Organic Solar cell

– Principle, Structure and Materials

2008/4/24
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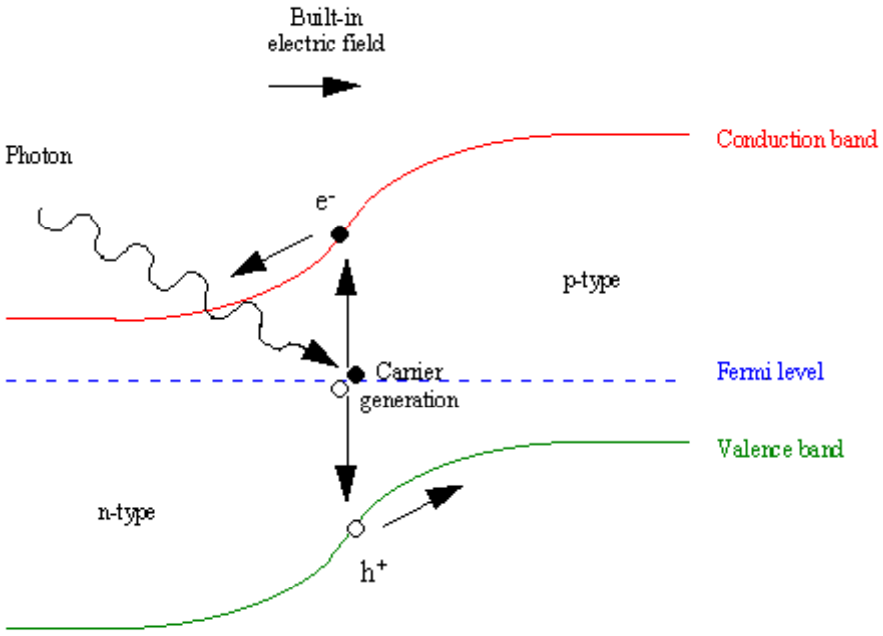
Overview

- Principle of Organic Solar cell
- Current research
- Problem of Organic Solar cell
- Solution and future research

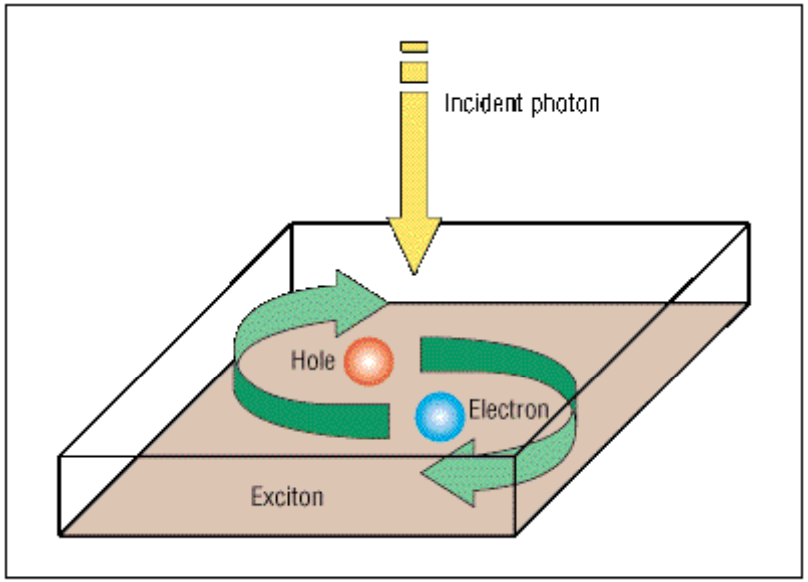
Principle of Solar cell



P-type & N-type
semiconductor
↓
PN junction

Electrons(holes) move anode
(cathode) spontaneously.

