ME4252 Nanomaterials for Energy Engineering

Nanostructured Solar Cells

Palani Balaya
mpepb@nus.edu.sg
6516 7644

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Dye-sensitized Solar Cell

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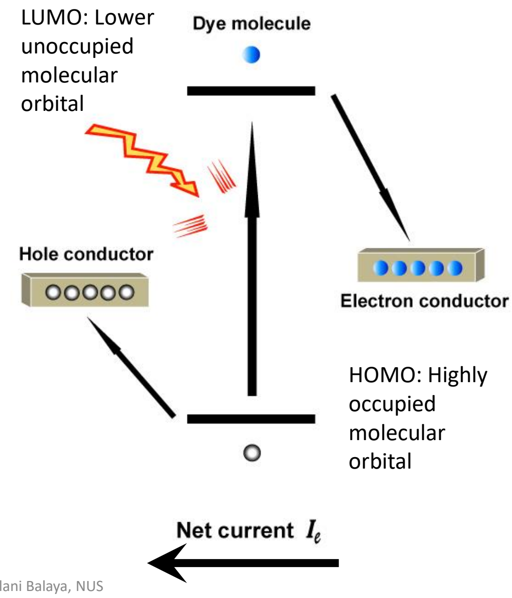
Nanostructured Solar Cell

- **Dye molecule**
  - electron hole pair splits because radiation interacts with the dye
  - the electron shifts over to the electric conductor and the hole shifts to the hole conductor



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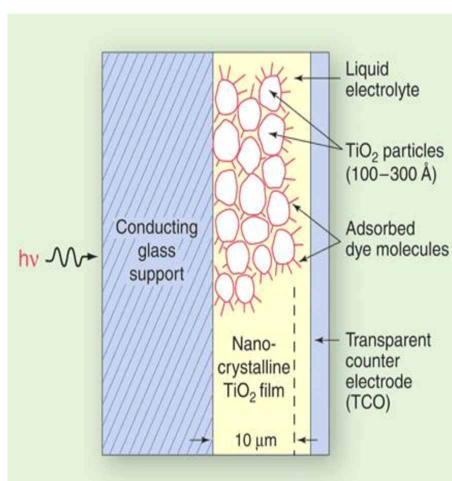
Design of Dye-sensitized Solar Cells

- Conducting electrode
  conducting glass support coated with conducting oxide.
- Nano structured dye-sensitized TiO_2 film
- Liquid electrolyte
- Counter electrode
  coated with conducting oxide with small amount of Pt



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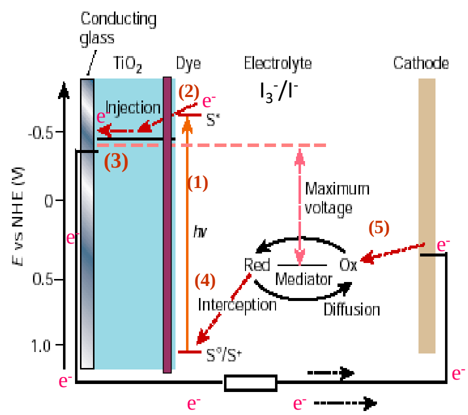
Working Principle of DSC

1. Photoexciton of dye
2. Injection of e⁻ into CB of TiO_2
3. Transport of e⁻ working electrode
4. Regeneration of oxidized dye by donation from electrolyte
5. Regeneration of electrolyte



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Dye sensitized nanocrystals achieve quantitative conversion of photons into electric current

The incident photon to electrical current conversion efficiency (external quantum efficiency) can reach close to 100 %

$$\eta = \eta_{abs} * \Phi_{inj} * \eta_{coll}$$

A key question is how electrons are quantitively collected from the disordered network of nanoparticles.

