Nanostructured Metal Oxide: Polymer Photovoltaic Devices

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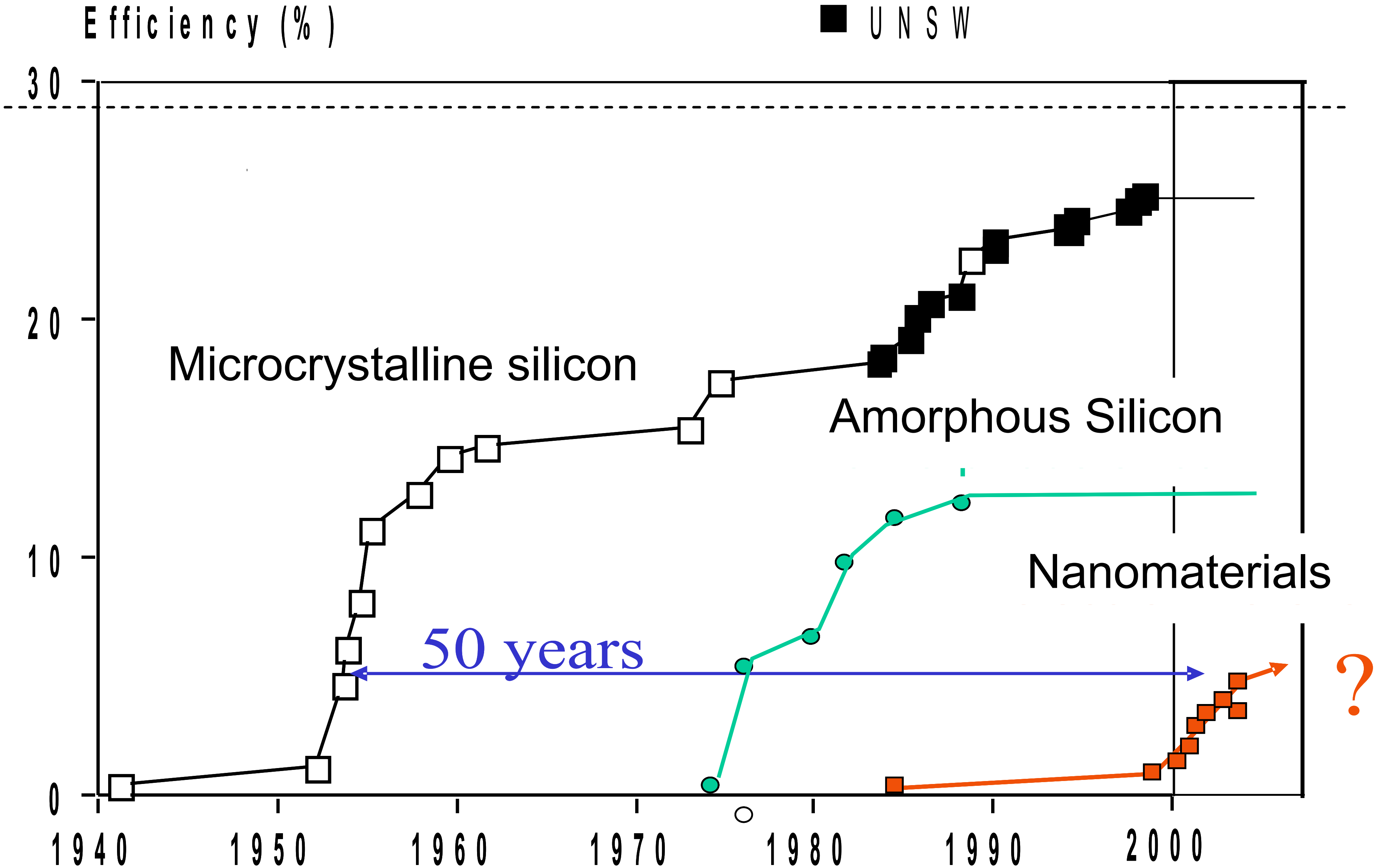
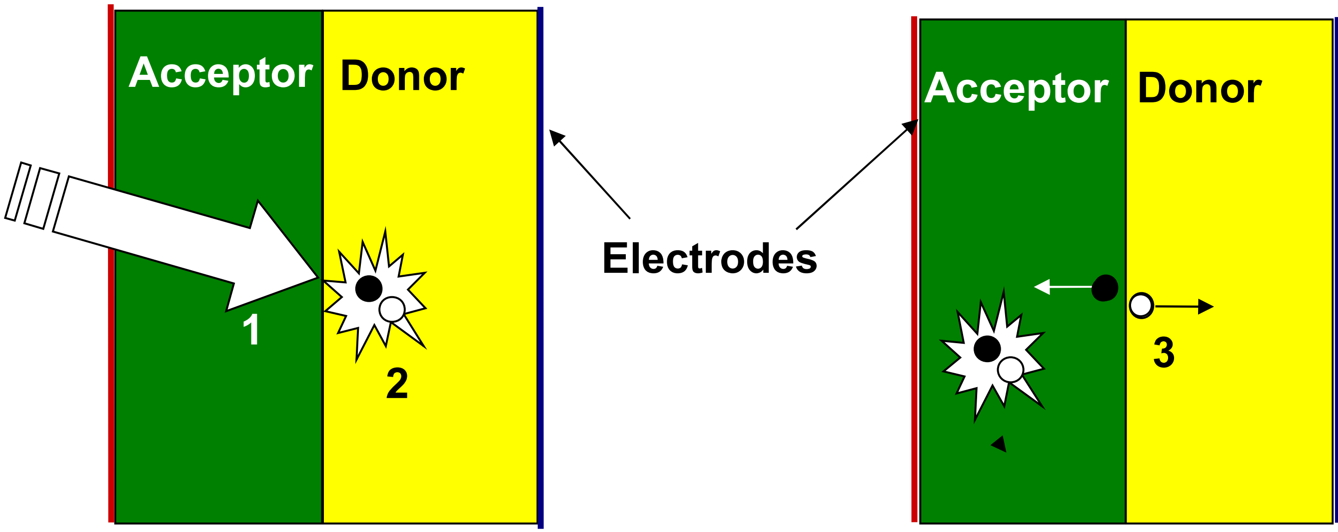
Outline

- Background
- Photovoltaic (PV) effect in nanostructured solar cells
- Why nanostructured PV materials?
- Key challenges
- Hybrid Metal Oxide/Polymer PV devices (Solar cells)
- Key steps in device design
- Effect of particle morphology & interface modification
- Conclusion

Micro- vs Nano Photovoltaic devices (Solar cells)

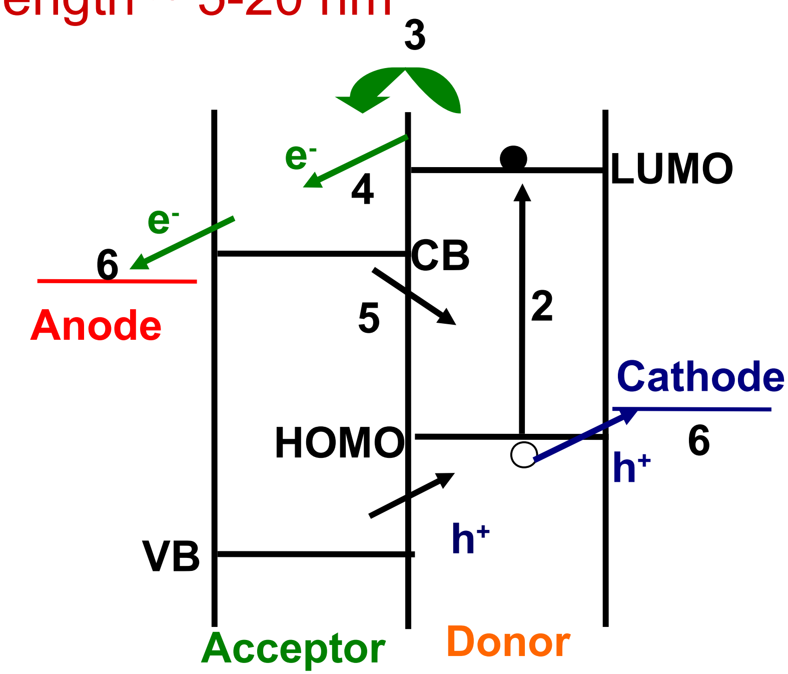


Photovoltaic effect in Nano solar cells

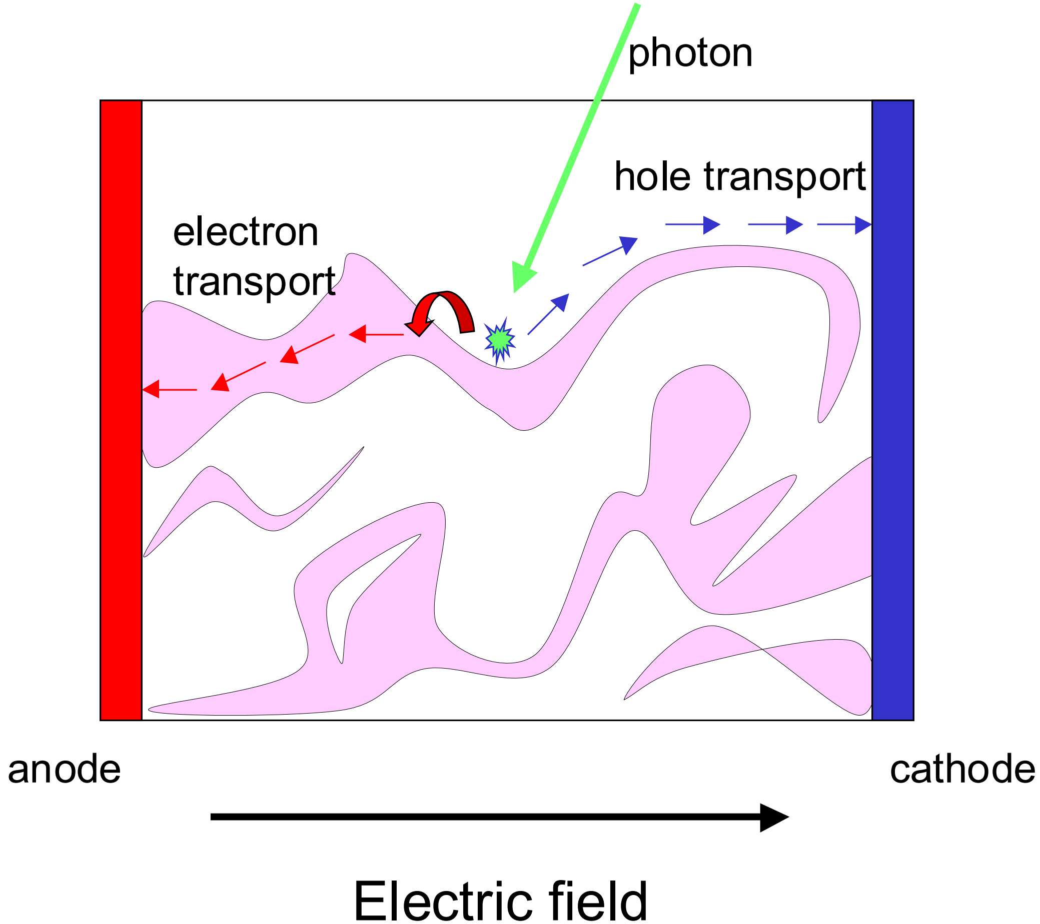


Exciton diffusion length ~ 5-20 nm

1. Absorption of light
2. Creation of electron-hole pair
3. Dissociation of electron-hole pair
4. Transfer of charges
5. Transport of charges
6. Recombination of charges
7. Collection of charges