Principle of OSC



Coulomb energy : $\frac{q^2}{4\pi\varepsilon\varepsilon_0 r}$

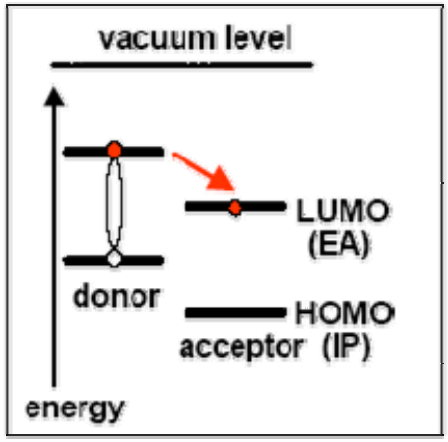
Organic semiconductor:
relatively low dielectric constant

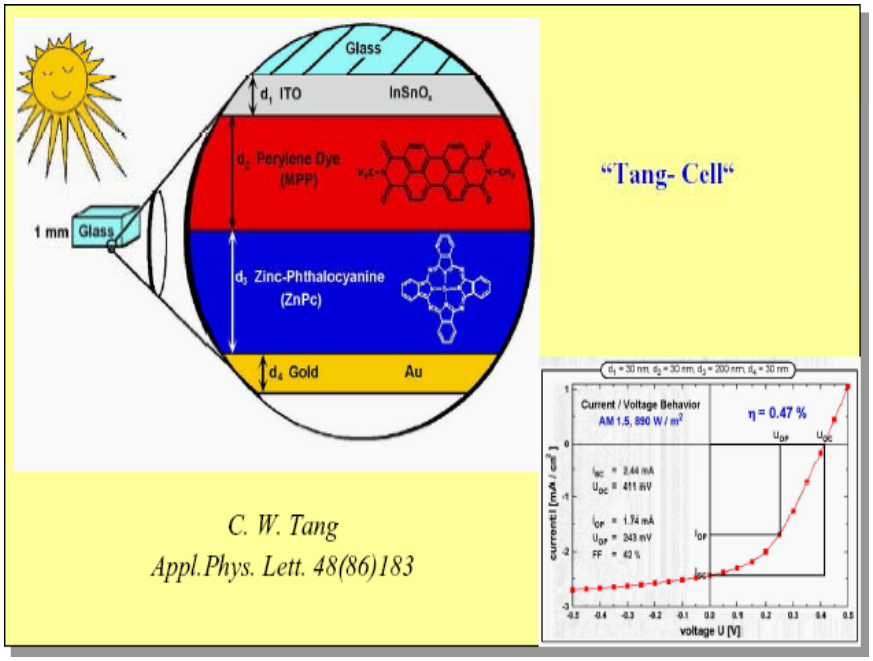
→ Coulomb E > Thermal E

→ Exciton formed

PICT (I) – Bilayer

- Exciton must be separated
- Need additional energy to separate exciton

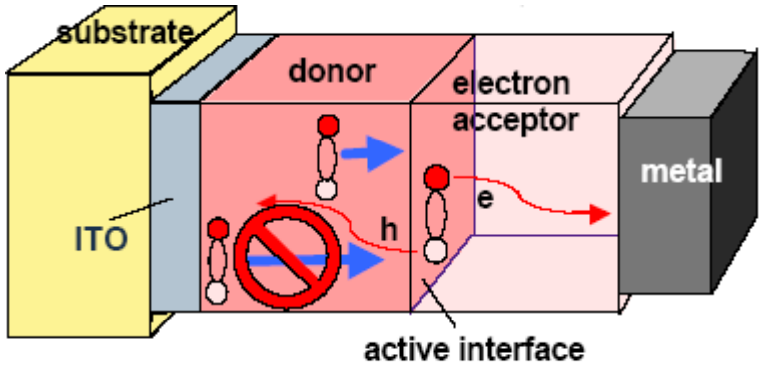




Limitation of Bilayer PV

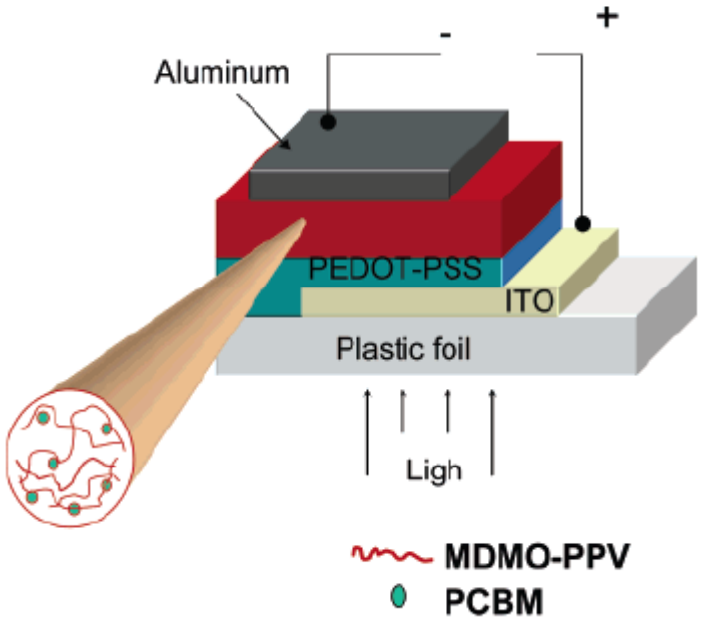
- Exciton diffusion length ~ 10nm
- Absorption layer width ~ 100nm

Many excitons cannot be separated