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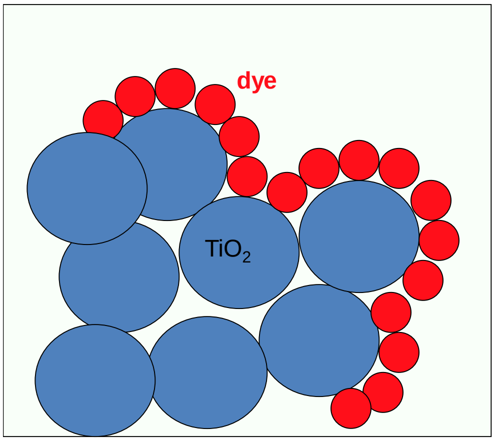
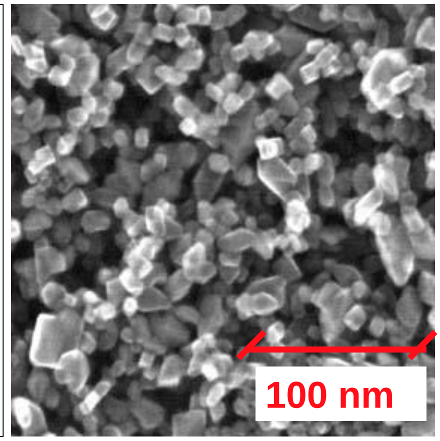
Role of nanoparticles in DSSC





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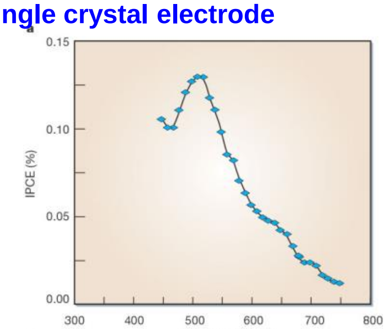
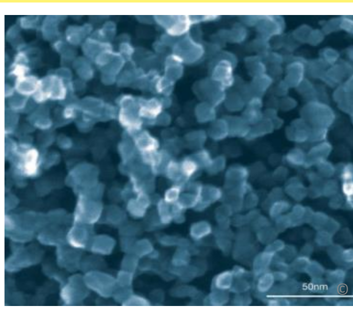
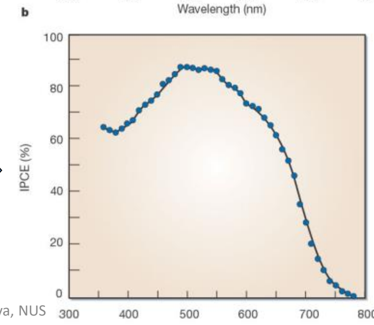
A dye sensitized nanocrystalline film generates over 1000 times more photocurrent than a single crystal electrode

single crystal of anatase



Nanocrystalline anatase film





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Electrochemical junctions

As $\Phi_{ele} > \Phi_n$, upon contact electrons flow from n-semiconductor into electrolyte until the Fermi level equalize, establishing a positive space charge layer in the n-semiconductor and an electric field at the interface which drives charge separation

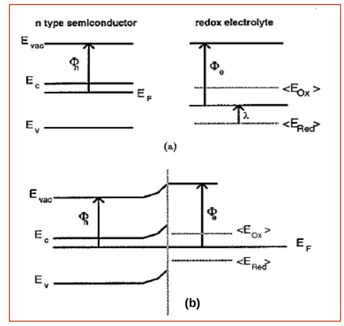

Fig. Band profile of electrochemical junction (a) before & (b) after contact

Under illumination, electrons will be transferred to the semiconductor surface, resulting in the semiconductor gaining a *negative charge and the* electrolyte a *positive charge, so providing a **photovoltage***

The oxidized species move away from semiconductor to electrolyte and recovers an electron at the counter electrode and regenerate the reduced form

Advantage:

The field is established spontaneously upon wetting the semiconductor surface

Disadvantage

In many material systems, the semiconductor surface is prone to react chemically with the electrolyte under illumination

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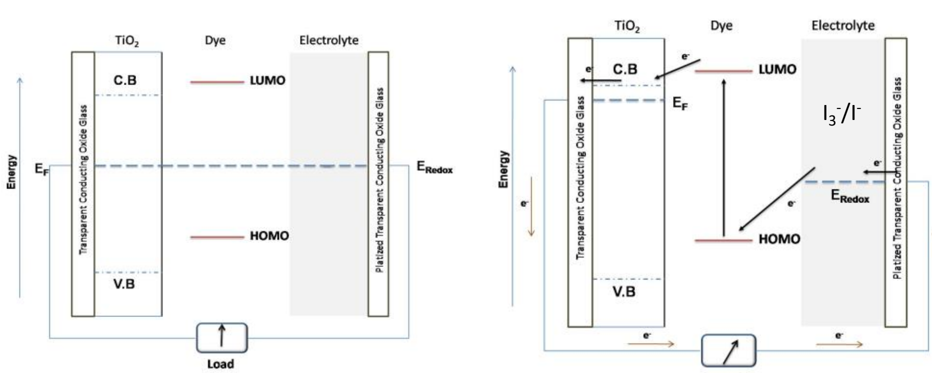
Dye sensitized solar cell in dark and upon illumination

Show the energy level diagram for a DSC when it is in dark. Draw the corresponding energy level diagram when the cell is illuminated with light. Indicate the direction of electron movement with arrows.