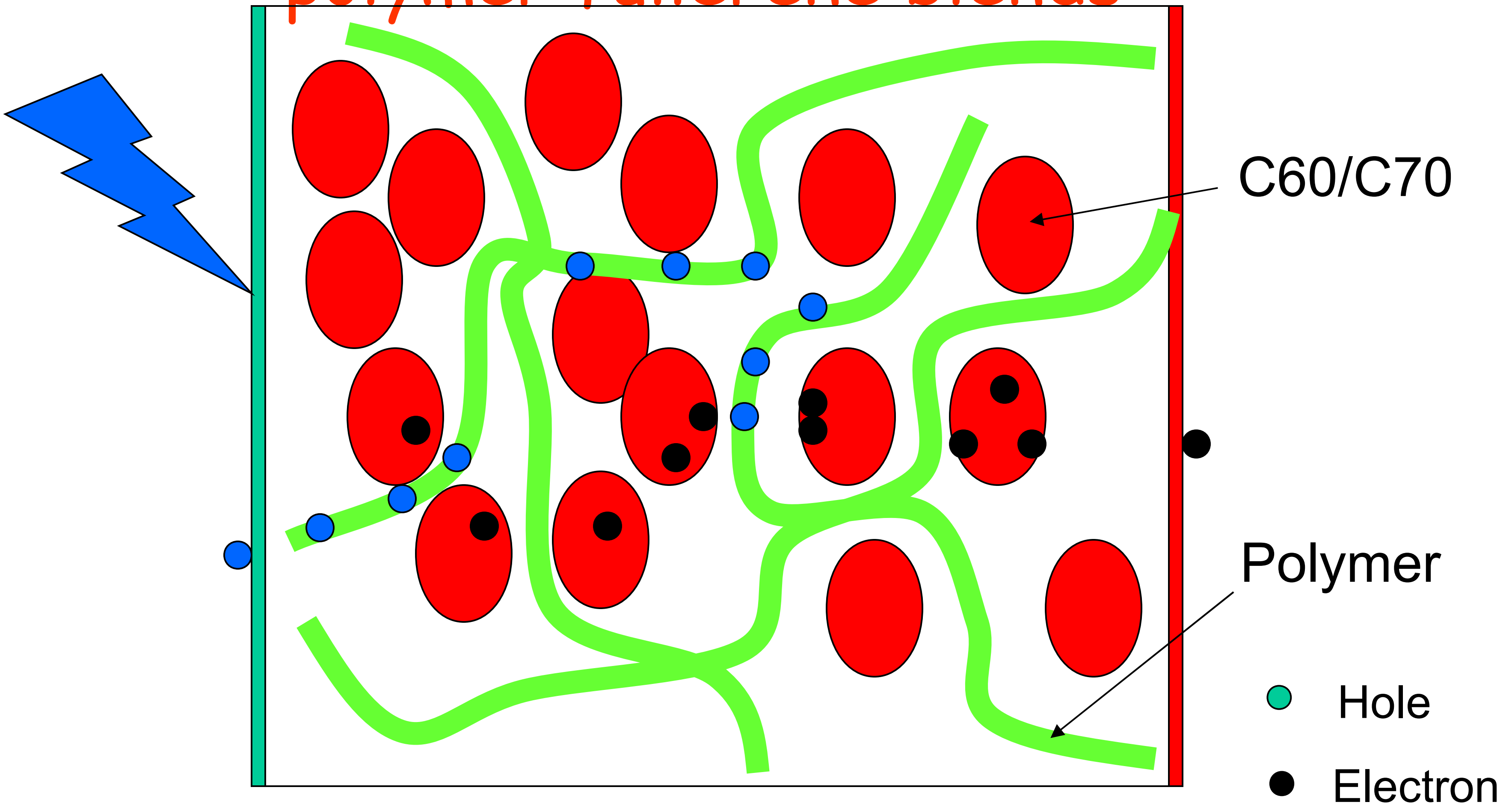


Blended nanostructured PV materials



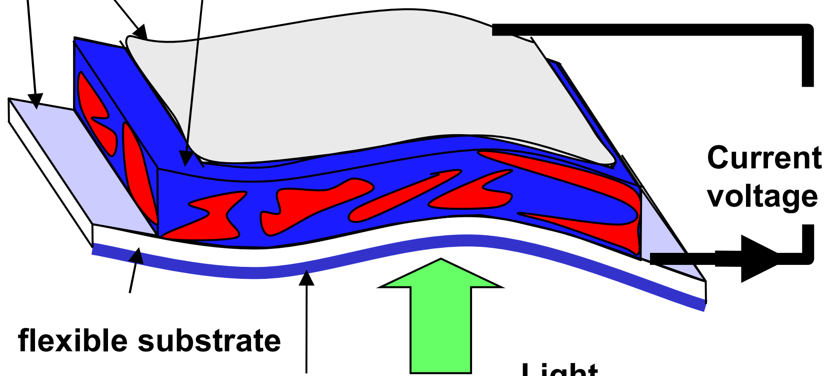
- Blend hole accepting with electron accepting material
- Length scale of blend ~ exciton diffusion length (~5-20nm)
- Charge separation at interface
- Continuous paths for electron and hole percolation

Photocurrent generation in polymer:fullerene blends



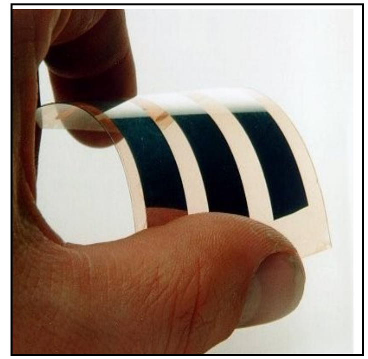
Polymer transports holes
Fullerene transports electrons
Optimum composition morphology dependent

Why nanostructured PV materials?



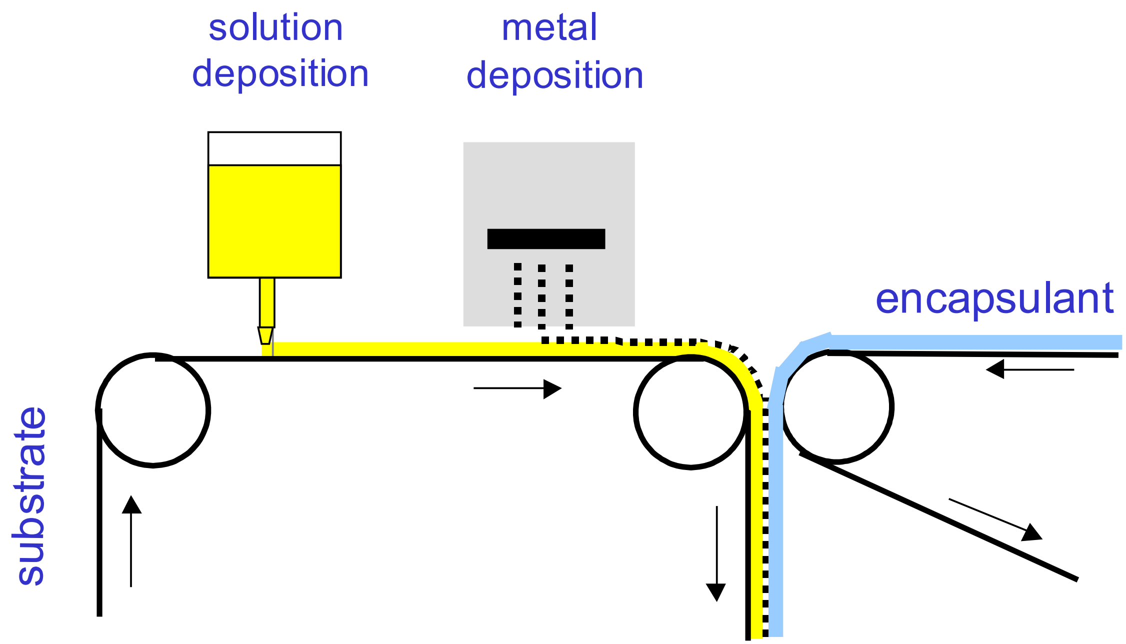
- Nanostructured photovoltaic materials enable low cost device fabrication
- Active layer ~100 nm thick
- Low temperature processing enables use of flexible substrates
- Highest efficiencies up to 5 % from blend of conjugated polymer with fullerenes

Why go soft?



Hard → Soft

- Low cost (< 1 US$ / W)
- Large area deposition
- Low weight
- Low material requirements
- Ease of fabrication
- Large field of application
- Colour, semi-transparency
- Mechanical flexibility



➢ However, there are constrains such as poor stability and low efficiency for commercialisation.

Why go for soft?

