Organic Solar Cells

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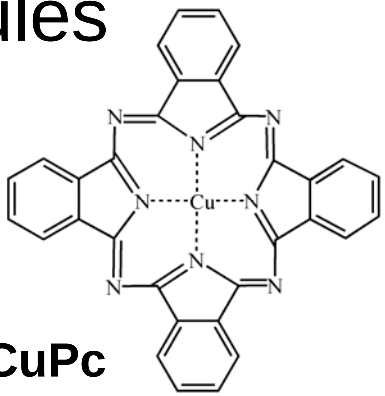
Conjugated (semiconducting) molecules

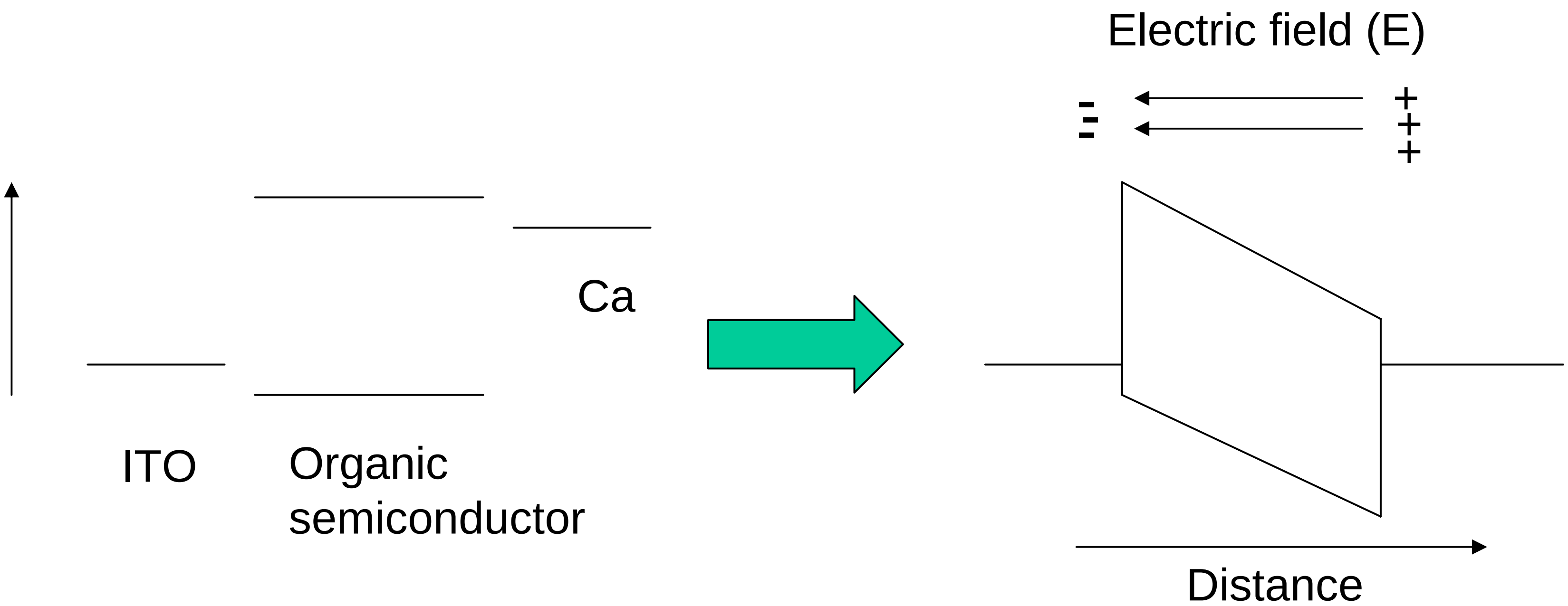


CuPc

Abundant: > 70,000 tons/year
Non-toxic
Low-cost: ~1$/g → 17¢/$m^2$
Stable

Peter Peumans (Stanford Electrical Engineering)

Single semiconductor organic PV cells

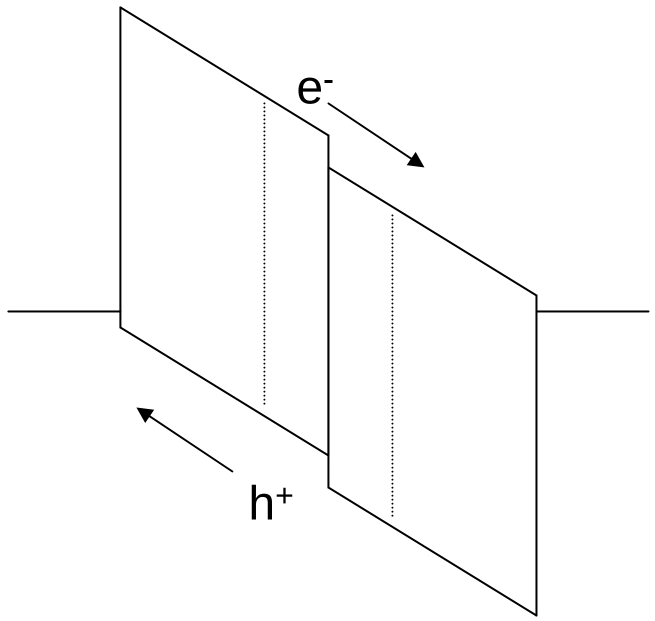


The film can be spin cast or evaporated.

