Organic solar cells

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Outline

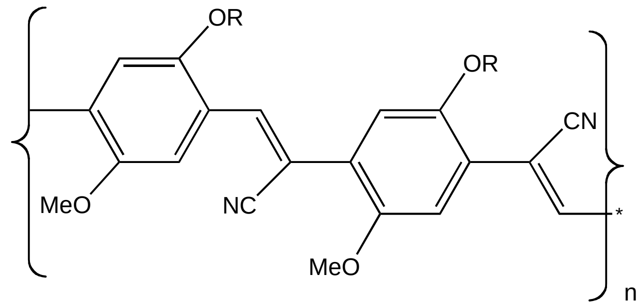
Why using organic materials

Fundamental aspects of organic semiconductors
- energy levels in molecular materials
- excitations in inorganic and organic SCs
- exciton diffusion

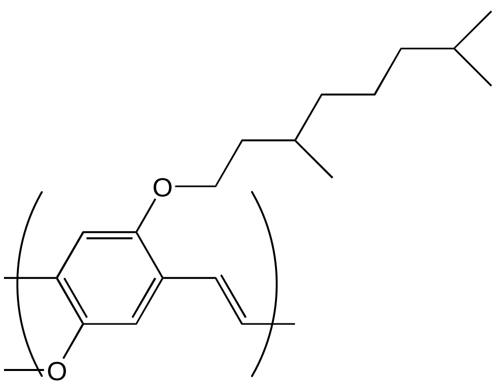
Examples of organic solar cells
- Dye sensitised solar cells
- Polymer bulk heterojunction cells

Organic materials in Photovoltaic cells

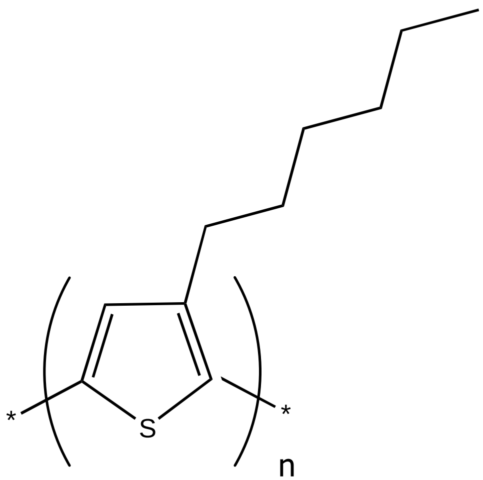
<u>Advantages</u>
- tailoring of opto-electronic properties



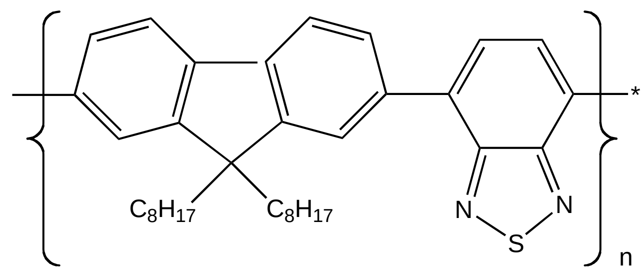
CN-PPV



MDMO-PPV



rr poly (3,hexyl)thiophene



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Organic materials in Photovoltaic cells

Advantages

- tailoring of opto-electronic properties
    - Variation of optical band-gap: colour
    - optimisation of the energy levels

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Organic materials in Photovoltaic cells

<u>Advantages</u>
- tailoring of opto-electronic properties
- large areas
- low temperatures (RT)
- processing from solution
- roll to roll manufacturing
- low substrate costs

} From experience with organic LEDS

Organic materials in Photovoltaic cells

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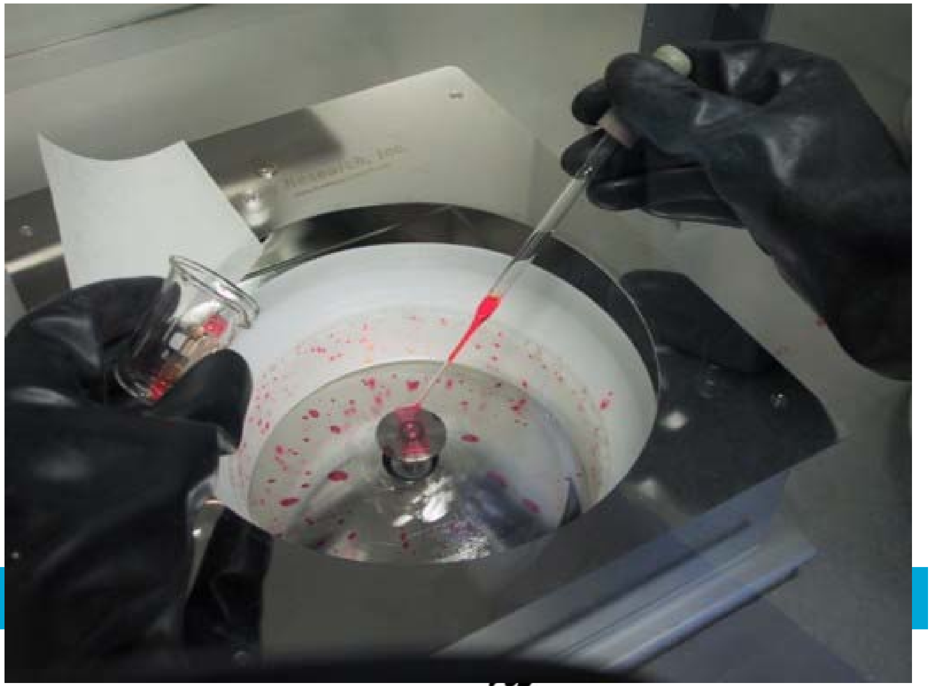

Organic materials in Photovoltaic cells

Advantages
- tailoring of opto-electronic properties
- large areas
- low temperatures (RT)
- processing from solution
- roll to roll manufacturing
- low substrate costs

(Possible) problems
- low mobility of charge carriers (p3.13)

$$v_i = \mu_i \xi$$

v : velocity

μ : mobility

ξ : electric field

μ_n (c-Si) > 1000 cm^2/Vs

μ_h (polymer) ≈ 0.1 cm^2/Vs

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Organic materials in Photovoltaic cells

<u>Advantages</u>
- tailoring of opto-electronic properties
- large areas
- low temperatures (RT)
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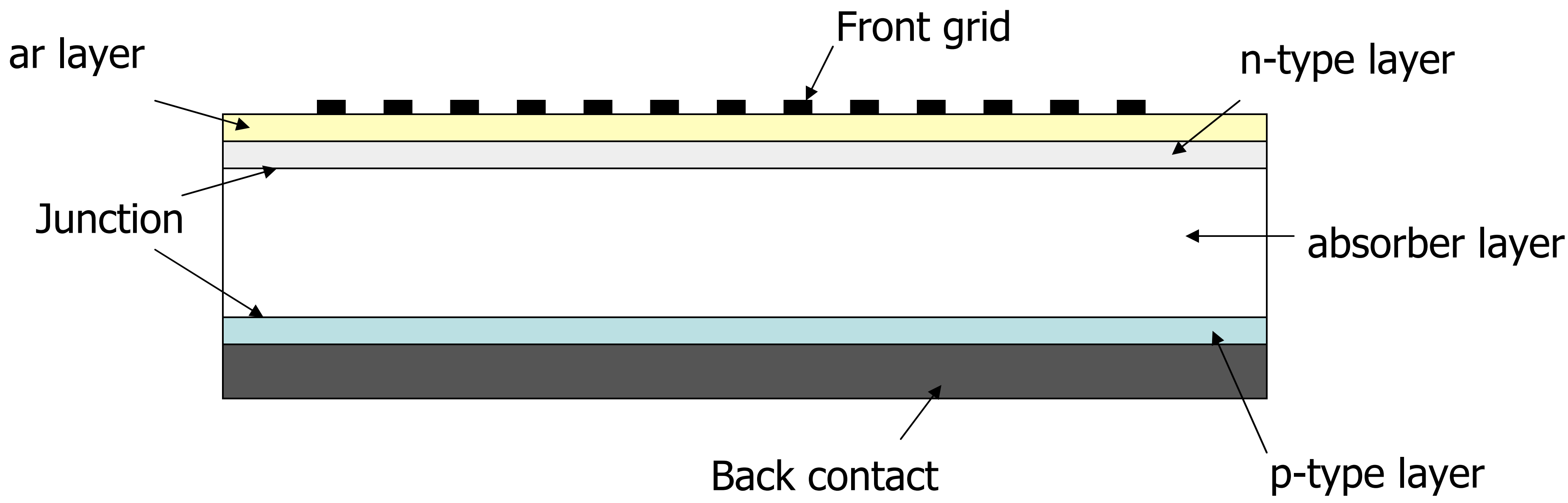
- low substrate costs

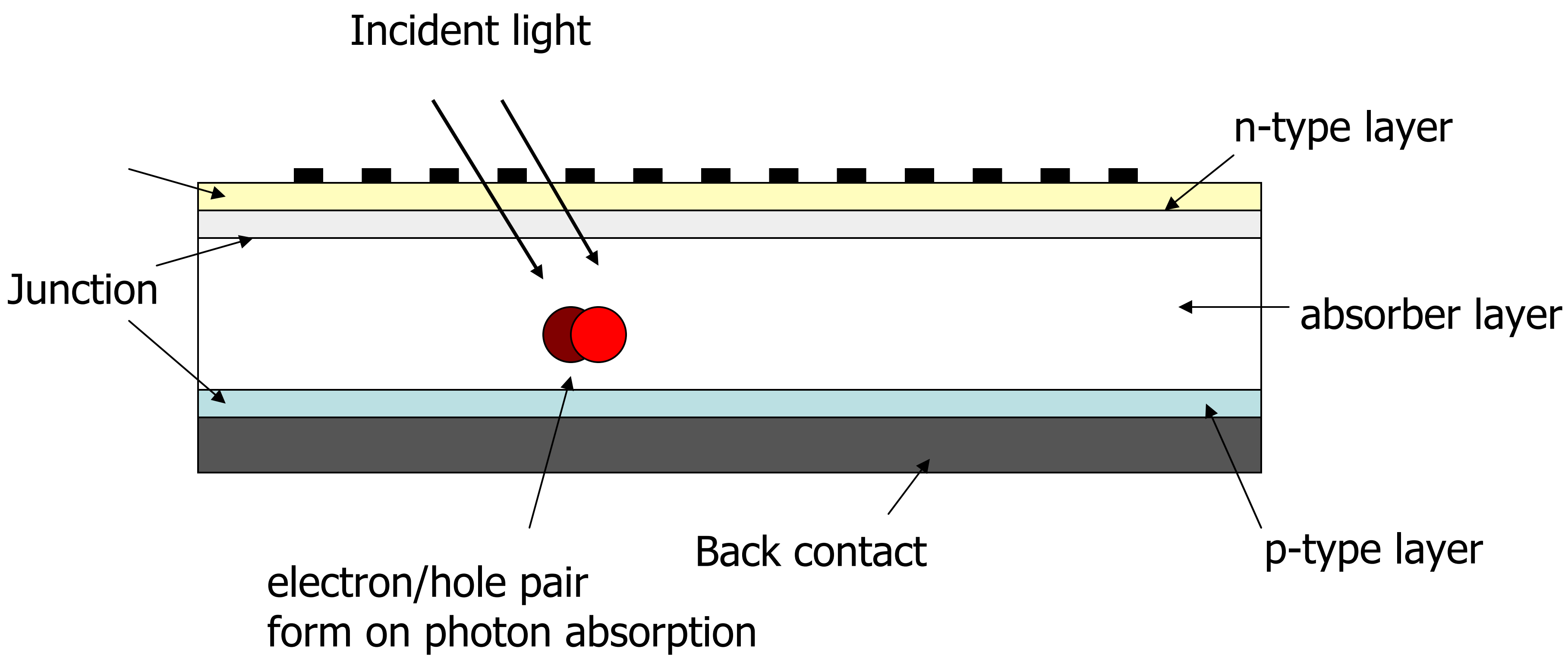
<u>(Possible) problems</u>
- low mobility of charge carriers
- photovoltaic performance (plastic cells: 5%, DSSC's: 10%)
- stability (10,00 hours minimum operational lifetime)

Crystalline silicon solar cells have efficiencies up to 20% combined with a lifetime > 20 years

Cross section of typical c-Si solar cells (3.2)