Potential Applications


Charging mobile using solar mat


Power dresses

Charging mobile

Solar bag

Flexible Solar phone

Solar lamp

Solar vehicles

Key challenges

- Narrow Spectral response
- Low mobility
- Short exciton diffusion length

P. Ravirajan *et.al*, Adv. Funct. Mater. **2005**,15, 609.

Cited 61 times
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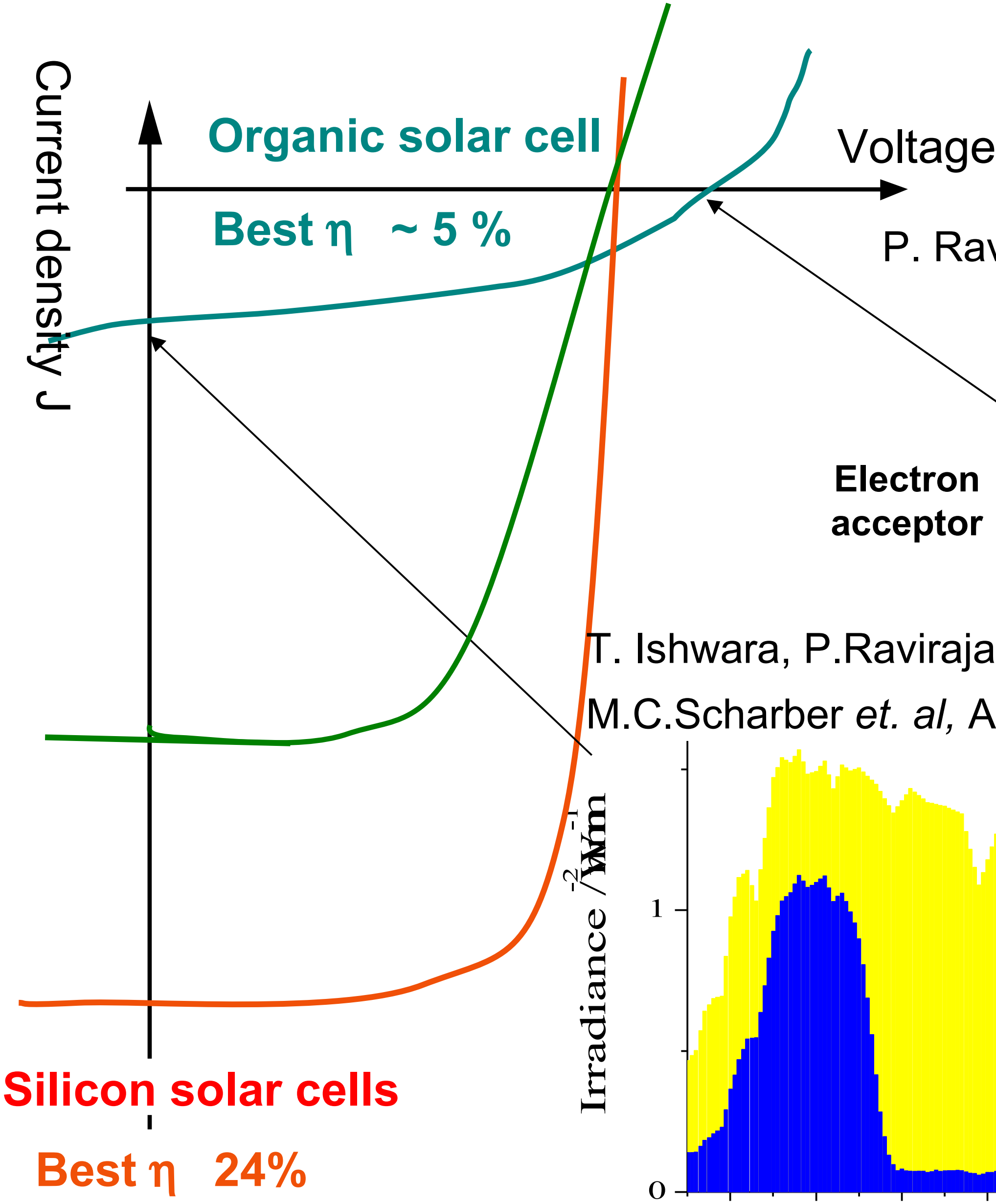
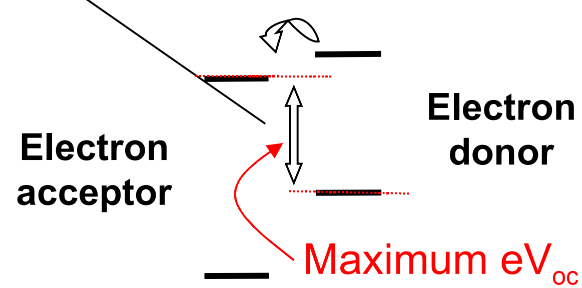
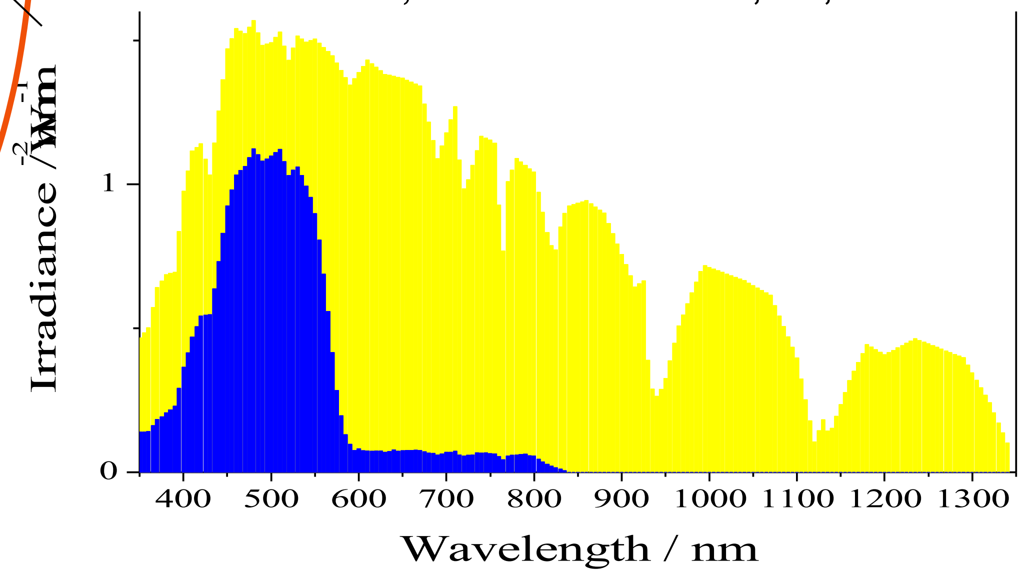




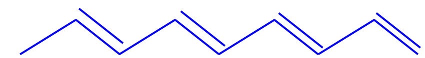
T. Ishwara, P.Ravirajan, *et. al*, Appl. Phys. Lett. 92, (**2008**) 053308

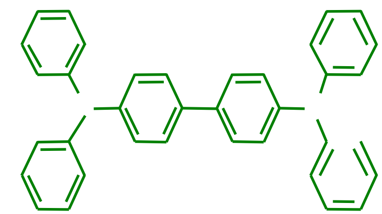
M.C.Scharber *et. al,* Adv. Mater. 2006, 18, 789–794.

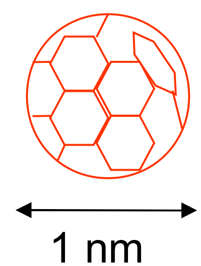


PV Materials in Nano PV devices (Solar cells)

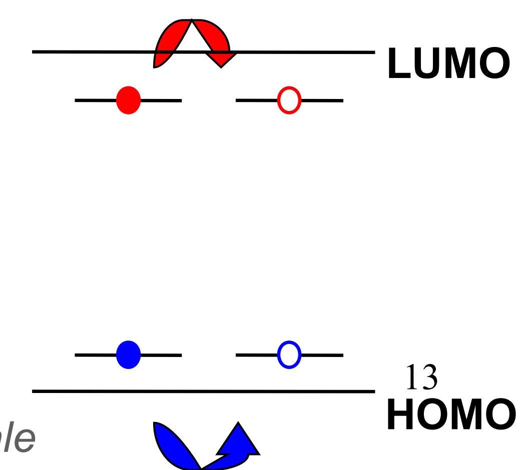
- Materials
  - semiconducting polymers and oligomers
  - conducting "small molecules"
  - dyes
  - fullerenes
  - liquid crystals
  - Metal Oxides