High exciton binding energy
Low mobility

Quantum efficiency < 1 %

Flat bilayer organic PV cells



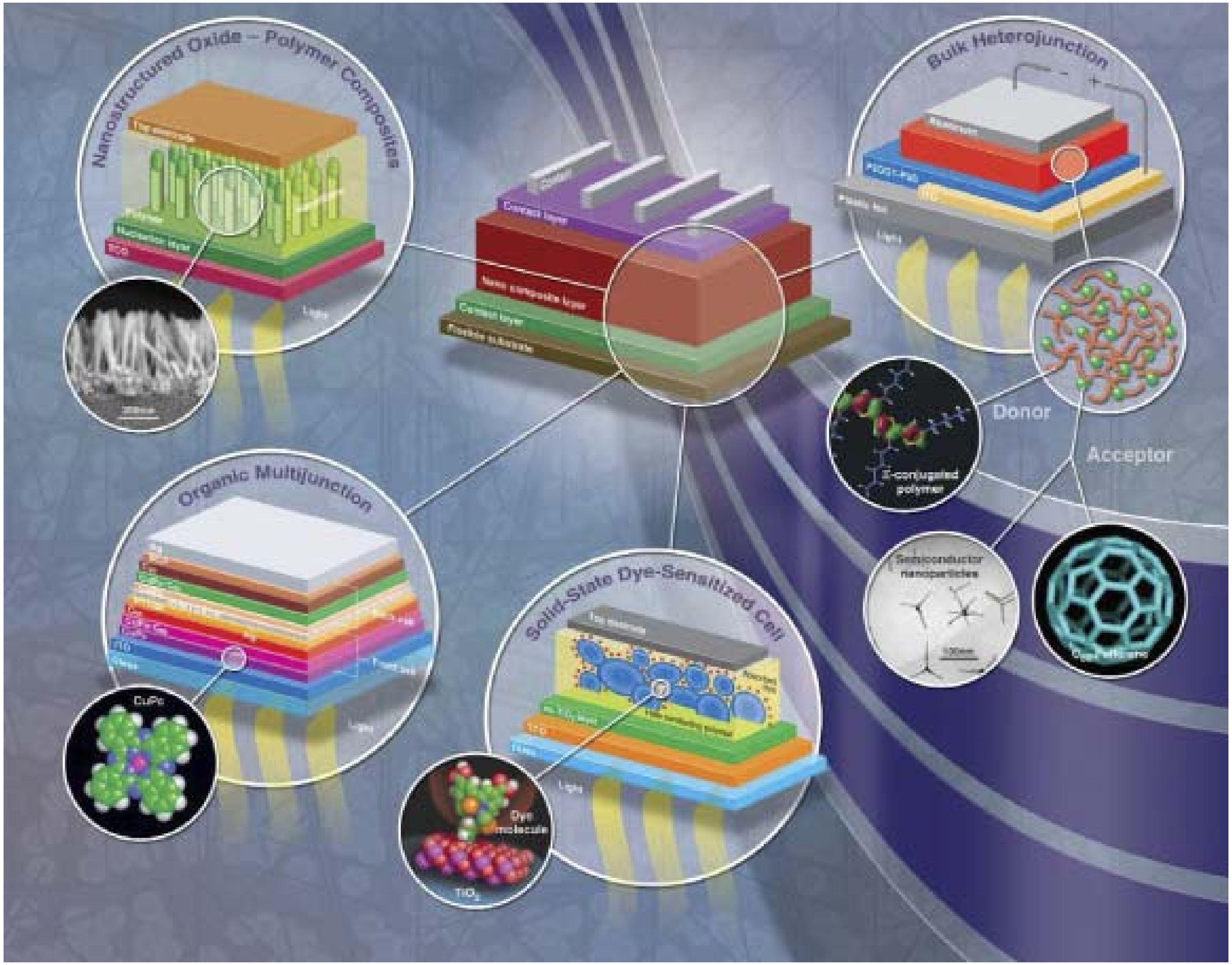
• Carriers are split at the interface.[1]

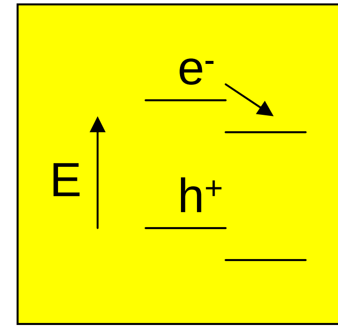
• They selectively diffuse to the electrodes.[2]

• Exciton diffusion length ~ 4-20 nm
• Absorption length ~ 100-200 nm

[1] C.W. Tang, *APL* **48** (1986) p. 183.
[2] B.A. Gregg, *J. Phys. Chem. B* **107** (2003) p. 4688.