Cross section of typical Si solar cells



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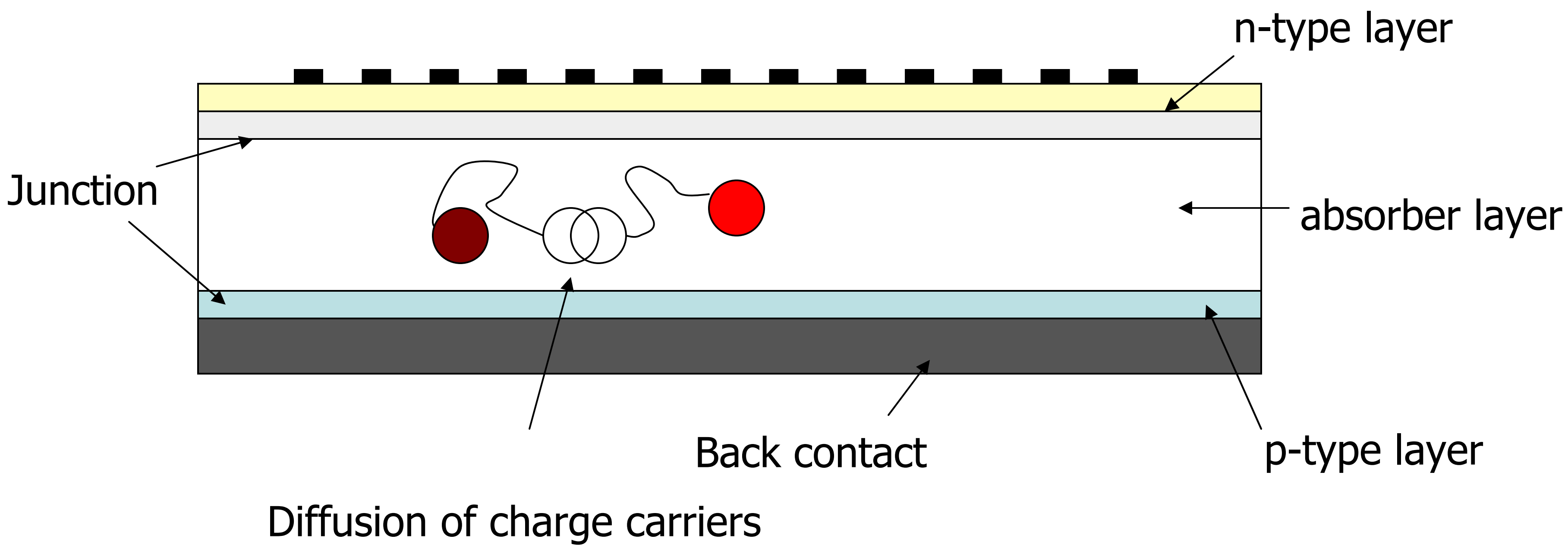
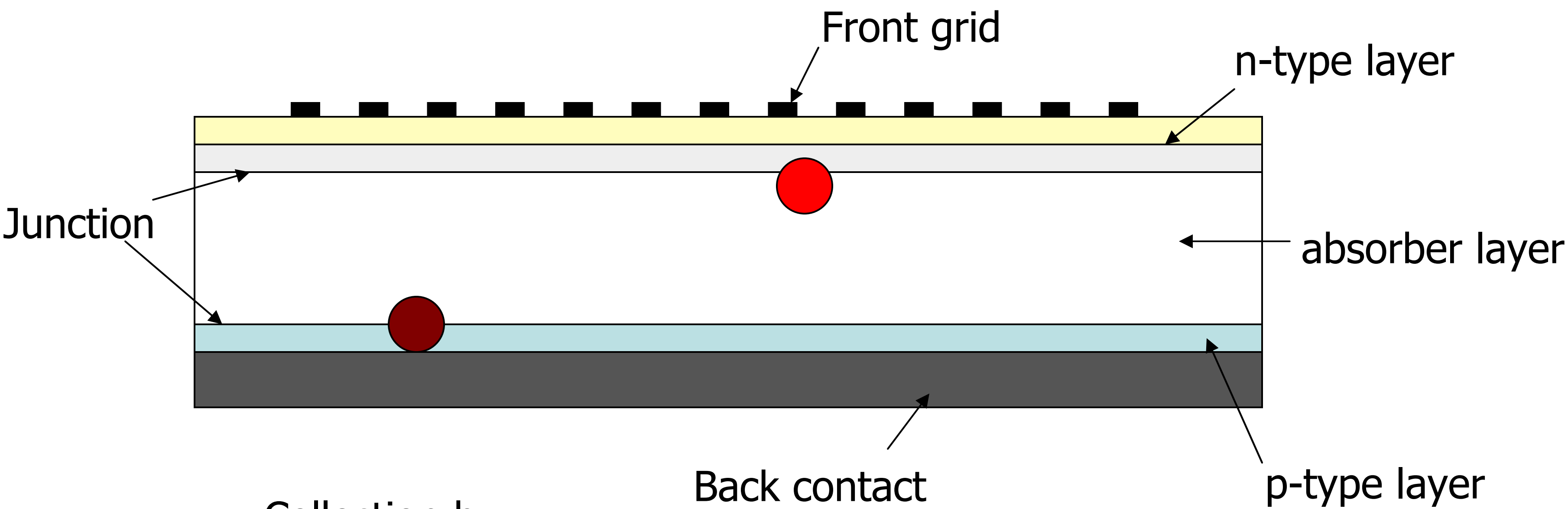
Cross section of typical Si solar cells



Cross section of typical Si solar cells



Collection by
internal electric field

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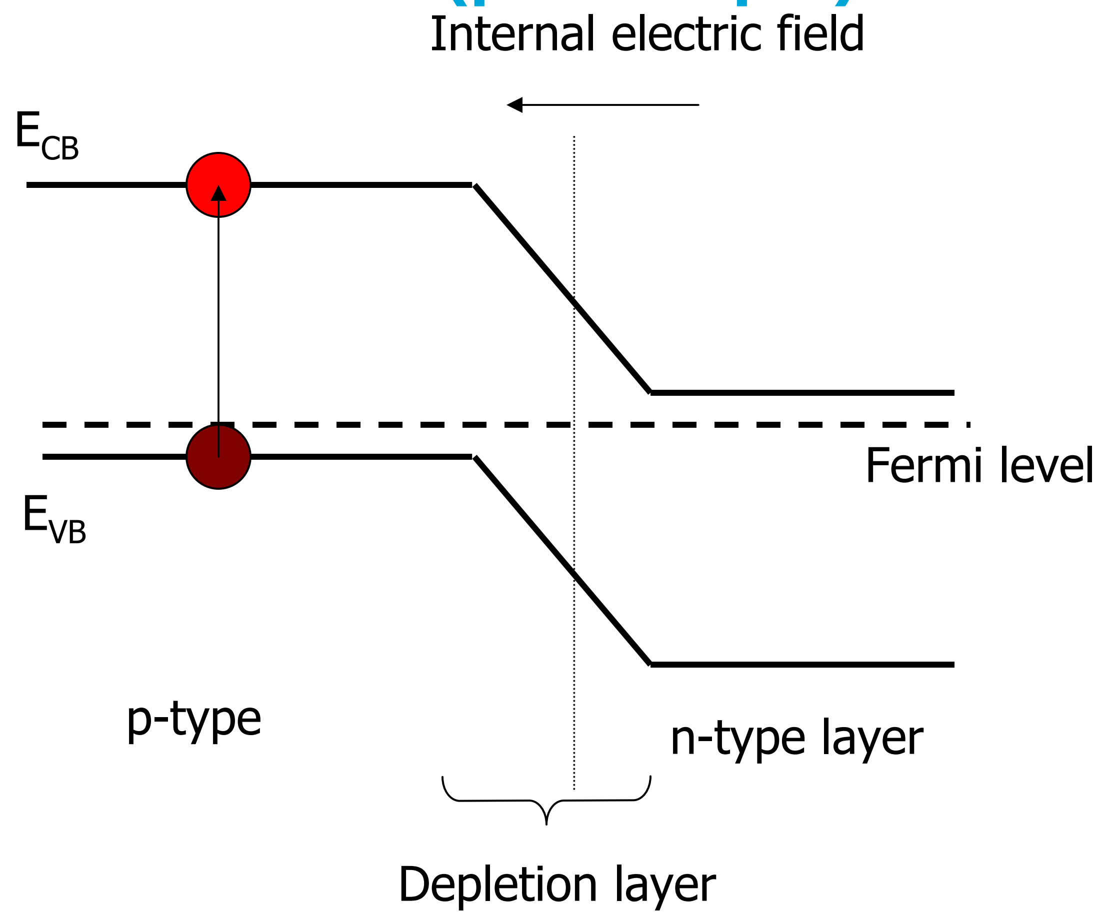
Homo Junction structure $V_a = 0$ V

(p 4.5 Chp 4)



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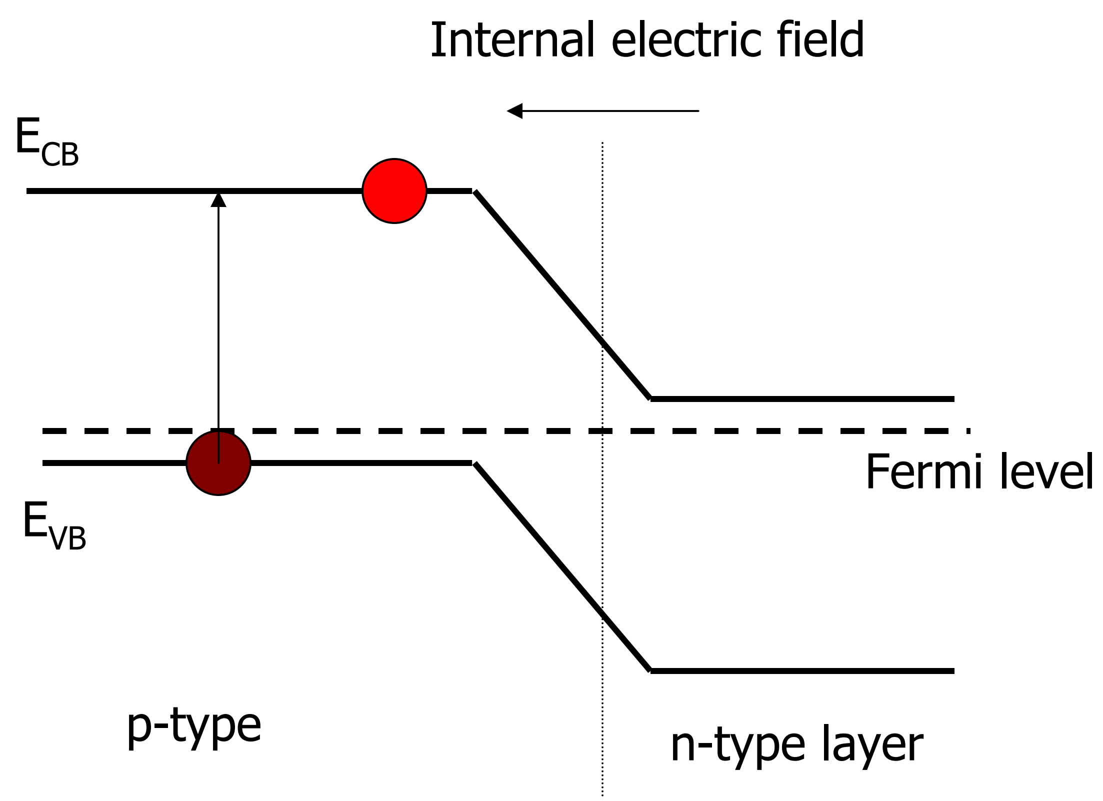
Homo Junction structure $V_a = 0$ V