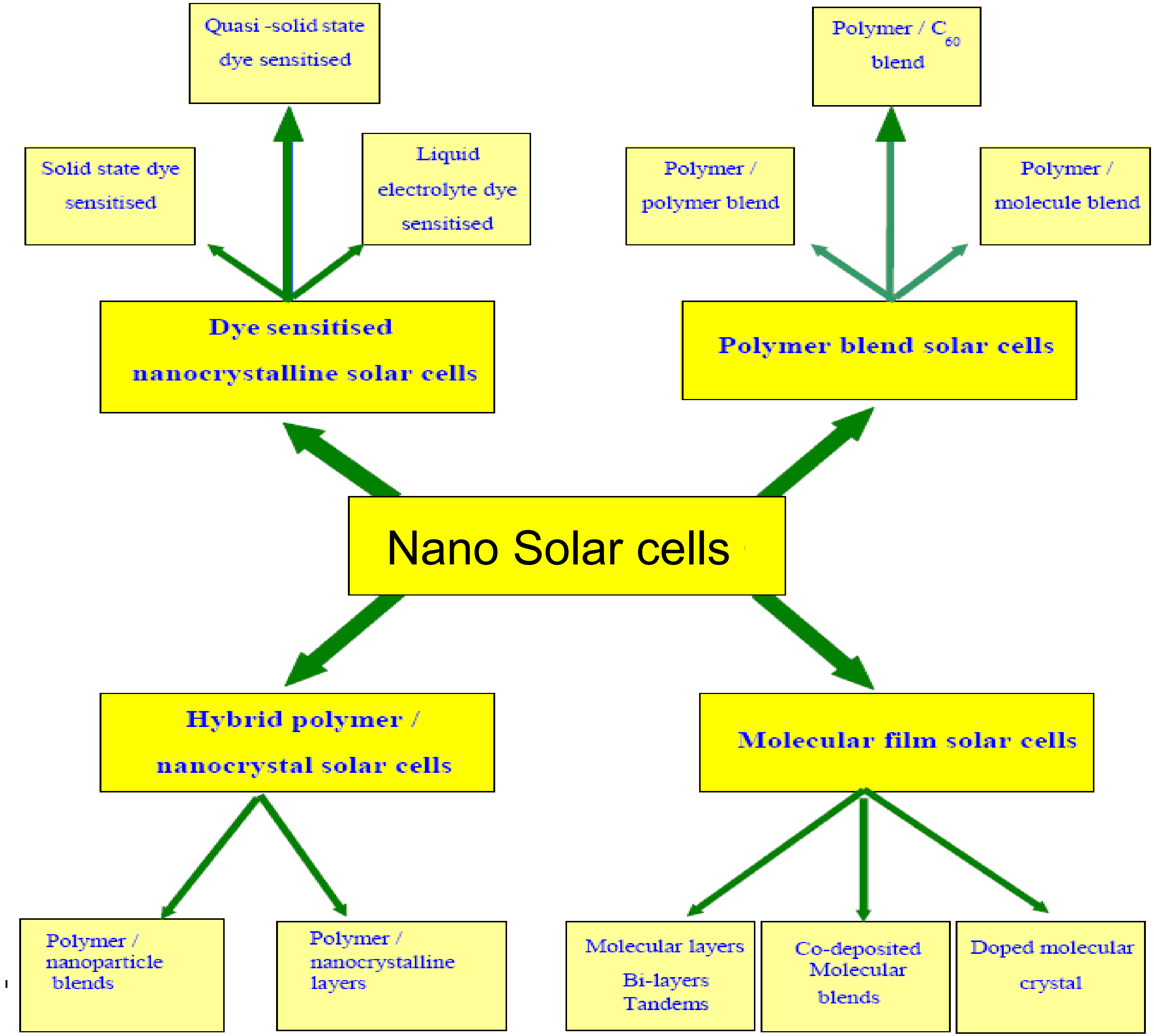






- Properties
  - molecular
    - bound 'excitons'
    - charge transport by polaron hopping
    - narrow absorption range
  - disordered
  - anisotropic



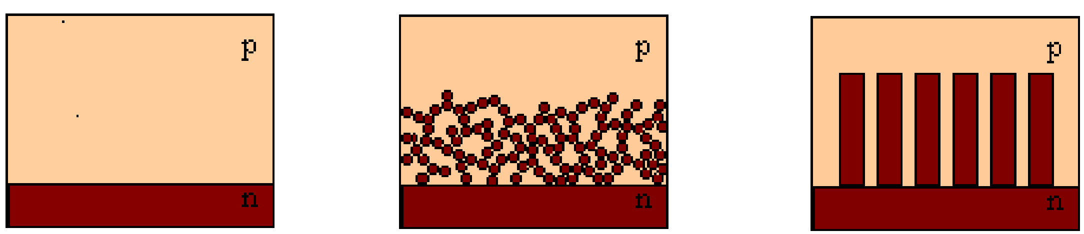


Quasi -solid state dye sensitised
Solid state dye sensitised
Liquid electrolyte dye sensitised
Polymer / C_{60} blend
Polymer / polymer blend
Polymer / molecule blend
Dye sensitised nanocrystalline solar cells
Polymer blend solar cells
Nano Solar cells
Hybrid polymer / nanocrystal solar cells
Molecular film solar cells
Polymer / nanoparticle blends
Polymer / nanocrystalline layers
Molecular layers Bi-layers Tandems
Co-deposited Molecular blends
Doped molecular crystal

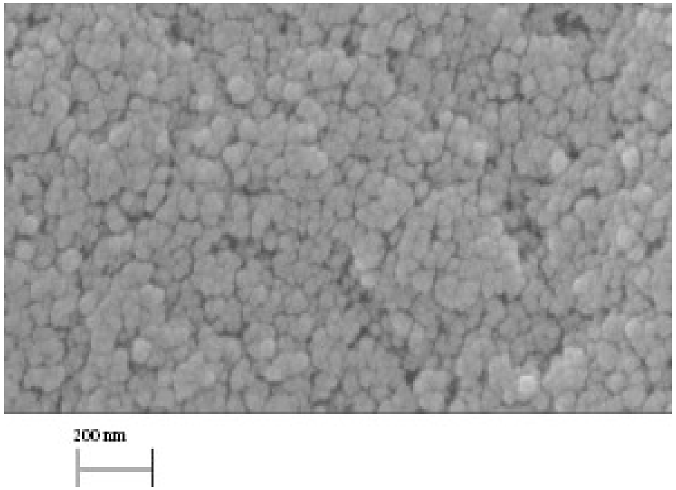
Hybrid Polymer/Metal Oxide Solar cells

Why Metal Oxides/Polymer Solar Cells?

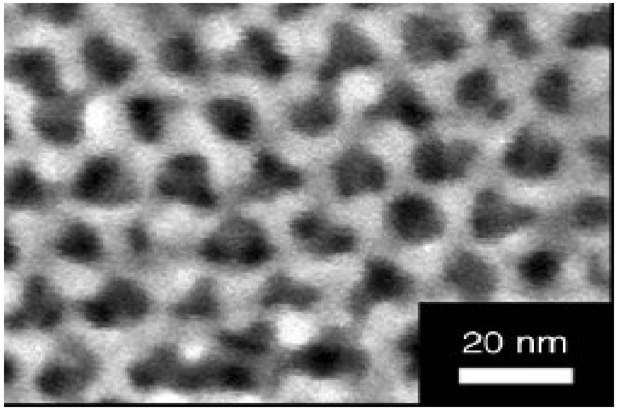
- Nanocrystalline metal oxides as alternative electron acceptors in donor-acceptor solar cells:
  - TiO_2, ZnO, SnO_2 effective acceptor materials for photoinduced charge transfer from conjugated polymers
  - Morphology can be controlled
  - Physical and chemical stability
  - Good electron transport
  - Facile fabrication and low cost
  - Large experience base from photocatalysis and DSSCs



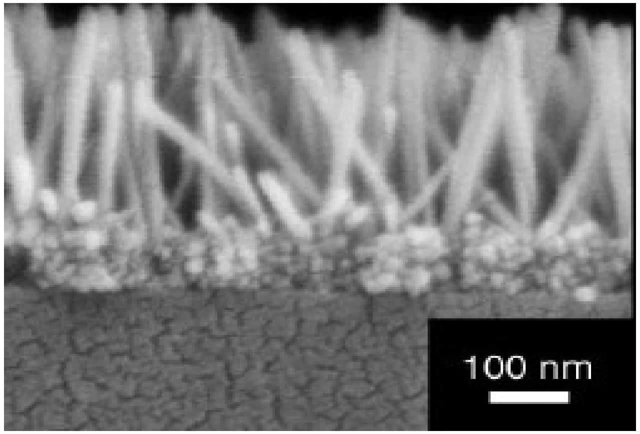
Nanostructured materials: the building blocks for Hybrid solar cells



Nano-particles (diameter ~ 10 nm)

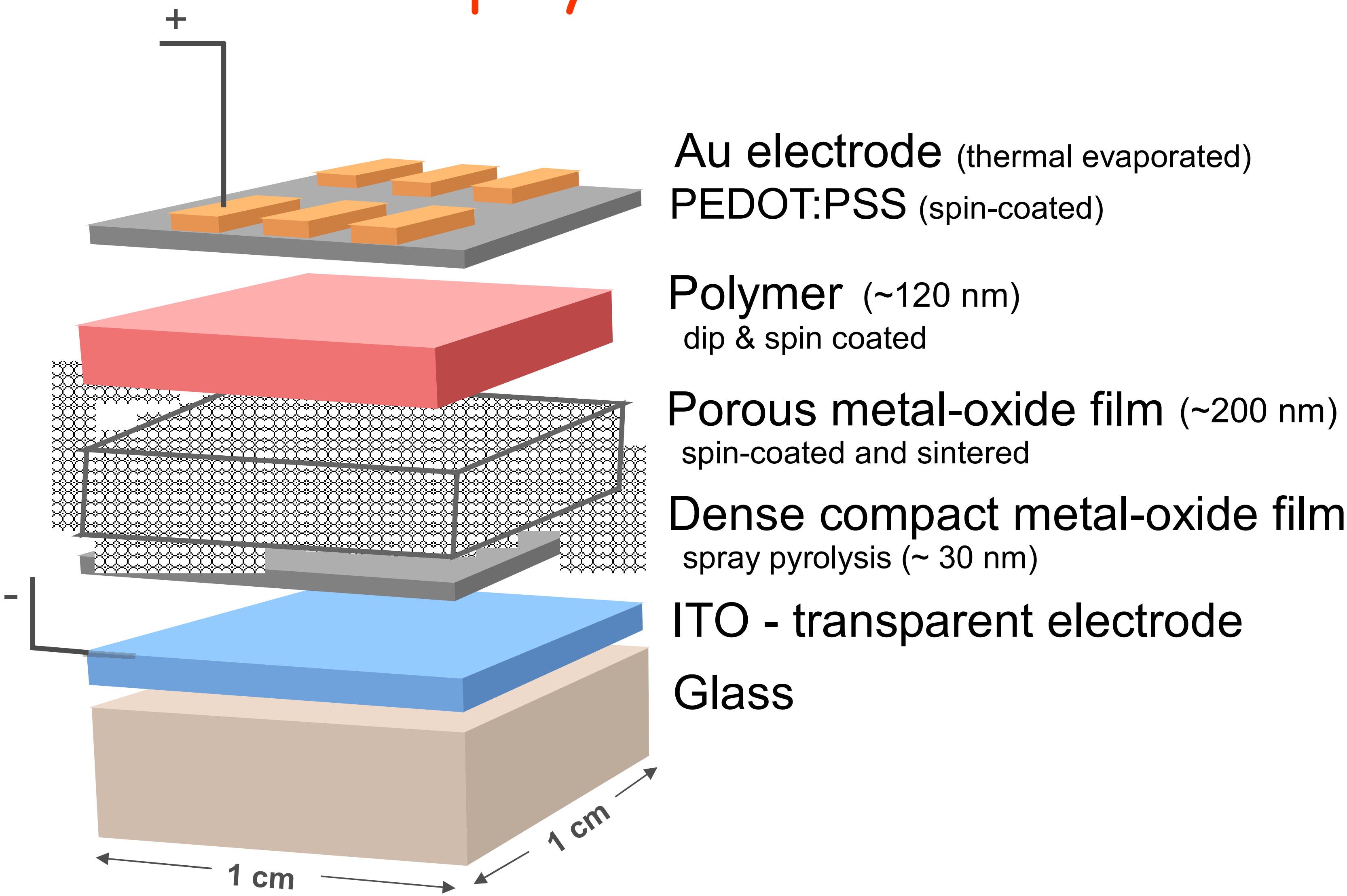


TiO_2 Nano-templates (pores ~ 10 nm)



