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香港浸會大學理學院
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Semitransparent Organic Solar Cells

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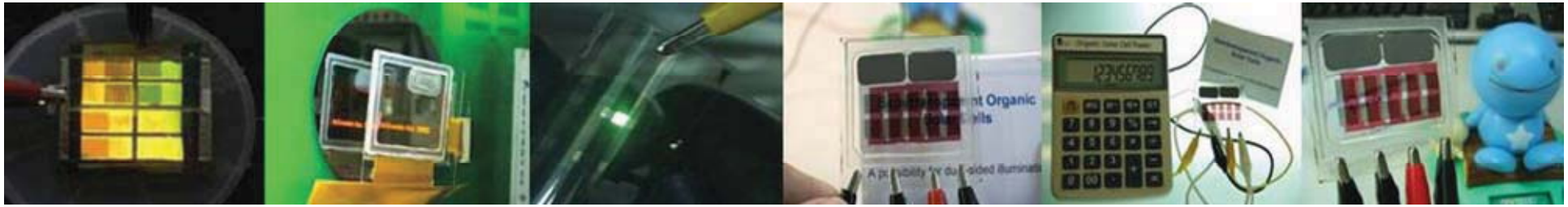

Outline

- A glimpse of photovoltaic technologies
- ITO-based transparent cathode
- Optical enhancement in semitransparent organic solar cells
- Applications of semitransparent OSCs
- Summary

Photovoltaic technologies

- Solar cells
  - Bulk
    - c-Si, poly c-Si
    - III-V semiconductor (GaAs, InP）
  - Thin Film
    - Thin film c-Si, a-Si, hybrid Si
    - II-VI semiconductor film (CdTe)
    - $CuInSe_2$, $Cu(InGa)Se_2$
  - Organic
    - Solid dye-sensitized solar cells
    - Organic/inorganic hybrid
    - Organic (polymer & small molecule)
  - Nano-structured
    - Nano-particle, nano-wire & quantum dot-based solar cells

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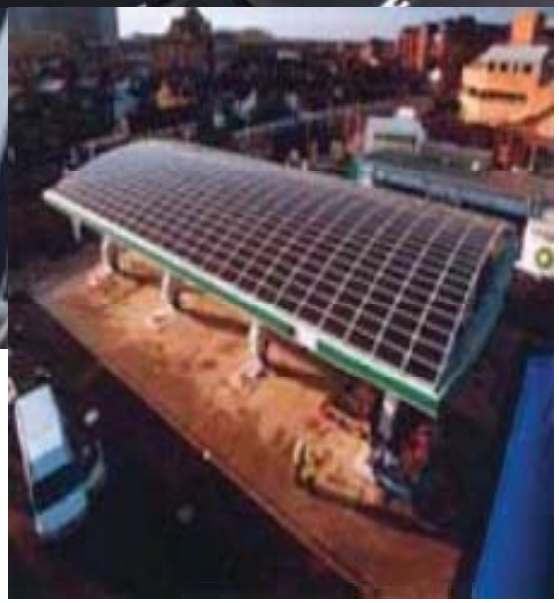
Si & thin film solar cells

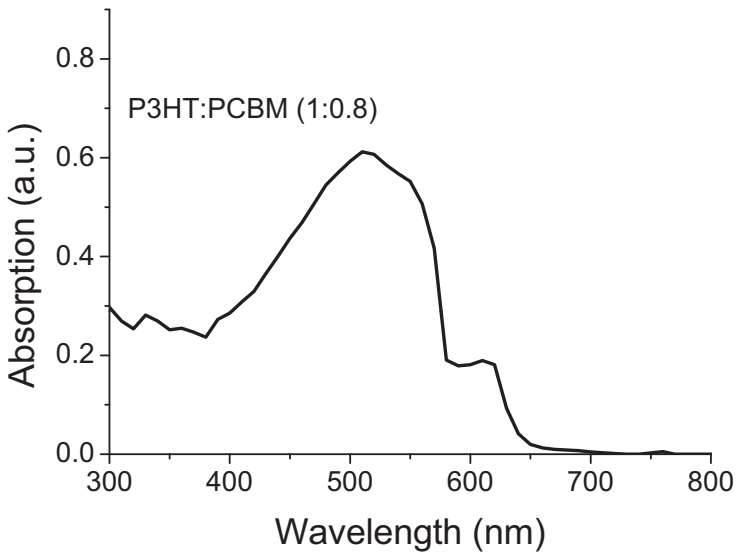


Other PV technologies

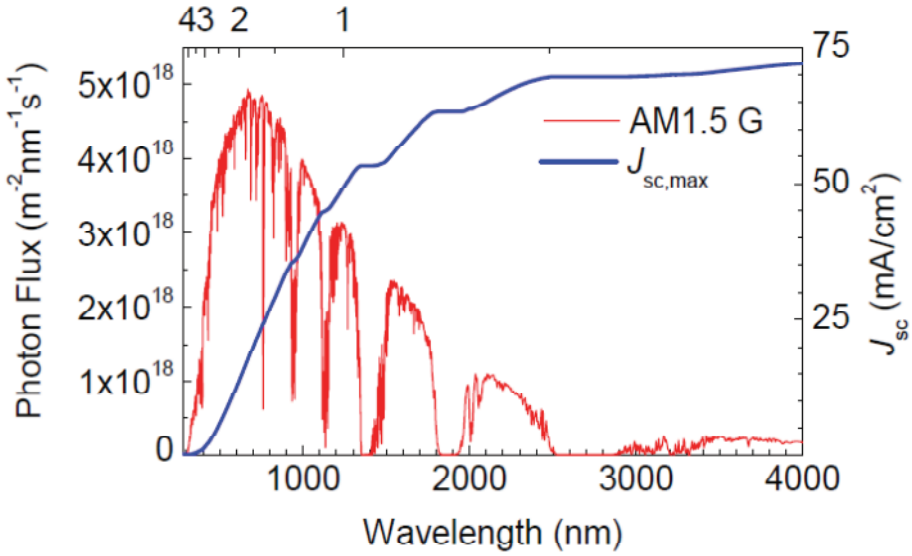
Type	Benefit or intended benefit (all are light weight compared to silicon)	Efficiency at which it is viable	Challenges
CIGS	High efficiency at low cost, long life, transparent , no disposal problems	10-15% i.e. now	Price of indium
CdTe	Fairly high efficiency (below CIGS, above others). Well	10-15% i.e. now for buildings	Cd is a poison, controlled disposal only, so not allowed in consumer goods etc, tough to print, supply of Te?
DSSC	Tolerant of polarized light, low level light, transparent, extreme angle of incoming light, choice of colors, no disposal problems	10-15% i.e. now	Liquids Price of ruthenium?
OSC	Low cost, huge materials varieties, tunable electronic/optical properties	8-10%	Cost, efficiency, stability, narrow spectrum