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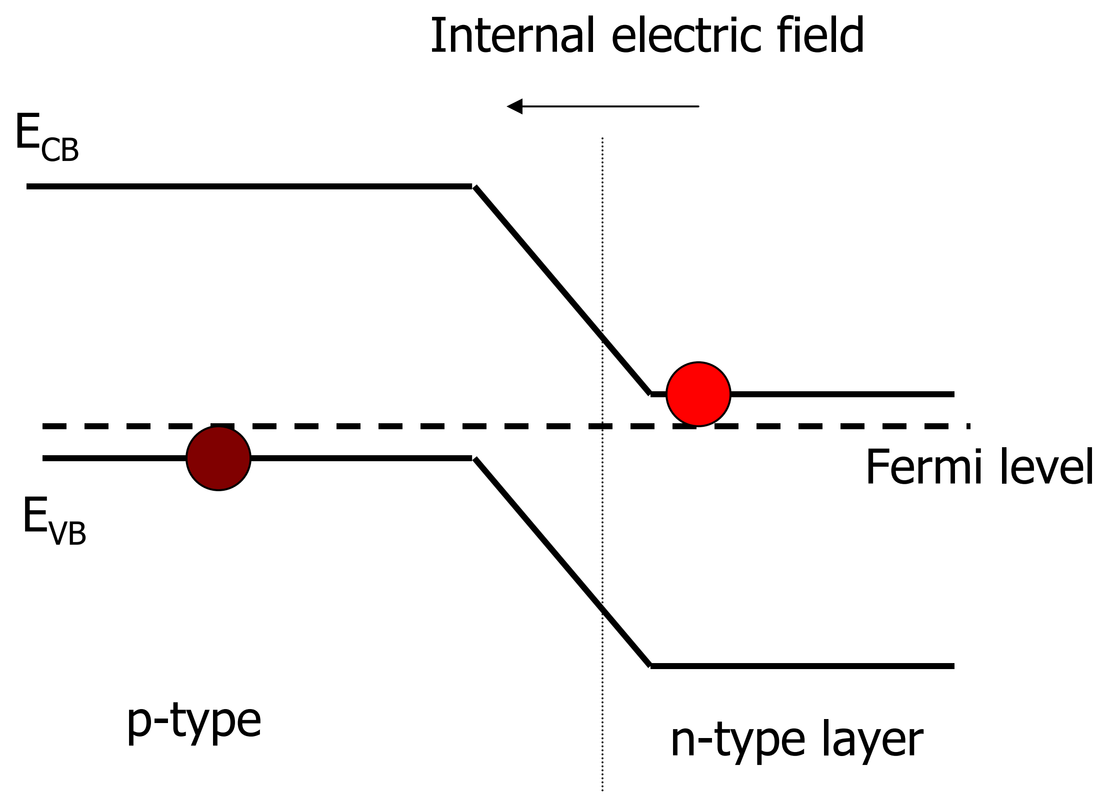
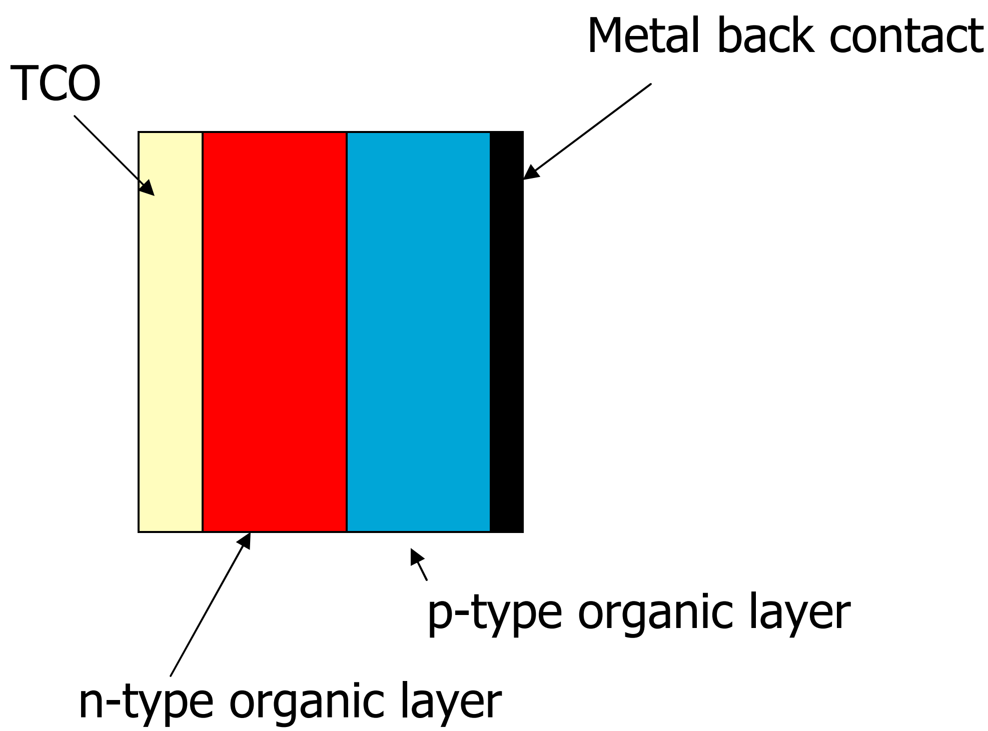
Homo Junction structure V_a = 0 V



Photovoltaic device based on molecular semiconductors?



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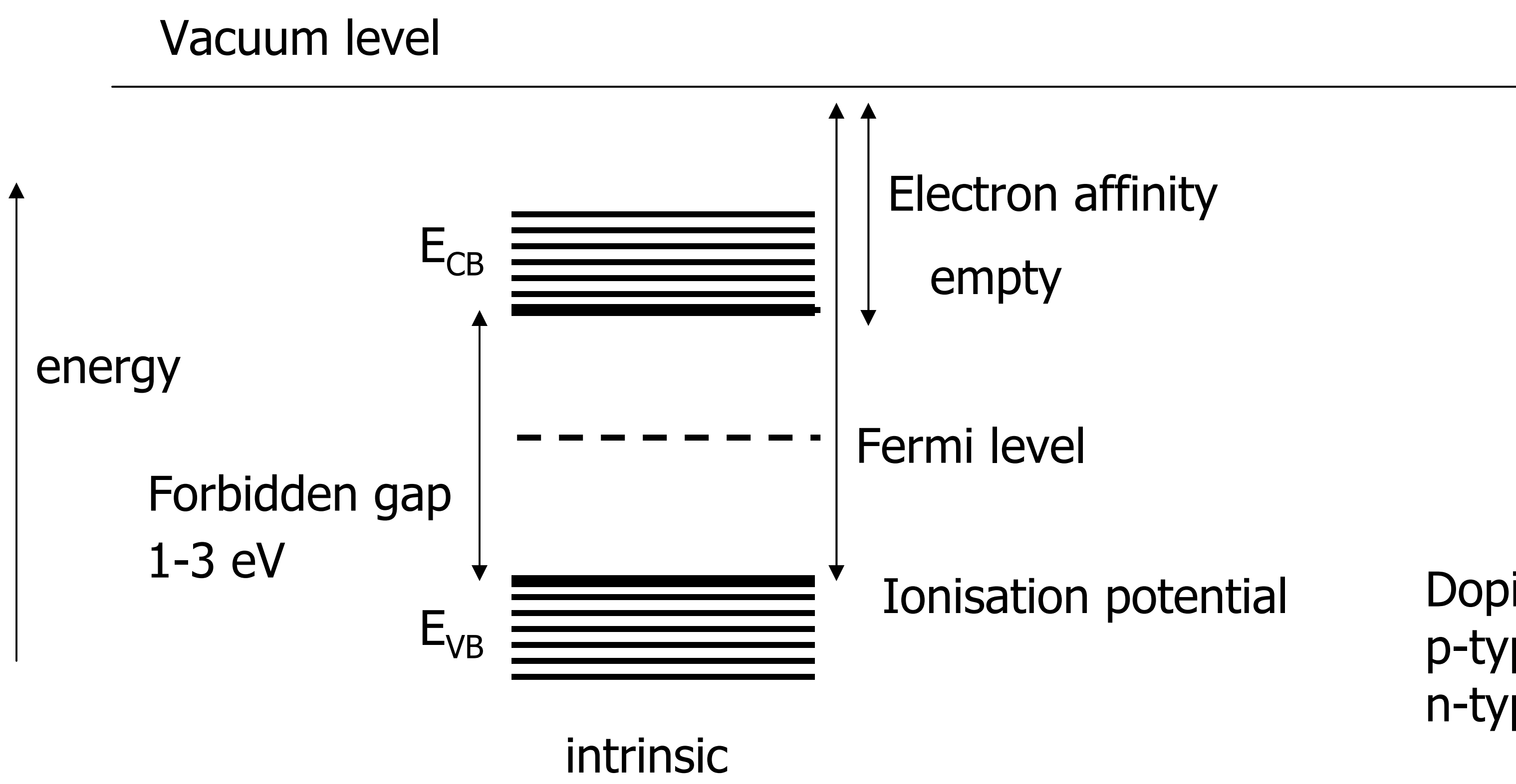
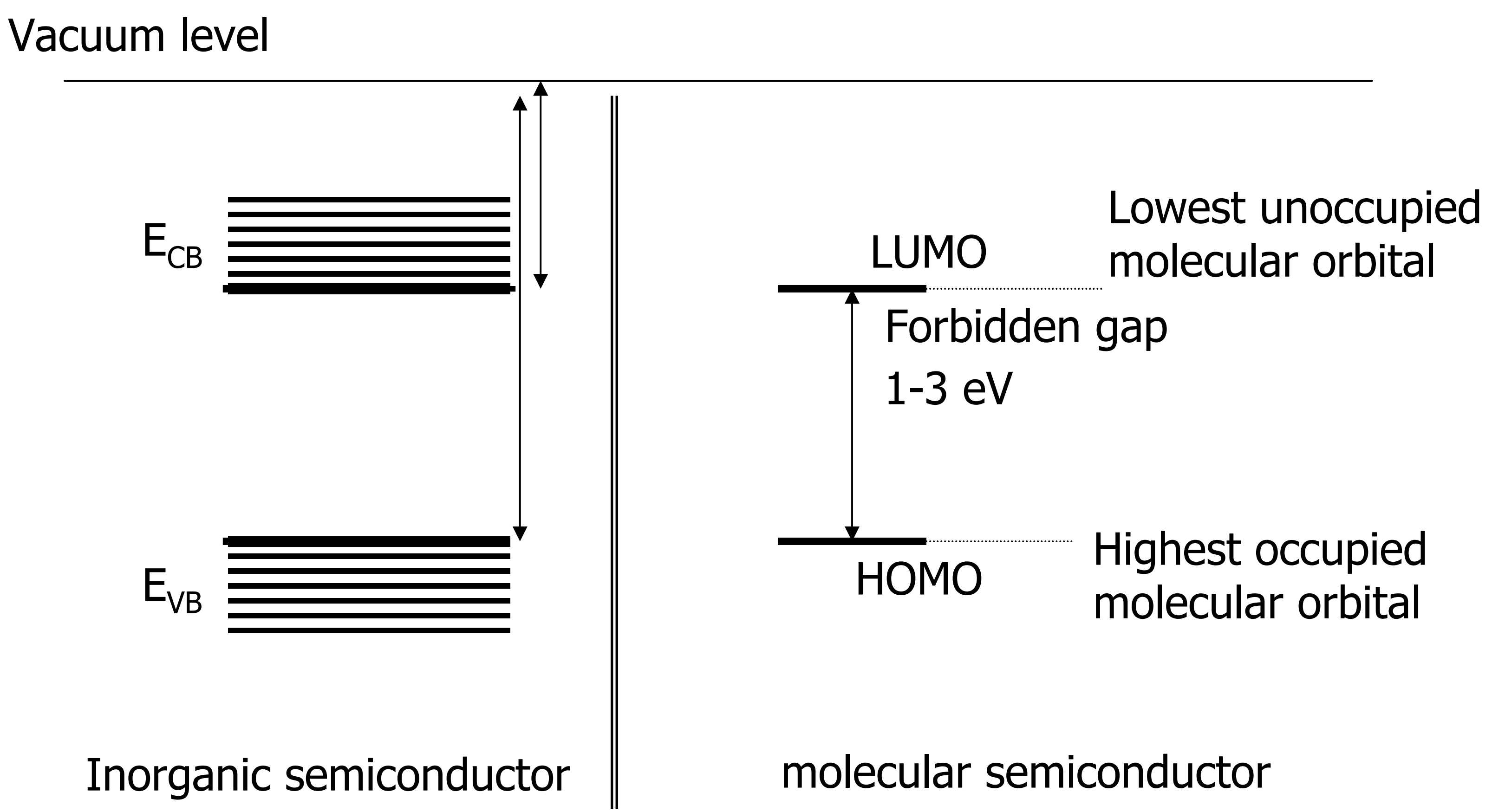
Semiconductors (3.11)