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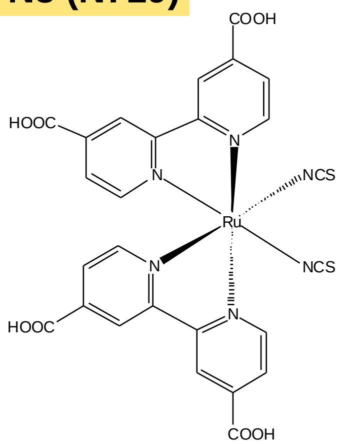
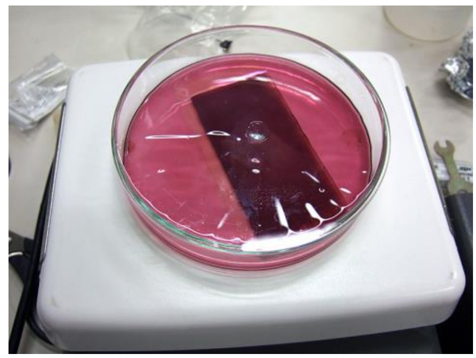
Ruthenium complexes are widely used as sensitizers due to their extraordinary performance and excellent stability

N3 (N719)

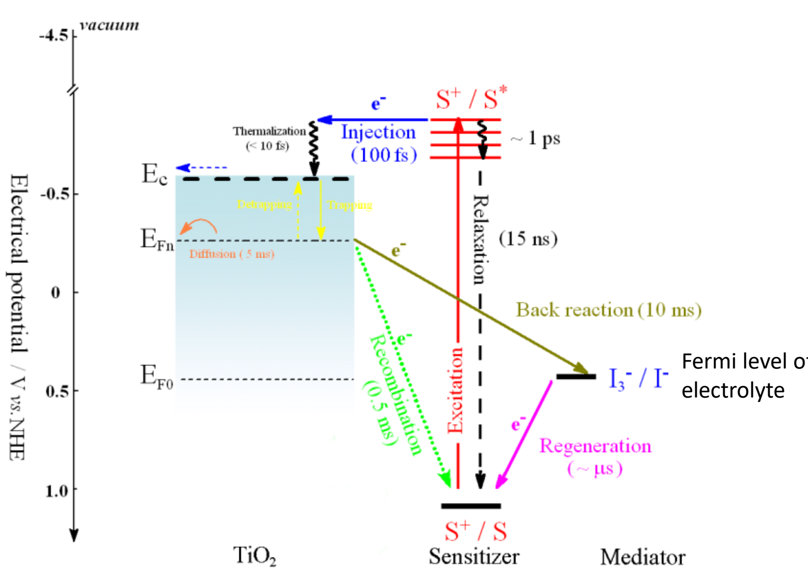


Spontaneous uptake of N3 sensitizer by a nanocrystalline TiO2 film supported on conducting glass



Nazeeruddin, M. K.; Kay, A.; Rodicio, I.; Humphry-Baker, R.; Mueller, E.; Liska, P.; Vlachopoulos, N.; Graetzel, M. J. American Chemical Society (1993), 115(14), 6382-90.