ZnO nanowires/rods (diameter ~ 20 nm)

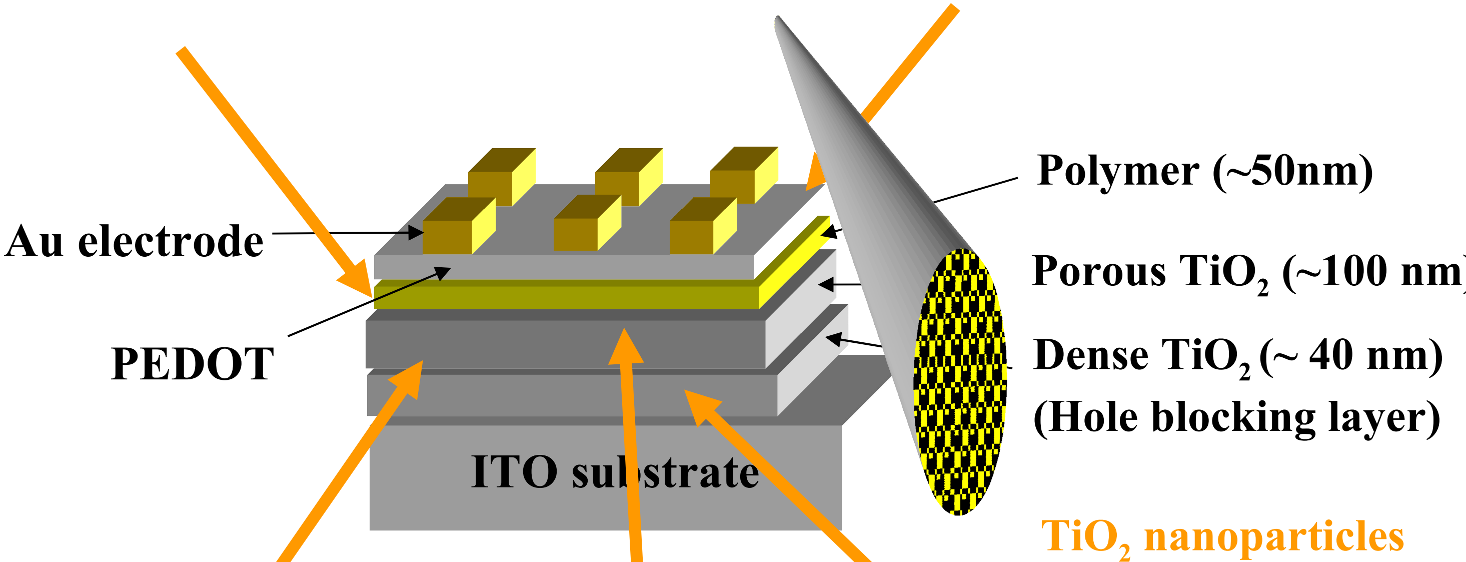
Optimised device structure for Metal oxide/polymer solar cells



Key steps in device design

5. PEDOT layer
- increases J_{sc} by **50 %.**
- removes 'kink' in J-V curve

4. Decreasing polymer thickness, increases both J_{sc} and V_{oc}.



3. Dip coated polymer layer increases FF and η by over 50 %

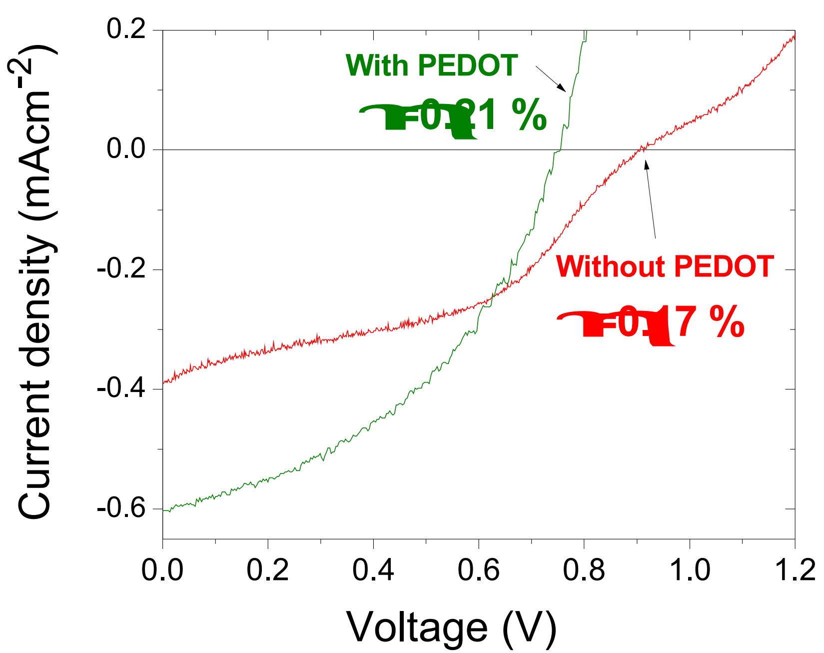
1. Dense layer prevents direct contact between polymer and ITO

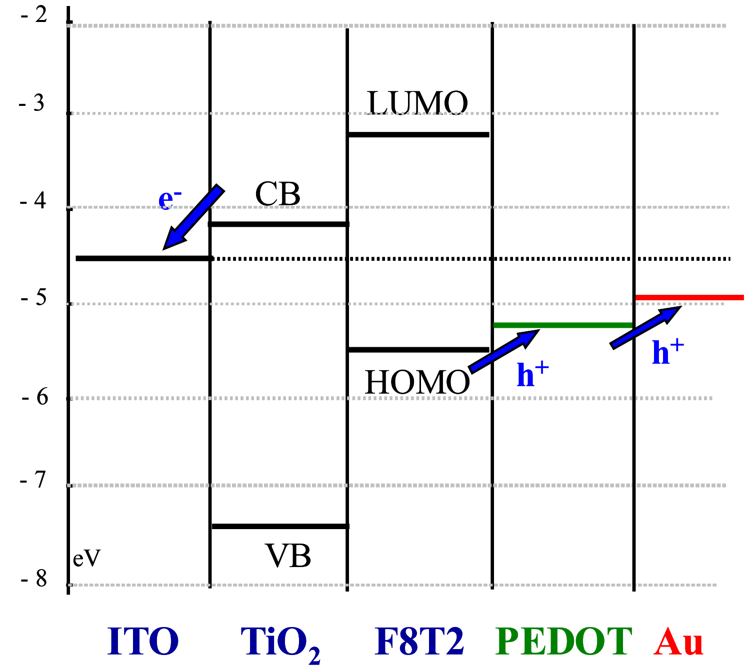
2. Porous layer increases **QE** by more than factor of **FIVE**.

P.Ravirajan *et. al*, *Appl.Phys.Lett.* ***2005***, *86, 143101.* **Cited 37 times**

P.Ravirajan *et. al*, *J. Mater. Chem.* ***2007***, *17, 3141.* **Cited 43 times**

Role of top electrode: Control of fill factor





- The 'kink' in J-V curve may due to interfacial energy step at polymer/metal

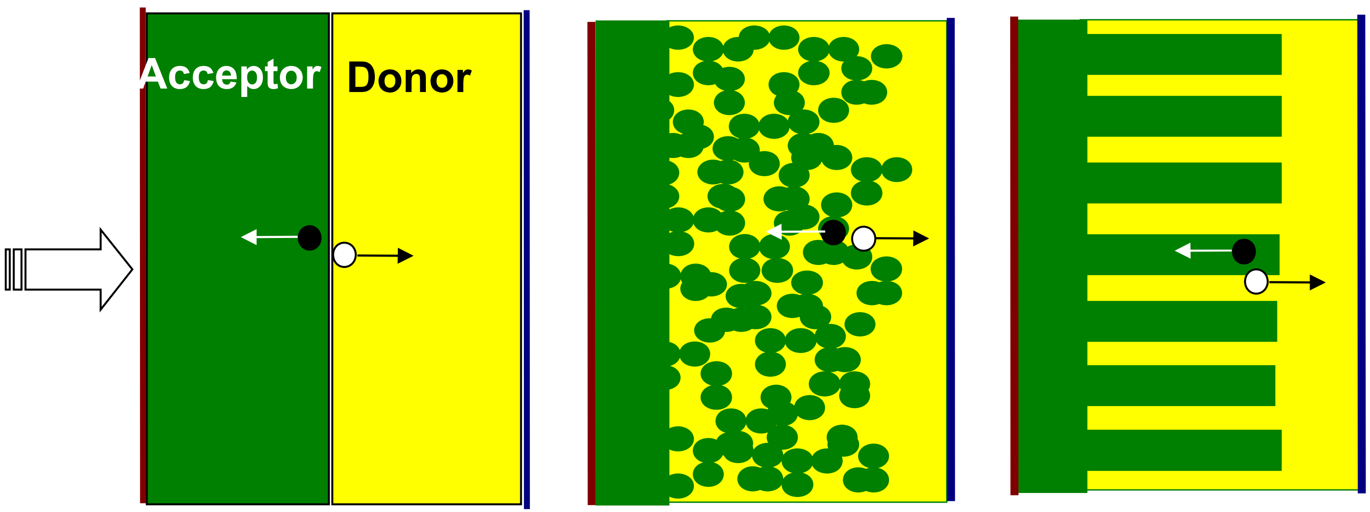
$$\Delta E_i = I_p\,(\text{polymer}) - \Phi_{work}(\text{metal})$$
$$= 0.6 \text{ eV for device without PEDOT}$$
$$= 0.2 \text{ eV for device with PEDOT}$$

- High energy step at hole collecting electrode impedes both charge injection and collection.
  - ➢ **Consistent with the theoretical modelling#.**