Doping leads to
p-type or
n-type SCs

Molecular semiconductors



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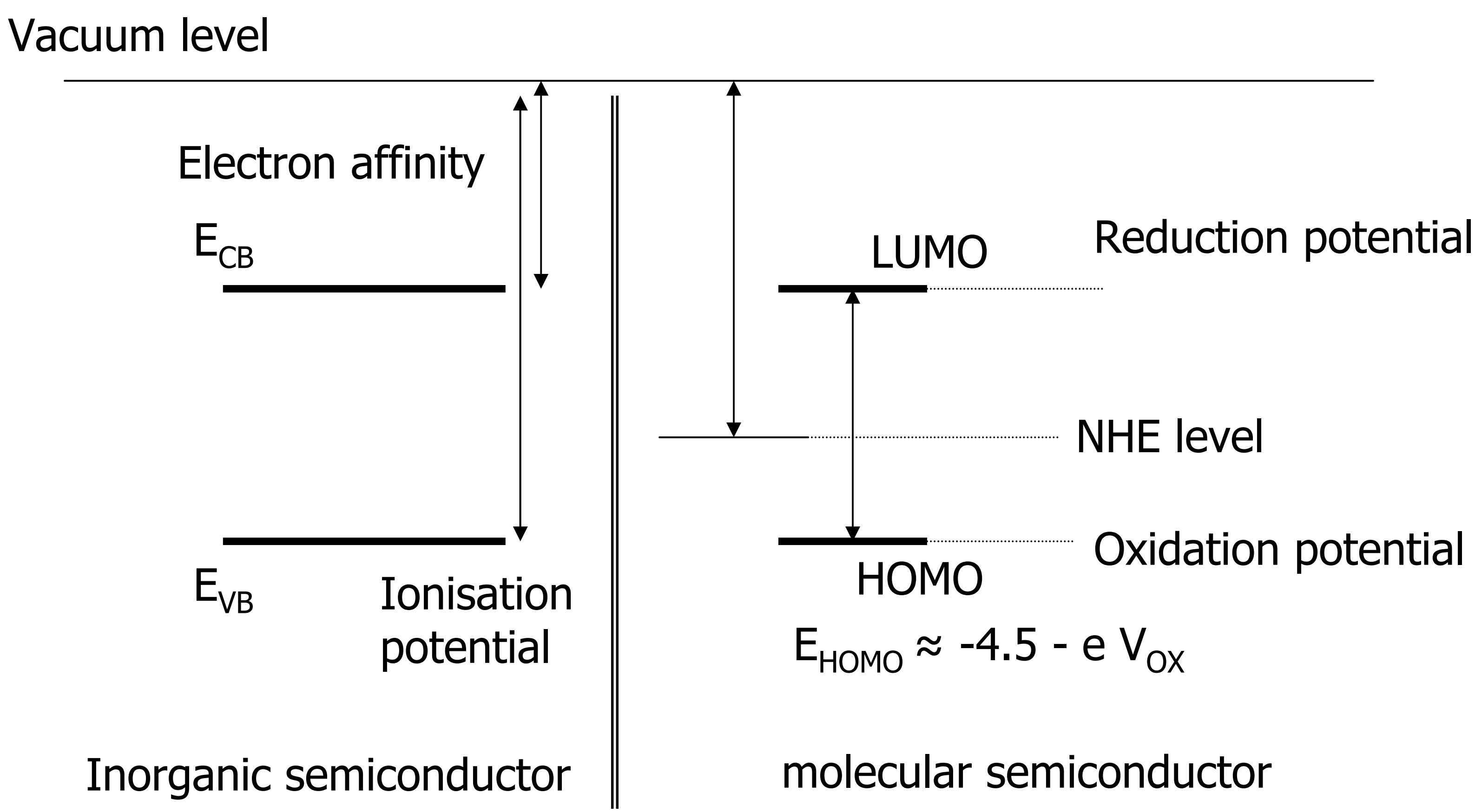
Energy levels



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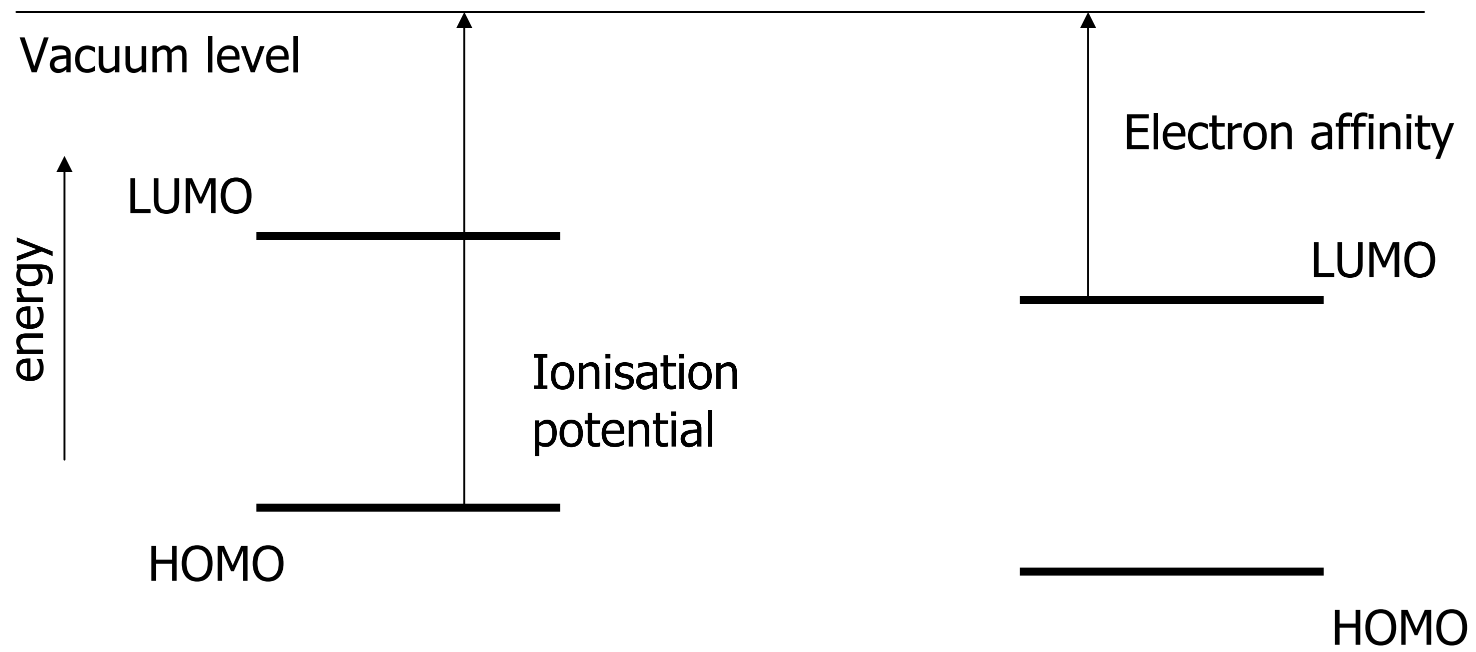
n- or p-type molecular semiconductors



Molecular material with a
low ionisation potential:
electron donor ⇒
p-type semiconductor

Molecular material with a
high electron affinity:
electron acceptor ⇒
n-type semiconductor

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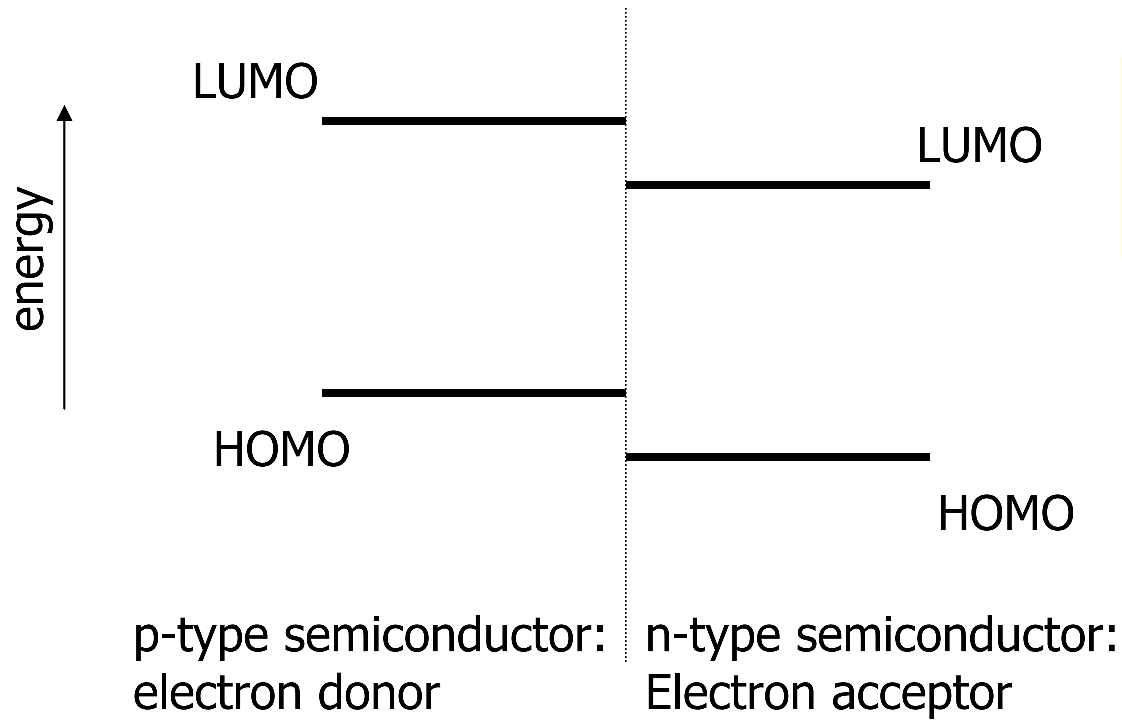
Junction based on molecular semiconductors



No free charge carriers:
no depletion layer
no internal electric field

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Excitations in inorganic and molecular semiconductors (isc vs msc)

A charge carrier becomes free from its Coulomb attraction to an opposite charge if the energy of attraction is less than k_BT

$$E = \frac{q^2}{4\pi\varepsilon\varepsilon_0 r_c}$$

If $E = k_BT$

$$r_c = \frac{q^2}{4\pi\varepsilon\varepsilon_0 k_B T}$$

q = electronic charge
ε_0 = permittivity of free space
r_c = critical distance

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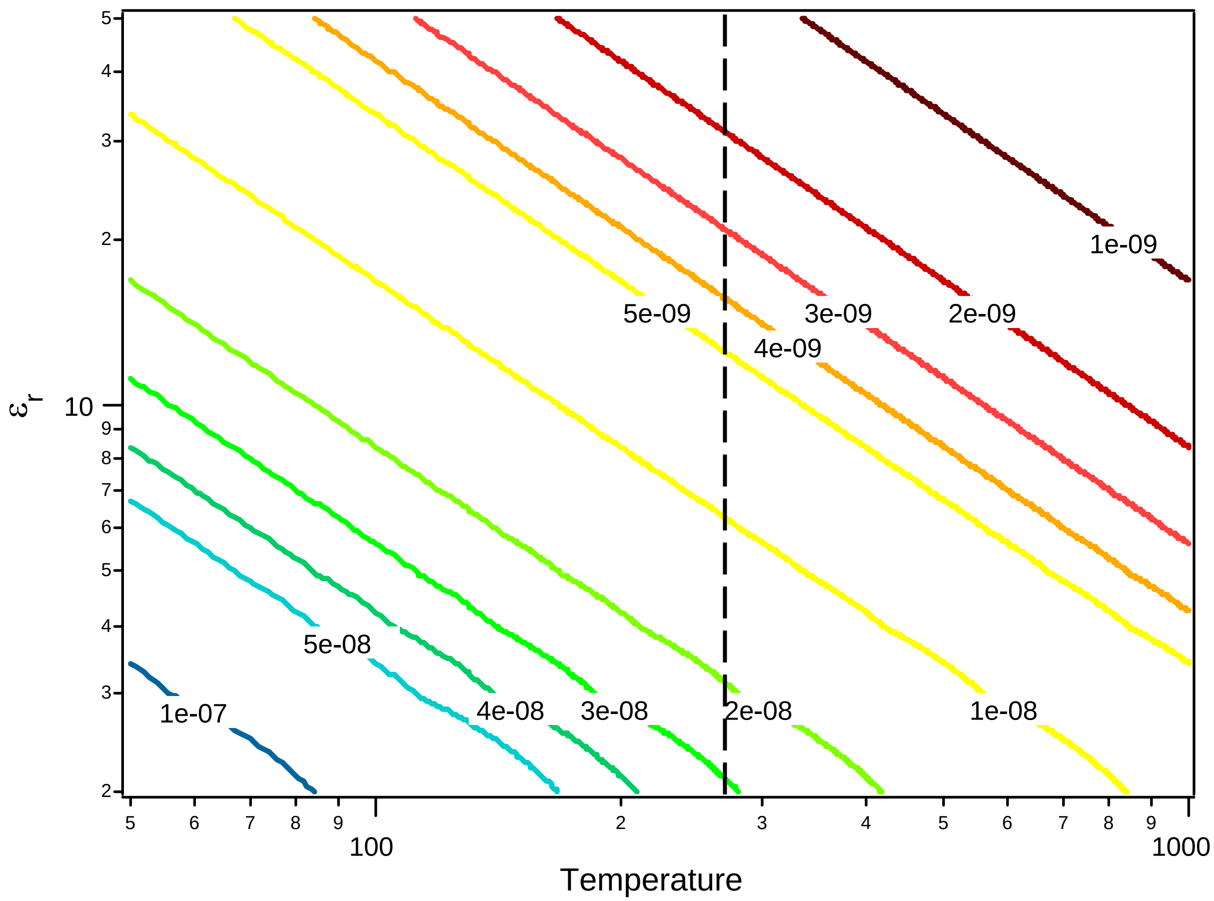
Dependence of R_c



