Multilayer Organic Photovoltaic Cells

MSE 395 – 29 May 2008

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http://www.yuma-solar.com/pvl.htm

Motivation

- Solar energy is abundant
- Current Si based PV systems are expensive
- Organic PV cells are cheap but inefficient
  - Large Si wafer plant – 88,000m^2 per year
  - Offset printing 1-10 hours for same area
  - Typical power efficiency: 2-4%
- Multilayer organic cells can have higher efficiencies than traditional single cells

Brabec, C.J.; et.al. *MRS Bull.* **30**, 50 – 52. 2005

Multilayer cells

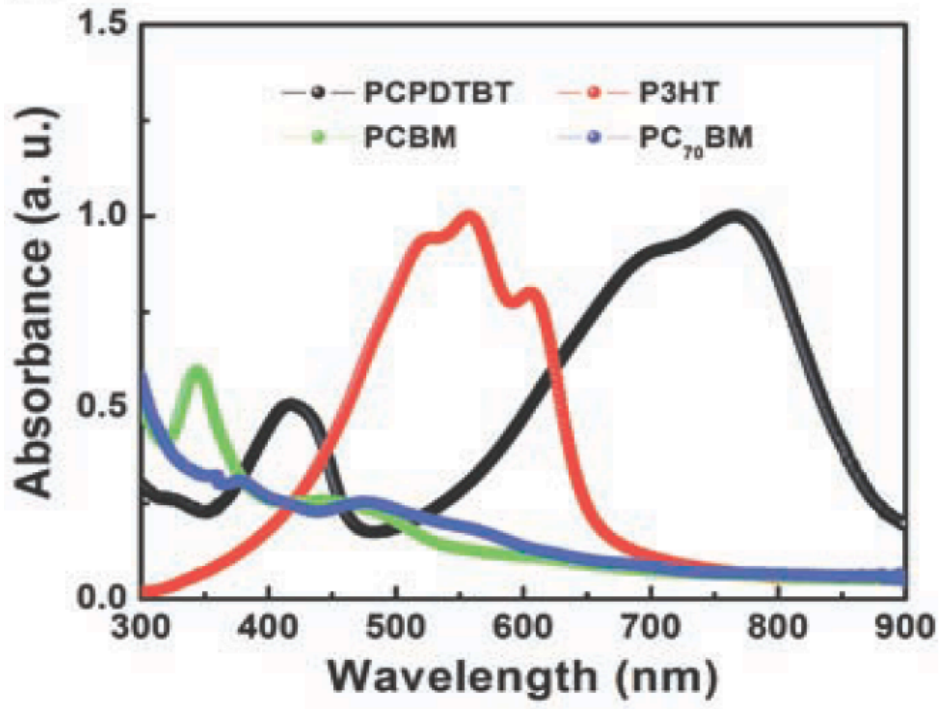
- What are multilayer or tandem organic PV cells?
- What advantages do these have over regular cells?
- What are the materials challenges facing improvement of these devices?

The multilayer cell

- Series connection of two organic PV cells
- Active layers are a mix of donor and acceptor materials