#**J. Nelson, J. Kirkpatrick and P.Ravirajan,** *Phys. Review B (**2004**), 69 (2004)* **Cited 40 times**

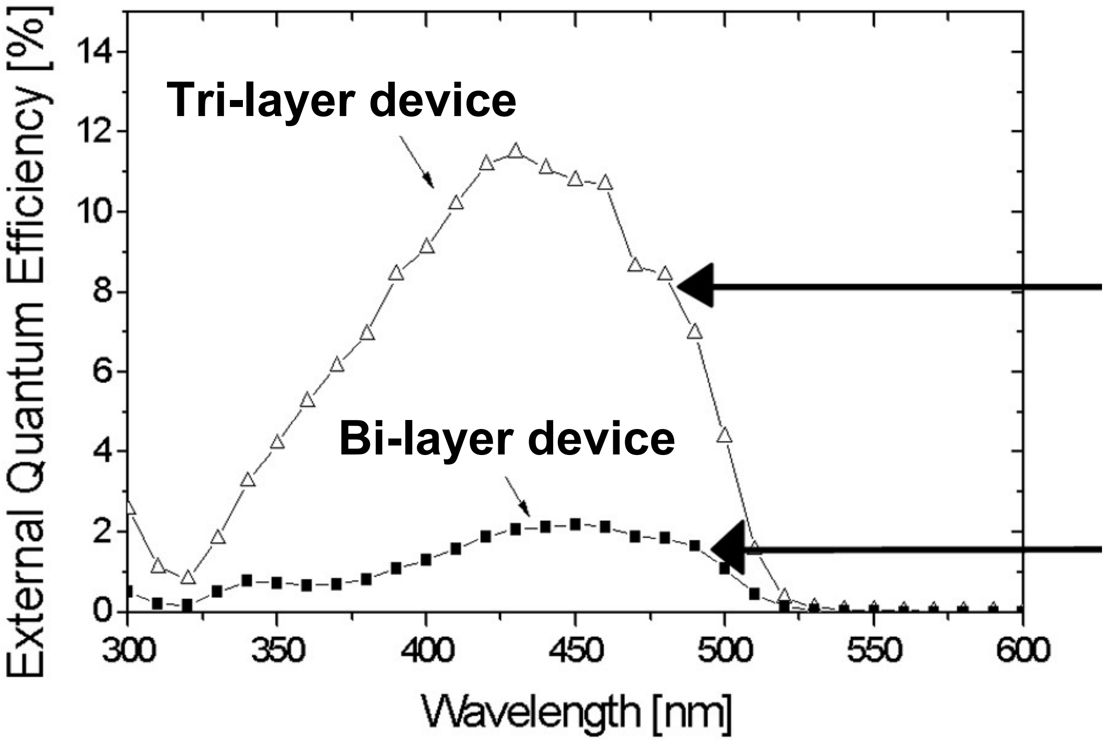
P.Ravirajan *et. al*, J. Appl. Phys. **2004**, 95, 1473. **Cited 66 times**

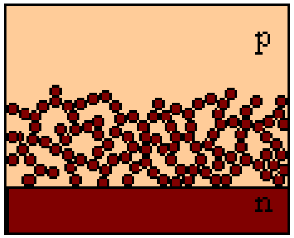
Modifying the microstructure

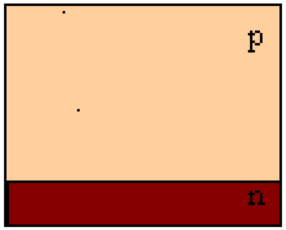


Rods may allow electrons to escape the interfacial region

Modifying the interface with nanoparticles







P.Ravirajan *et. al*, J. Appl. Phys. **2004**, 95, 1473.

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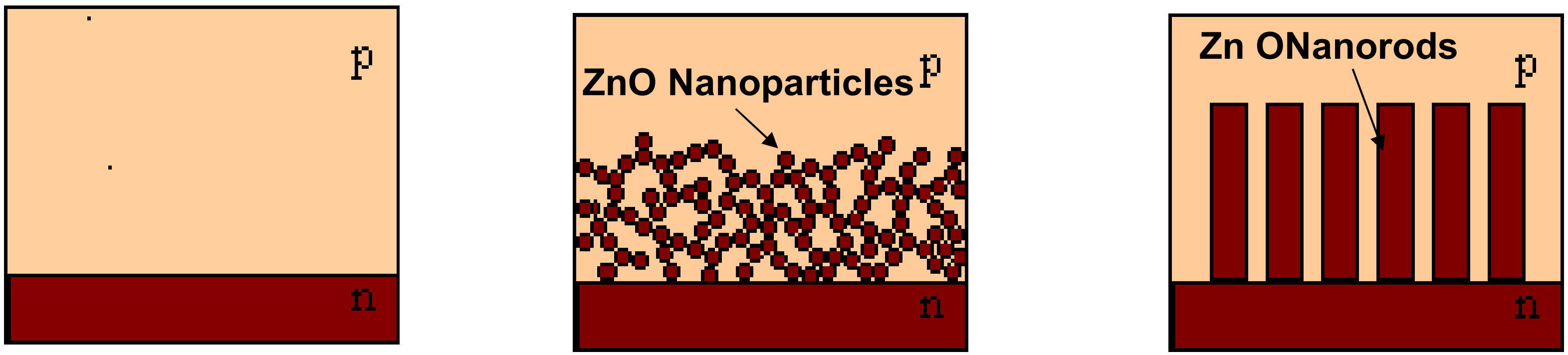
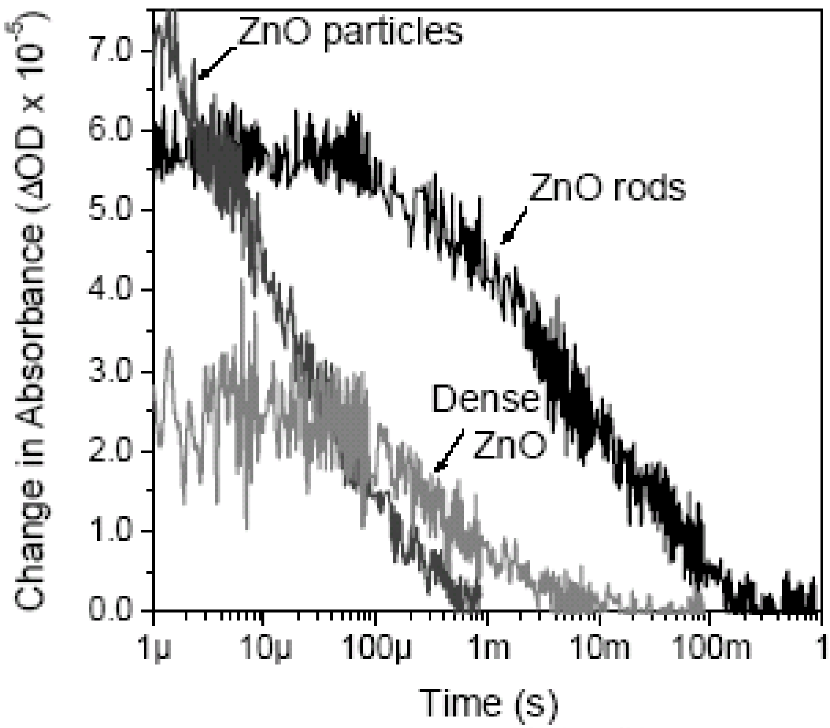
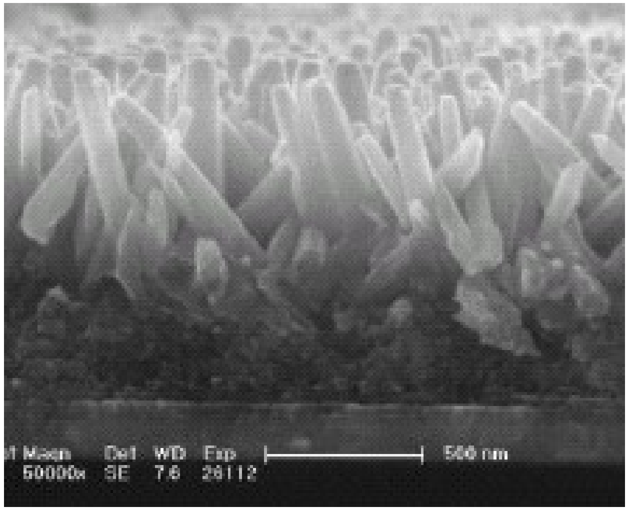
Effect of particle morphology