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Bohr radius

$$r_B = r_0 \varepsilon \frac{m_e}{m_{eff}}$$

r_B = Bohr radius of carriers
r_0 = Bohr radius of hydrogen atom in the groundstate (0.53Å)
ε = dielectric constant
m_e = mass of free electron in vacuum
m_{eff} = effective mass of electron in SC

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Excitation leads in case of

- isc to free charge carriers and

- msc to excitons (coulomb bound electron/hole pair)

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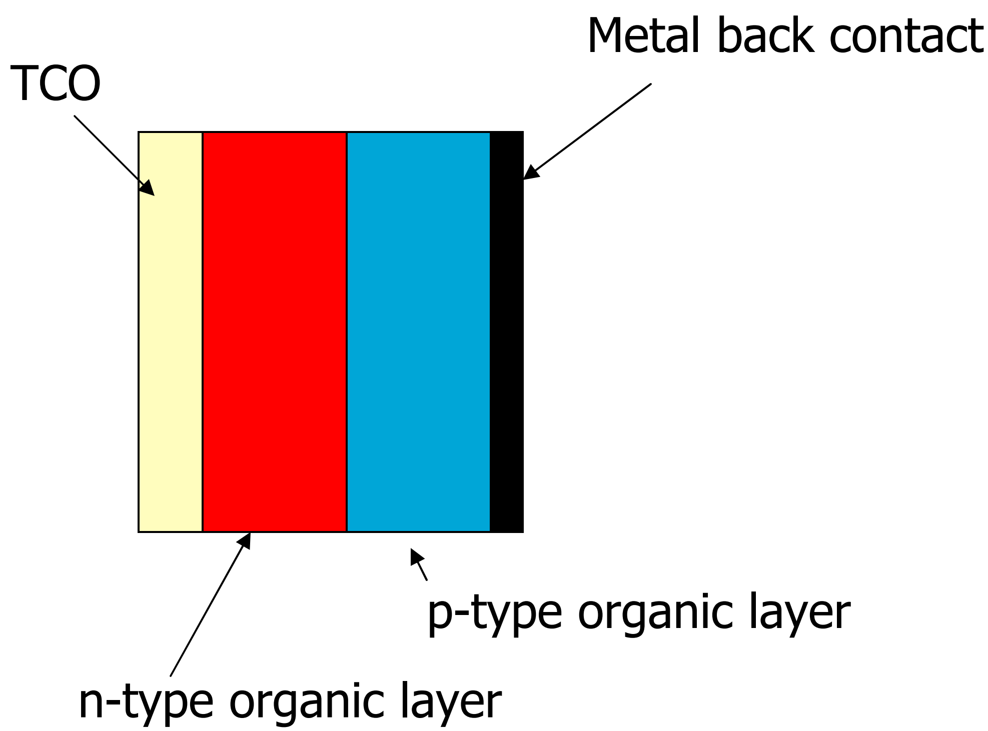
Photovoltaic device based on molecular semiconductors?



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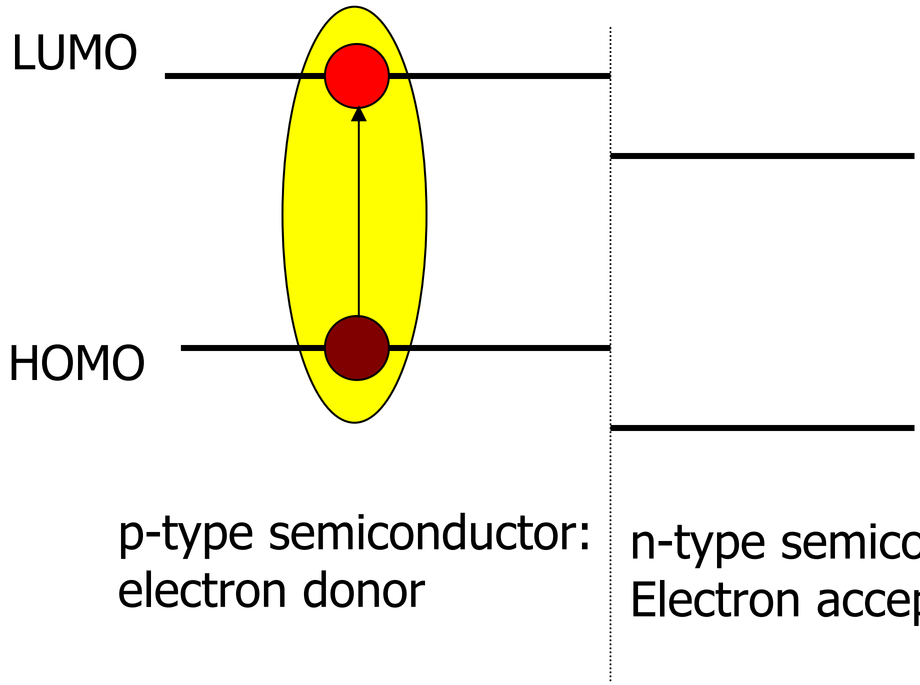
Excitation in organic junction

Exciton: Coulombic bound
electron hole/hole pair



p-type semiconductor:
electron donor

n-type semiconductor:
Electron acceptor

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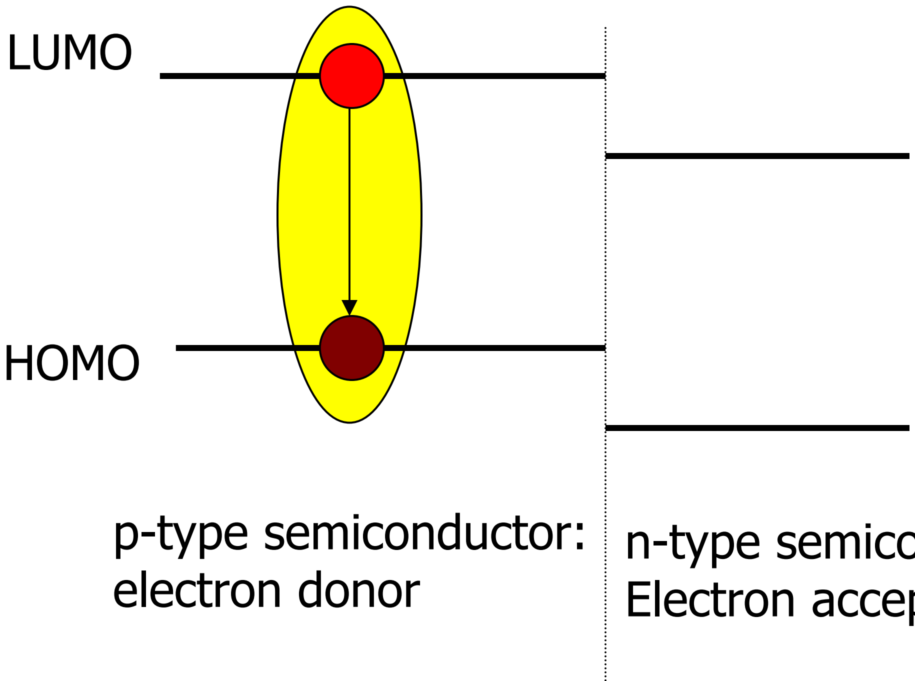
organic junction



p-type semiconductor:
electron donor

n-type semiconductor:
Electron acceptor

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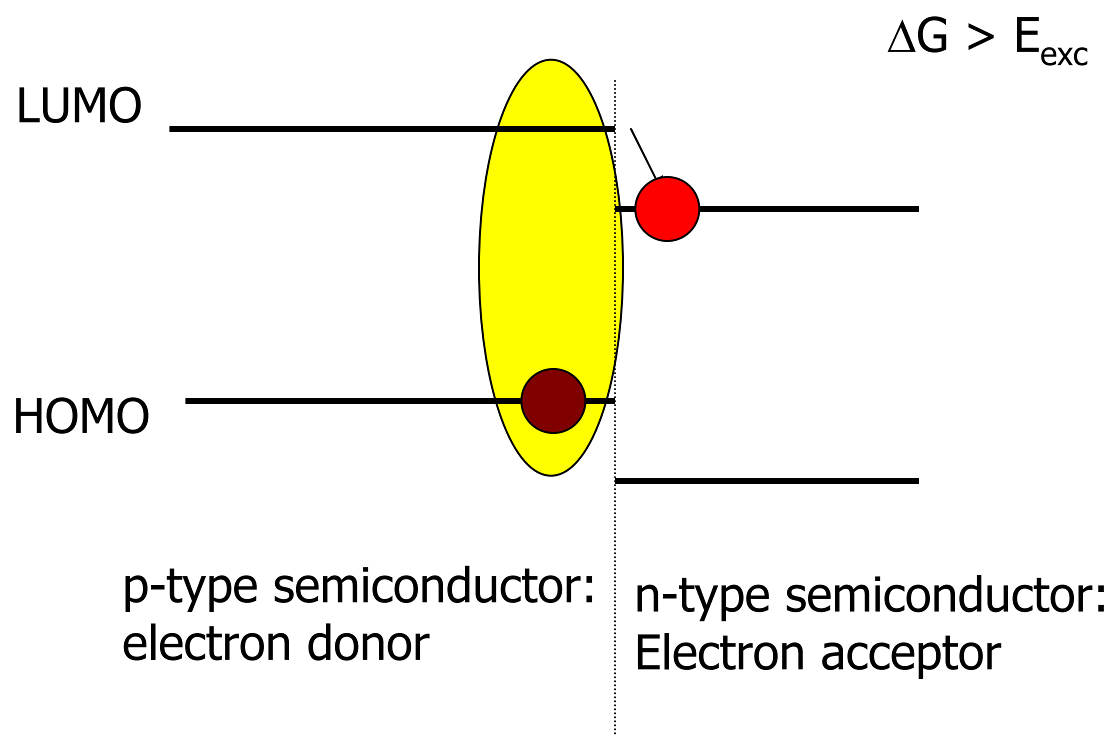
Excitation near interface



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Molecular based organic photovoltaic device

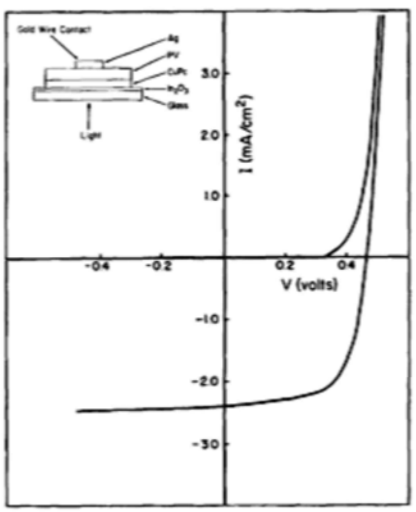


FIG. 1. Configuration and current-voltage characteristics of an ITO/CuPc (250 Å)/PV(450 Å)/Ag cell.

CuPc

PV

Phthalocyanine

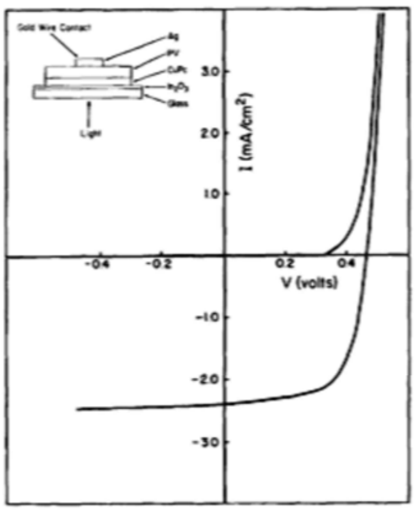
p-type material

Perylenediimide
n-type material

η <=1%

Tang, C.W., *Two-layer organic photovoltaic cell.* Appl. Phys. Lett, 1986. 48(2): p. 183-185.