Limitations in OSCs

Narrow absorption band



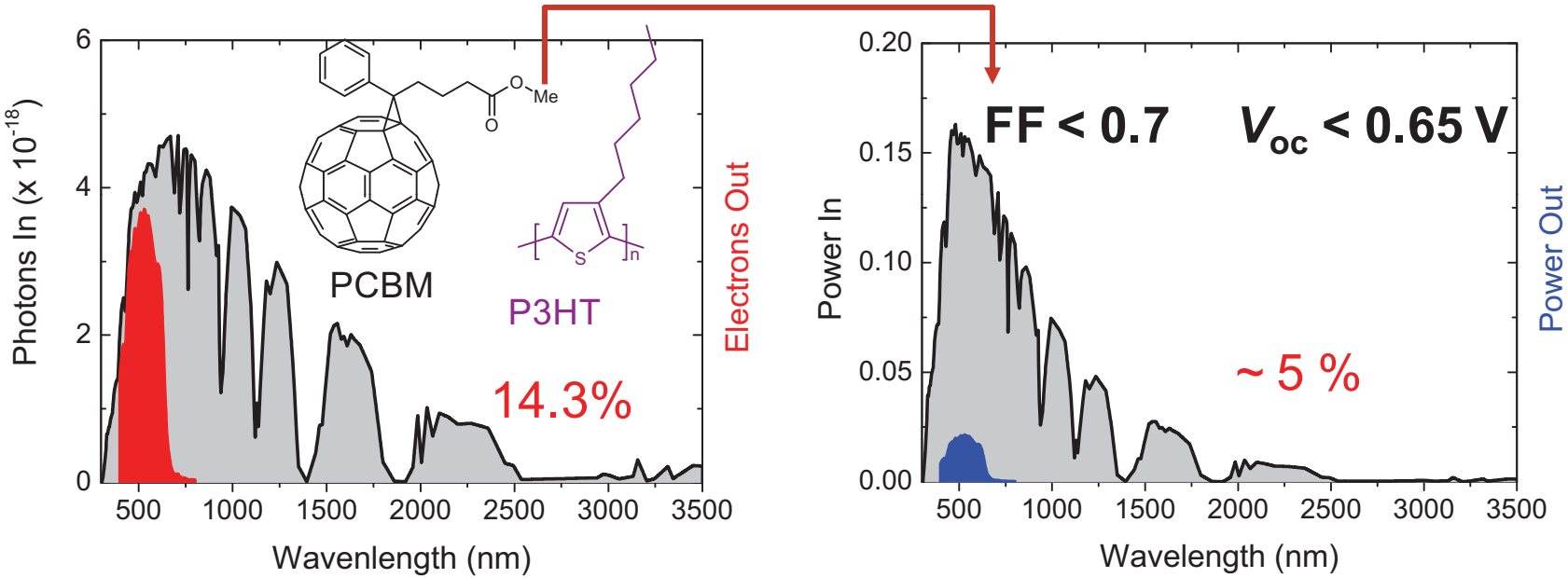
Solar spectrum and available photocurrent



- It limits the absorption and thus short circuit current density
- Low carrier mobility (~ 10^{-6} to 10^{-3} cm^2/Vs)
  - Active layer cannot be too thick <300nm
  - Fill factor affected due to the large series resistance

Limitations in OSCs

Inefficient utilization of the solar energy by current available materials.



Possible approaches:

- Low band gap photoactive materials
- Tandem cells
- Light in-coupling features , light harvesting

Advantages of OSCs

- Solution processable, lightweight, translucent & flexible, potential low cost
- Roll to roll coating technologies could realize scalable production process with high productivity
- Less energy consumption during fabrication process, less CO_2 emission.

Power generation windows

Architectural surfaces

Flexible, transparent & decorative

Motivation and challenges

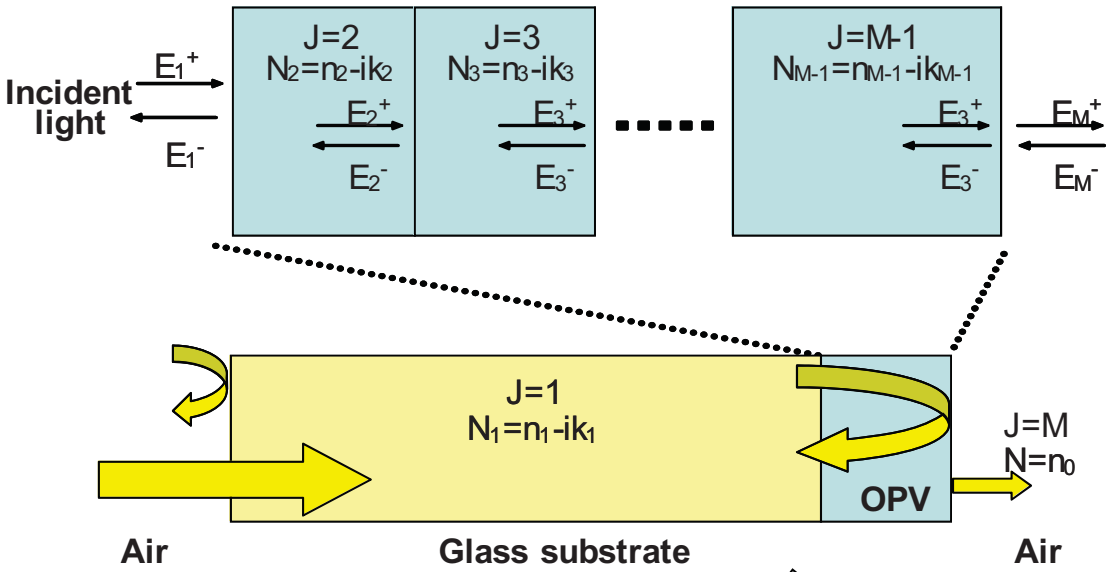
- Perceived benefits of OSC technologies
  - Lower cost, higher volumes, greater flexibility, light weight, size and shape
  - New device concepts, inverted, translucent
  - The best research OSC efficiency approaching 10%
- Technical challenges
  - New semiconducting and conducting materials with tunable electronic and optical properties
  - Efficient charge collection properties at organic/electrode interface
  - light harvesting, solution processing stability, thin film encapsulation…

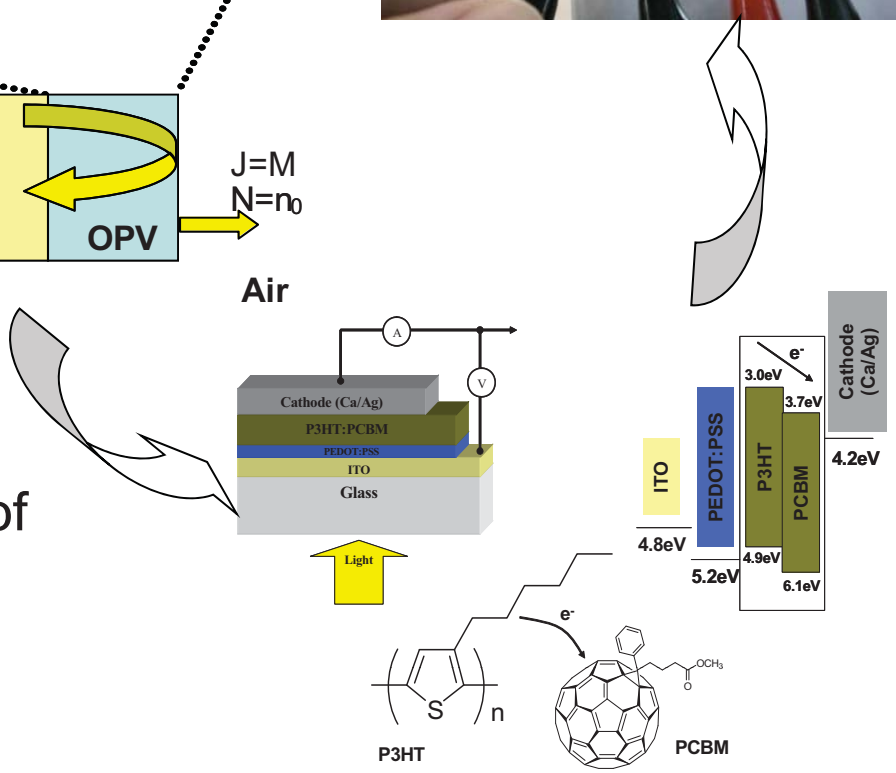
Conversion steps

Conversion step	Incident photons	Loss mechanism
Light absorption		- Reflection, Transmission - Spectral mismatch
Exciton generation		- Exciton recombination
Exciton diffusion		- Excition transfer with recombinations - No charge separation and subsequent recombinations of excitons
Charge separation		- Recombination of charges - Limited mobility of charges
Charge transport		- Recombination near electrodes - Energy barrier at electrodes