Nanostructured Cells





Excitons are split at interfaces.

Separating the electrons and holes enables the use of low quality materials

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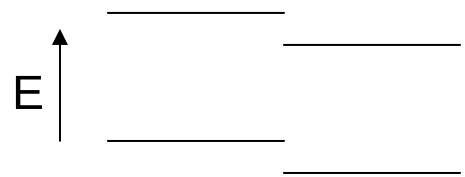
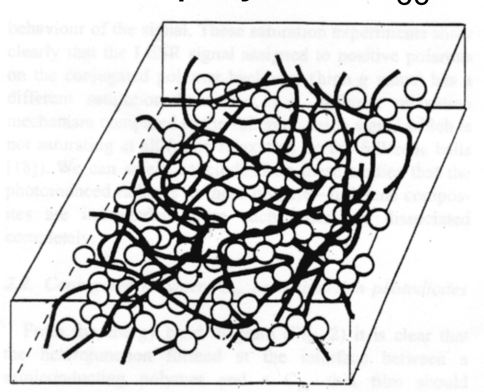
Bulk heterojunction PV cells made by casting blends



Polymer Electron acceptor

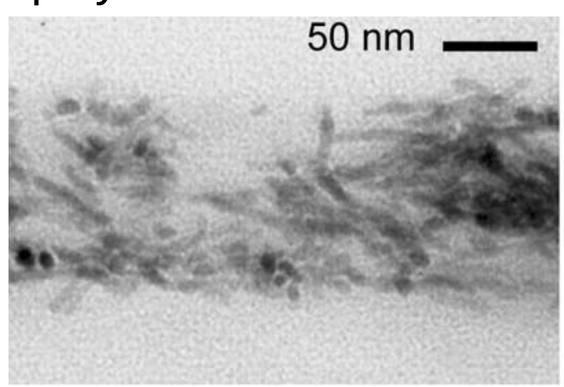
absorber	electron acceptor		Energy conversion efficiency (AM 1.5)
Polymer	C_{60} derivative	Heeger	4.9 %
Polymer	polymer	Friend	1.9 %
Polymer	CdSe nanorods	Alivisatos	1.7 %
Polymer	ZnO nanocrystal	Janssen	1.6 %

polymer/C_{60} blend



Heeger et al. *Science* **270** (1995) p. 1789.