Advantages over single layer cells

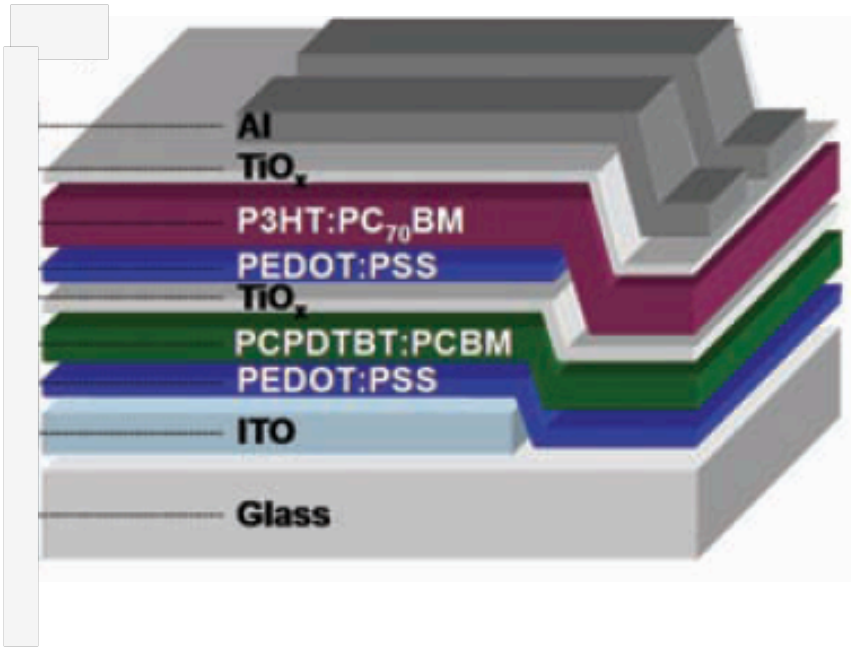
- Polymers have narrow absorption bands
- Multiple active layers allow absorption over a wider range of the spectrum



Kim, J.Y.; et.al. *Science*. **317**, 222 – 225. 2007.