Photo-induced interfacial charge separation occurs within femtoseconds



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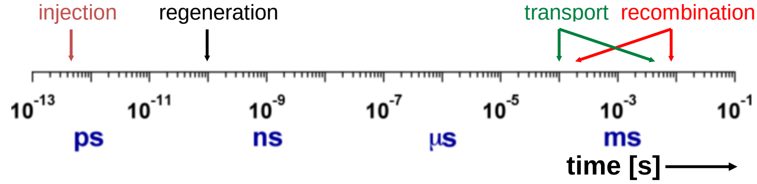
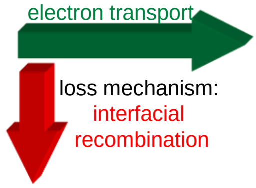
Dynamic Competition





Competition ⇒

Electron diffusion length

$$L_n = \sqrt{D_n \cdot \tau_n}$$

τ_n: electron lifetime
D_n: electron diffusion coefficient

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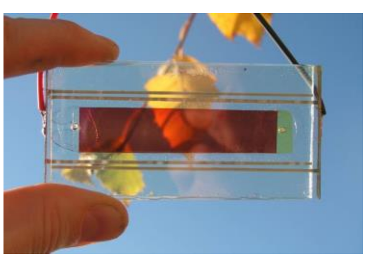
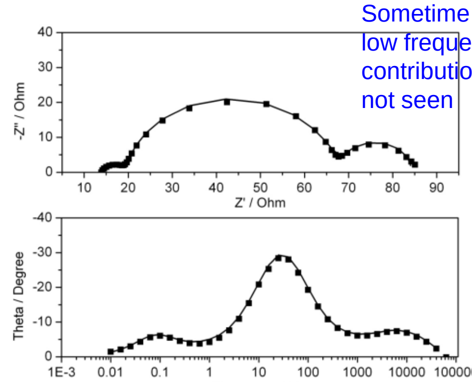
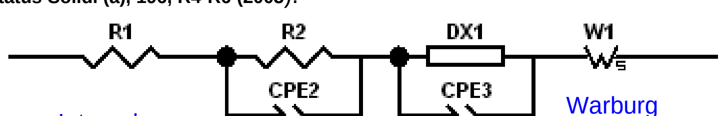
Impedance studies of mesoscpic solar cells





Sometime this low frequency contribution is not seen

Abayev, A. Zaban, F. Fabregat-Santiago, J. Bisquert
Physica Status Solidi (a), 196, R4-R6 (2003).



Internal resistance

Impedance for charge transport

Impedance for back transfer - recombination

Warburg impedance for ions or redox molecules

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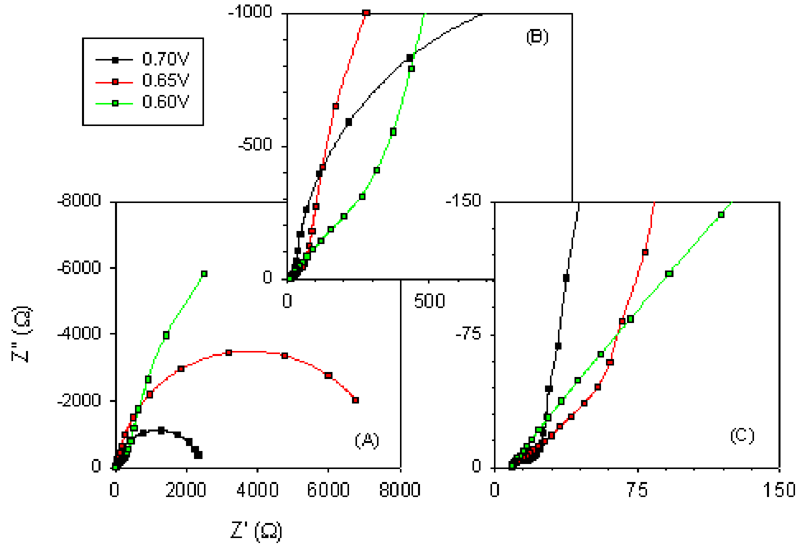
Nyquist impedance plot for a 11.2 % cell reveals electron diffusion and interfacial back reaction dynamics



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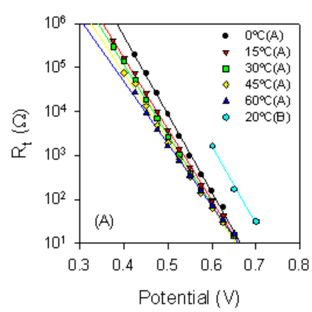
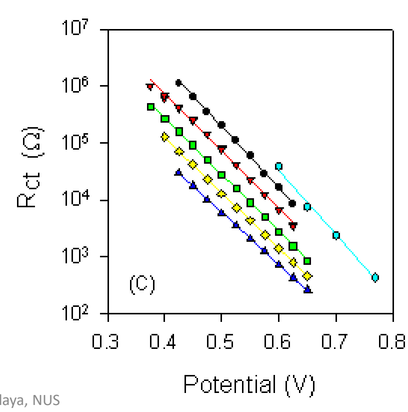
Transport resistance/Ohm