polymer/nanorod blend



Alivisatos et al., *Science* **295** (2002) p. 2425

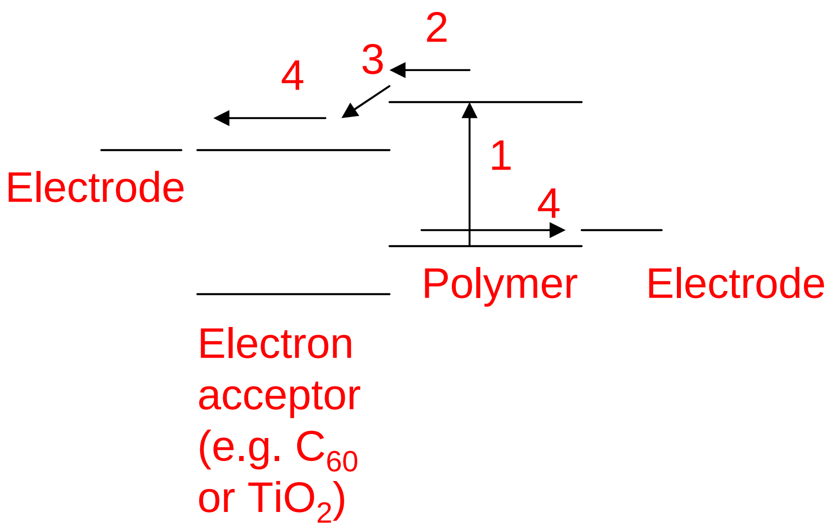
☺ fabrication is simple

☹ not all excitons reach at interface

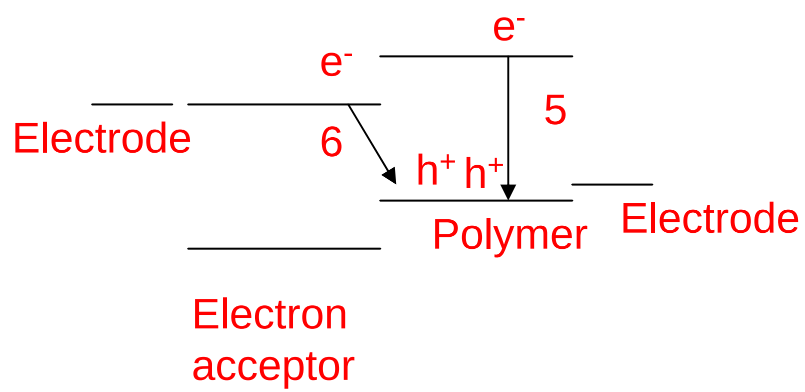
☹ there are deadends

Processes in bulk heterojunction PV cells

Desirable



Undesirable recombination events



1 Absorption

2 Exciton diffusion
3 Forward electron transfer

competing

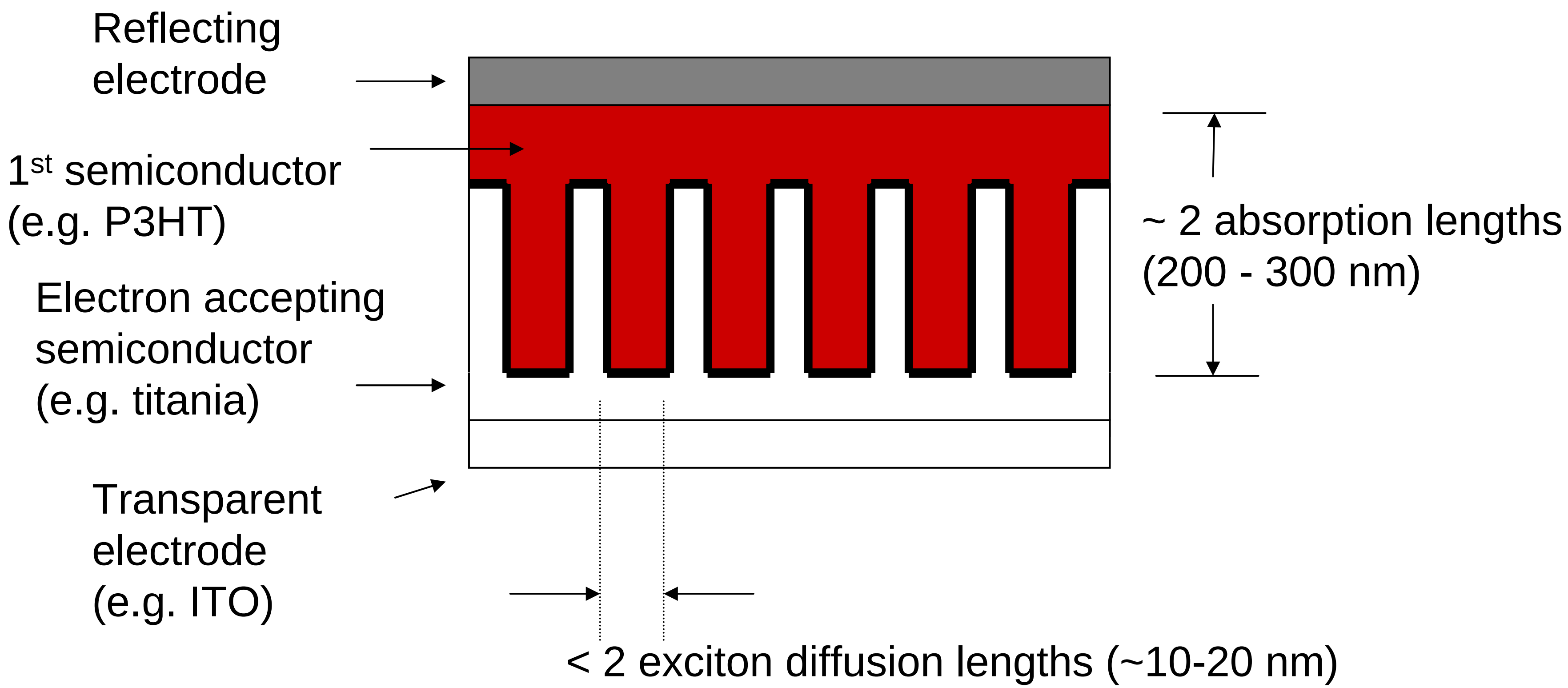
5 Geminate recombination (1 ns)