Separated charges at electrodes

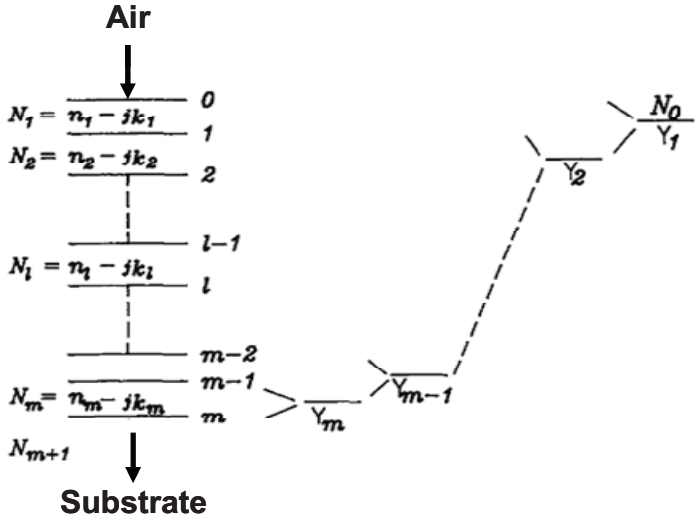
OSC is a thin film system

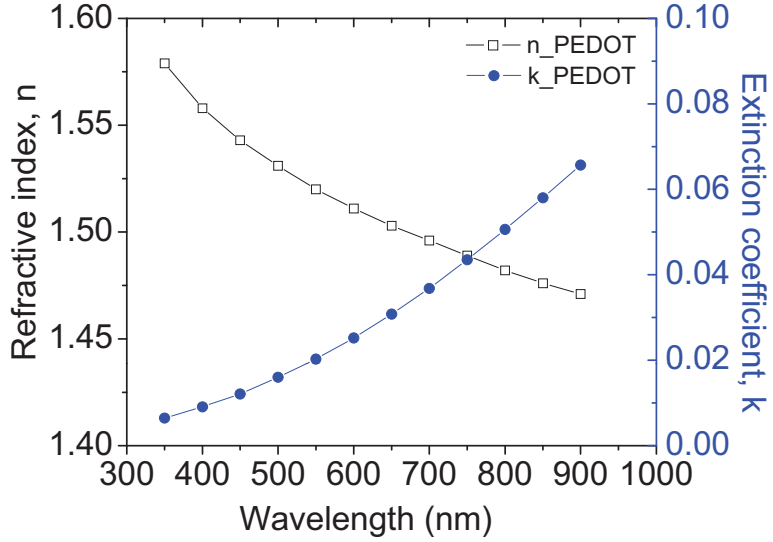


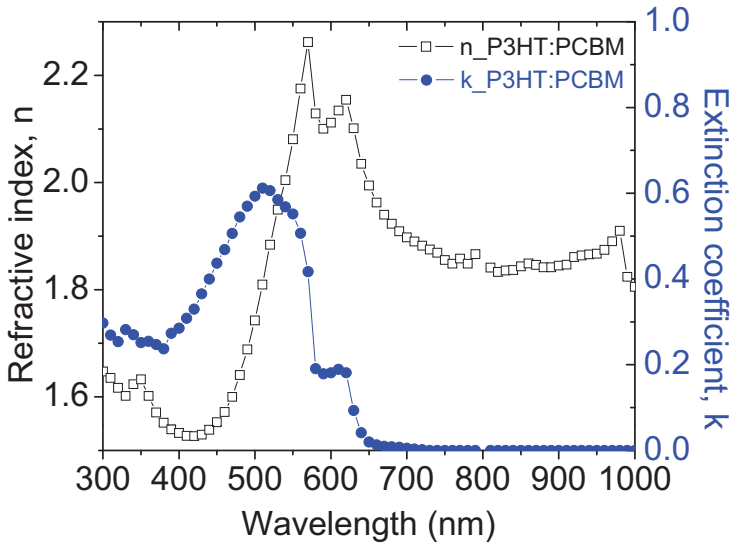


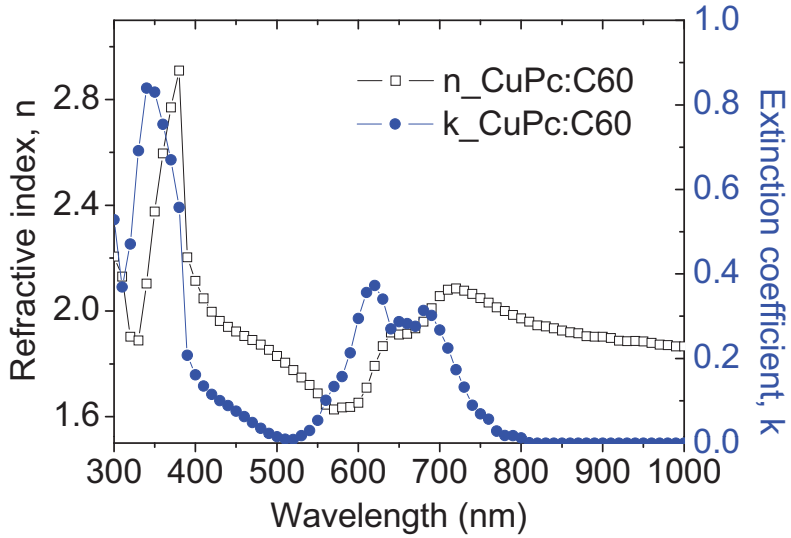
Schematic representation of a thin film OSC

Optical constants



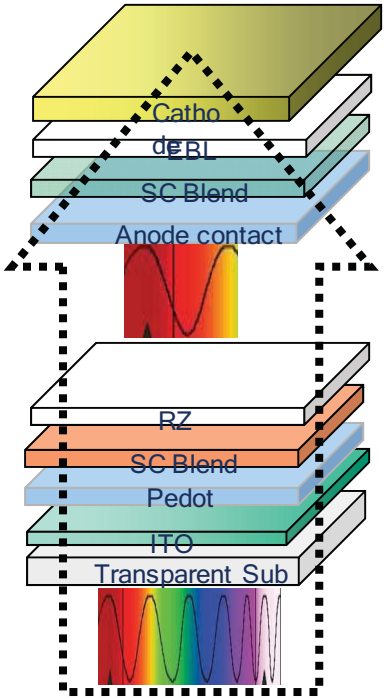


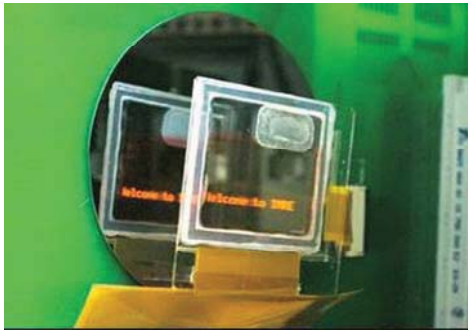




Interlayer:

1) Thin metal layer
   - Discontinuous and high reflectivity in NIR
2) Oxide/organic interlayer
   - Limited lateral conductivity
3) TCO electrode is suited for application in
   - Organic, inorganic and hybrid solar cells
   - Simple, effective and low cost technology
   - Greater fabrication flexibility