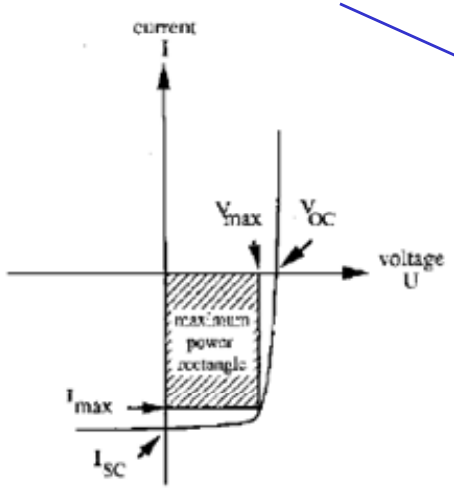
PICT(II) – Bulk heterojunction

- Blend of the donor and acceptor components in a bulk volume
- Phase separation : 10~20nm
- Charge transfer time : ~45 fs
  Christoph J. Brabec et al, Chem.Phys. Lett. 340 (2001) 232
- Recombination time : ~ ms



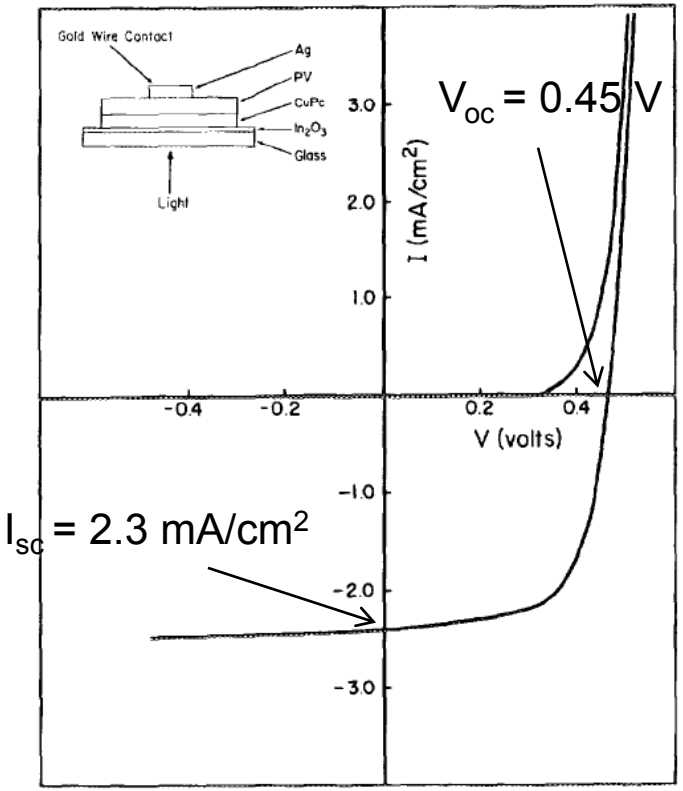
Power Conversion Efficiency

V_{oc}	I_{sc}	FF
• Open circuit voltage • Related to bandgap	• Short circuit current • Related to absorption, charge transfer	• Fill factor = $\frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}}$ • Related to resistance