4 Charge transport to electrodes

competing

6 Back electron transfer (1 μs ?)

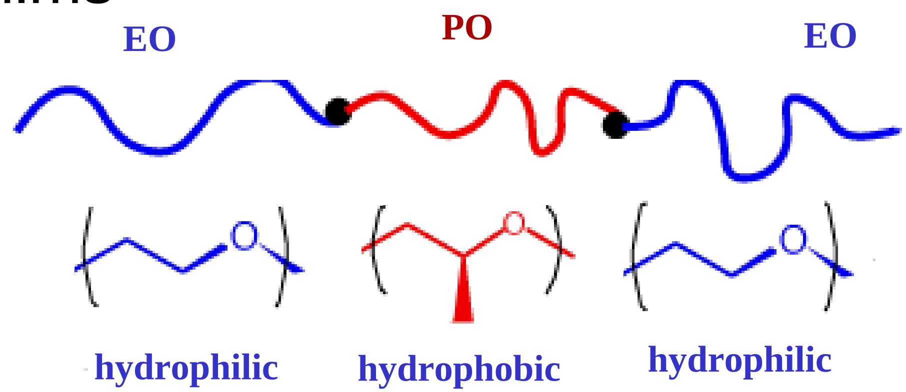
Ordered bulk heterojunctions



- Almost all excitons can be split
- No deadends
- Polymer chains can be aligned

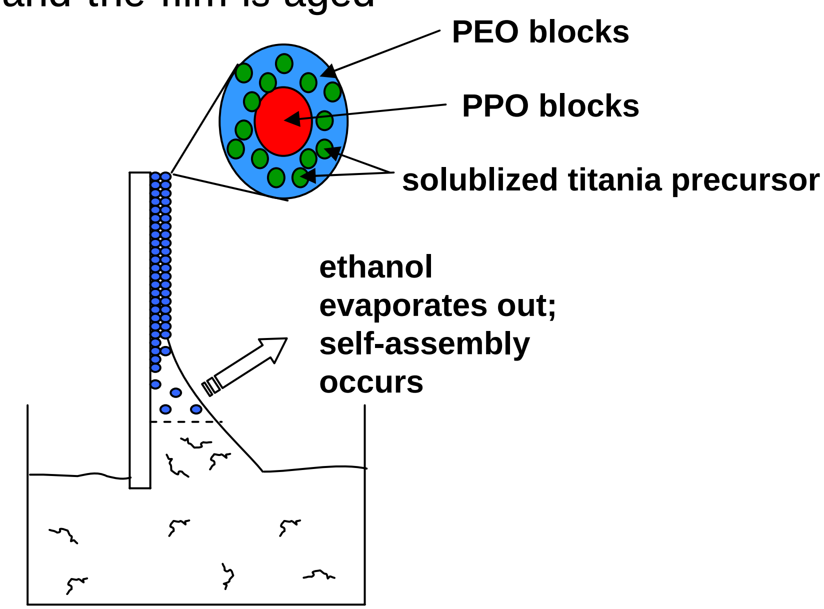
- Easy to model
- Semiconductors can be changed without changing the geometry.

One way to make nanoporous films

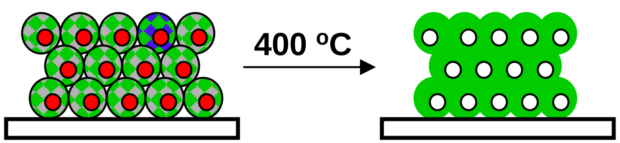


① Titanium ethoxide,
HCl,
P123 tri-block copolymer
and ethanol are mixed
in a beaker