Voltage of molecular based organic photovoltaic devices



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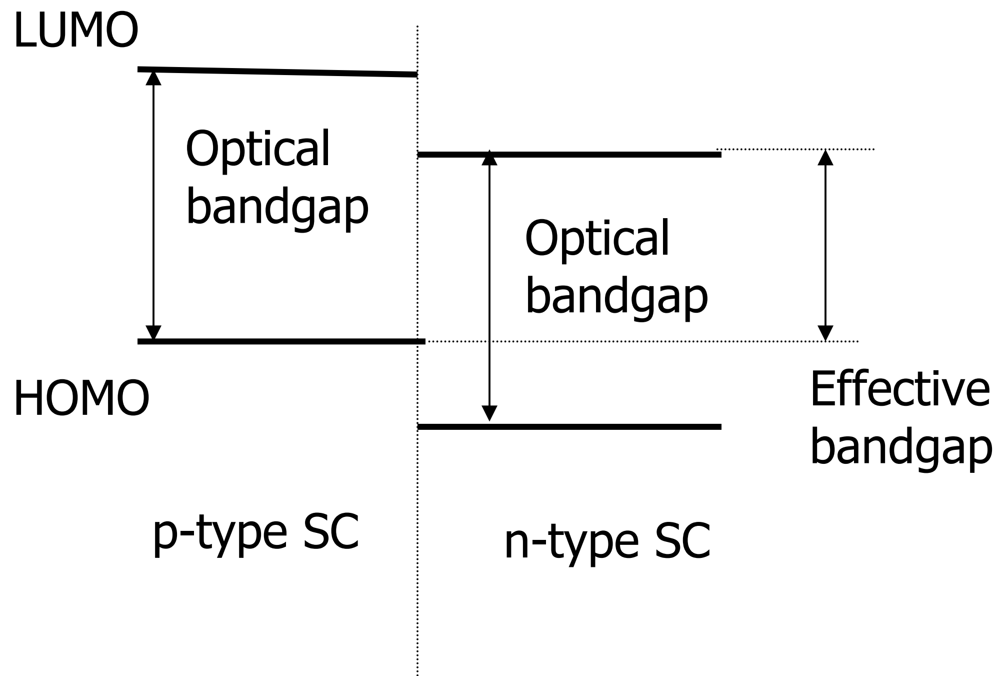

Tang, C.W., *Two-layer organic photovoltaic cell.* Appl. Phys. Lett, 1986. 48(2): p. 183-185.

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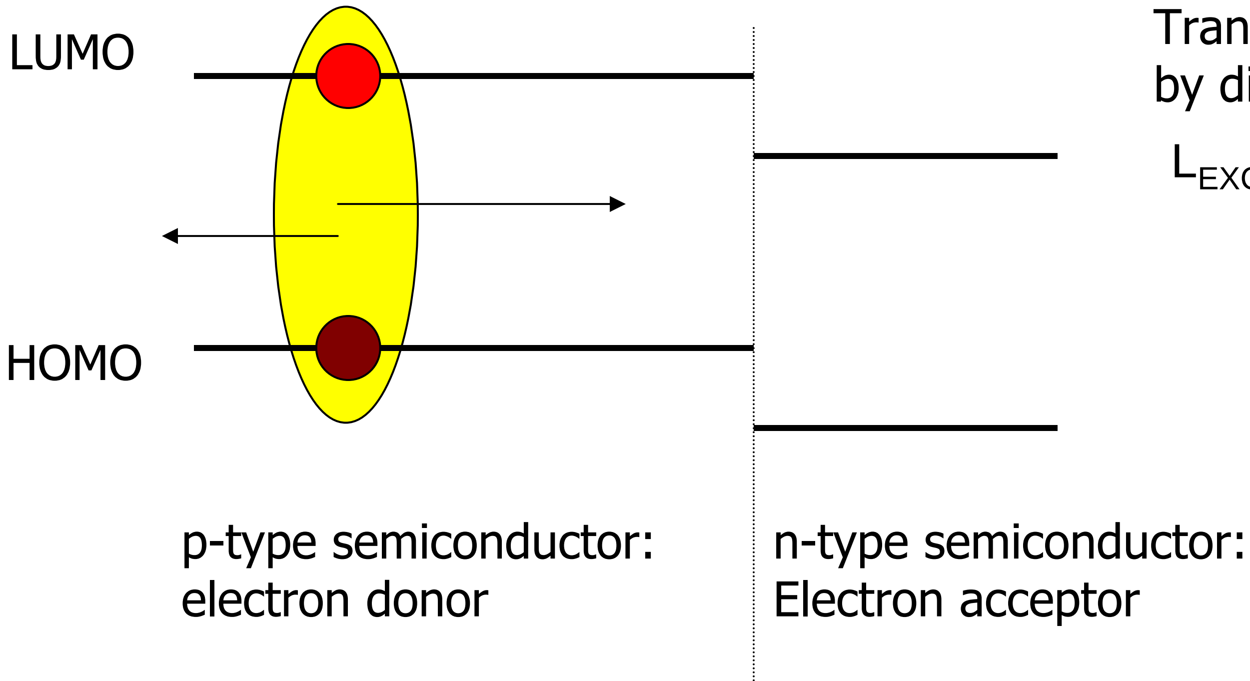
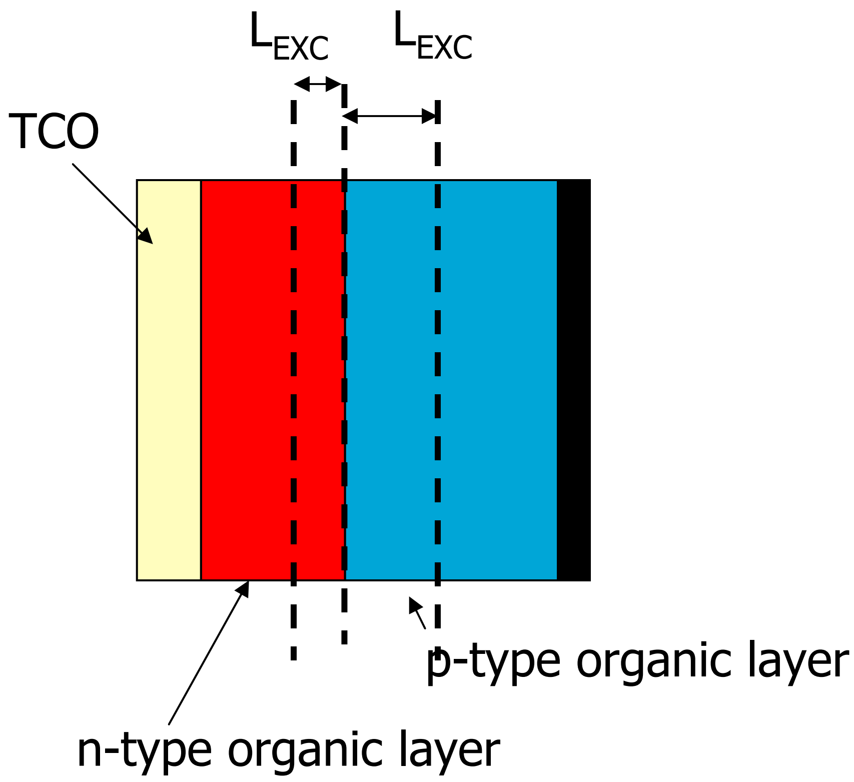
Current of molecular based organic photovoltaic device



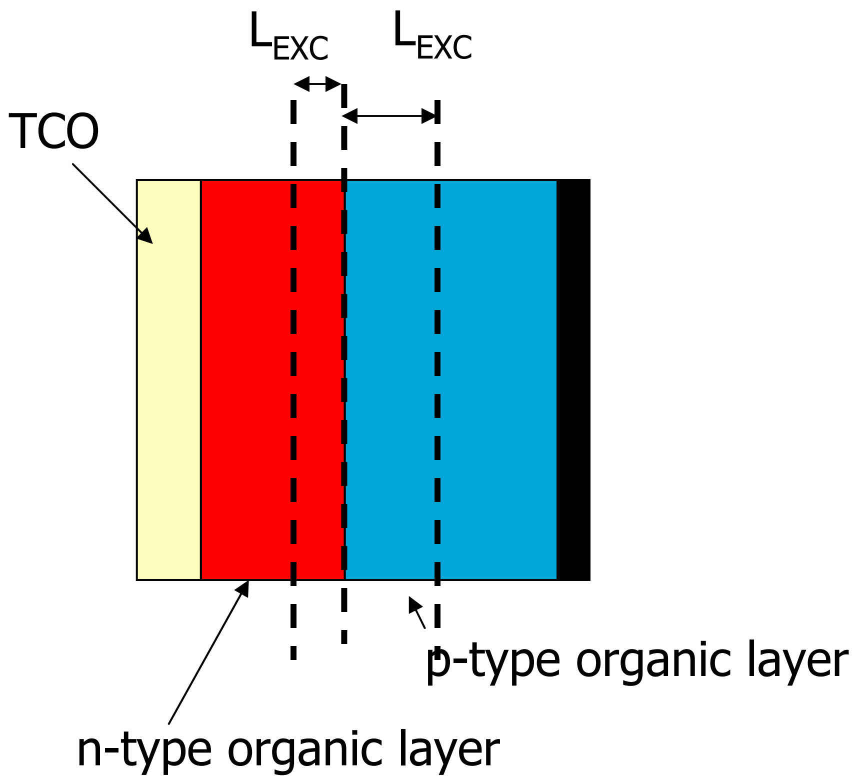
Transport of excitons by diffusion (Chp 3):

$$L_{EXC} = \sqrt{D_{EXC}\tau_{EXC}}$$

Molecular based organic photovoltaic device



Molecular based organic photovoltaic device



Solution:
increase the interfacial area

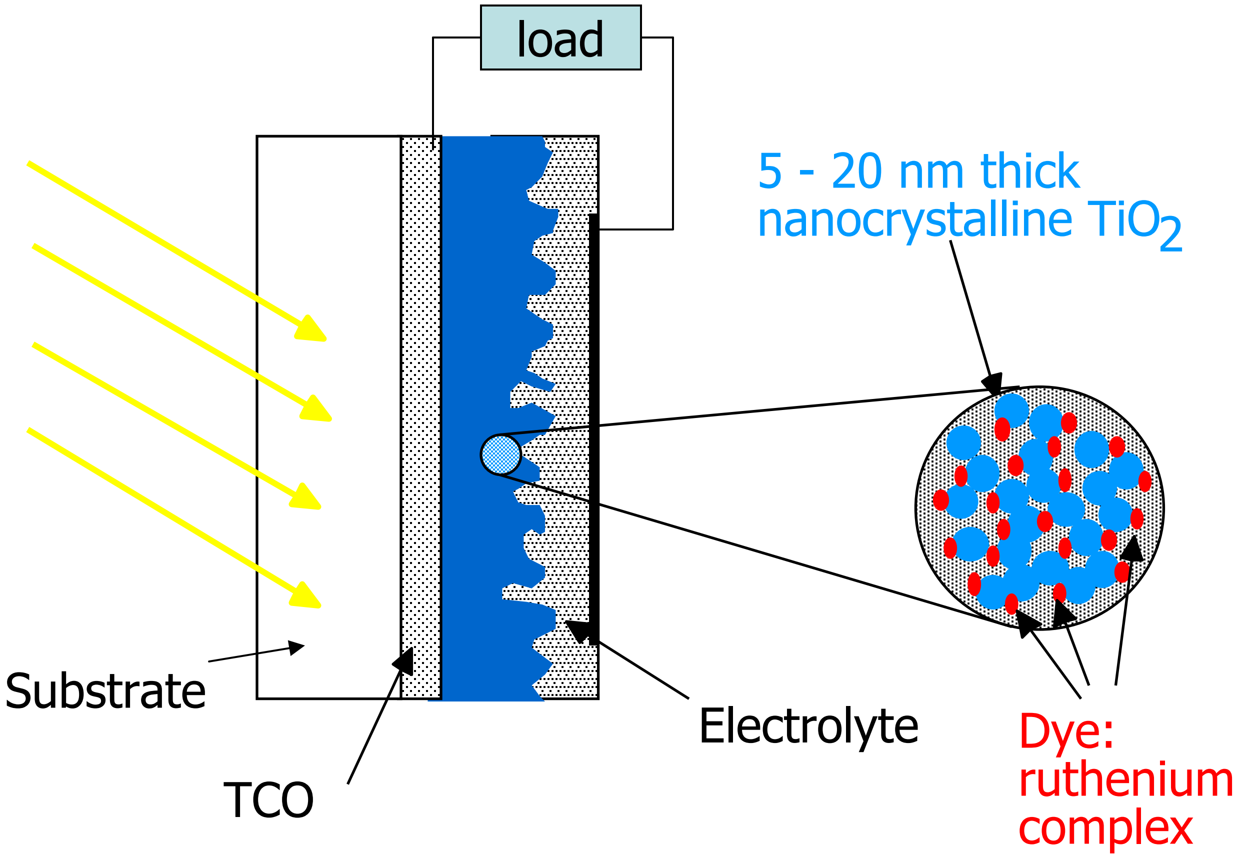
Outline

Why using organic materials

Fundamental aspects of organic semiconductors
- excitations inorganic and organic SCs
- energy levels in molecular materials
- exciton diffusion

Examples of organic solar cells
- Dye sensitised solar cells
- Polymer bulk heterojunction cells

Dye sensitised solar cells (Graetzel cells)



