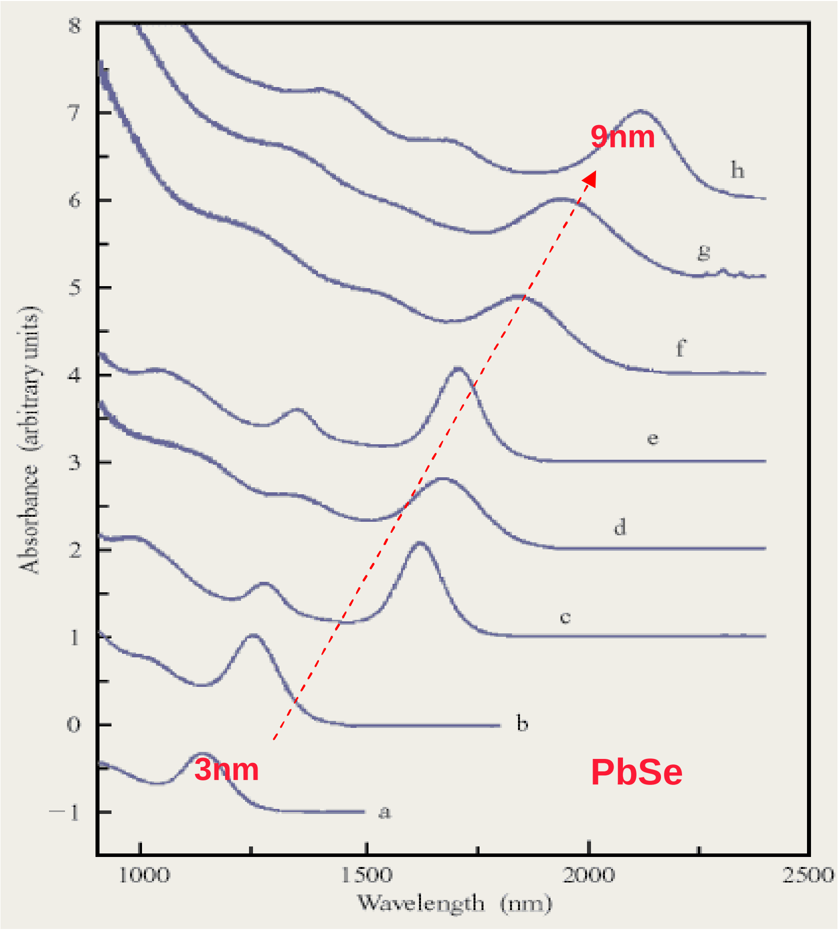
1. **Materials improvement**
   - ***1.1*** ***Nanocrystals Optimization***
   - ***1.2*** ***polymers with functional groups***
   - ***1.3*** ***nanocomposites design***

2. **New techniques**
   - ***2.1*** ***Self-organization and controlled assembly***
   - ***2.2*** ***lithography technique--control exciton diffusion length and surface***
   - ***2.3*** ***singlet-triplet exciton conversion***
   - ***2.4*** ***Air-stable solar cell***
   - ***2.5*** ***tandem solar cell***