Power conversion Efficiency : $\frac{V_{oc} * I_{sc} * FF}{\text{Input Power}}$

OSC I – Idea about Bilayer



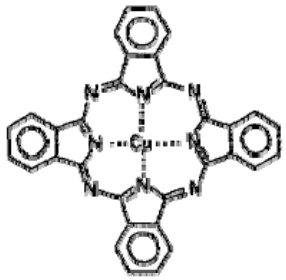
In the early 1970s, efficiency was only 10^{-5} %

Breakthrough using a bilayer

Thickness : CuPc(250Å), PV(450Å)

FF = 0.65

η(efficiency) = 0.95% (AM2, 75mW/cm²)

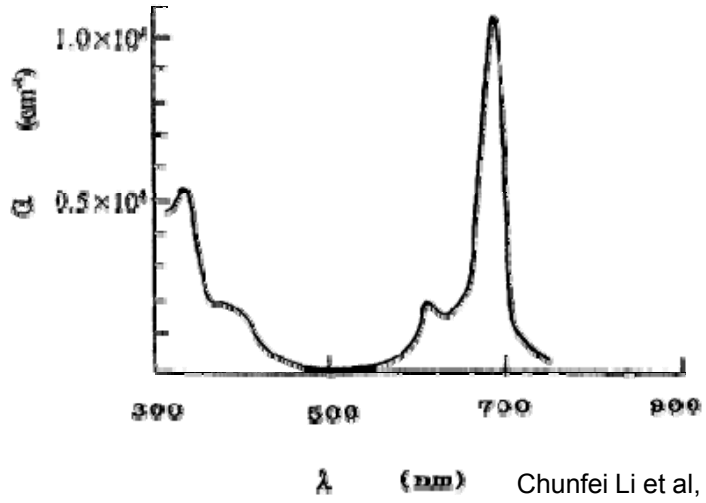


CuPc

PV

C.W. Tang, Appl. Phys. Lett. 48 (1986) 183

OSC I – Problem



Chunfei Li et al, Phys. Rev. A, 49 (1994) 1149

Problem	Solution
Narrow absorption range	Need material that has wide absorption
CuPc thickness > exciton diffusion length	Need new structure

OSC II – Idea about BHJ

C_{60} is a great electron acceptor due to high electron affinity

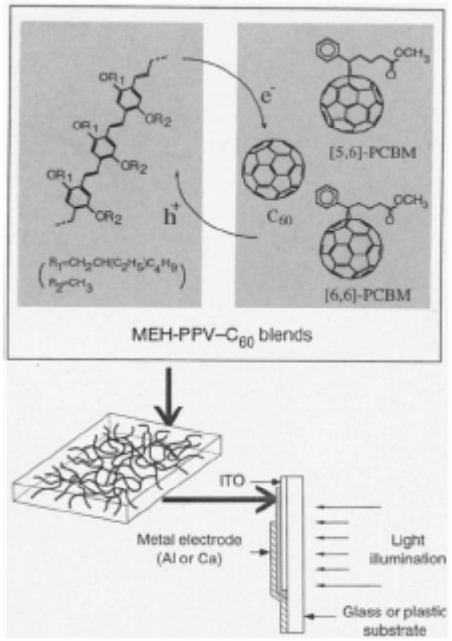
Two problems

insoluble

PPV thickness

attach chain (PCBM)