② the mixture is dip coated
and the film is aged

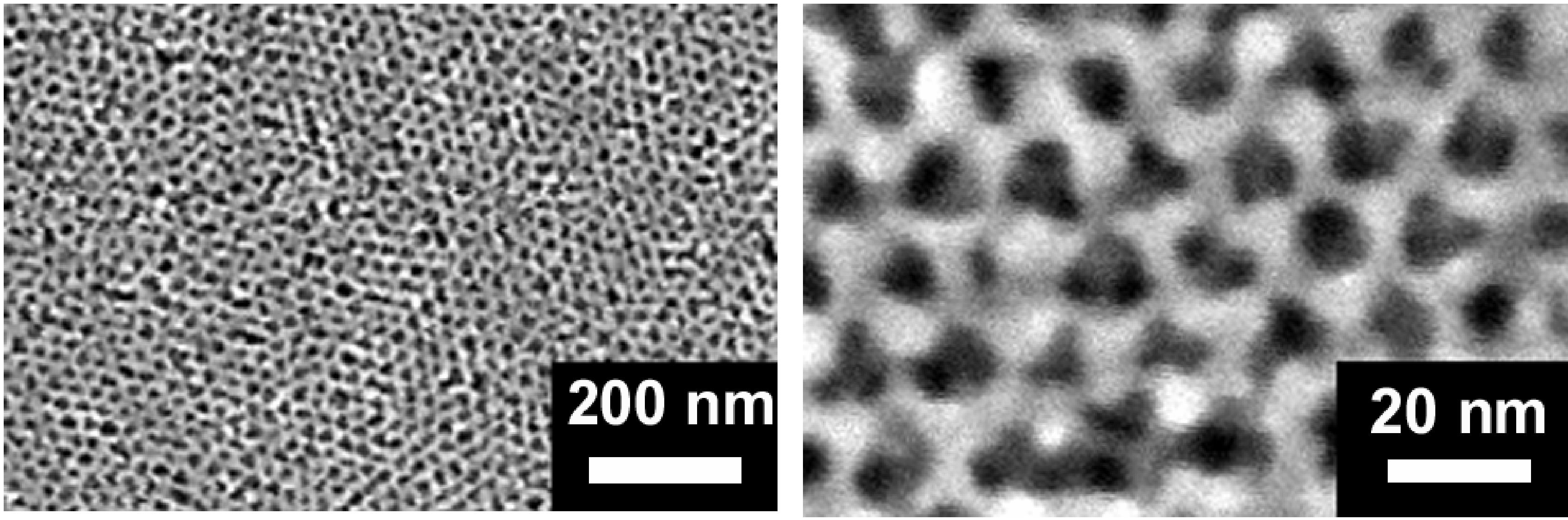


③ The film is calcined at 400 ^{o}C
to burn out the block copolymer



G.D. Stucky et al. *Chem. Mater.* **14** (2002) p. 3284.
C. Sanchez et al. *JACS* **125** (2003) p. 9770.

Mesoporous titania films

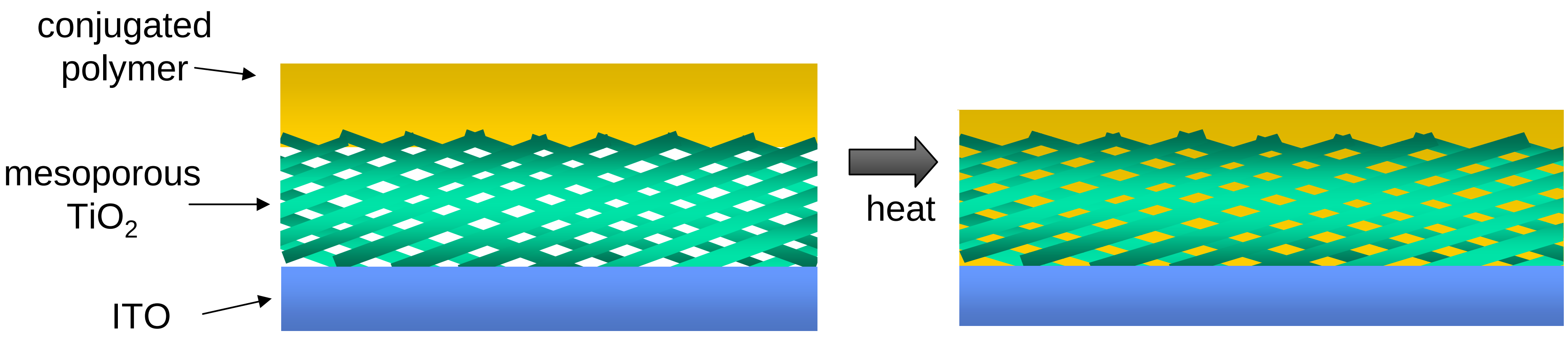


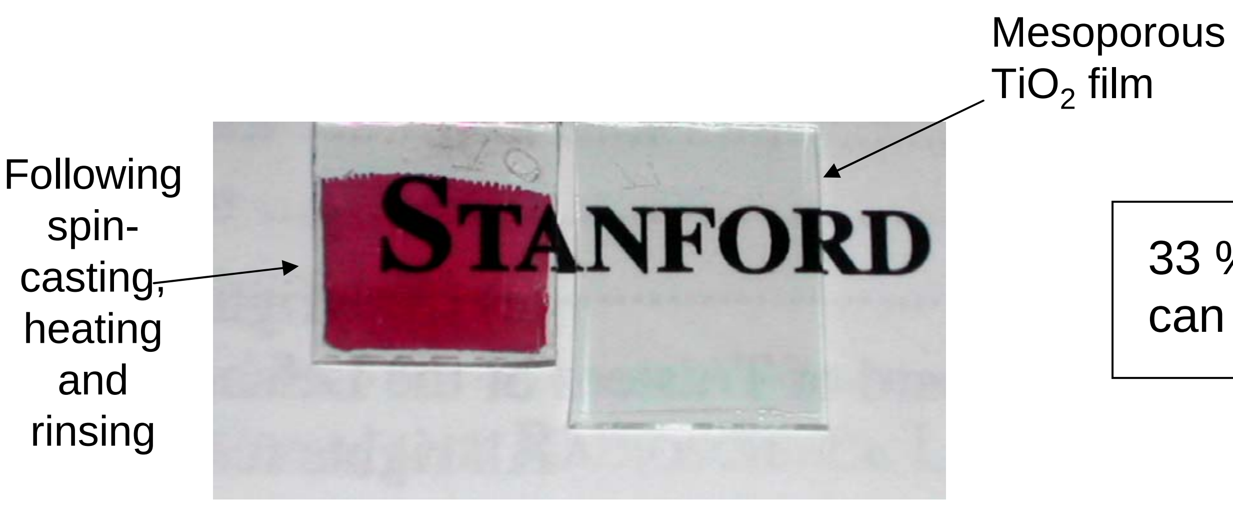
☺ Film thickness can be varied from 50 - 300 nm
☺ Pore radius: 4 nm in the plane and 2-3 nm perpendicular to the plane
☺ Film quality is very high