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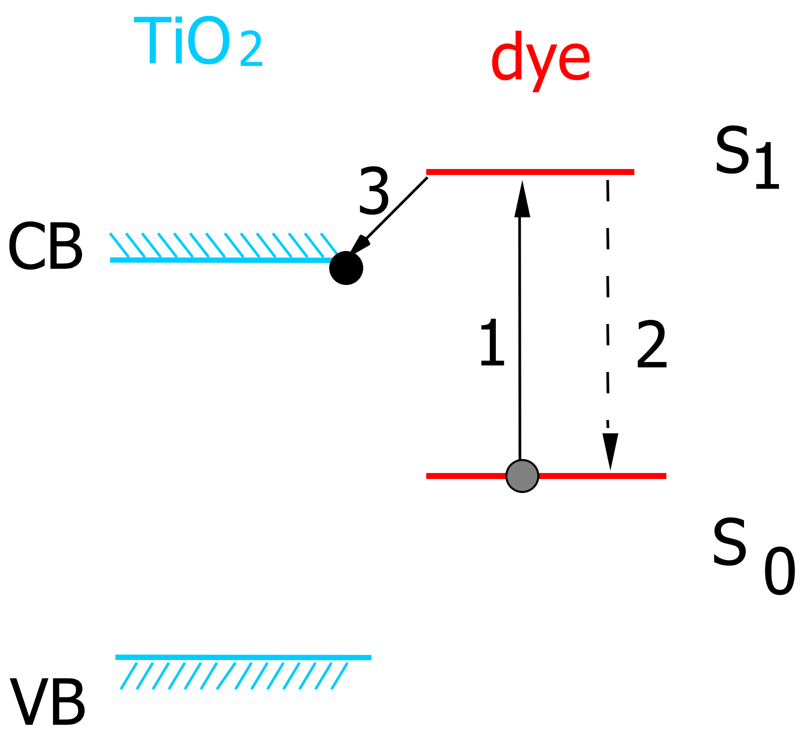
Primary Processes



1: photo-excitation
2: (non)radiative decay
3: electron transfer

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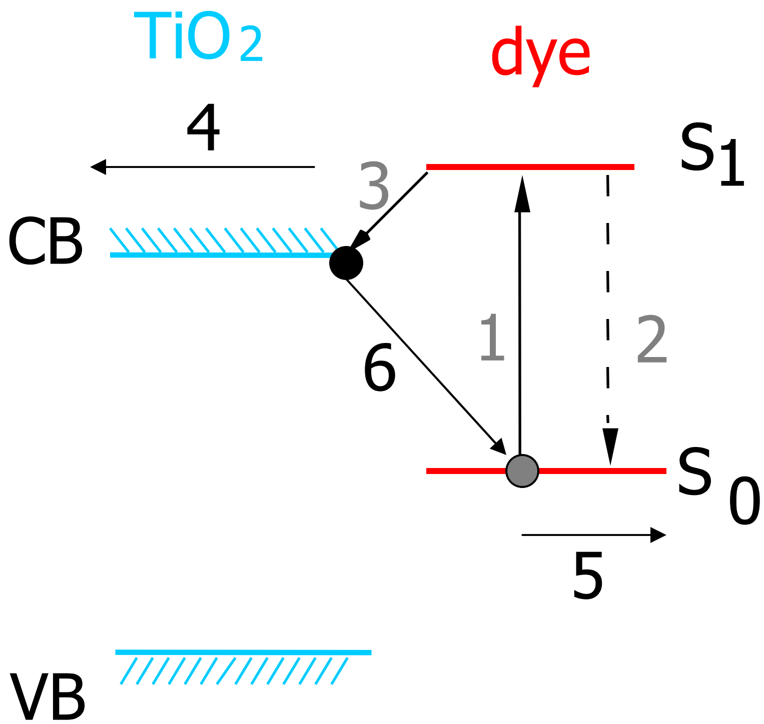
Secondary Processes



1: photo-excitation
2: (non)radiative decay
3: electron transfer

4: electron transport
5: hole transport

6: recombination

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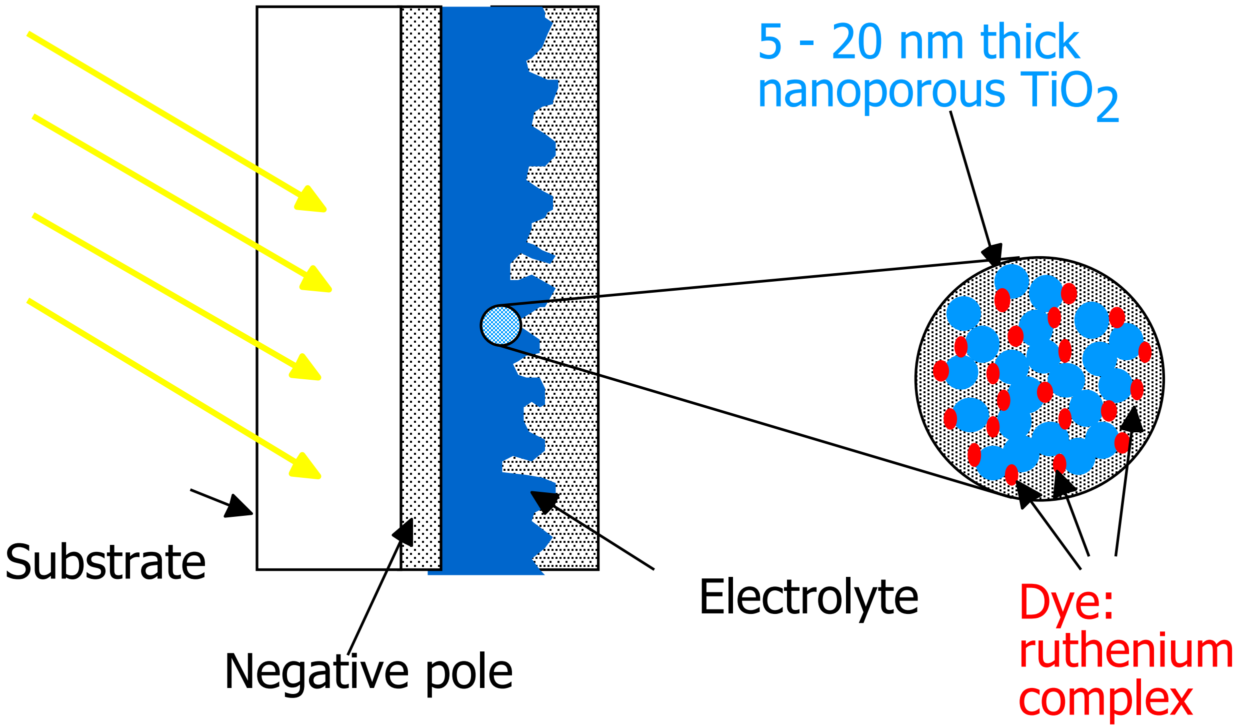
Electron transport via particles



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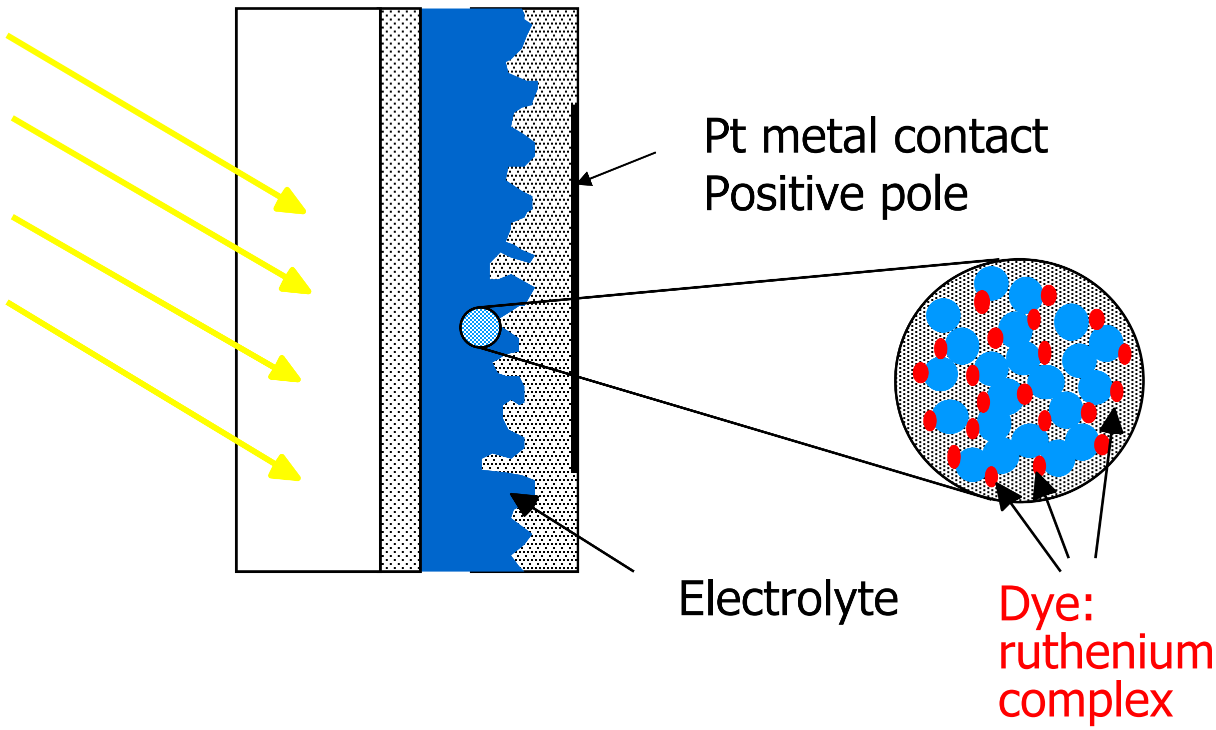
Hole transport by redox couple



$2Dye^{+} + 2I^{-} \longrightarrow 2Dye + I_2$ At dye/electrolyte interface

$I_2 + 2e^{-} \longrightarrow 2I^{-}$ At electrolyte/Pt interface

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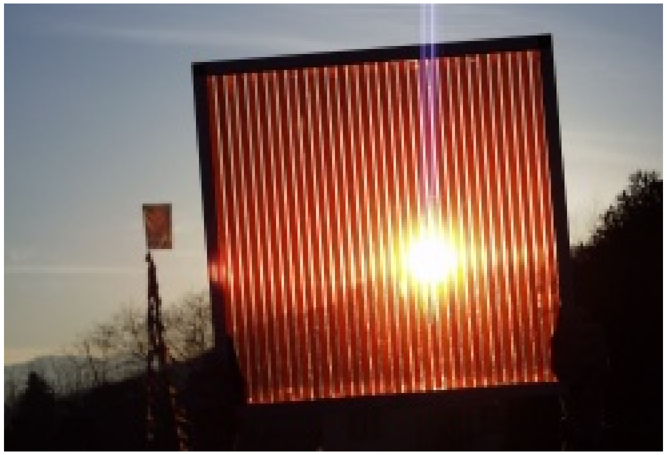
DSSCs on the market



•First large area dye solar cell modules
•made with industrial materials & methods
•45 x 45 cm surface, 33 serially connected cells

dye_solar_cells.htm

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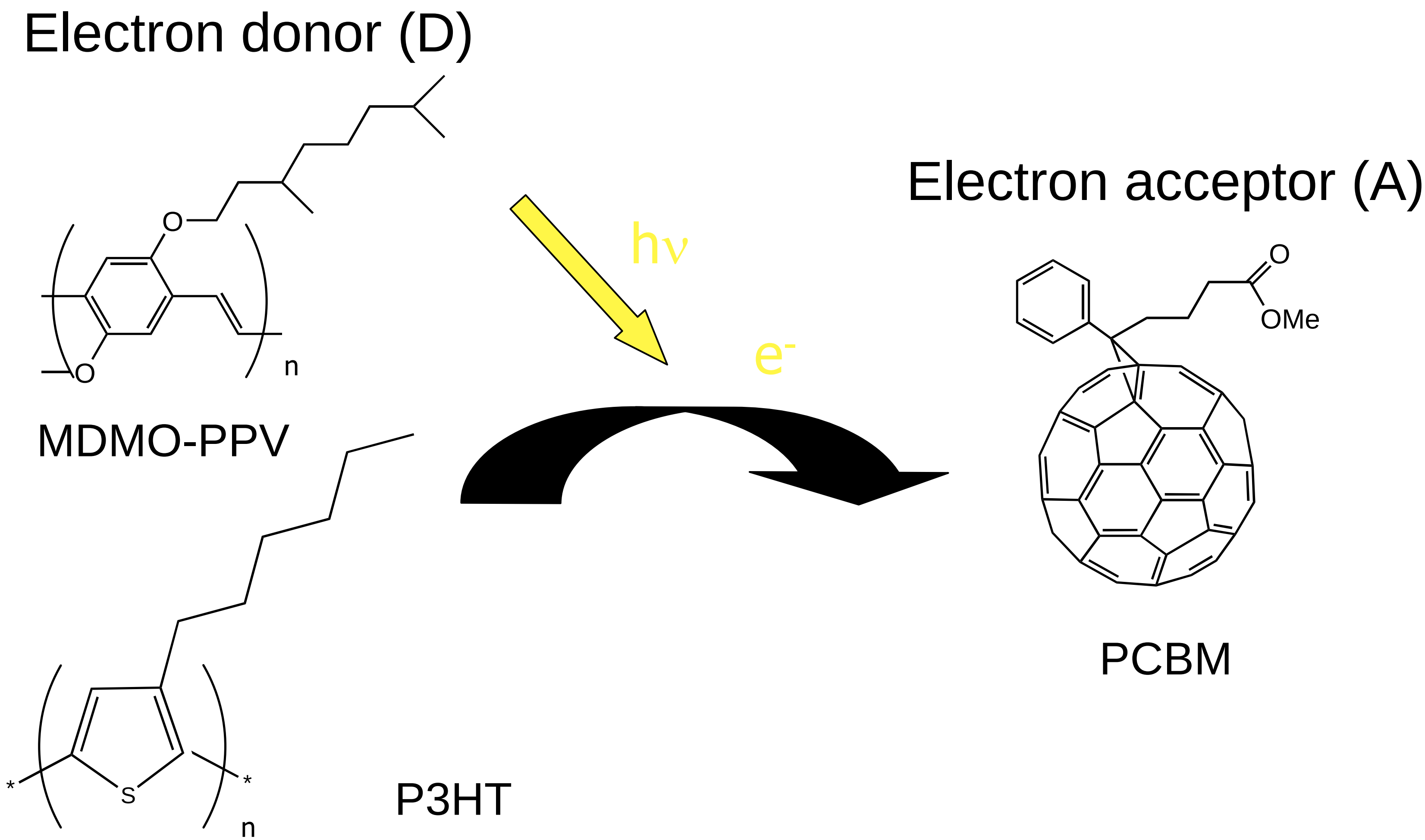
Present developments on DSSC