1.Materials improvement

………1.1 nanocrystals optimization

Harvest of near Infrared light in PbSe-polymer HSC



- **Improved Absorption**
- **Cadmium free- Material (no n-toxic)**

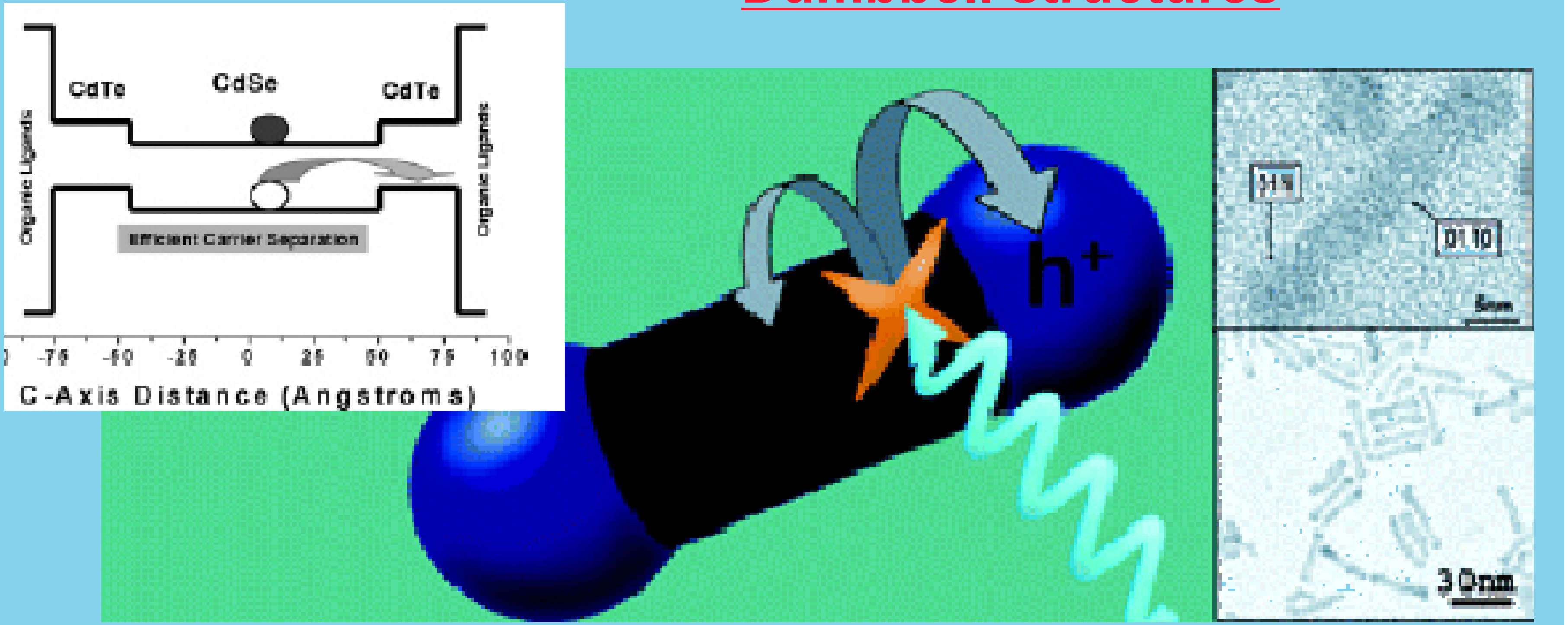
Applied physics letters, 88, 183111, 2006, PCE is 0.14%