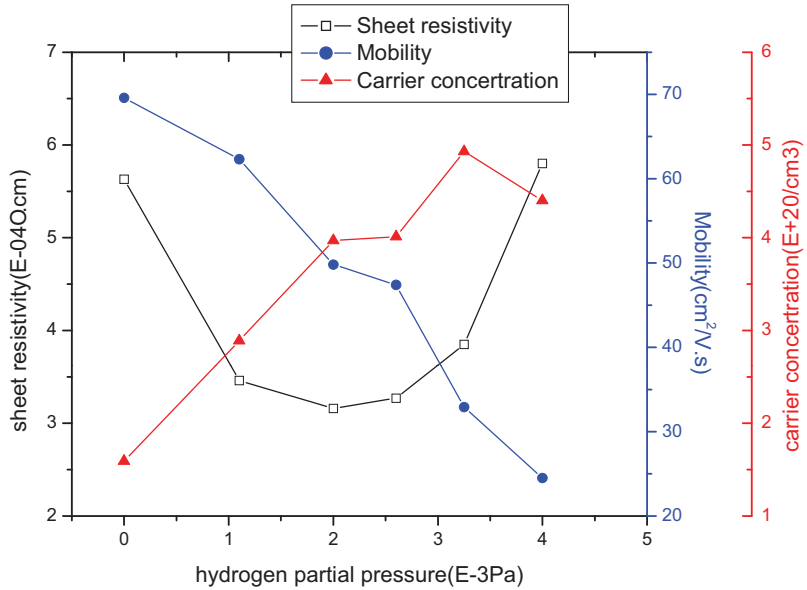


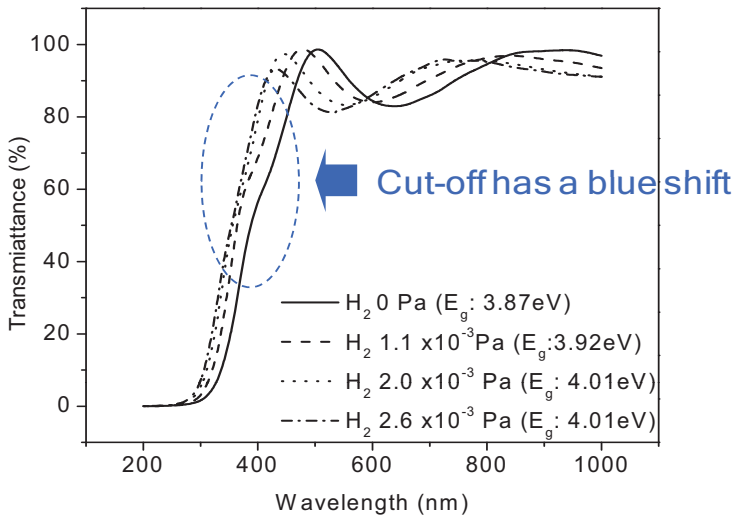
High performance TCO (ITO)

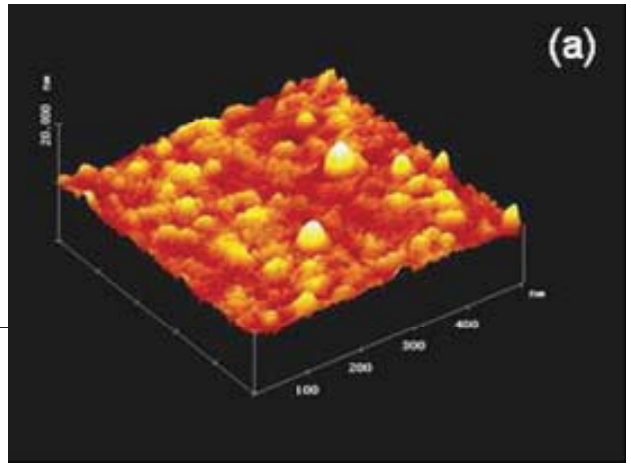
- Low resistance, high transparency with smooth surface
- Compatibility of device fabrication with no damage to the underlying functional organic layers
- Excellent delineation and adhesion capabilities
- Size, shape and substrate flexibility
- Lower cost and higher volumes
- Emerging new applications:

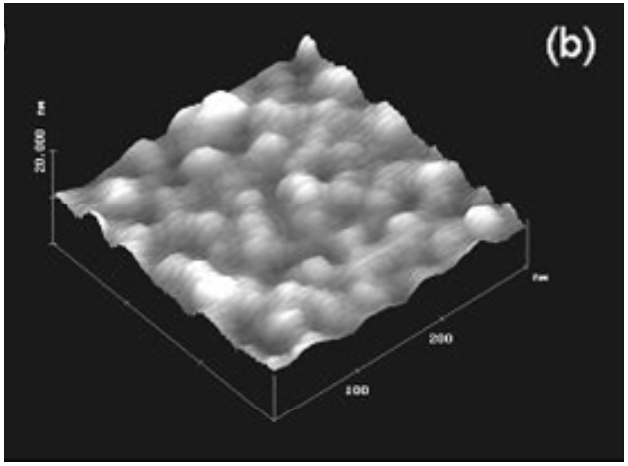
  Flexible electronics including FOLED displays, lighting, OSC, organic sensors …

Low processing temperature ITO





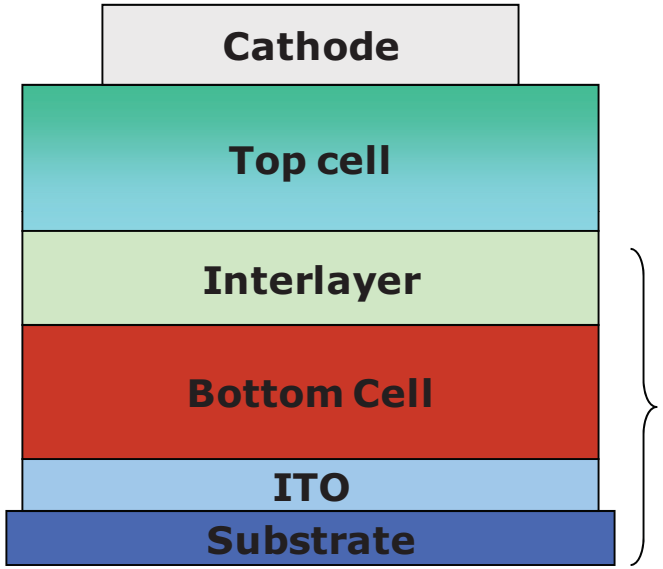


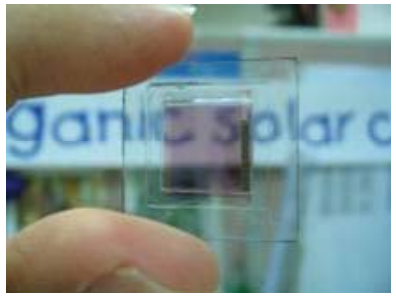


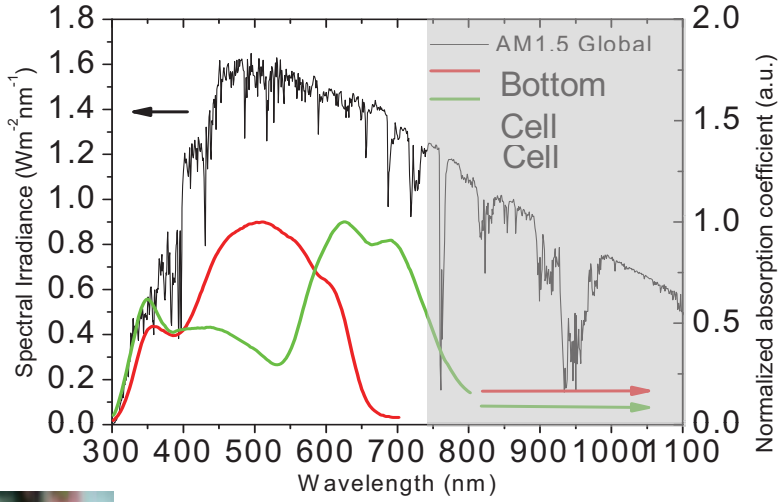
Low processing temperature ITO

- Deposition at a temp < 60°C
- TCO (ITO, AZO, IZO)/PC & PET etc.
- T(λ) over 85%
- Rs~ 25 Ω/sq, ~130nm, for ITO
- Smooth surface, rms < 1.0 nm
- Low stress
- High etching rate
- No damage to the underlying organic/polymer materials
- Applications: top-emitting OLEDs, FOLED, tandem & semitransparent OSCs, integrated org electronic devices …