Key circuit parameters for cell operation derived



recombination resistance/Ohm



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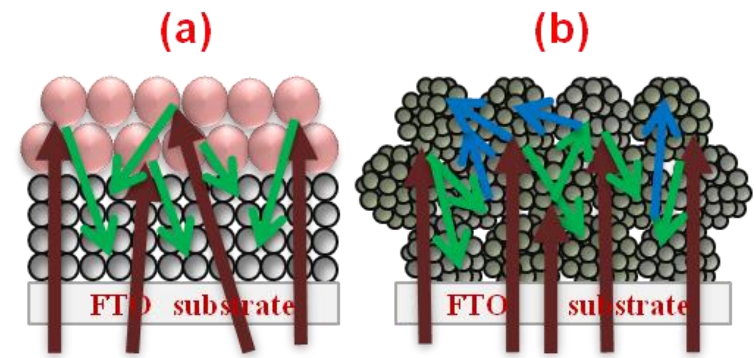
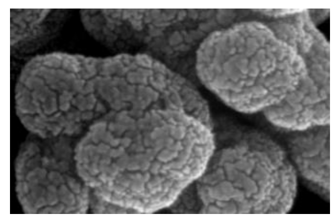
Schematics of structure of bifuctional (a) and multi-functional (b) photoanodes



Mesoporous TiO2 helps with multifunctional properties



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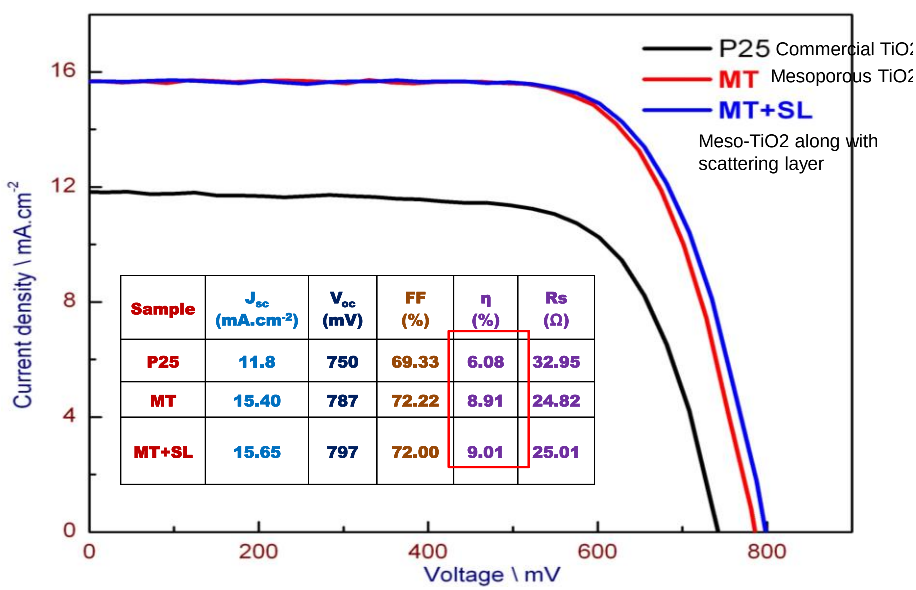
Photovoltaic performance



Sample	J_{sc} (mA.cm^{-2})	V_{oc} (mV)	FF (%)	η (%)	Rs (Ω)
P25	11.8	750	69.33	6.08	32.95
MT	15.40	787	72.22	8.91	24.82
MT+SL	15.65	797	72.00	9.01	25.01