1.Materials improvement

………1.1 nanocrystals optimization

b. Novel CdTe-CdSe semiconductor nanocrystal heterostructures

Dumbbell structures

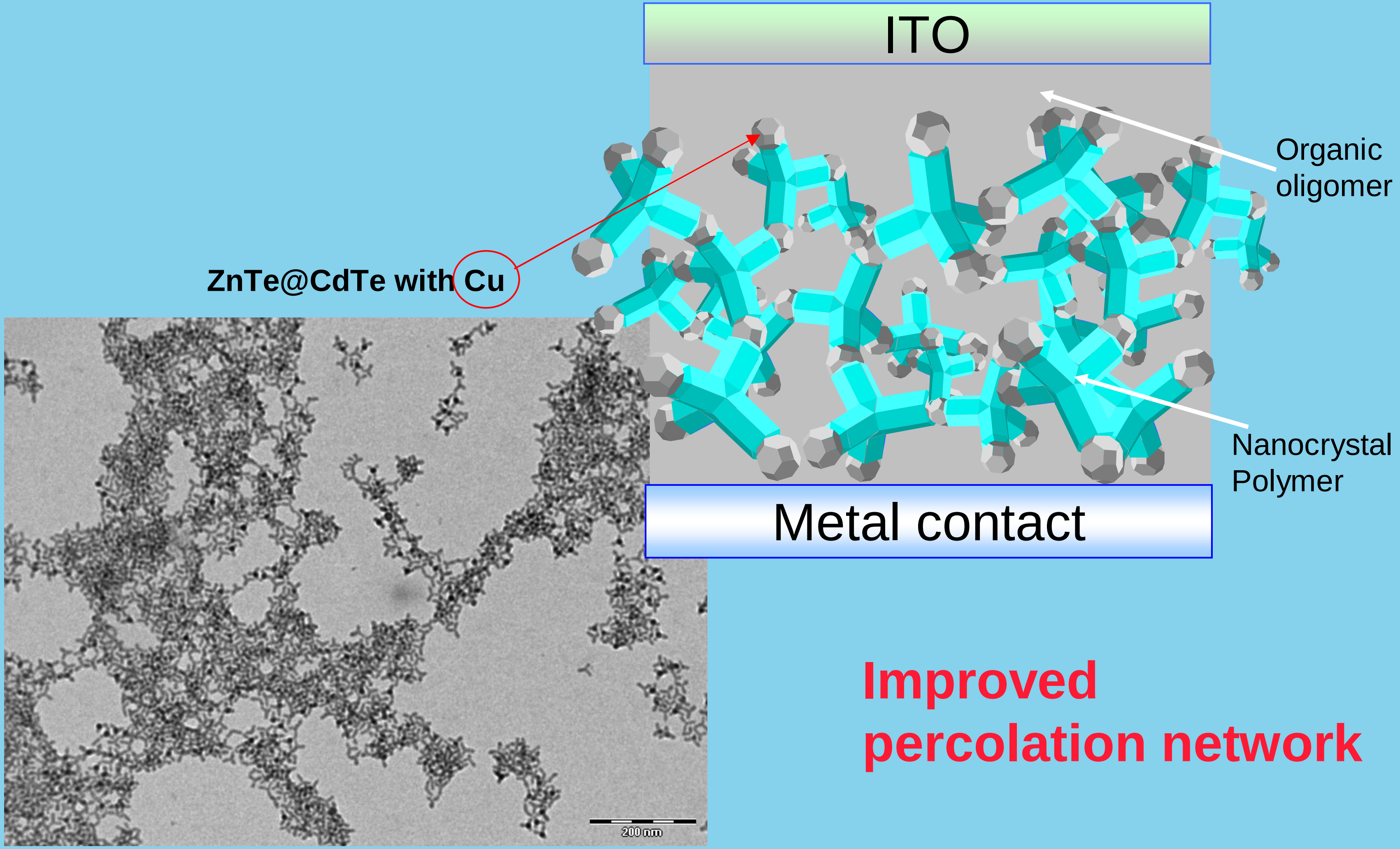


JACS communications 128,12590,2006.
J. Phys. Chem. C, 111, 6538, 2007,
single component PCE is 0.003%, Hybrid device PCE is 0.16%.

1.Materials improvement

………1.1 nanocrystals optimization

C. Nanocrystals networks



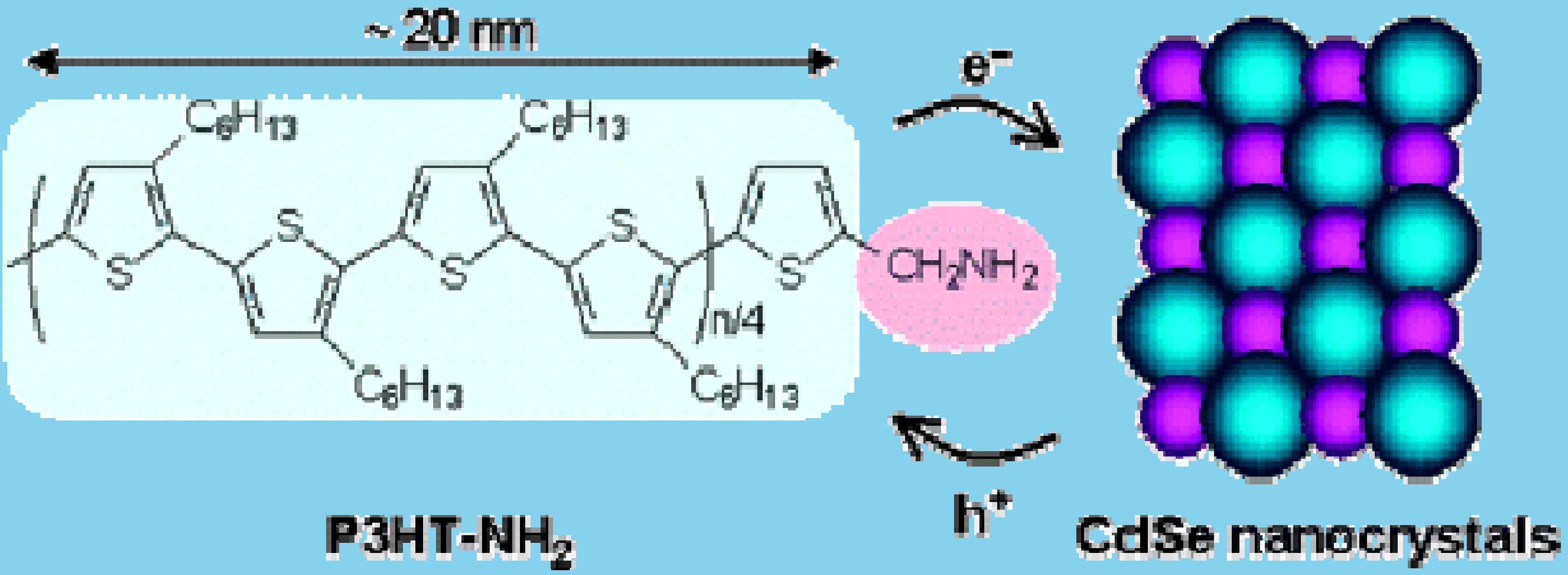
Improved percolation network

Nanotechnology, 17, 706, 2006,

1.Materials improvement

----1.2 polymers with functional groups

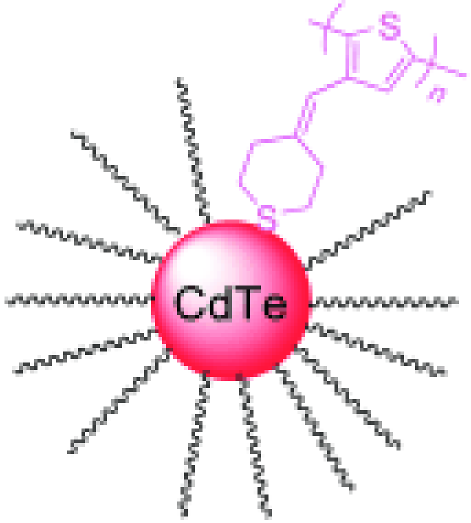
Employing End-Functional Polythiophene To Control
the Morphology of Nanocrystal-Polymer Composites in Hybrid Solar Cells



JACS communications 126, 6550, 2004, PCE is around 1.6%.