- improvement of absorption of dye molecules to absorb all sun light with $\lambda < 1000$ nm
- omit the liquid phase by using solid state hole conductor to avoid leakage
- usage of ordered nanowires to optimize electron transport properties

Polymer solar cells



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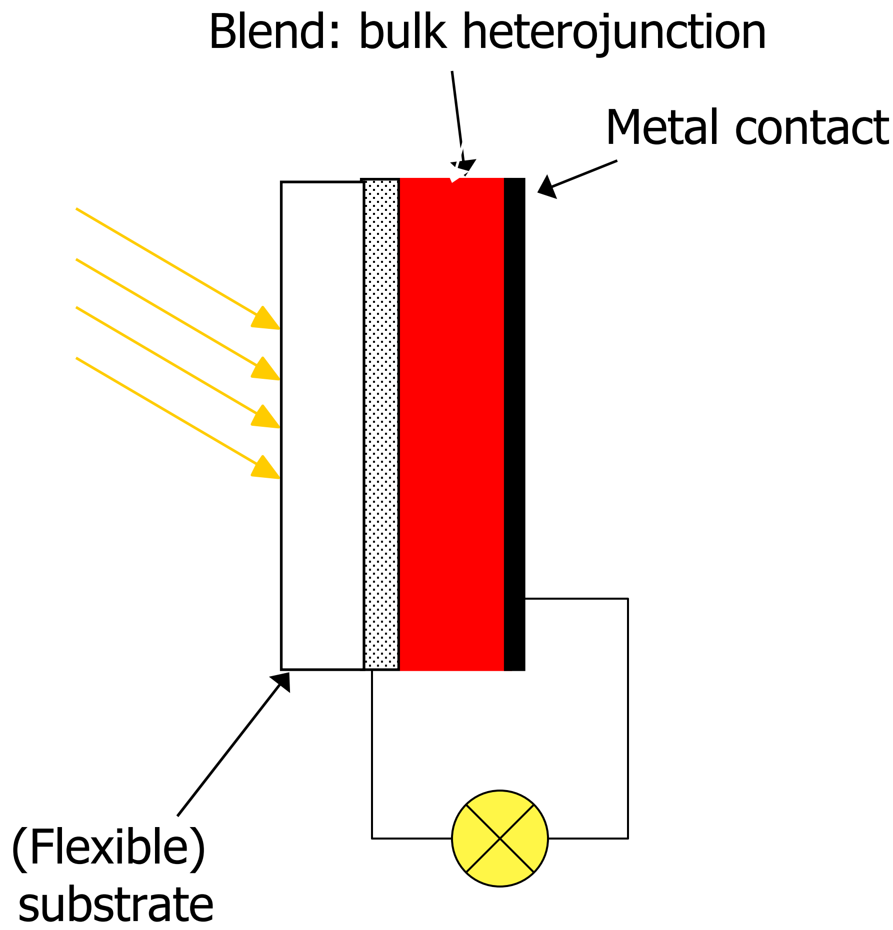
Photovoltaic Cell



- η: ca 5 %
- Flexible
- Cheap materials
- Simple processing
- Tunable color
- Thin layers

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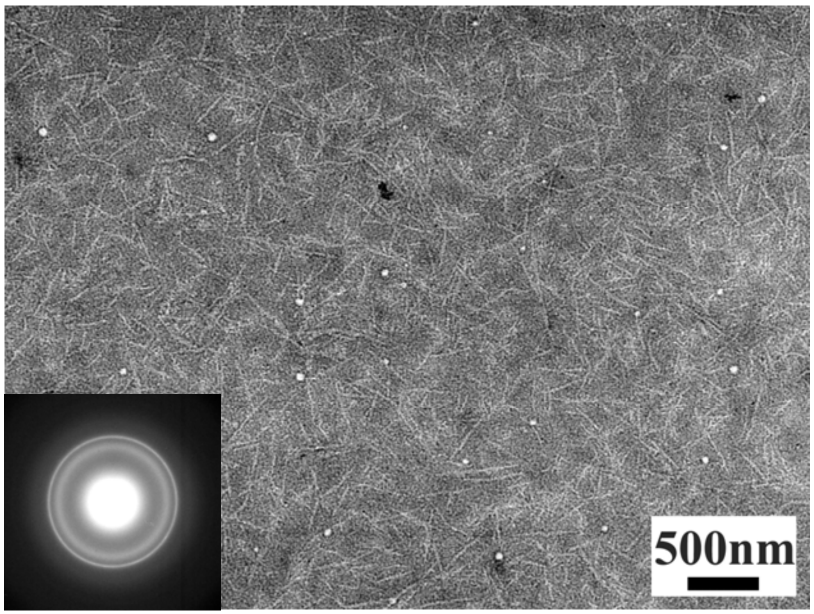
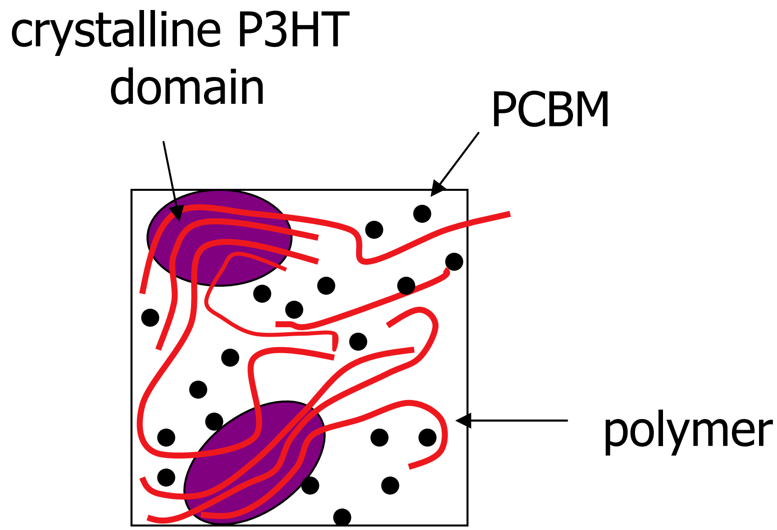
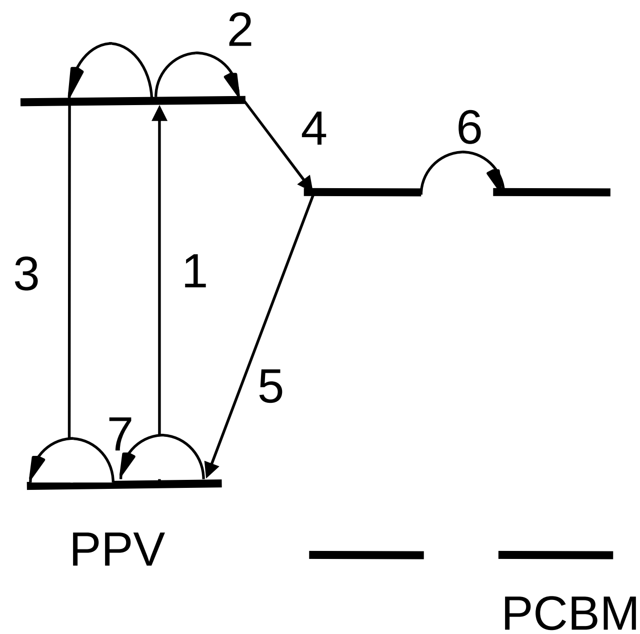
Nano morphology of bulk heterojunction (TEM)



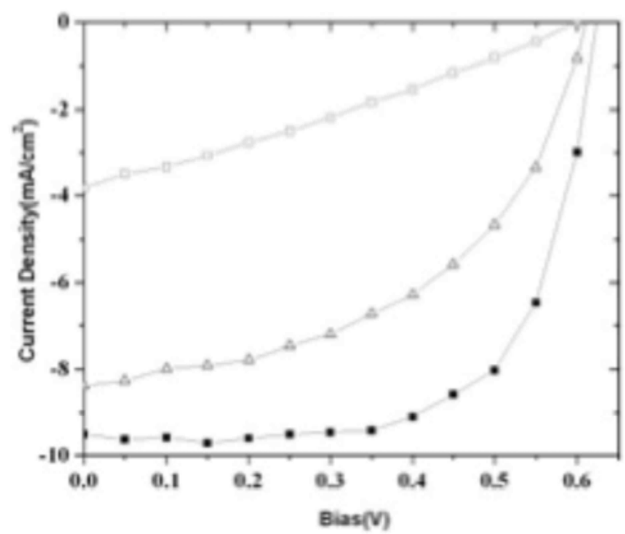


Polymer solar cells



1: Excitation
2: Exciton migration
3: (Non)radiative decay
4: Charge separation
5: Charge recombination
6: Electron transport
7: Hole transfer

V_{OC} = 0.6 V
Isc = 0.97 mA/cm^2
FF = 0.68
η = 5%



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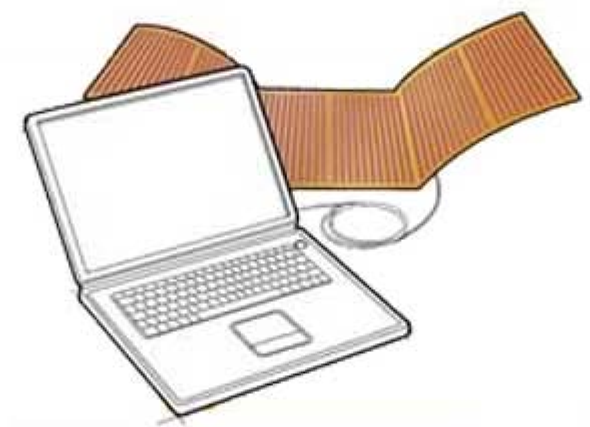
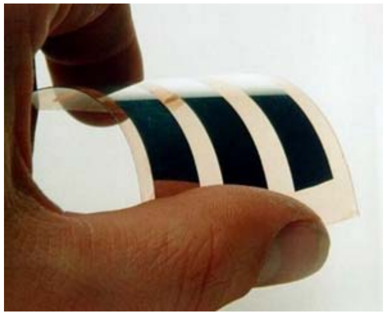
Plastic solar cells on the market





•http://www.konarkatech.com

Present developments on polymer solar cells

- Reduce bandgap of polymeric materials to absorb all sun light with $\lambda < 1000$ nm

- Optimize energy levels to avoid additional energy loss during charge separation

- enhance crystallinity of materials to improve charge carrier transport

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Questions

- Which factors do affect the potential in a polymer solar cell?
- Calculate the critical distance in a photoactive blend layer with ε=4.5 at room temperature
- Calculate the minimum thickness of an organic blend layer consisting of a 1 tot 1 mixture of a conjugated polymer and a wide bandgap SC in order to absorb 90 % of the incident light. Neglect the reflection; the polymer has an $\alpha = 18 \times 10^{6} m^{-1}$
- Calculate the average period it takes for an exciton to cross 5 nm in a molecular material. The exciton lifetime is 2 ns and the exciton diffusion length is 25 nm.