P.Ravirajan et. al, J. Phys. Chem. B, **2006**, 110, 7635-7639

Cited 108 times



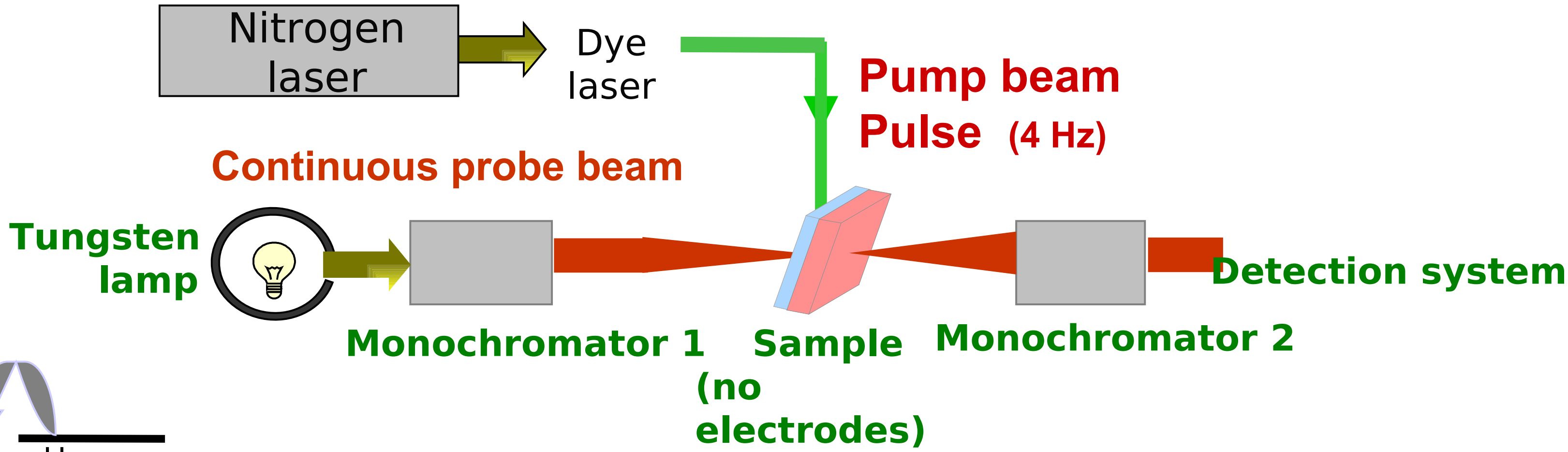


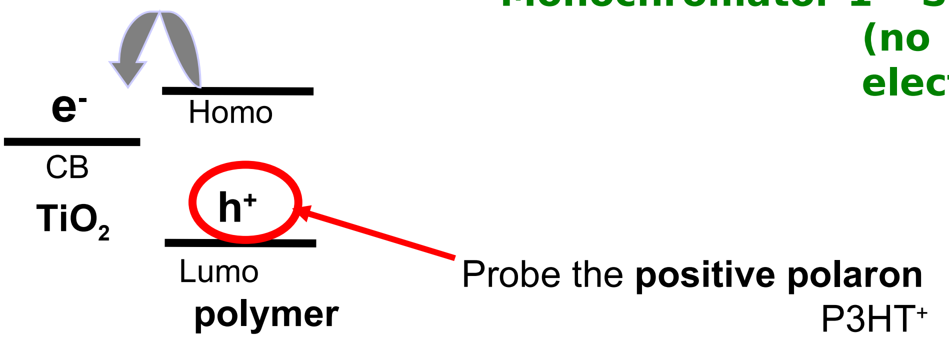
A.M.Peiro, P.Ravirajan *et al.*,
J. Mater. Chem., **2006**, 16, 2088.

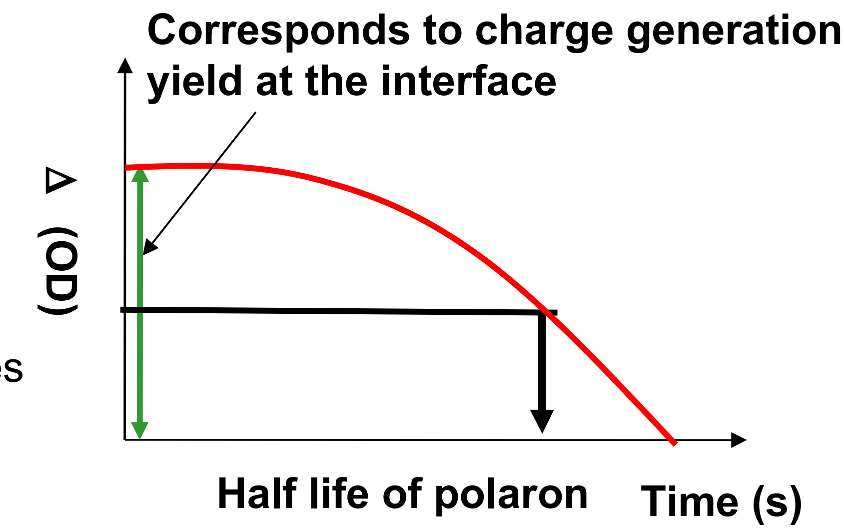
Rods allow electrons to escape quickly from the interfacial region

Cited 43 times

Transient Absorption Spectroscopy (TAS)







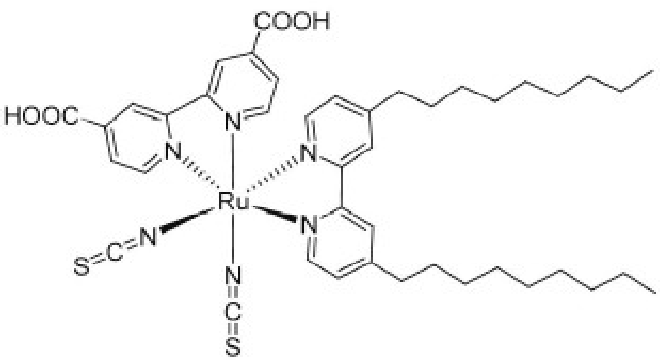
- The sample is excited by a pump pulse and charges are generated at the interface.
- The charge yield is monitored by a probe beam.

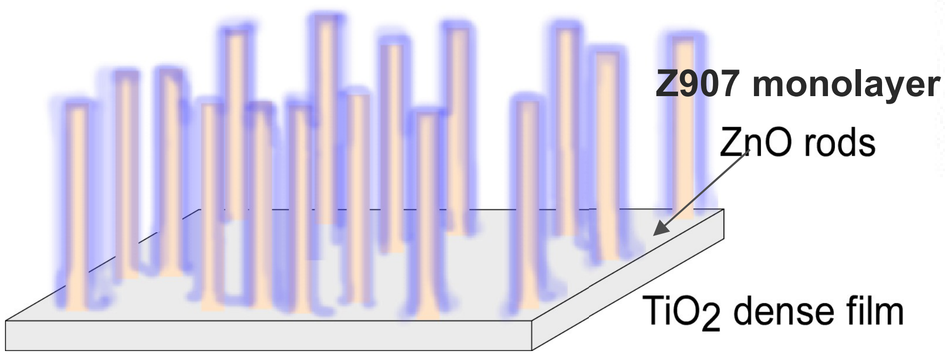
TAS → √ Charge generation yield
√ Charge recombination time

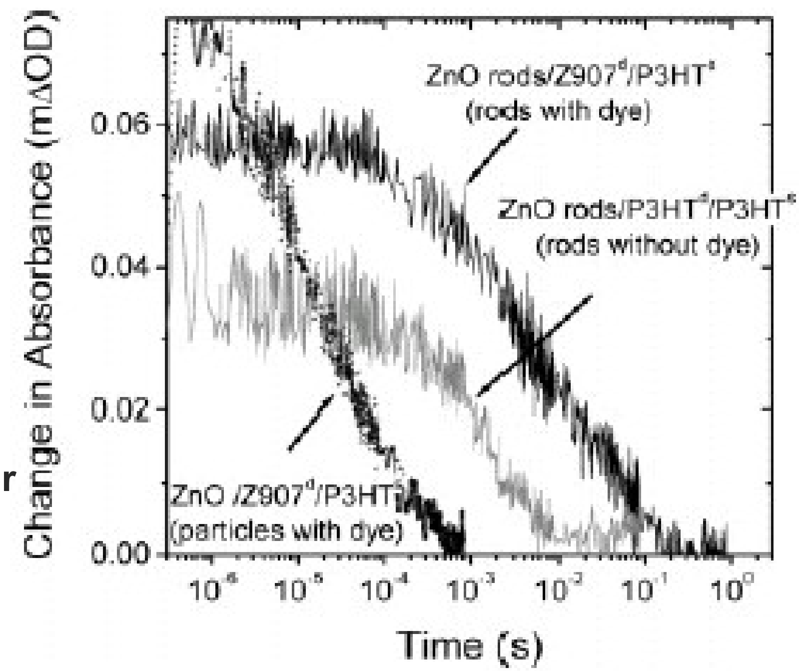
Pump λ = 520 (max abs. of polymer P3HT)
Probe λ = 900 (max abs. of polymer polaron $P3HT^+$)

Modifying the Nanointerface

- Chare recombination in ZnO nanorods structure treated with an amphiphilic molecular interface layer is remarkably slow, with a half-life of ~6 ms.