☹ Pores are not straight

Adv.Func.Mat., **13** (2003) p. 301

Melt infiltration

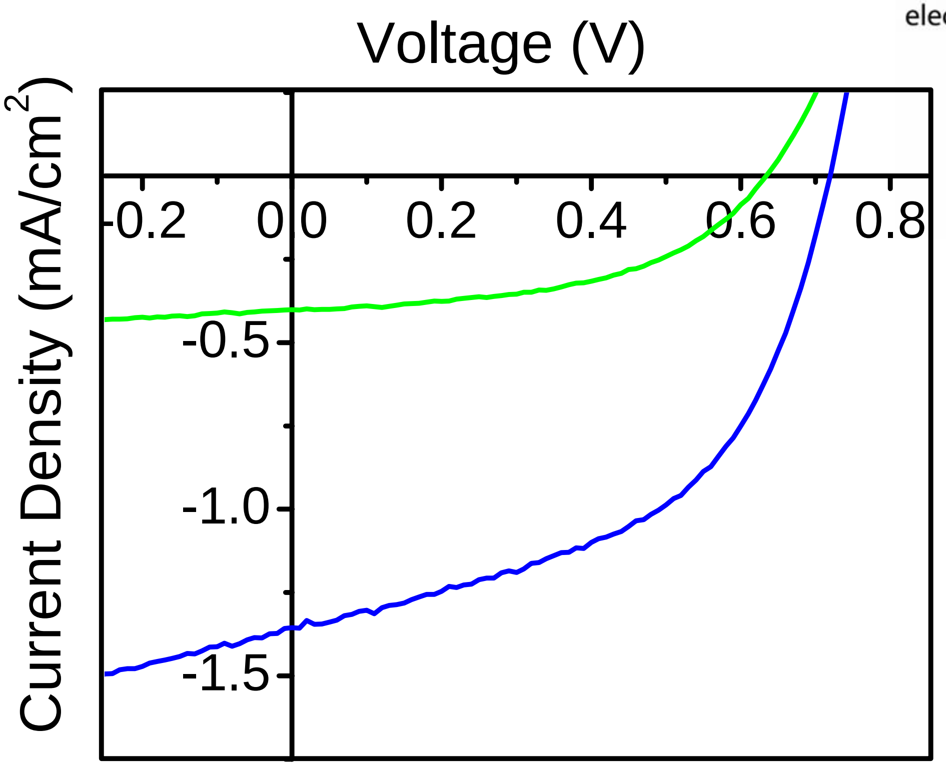


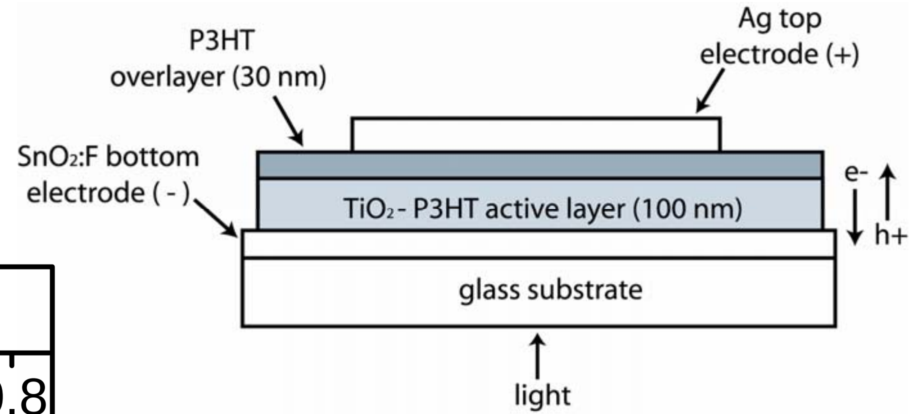


33 % of the volume of the film can be filled in several min.