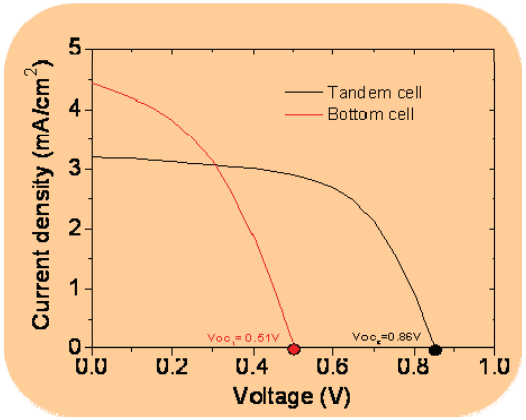
Stacked OSCs



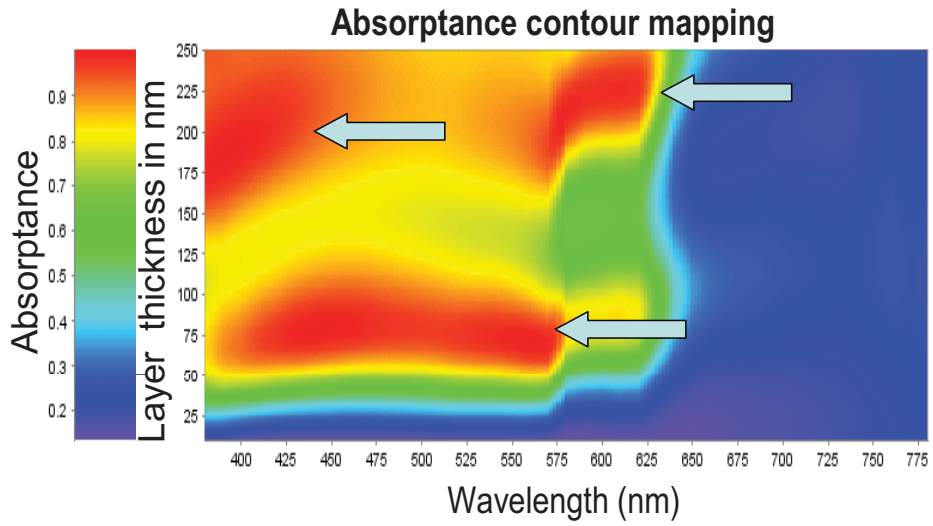




- An increased V_{oc}, photocurrent matching required
- Thinner active layer for better charge transport
- Extensive spectral response



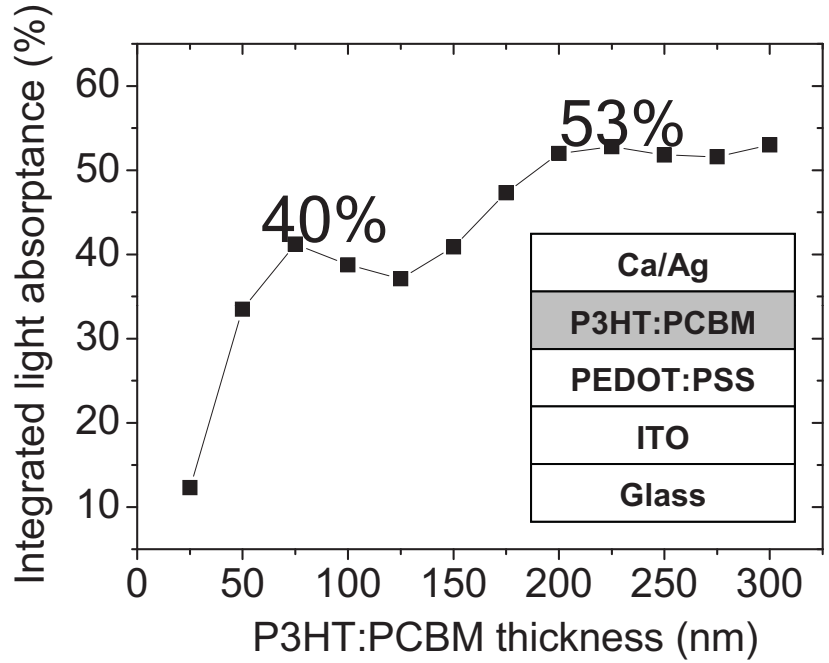
Integrated absorptance



Integrated absorptance of P3HT:PCBM layer:

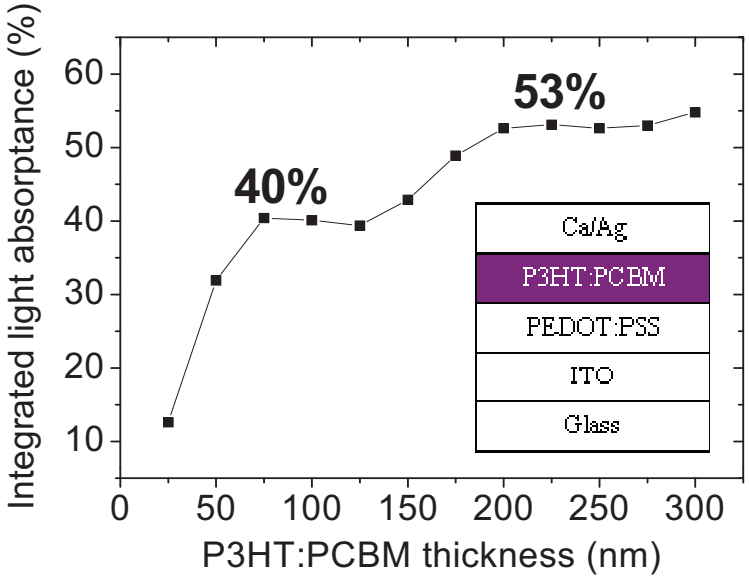
$$\overline{A}_{P3HT:PCBM}(\lambda) = \frac{\int A_{P3HT:PCBM}(\lambda)F(\lambda)d\lambda}{\int F(\lambda)d\lambda}$$