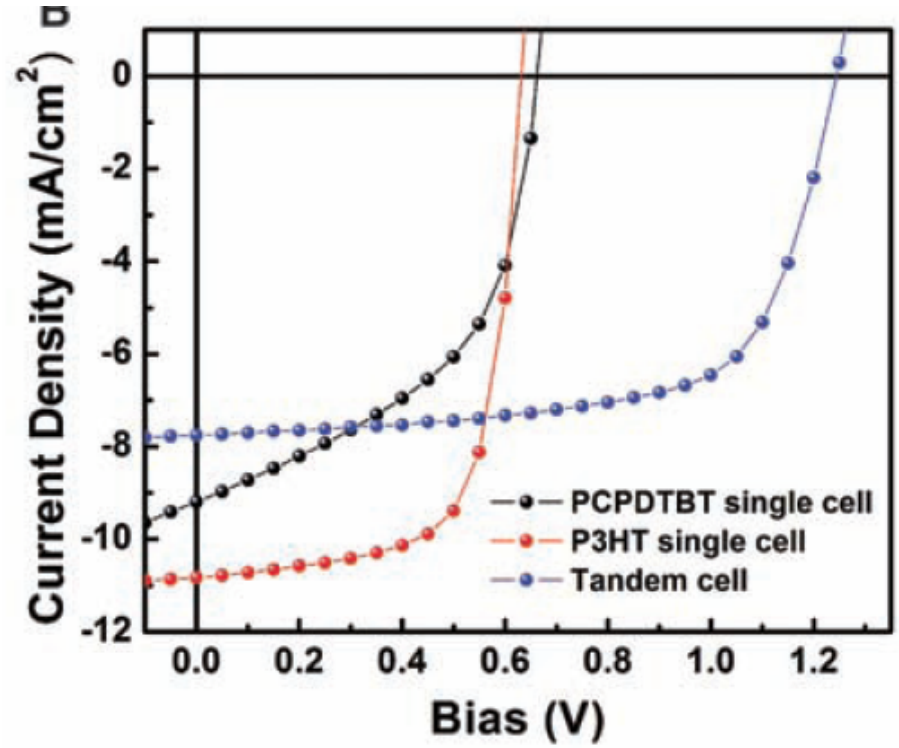
Multilayer cell performance

	Front	Back
Donor	PCPDTBT	P3HT
Acceptor	PCBM	$PC_{70}BM$



FF = 0.67

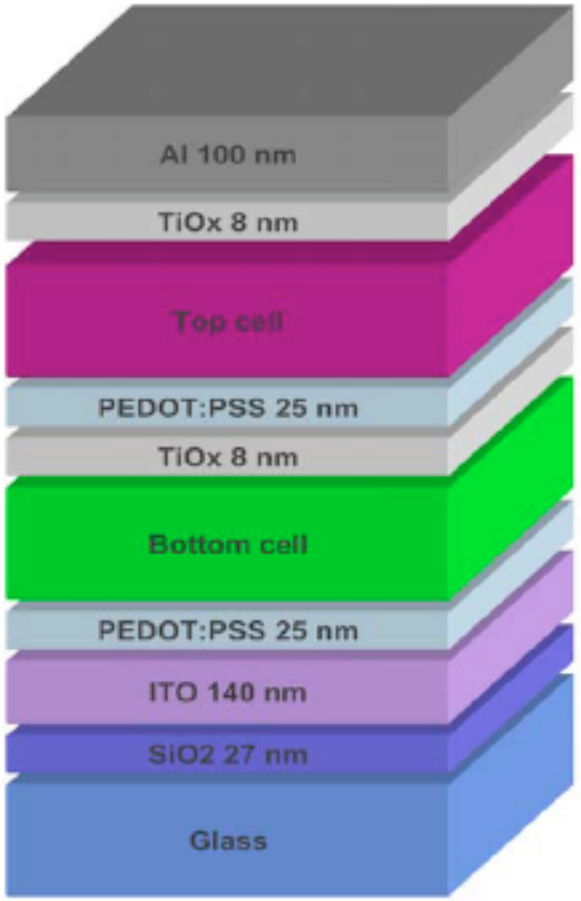
η = 6.5%



Kim, J.Y.; et.al. *Science*. **317**, 222 – 225. 2007.

General challenges

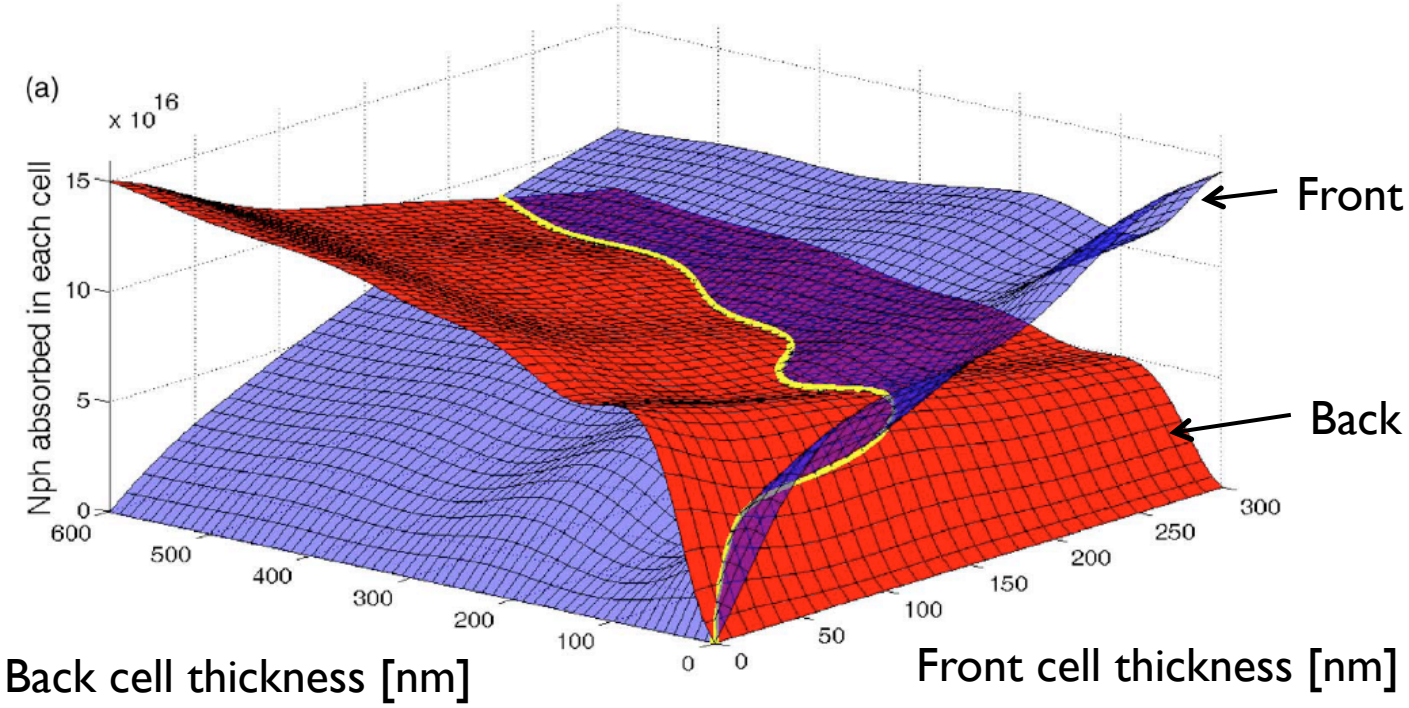
- Many variables
  - Donor & acceptor materials (2 pairs)
  - Interlayer material
  - Layer thickness
  - Layer order
- Device optimization is complicated
  - 200 cell designs tested
  - "Inverted" cell – small bandgap material in the front, not intuitive
- Need predictive technique to streamline process