1.Materials improvement

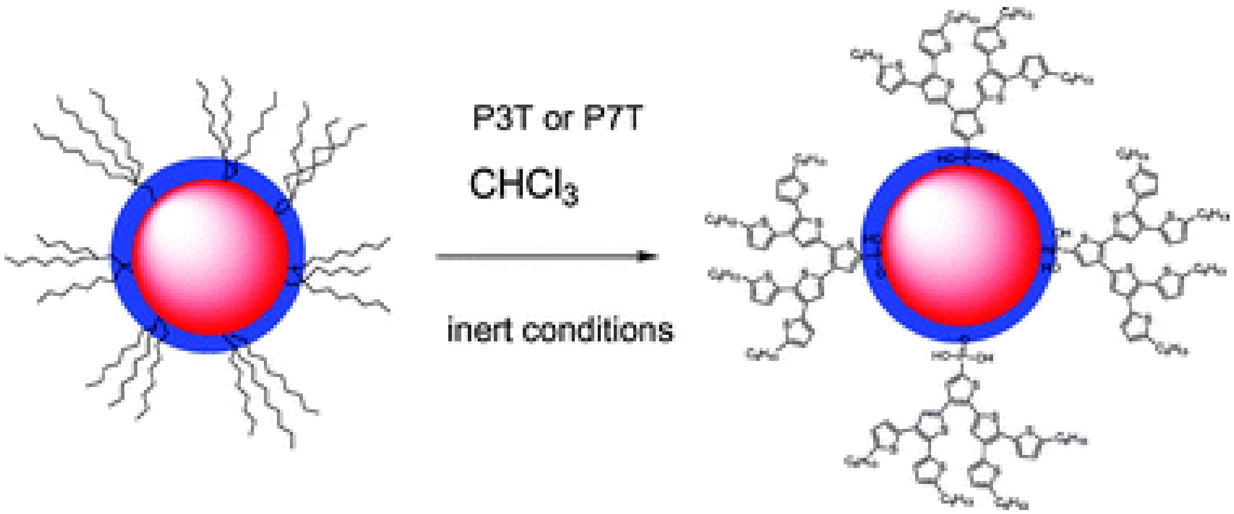
----1.3 Nanocomposites design



- *Photoinduced charge separation*
- *Electronic contact*

Chem. Eur. J. 12, 8075, 2006

Organic-Inorganic Nanocomposites via Directly Grafting electroactive surfactants onto Quantum Dots Reasearch mainly focused on new electroactive surfactants



Device results,

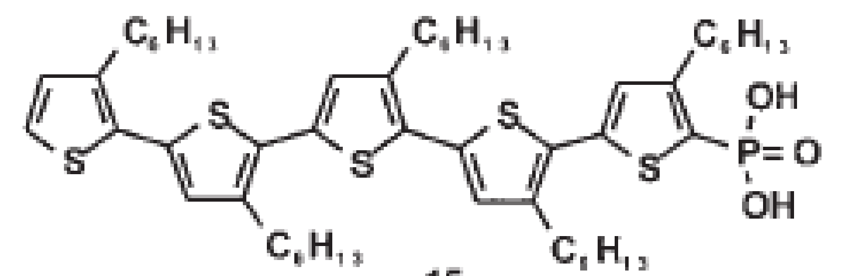
Voc is 0.6V
Isc is 0.00156mA/cm2
FF is 0.3
PCE is 0.29%.

Chem. Mater. 16, 5187, 2004
Dalton Trans. 2778, 2006

- **Electroactive surfactant---good charge separation and charge transfer**
- **Optimized size and shape of nano particles---good electron transport properties**
- **Ideal nanocomposites---with electroactive surfactant and networks**

In order to have ideal nanocomposits,

1. Synthesis of electroactive surfactant
- the head groups must have high affinity for Ncs, like phosphonic acid group
- the end groups must provide solubility in a chosen solvent, like alkyl substituents