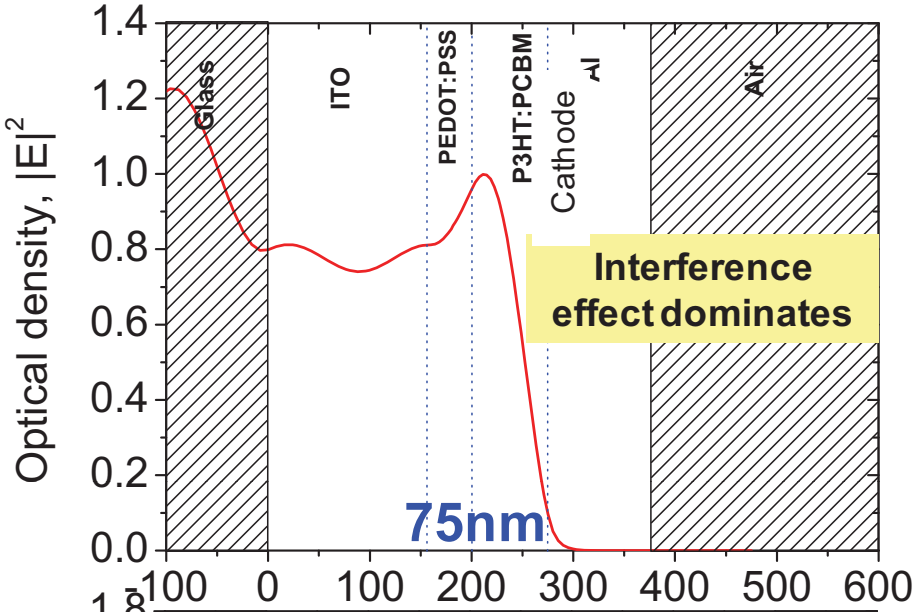
ITO/PEDOT:PSS/P3HT:PCBM/Ca/Ag

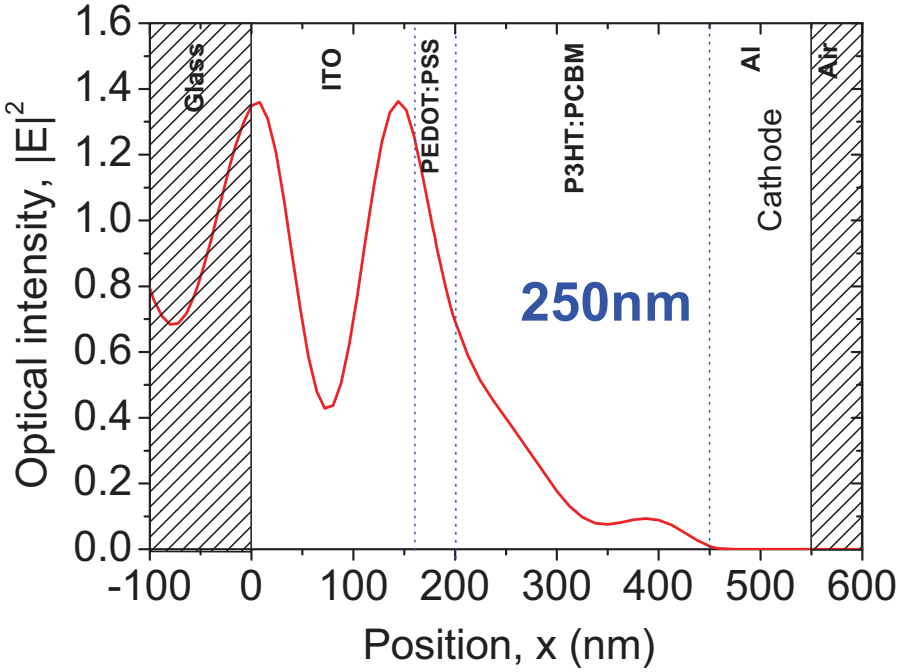


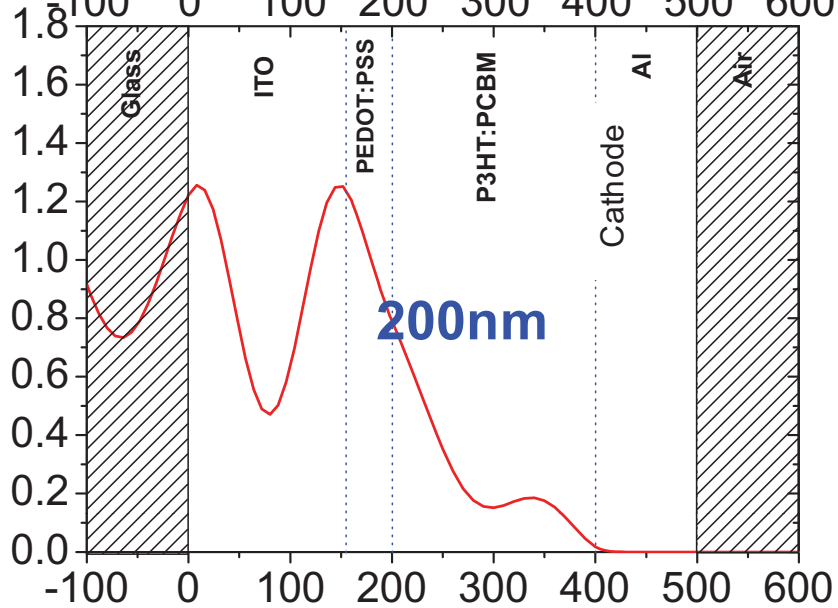
- Maximum absorption for P3HT:PCBM based OSCs occurs at 75nm, 200nm and 250nm.
- Oscillation absorption behavior → interference effect.

Light distribution





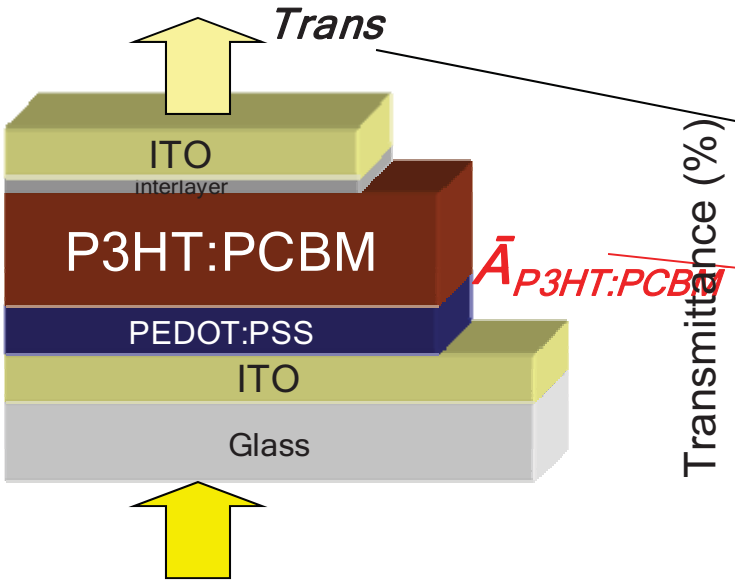


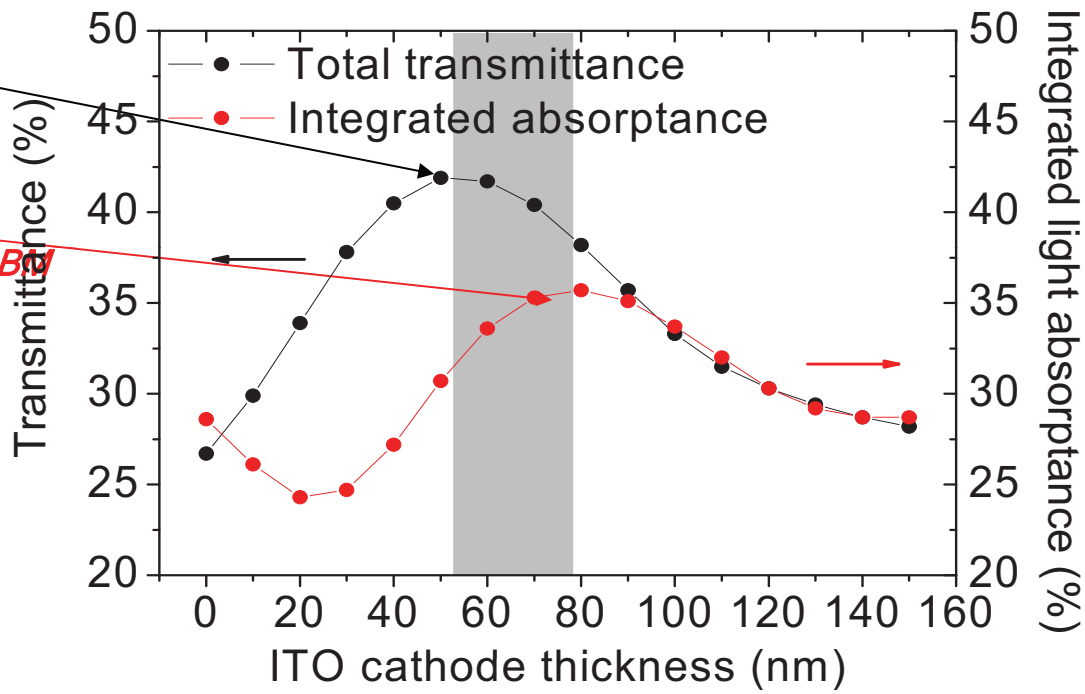


Appl. Phys. Lett. 90 (2007) 103505.