Adv.Func.Mat., **13** (2003) p. 301

Photovoltaic cells





<u>At 33 mW/cm^2, 514 nm:</u>

η_{pwr} = 1.5 %

FF = 0.51

EQE = 10 %

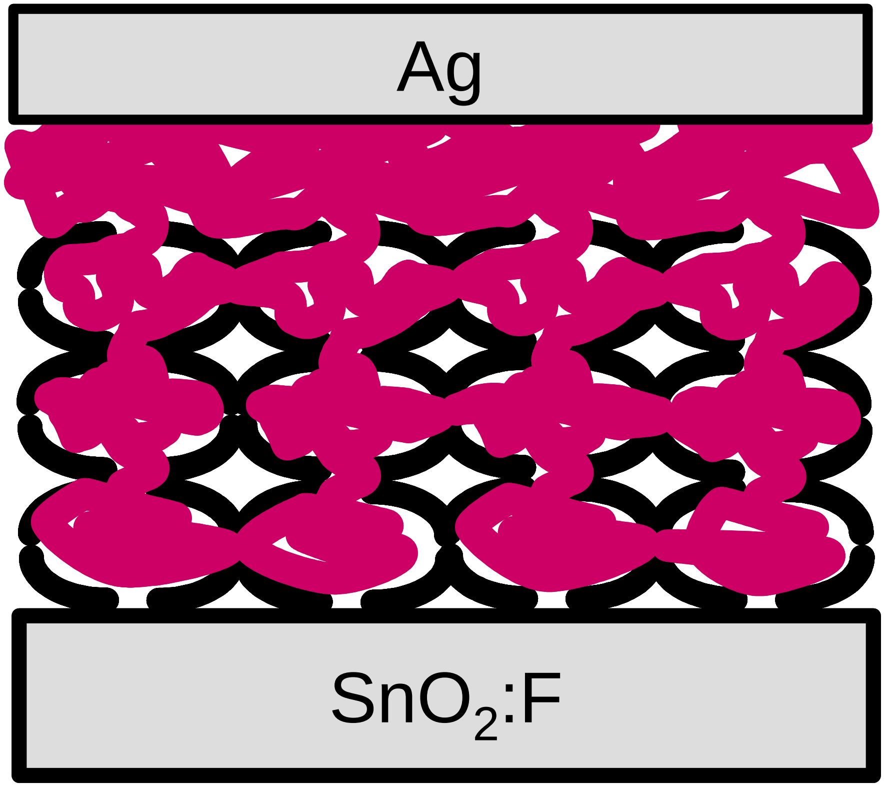
η_{pwr} would be ~ 0.45% under actual sunlight

Blue: Mesoporous titania

Green: Solid (nonporous) titania

App. Phys. Lett. **83** (2003) 3380

Photocurrent is only generated at the top

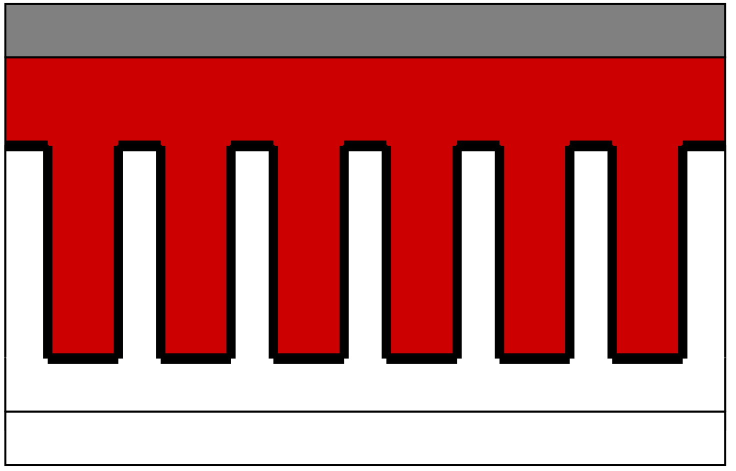


App. Phys. Lett. **83** (2003) 3380

A path to 20 % efficiency

20 % efficiency can be achieve if

1.) We find a method for patterning 20-nm-wide straight holes that are 200 nm deep in a suitable semiconductor.



2.) We reduce the bandgap to absorb more light.

3.) The energy loss associated with electron transfer is reduced.

4.) The charge carrier mobility is improved and the interface is engineered to almost eliminate recombination.

5.) We stack cells of different bandgaps to harvest more of the solar energy.

Review: Coakley and McGehee, *Chemistry of Materials*, 16 (2004) 4533-42.