15

2. Synthesis of size and shape controlled Ncs

3. Ligand exchange to displace TOPO and
   create desired NCs-surfactant complexes

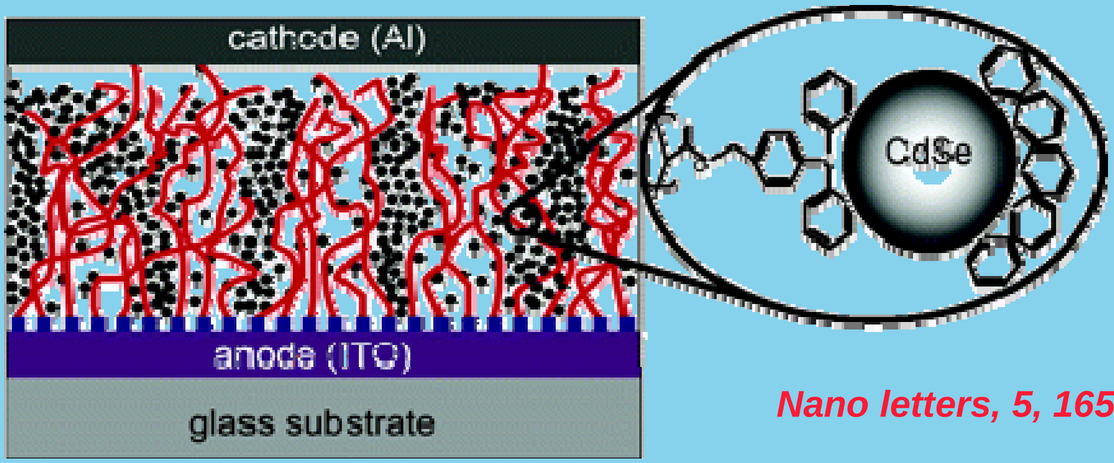
4. Create networks

2. New techniques

-----2.1 *Self-organization and controlled assembly*

a. Self-Organization of Nanocrystals in Polymer Brushes.

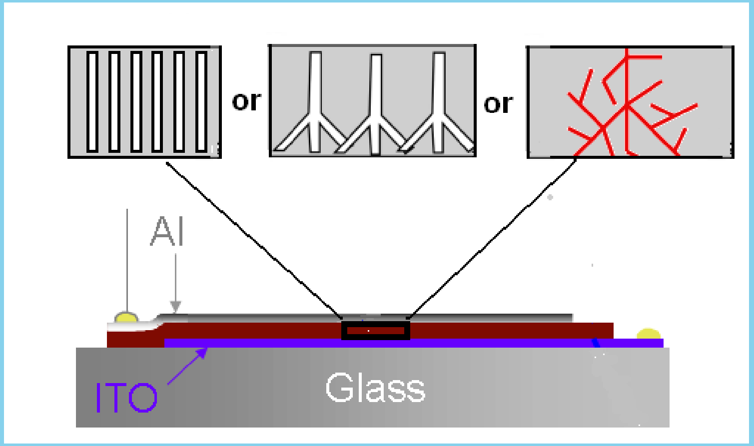
Process,
ITO
Linker growing
Polymer growing
Ncs self-organization
Evaporation (Al)



Nano letters, 5, 1653, 2005,

b. Controlled assembly of hybrid bulk-heterojunction solar cells

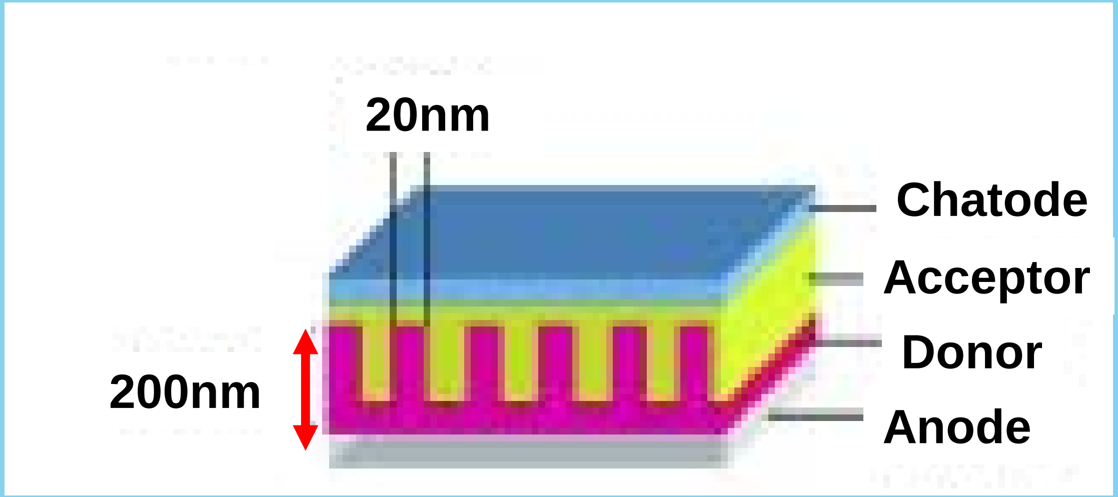
Process,
ITO cleaning
Linker growing
Ncs assembly
Polymer spincasting
Evaporation (Al)