Dennler, G.; et. al. *J. App. Phys.* **102**, 123109. 2007.

Optical calculations

- Goal: balanced cell
- Potential improvements: 9% with thicker PCPDTBT layer



Dennler, G.; et.al. *J. App. Phys.* **102**, 123109. 2007.

Dennler, G.; et.al. *Adv Funct. Mater.* **20**, 579 – 583. 2008.

Challenges for interlayer materials

The interlayer should be:

- transparent (usually)
- conductive (for electrons or holes)
- a mediator of electron – hole recombination
- compatible with adjacent materials
- deposited with solution based techniques

- Thin metal layers – used in early cells, but coming back
- ITO – high work function, bad contacts
- TiO_x – best performance so far, solution process

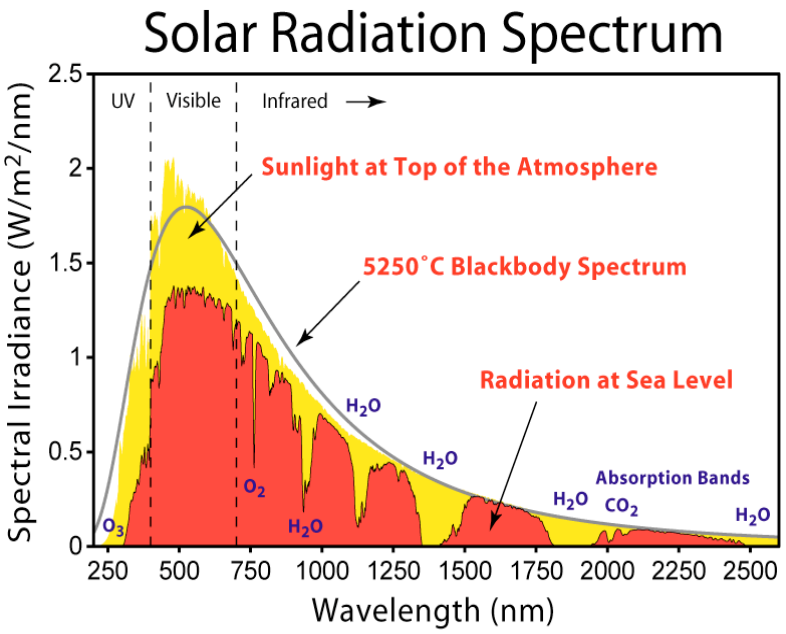
Hadipour, A.; et.al. *Adv. Funct. Mater.* **18**, 169 – 181. 2008.