P.Ravirajan et. al, J. Phys. Chem. B, **2006**, 110, 7635-7639

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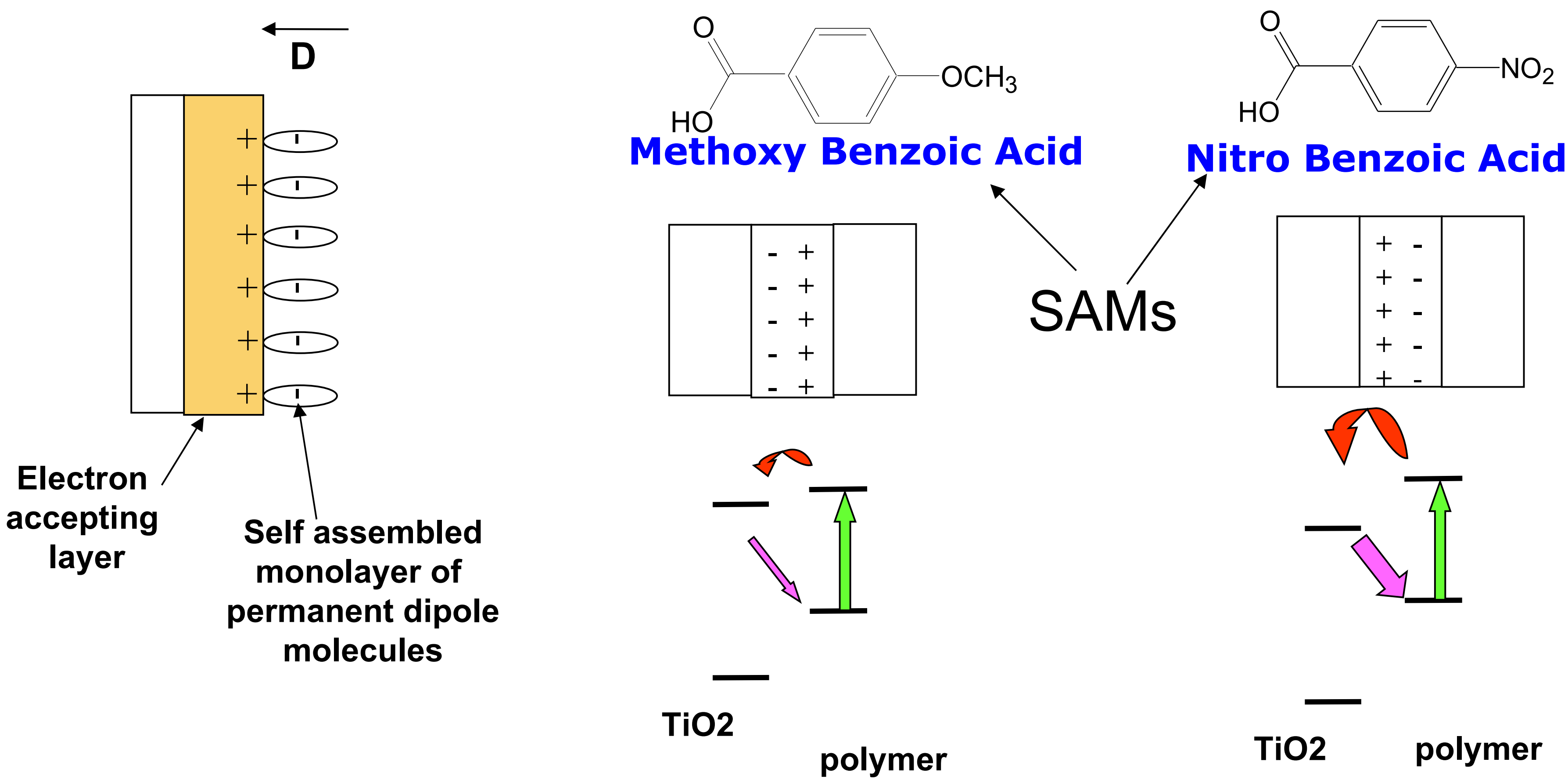
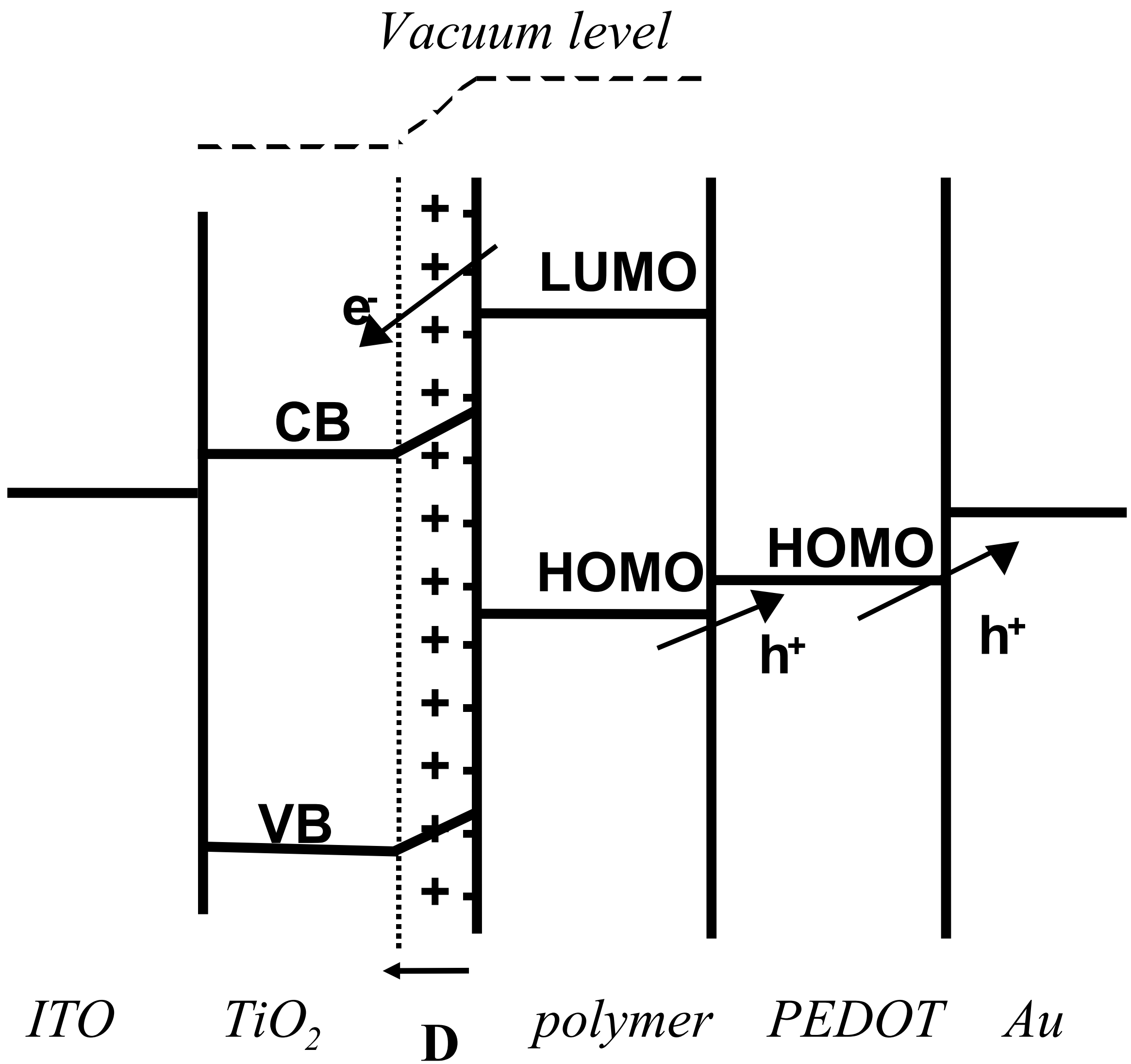
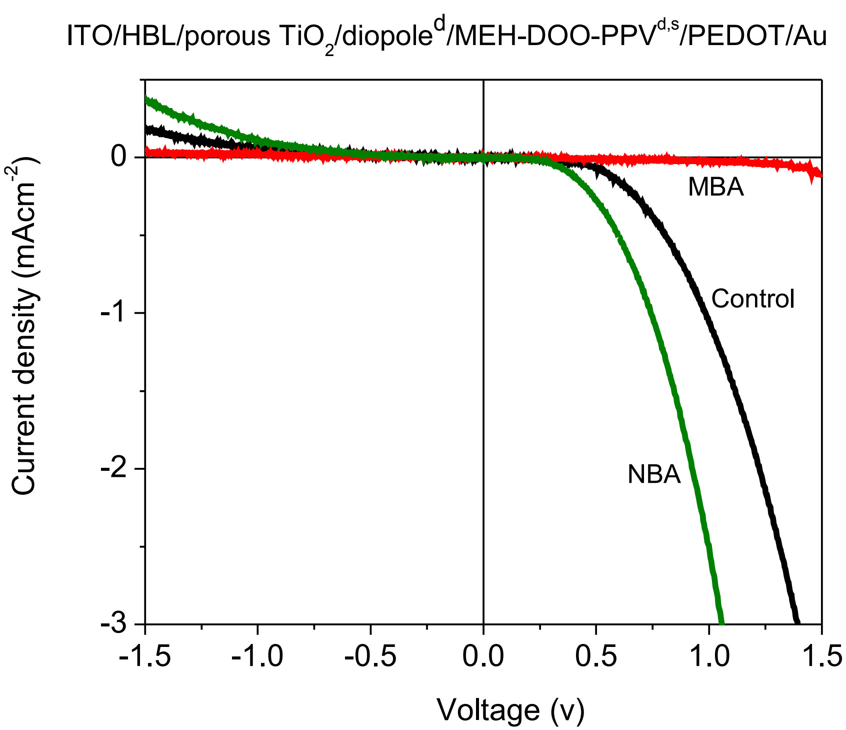
Modifying the Nanointerface

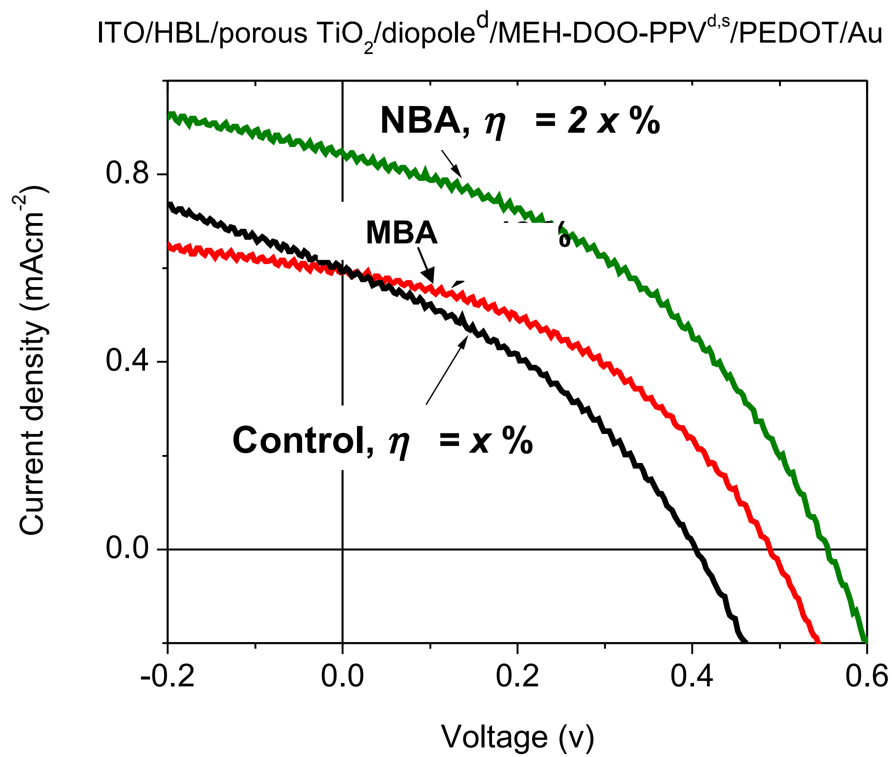


- Voc is controlled by acceptor LUMO - donor HOMO
- Modifying interface may modify Voc, and may reduce both charge separation and recombination rate


Vacuum level
LUMO
e-
CB
HOMO
HOMO
h+
h+
VB
ITO
TiO2
D
polymer
PEDOT
Au

Effect of SAMs on device JV





η =x %

- Expected effect on current, but increase Voc in both cases
- SAM layer has an additional function - insulating layer? [similar to effects seen with Al_2O_3 barrier coating]

Conclusions

- Rapid progress in nanostructured photovoltaic devices
- Wide range of promising materials and designs
- Advantages at low light levels and high temperature
- Low cost, low temperature fabrication possible
- Limitations:
  - weak red absorption
  - poor air stability
  - low charge mobilities

Thank you for your attention