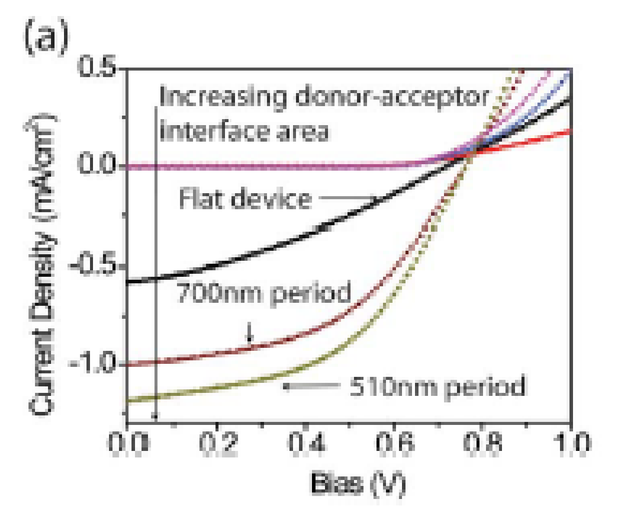
J. Phys. Chem. B 110, 25543, 2006, PCE is still low 1%.

2. New techniques

2.2 lithography technique— control exciton diffusion length and surface

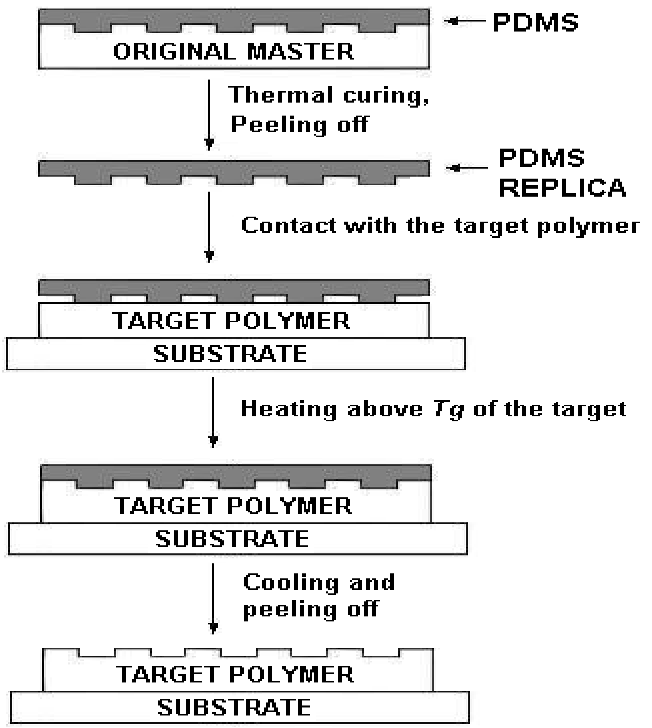


An ideal diagram of solar cells structure

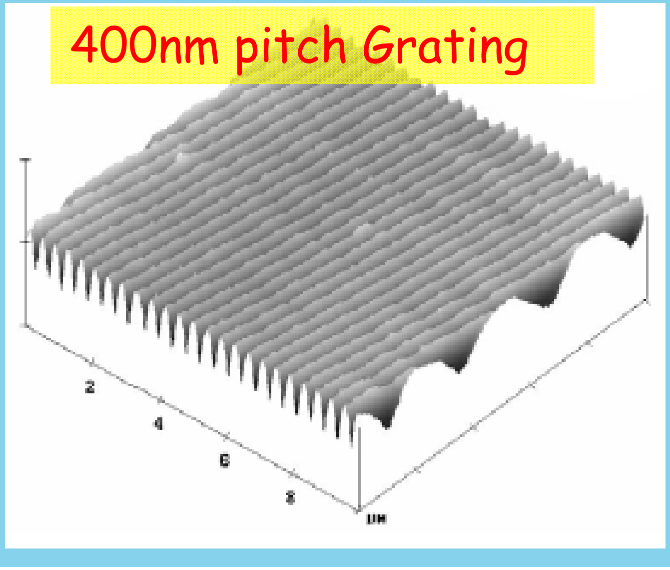


Applied physics letters, 90, 123113, 2007

Imprinting techniques



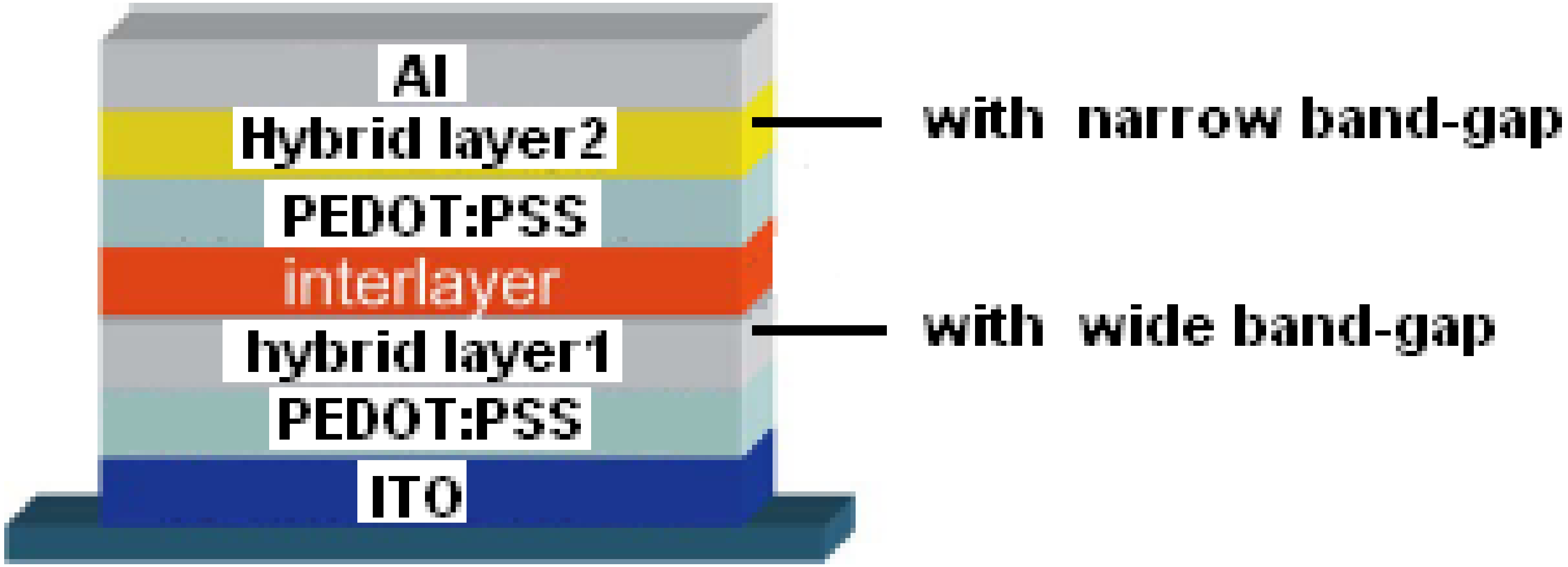
PDMS
ORIGINAL MASTER
Thermal curing, Peeling off
PDMS REPLICA
Contact with the target polymer