Conclusion

- Multilayer cells are in early stage of development
- Room for improvement in:
  - Interlayers
  - Processing
  - Active materials
- Cell architecture optimization: calculation & experiment

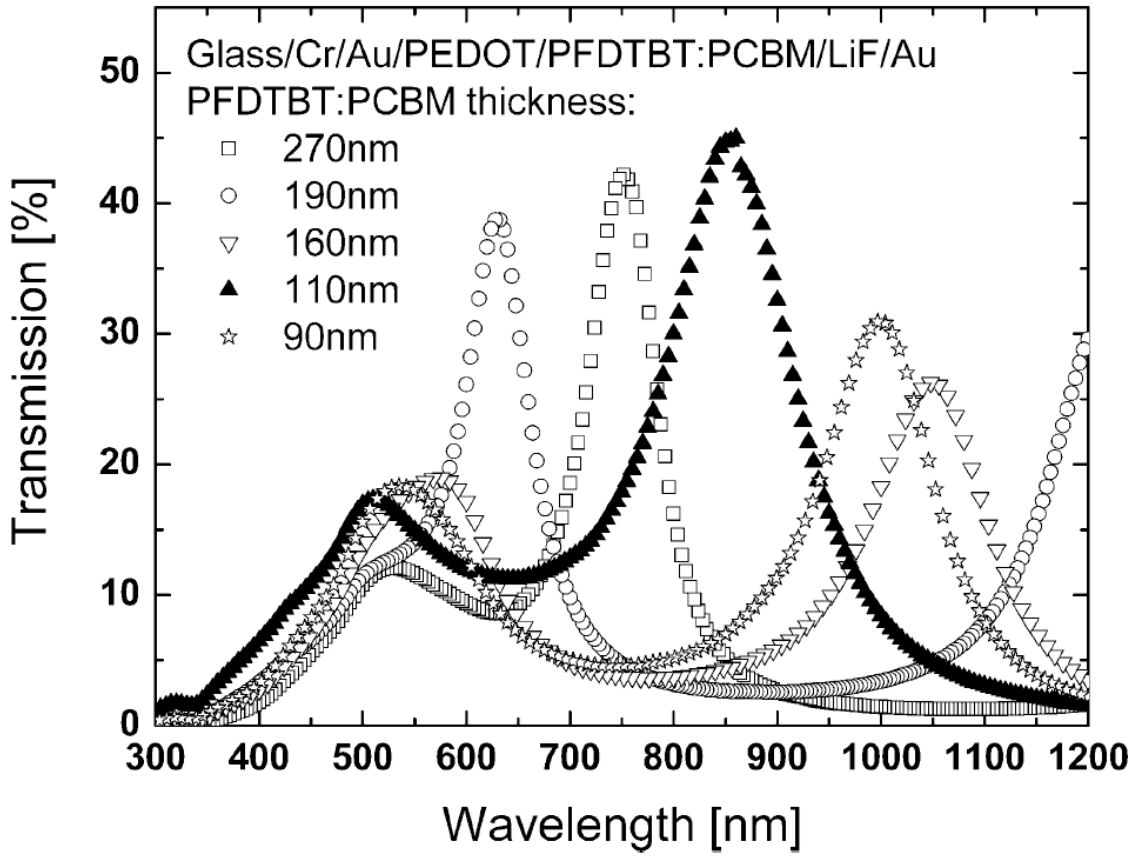
Polymers

- **P3HT**: poly(3-hexylthiophene)
- **PCBM**: [6,6]-phenyl-C61 butyric acid methyl ester
- **$PC_{70}BM$**: [6,6]-phenyl-C71 butyric acid methyl ester
- **PCPDTBT**: poly[2,6-(4,4-bis-(2-ethylhexyl)-4H-cyclopenta[2,1-b;3,4-b']dithiophene)-alt-4,7-(2,1,3 benzothiadiazole)]
- **PEDOT**: poly(3,4-ethylenedioxylenethiophene)
- **PSS:** polystylene sulfonic acid