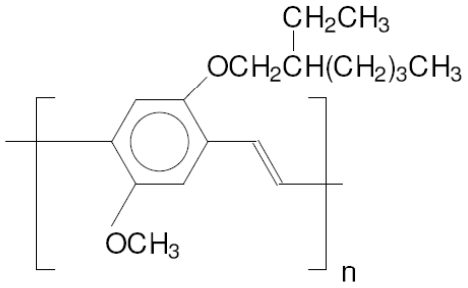
Bulk heterojunction



η = 2.9% under 20mW/cm^2
at 430nm light

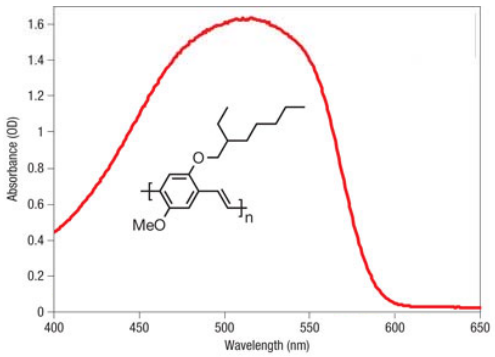
G. Yu et al, Science. 270 (1995) 1789

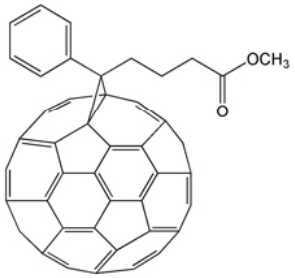
OSC II – Problem



MEH-PPV

MEH-PPV bandgap : 2.1eV

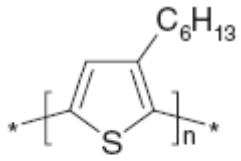




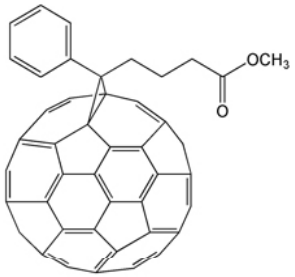
PCBM

Problem	Solution
PPV has large band-gap	Need low band-gap material
Efficiency is not high	Morphology control

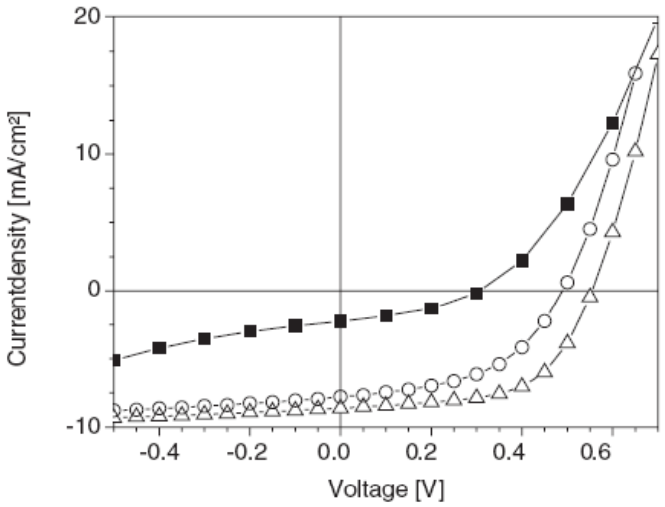
OSC III – Idea about P3HT



P3HT (Donor)



PCBM (Acceptor)



filled squares: as produced

open circles: annealed solar cell

open triangles: annealing and applying an external electric field

as produced

V_{oc} : 0.3V
I_{sc} : 2.5 mA/cm²
FF : 0.4
η : 0.4%

annealed

V_{oc} : 0.55V
I_{sc} : 8.5 mA/cm²
FF : 0.6
η : 3.5%

F. Padinger et al, Adv. Funct. Mater. 13 (2003) 85

OSC III – Idea about P3HT

Advantage of P3HT

- relatively low band gap (1.9eV < PPV)
- Good crystallinity → High hole mobility, low serial resistance

Remain problem

- It only absorbs visible light.
- Optical destructive interference

Solution

- Making a tandem cell using low band-gap material
- Using Titanium Oxide as an Optical Spacer (→ 5% efficiency)

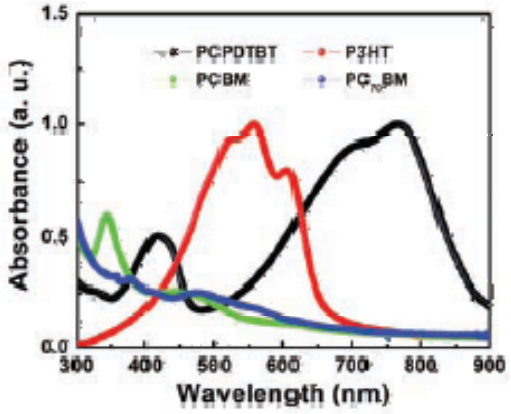
J.Y. Kim et al., Adv. Mater. **18**, 572 (2006)