Semitransparent OSCs

- two competing performance indexes: $T(\lambda)$ & $A(\lambda)$



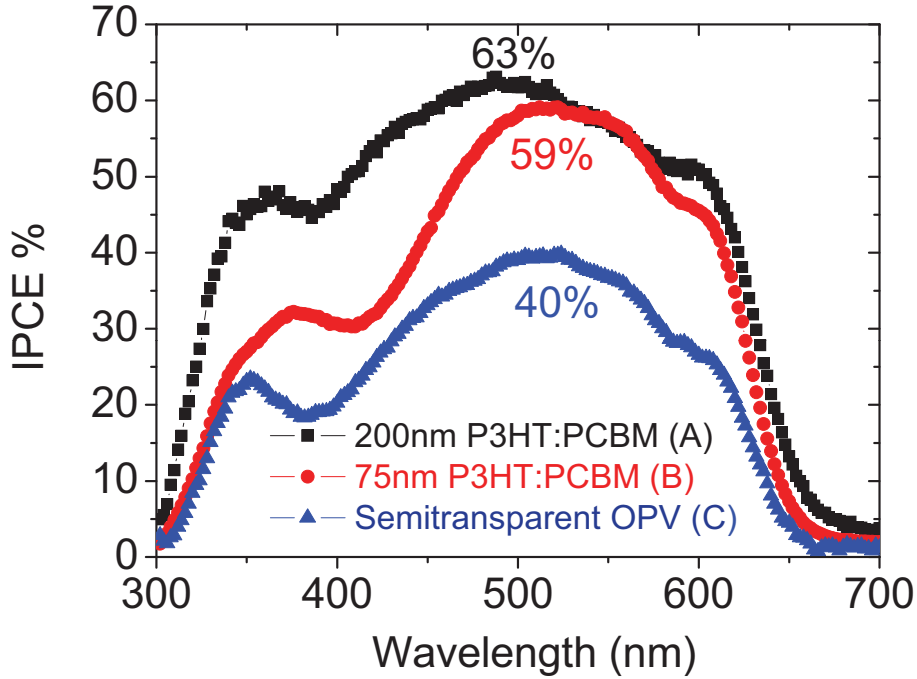


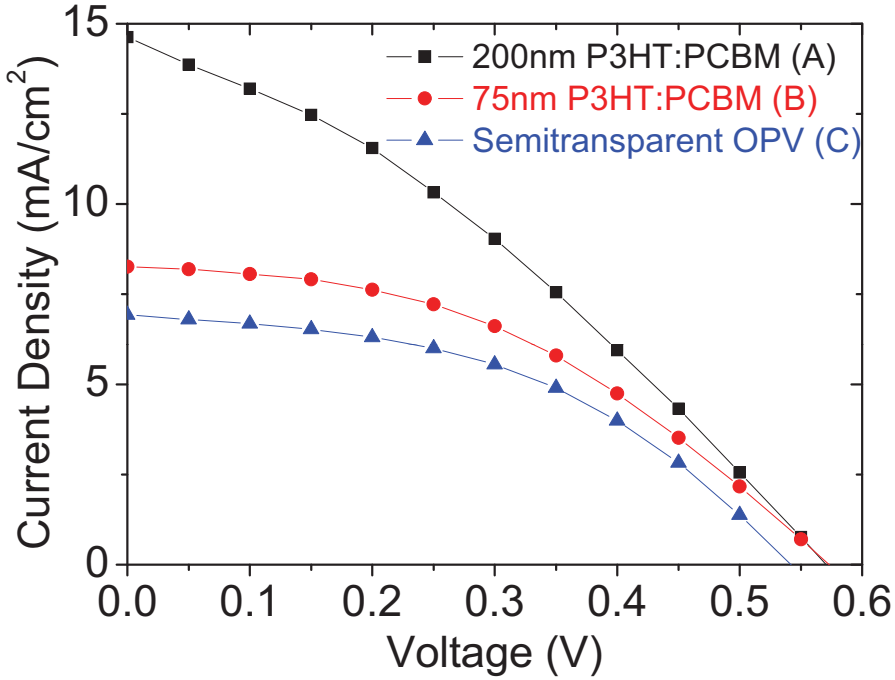
- ITO acts as refractive index matching layer to enhance the $T(\lambda)$
- ITO improves the lateral conductivity of the top cathode

Appl. Phys. Lett. 90 (2007) 103505.

Semitransparent OSCs

- Device characteristics

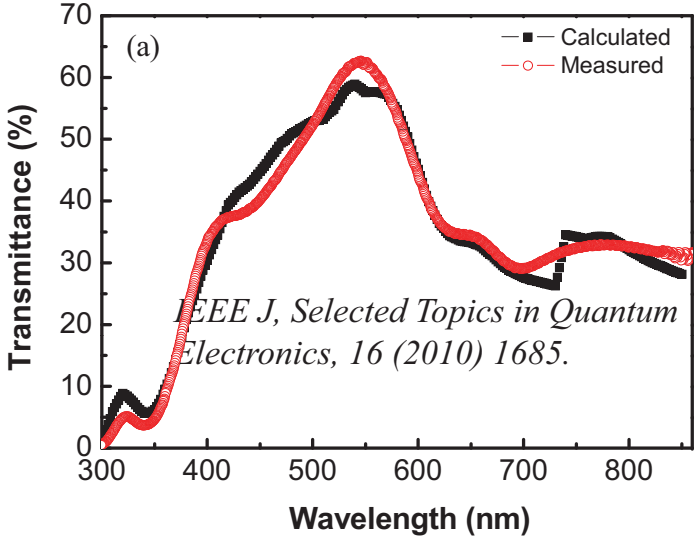


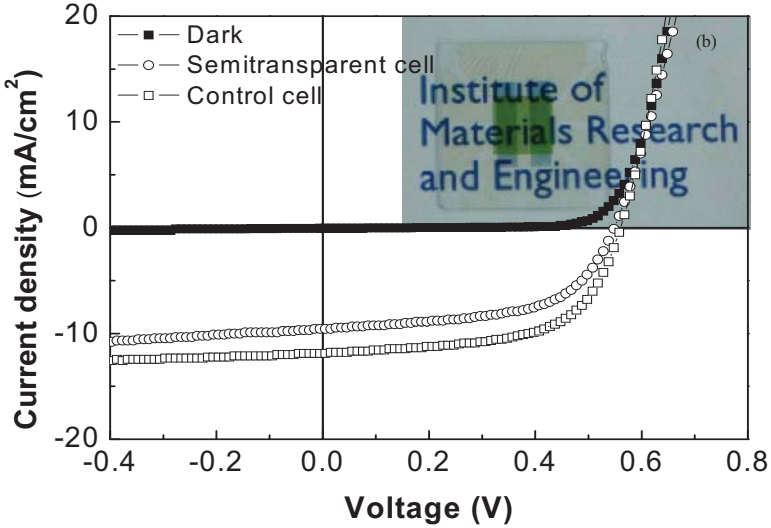


Devices	V_{oc} (V)	J_{sc} (mA/cm^2)	FF%	PCE%
A	0.57	14.77	34	2.8
B	0.57	8.22	43	2.0
C	0.54	6.67	51	1.83

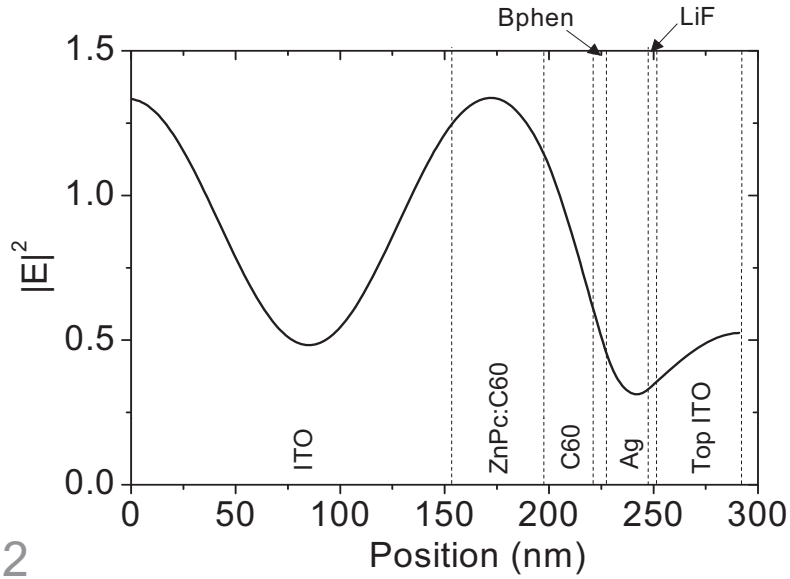
Semitransparent OSCs:

ITO/ZnPc:C_{60}/C_{60}/BPhen/Ag/ITO(40nm)