TARGET POLYMER
SUBSTRATE
Heating above Tg of the target
TARGET POLYMER
SUBSTRATE
Cooling and peeling off
TARGET POLYMER
SUBSTRATE



400nm pitch Grating

2. New techniques

------ Tandem Solar cells



Because the two cells are in series, V_{OC} is increased to the sum of the individual cells.

The front single cell shows,
V_{OC}=0.66V
J_{SC}=9.2mAcm-2
FF=0.50
PCE=3.0%

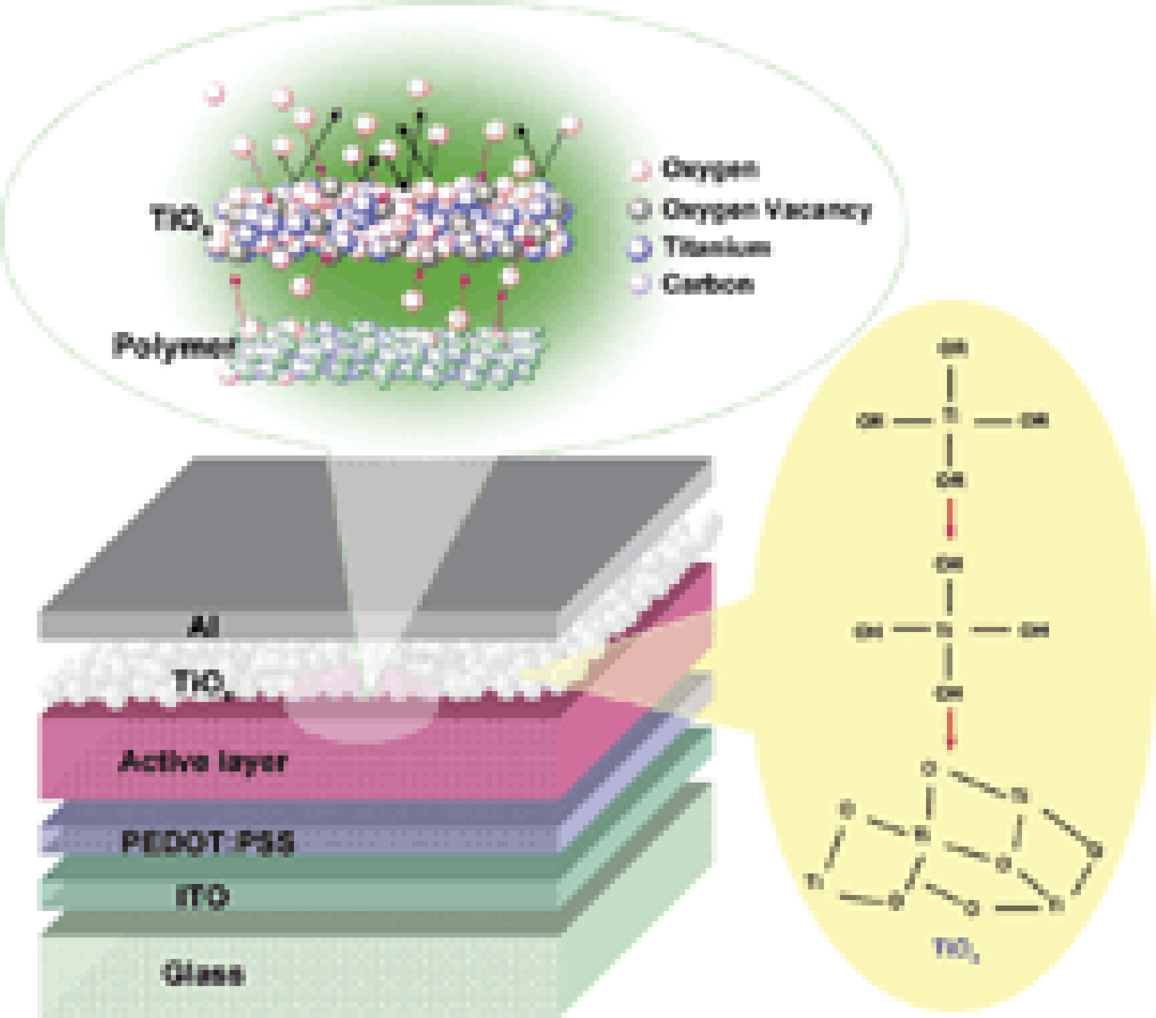
The back single cell shows,
V_{OC}=0.63V
J_{SC}=10.8mAcm-2
FF=0.69
PCE=4.7%