http://www.globalwarmingart.com/wiki/Image:Solar_Spectrum_png

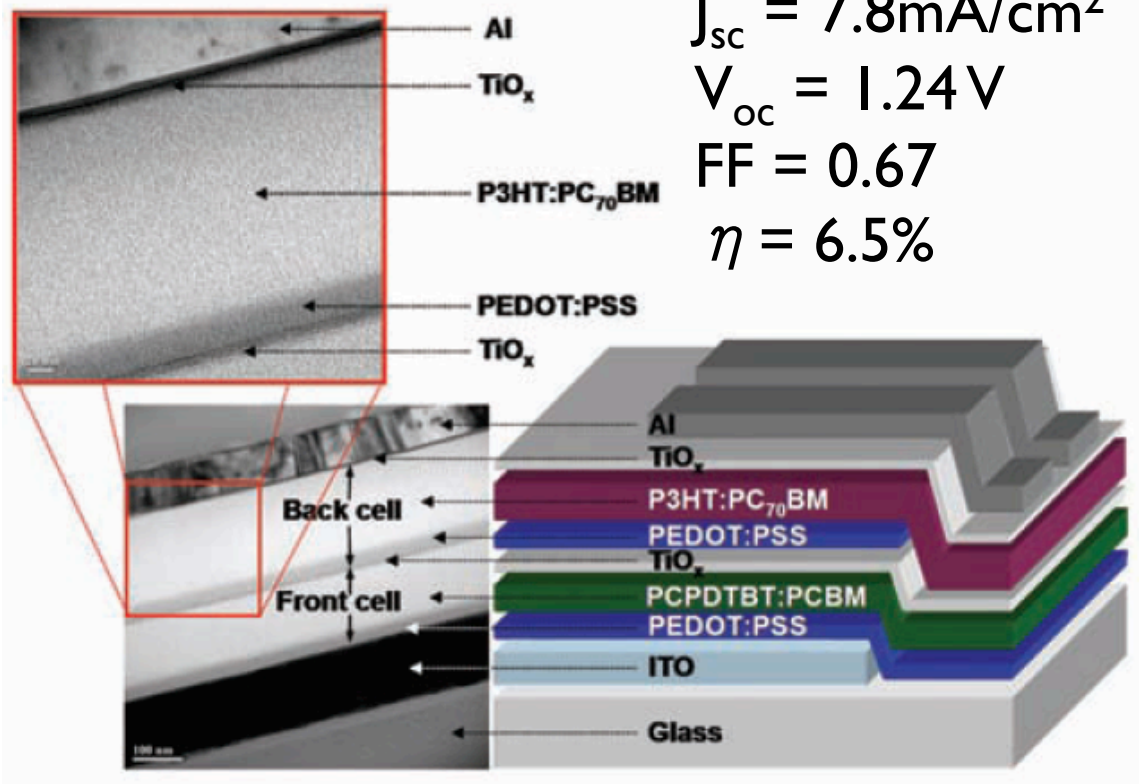
Intelayers and optical cavities



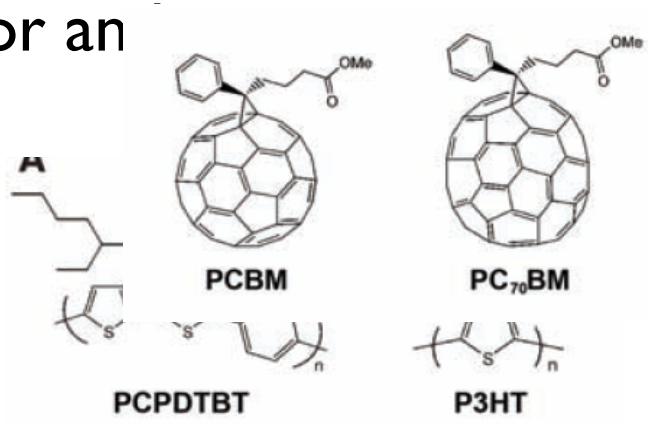
Hadipour, A.; Boer, B.; Blom, P.W.M.; *Adv. Funct. Mater.* **18**, 169 – 181. 2008.