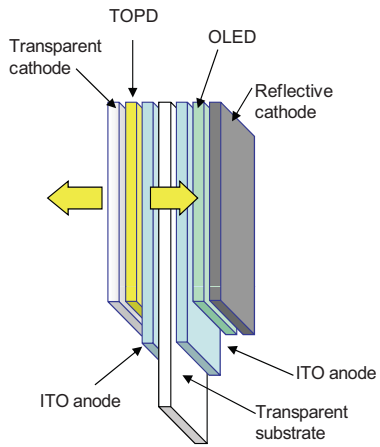




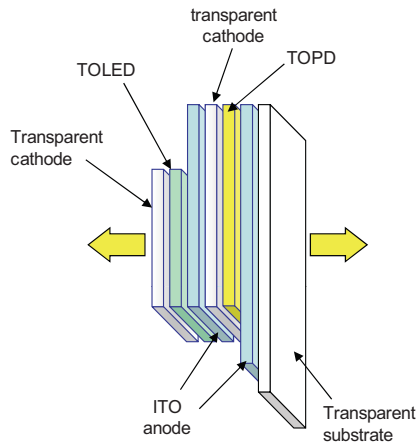
Device	V_{OC} (V)	FF (%)	J_{SC} (mA/cm^2)	η (%)
Control device	0.56	60 ± 1	11.8 ± 0.3	4.0 ± 0.2
Semitransparent photovoltaic cell	0.55	57 ± 1	9.6 ± 0.2	3.0 ± 0.1



Semitransparent OSCs: integrated OSC/OLED



Type-1



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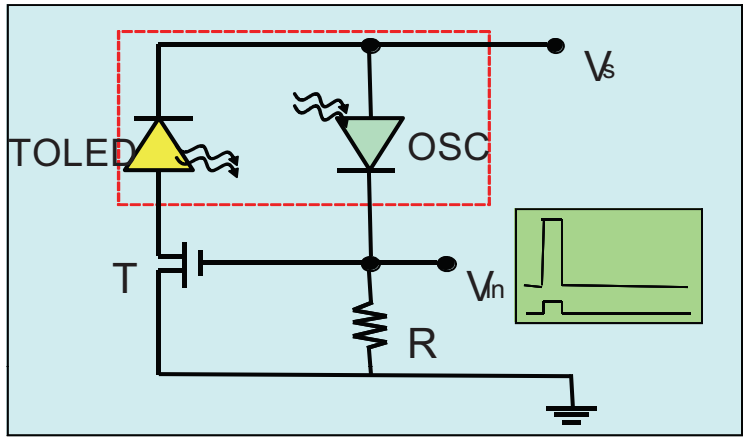
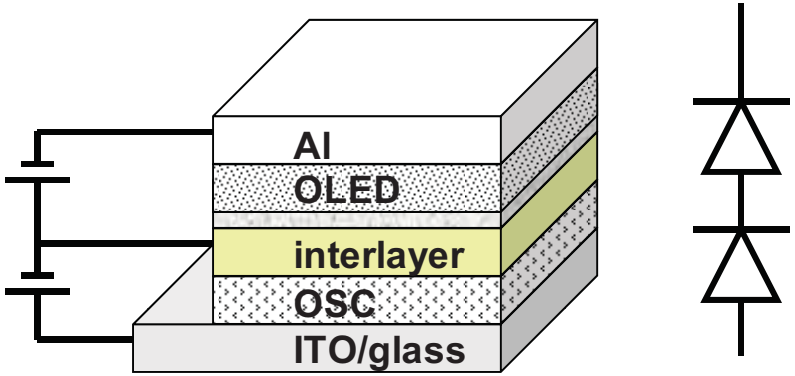
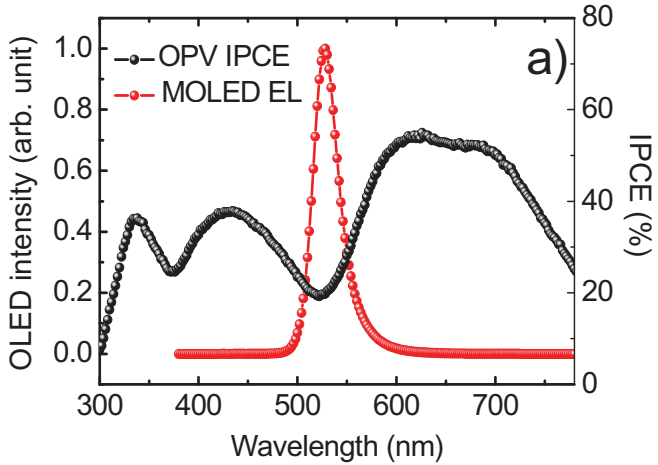


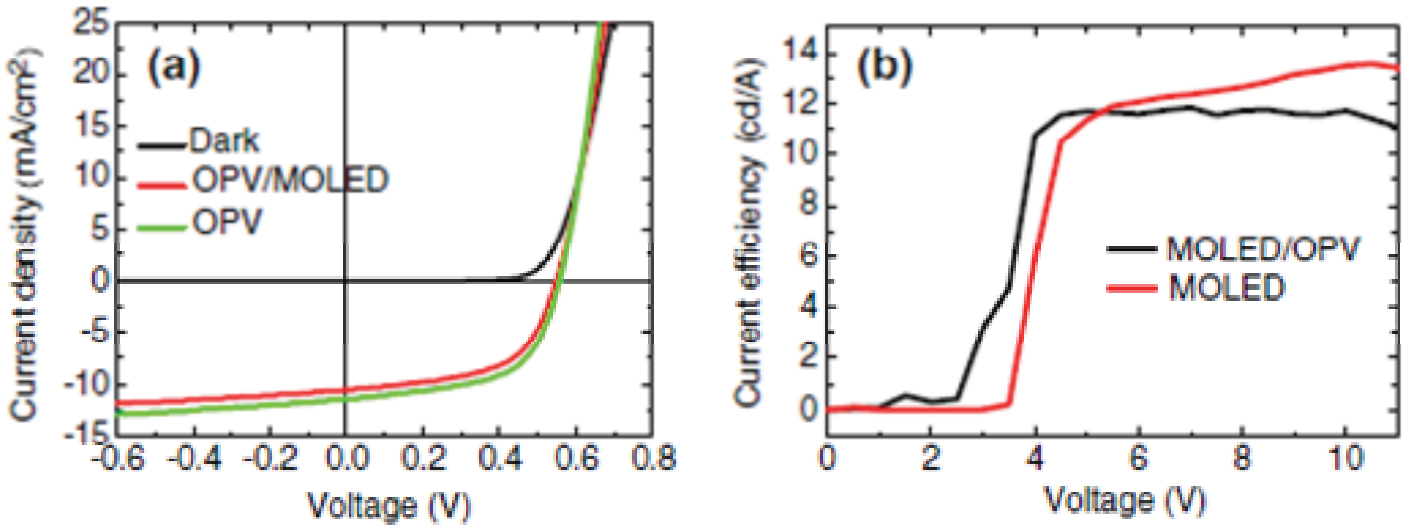




ZnPc:C_{60}-OSC/interlayer/Alq3:C545-OLED

Org. Electron. 12 (2011) 1429

ITO/OSC-ZnPc:C_{60}/interlayer/MOLED-Alq_3:C545



Device	EL peak position (nm)	FWHM (nm)	Luminous efficiency (cd/A)	
Control OLED	526	32	10.5 (@ 4.5V)	
OSC/OLED	521	33	11.5 (@ 4.5V)	
Device	V_{OC} (V)	FF (%)	J_{SC} (mA/cm^2)	PCE (%)
Control OSC	0.56	58.9	11.4	3.76
OSC/OLED	0.55	57.2	10.5	3.30

Org. Electron. 12 (2011) 1429

Summary

- Semitransparent OSCs
  - Optical admittance analysis
  - Transparent electrode and optical coupling
  - Multi-junction OSCs, WOLED lighting, optical sensors etc.
- Applications
  - Power generation windows
  - Architectural surfaces
  - Car windshield
  - Tension membrane

Thank you