The tandem cell shows,
V_{OC}=1.24V
J_{SC}=7.8mAcm-2
FF=0.67
PCE=6.5%

Science, Vol 317,222, 2007

2. New techniques

----2.4 Air-stable solar cell



The TiO*x* layer,
Acts as a good electron transport layer,
prevents the intrusion of oxygen and humidity into the polymers,

-------improving the lifetime of unpackaged devices exposed to air by nearly two orders of magnitude.

By introducing a titanium oxide (TiO*x*) layer, devices show excellent air stability and enhanced performance.

Adv. Mater. 19, 2445, 2007

2. New techniques

------2.3 singlet-triplet exciton conversion

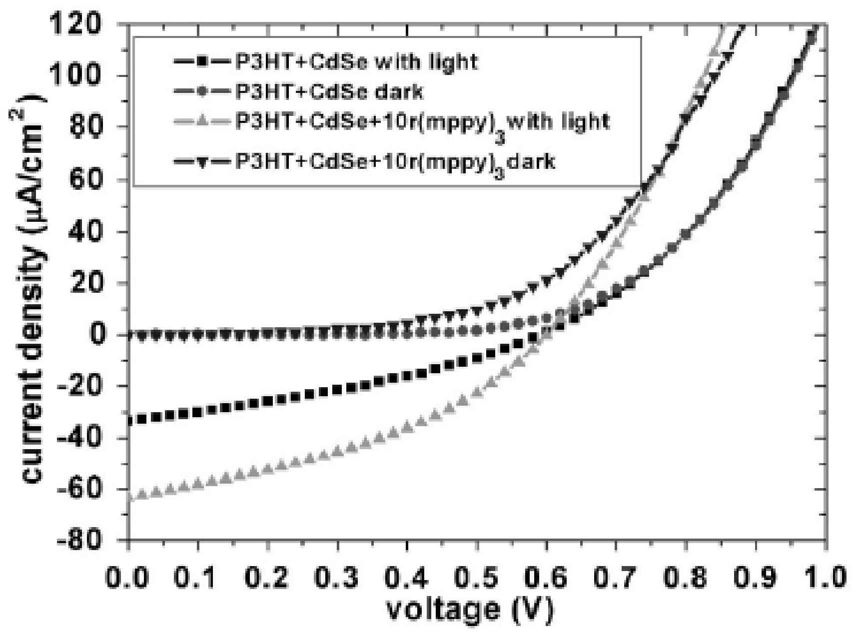


FIG. 3. Dark and photovoltaic responses of hybrid solar cells made from P3HT/CdSe with and without Ir(mppy)$_3$, showing 100% increase in short-circuit current upon doping of Ir(mppy)$_3$.

Hybrid solar cells made of P3HT/CdSe With the addition of Ir complex were fabricated, and great enhancement in their photovoltaic response was observed.

---Appl. Phys. Lett. 90, 133509, 2007

- ***The exciton diffusion length depends on exciton mobility and lifetime***
- ***Upon blending triplet metal complex with polymers, the intersystem corssing (ISC) rate in polymer can be greatly enhanced and the triplet exciton population would increase a lot, leading to a greating improved PV response.***

Future work--- we can work on such system.

Why Hybrid Organics-Inorganic Nanocrystals Solar Cell?

Combine advantages of inorganic material, such as stability, with advantages of organics, such as cheap fabrication technology….