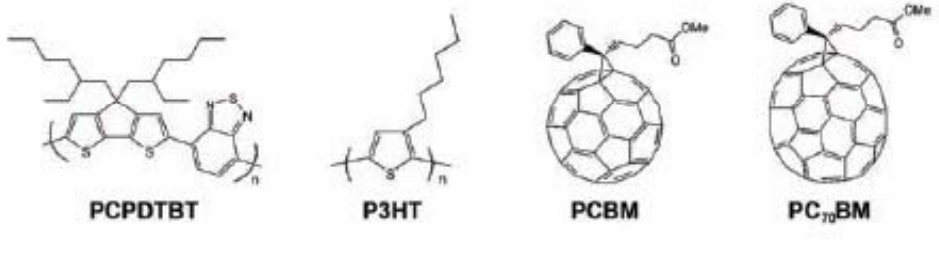
OSC IV – Idea about Tandem

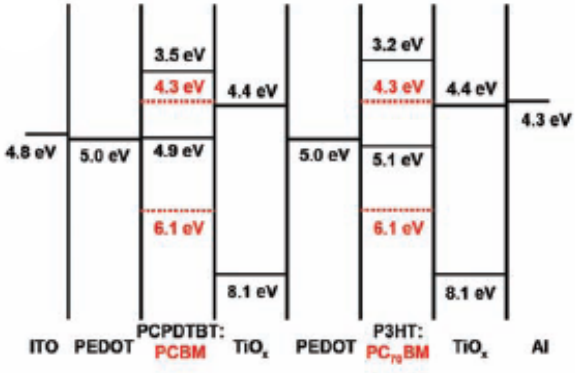
- 52% of solar energy is in IR range
→ band-gap should be small than 1.7eV

- PCPDTBT : 1.4eV band-gap
→ However, PCPDTBT cannot absorb 400~600nm range light (the most powerful range in sunlight).

⇒ Tandem cell structure

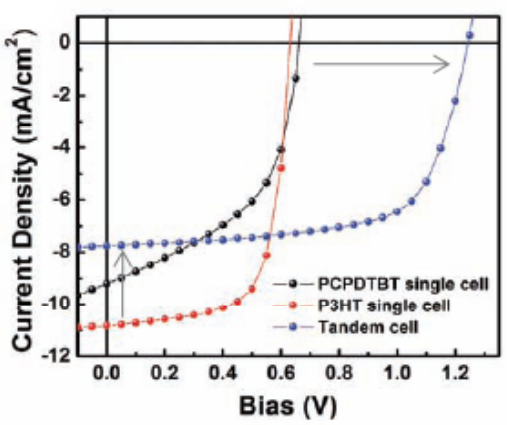


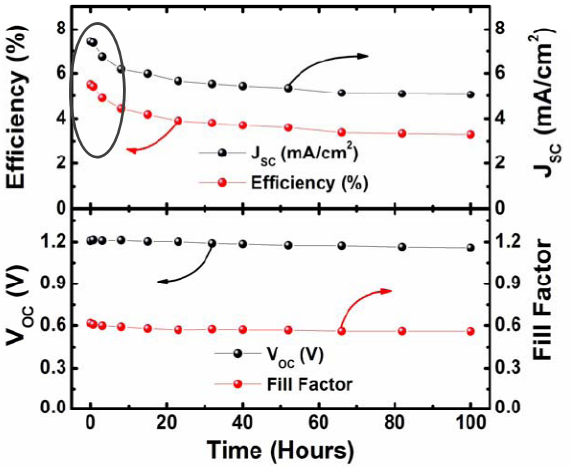




J.Y. Kim, K. Lee, N.E. Coates, D. Moses, T.Q. Nguyen, M. Dante, A.J. Heeger, Science 317, (2007), 5835

OSC IV – Idea about Tandem





- V_{oc} of the tandem cell : 1.24 V
- J_{sc} of the tandem cell : 7.8 mA/cm^2
- η_e of the tandem cell : 6.5%

Because two photovoltaic cells are in series, J_{sc} is lower than the each single cell.