The multilayer cell

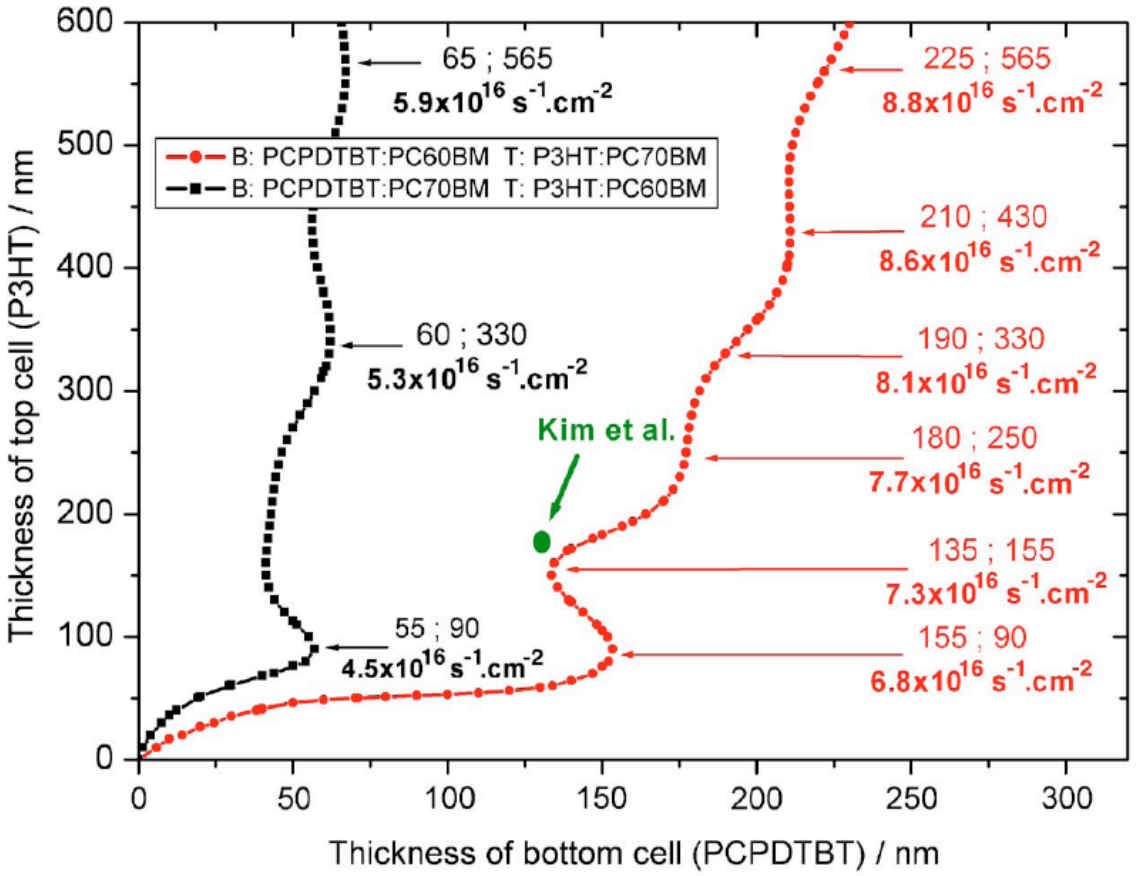
- Series connection of two organic PV cells
- Each active layer is a mixture of donor an materials



J_{sc} = 7.8mA/cm^2
V_{oc} = 1.24V
FF = 0.67
η = 6.5%



Aceptors


Thickness of top cell (P3HT) / nm
Thickness of bottom cell (PCPDTBT) / nm
0
100
200
300
400
500
600
0
50
100
150
200
250
300
B: PCPDTBT:PC60BM T: P3HT:PC70BM
B: PCPDTBT:PC70BM T: P3HT:PC60BM
65 ; 565
5.9x10^16 s^-1.cm^-2
60 ; 330
5.3x10^16 s^-1.cm^-2
55 ; 90
4.5x10^16 s^-1.cm^-2
Kim et al.
225 ; 565
8.8x10^16 s^-1.cm^-2
210 ; 430
8.6x10^16 s^-1.cm^-2
190 ; 330
8.1x10^16 s^-1.cm^-2
180 ; 250
7.7x10^16 s^-1.cm^-2
135 ; 155
7.3x10^16 s^-1.cm^-2
155 ; 90
6.8x10^16 s^-1.cm^-2