- Still problem

▪ Long-term stability
▪ LUMO level of polymer and PCBM is too big.

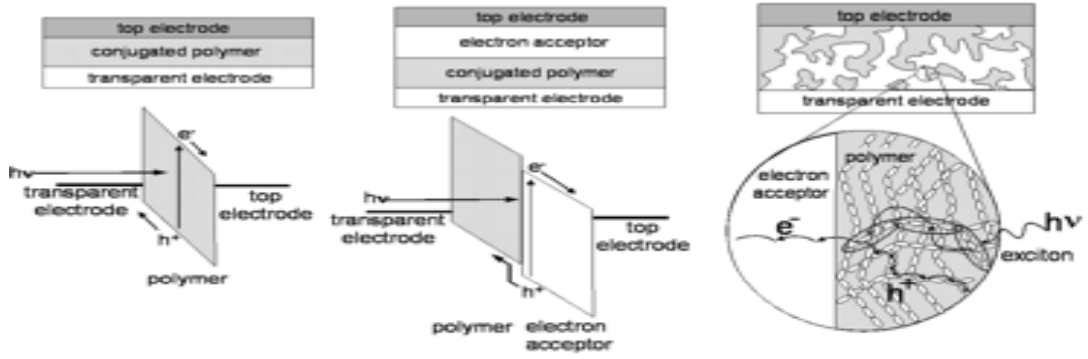
J.Y. Kim, K. Lee, N.E. Coates, D. Moses, T.Q. Nguyen, M. Dante, A.J. Heeger, Science 317, (2007), 5835

Conclusion

• Organic Solar Cells produce excitons, therefore there are donor-acceptor layer.

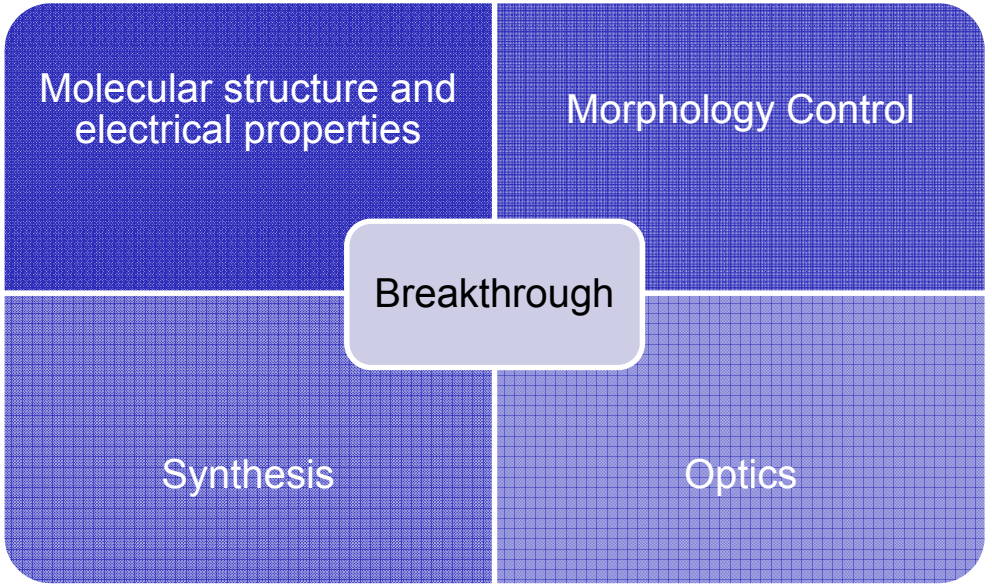
• In order to increase efficiency, new material has to be synthesized.

• Morphology control is important as well.



~10^{-5}% ~2% ~5%

Conclusion


Molecular structure and electrical properties
Morphology Control
Breakthrough
Synthesis
Optics