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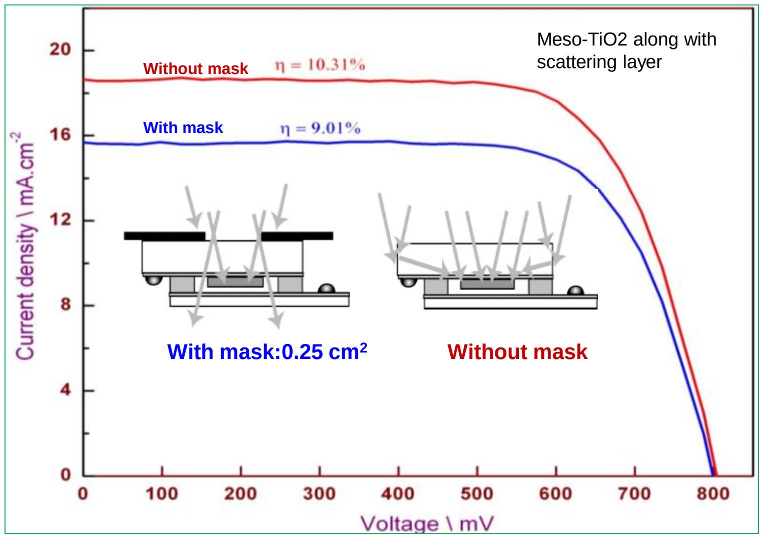
Photovoltaic performance



Eletrode:15 µm MT+ 4 µm SL

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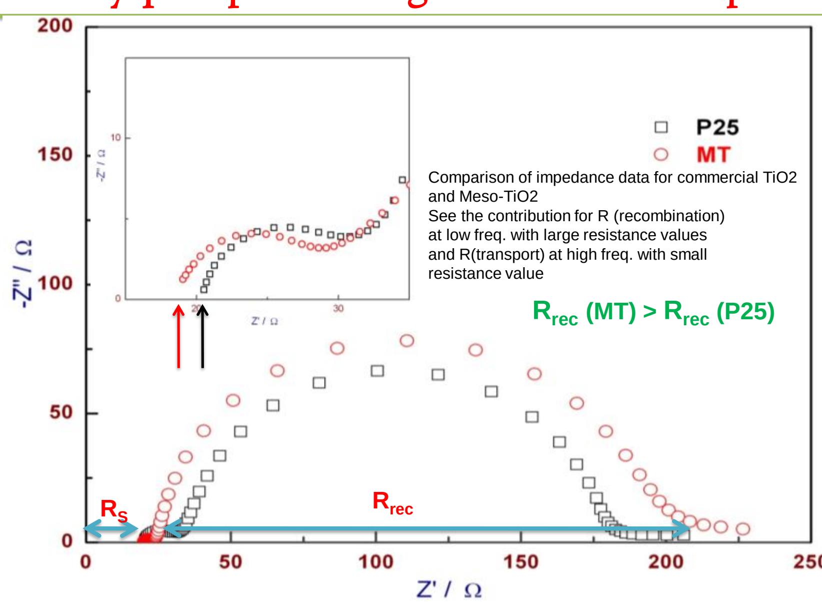
Nyquist plots: charge transfer & transport



R_S : Series resistance ; R_{rec} : Charge recombination resistance

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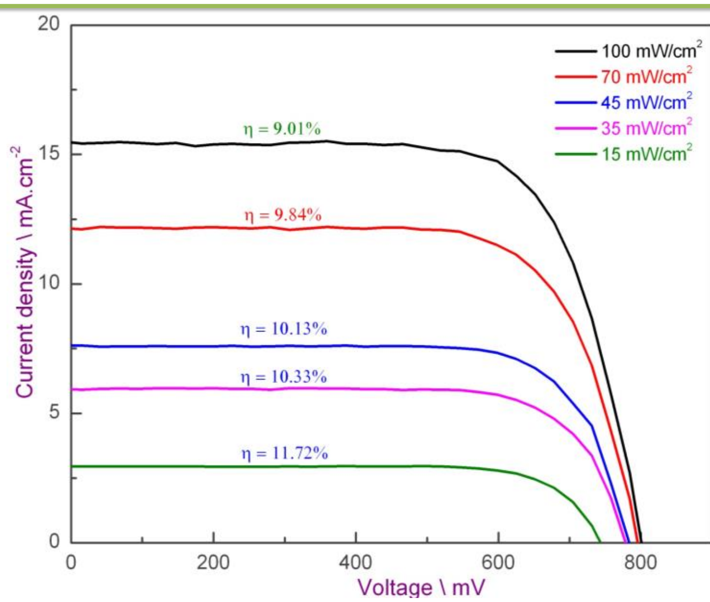
PV performance under different illuminations



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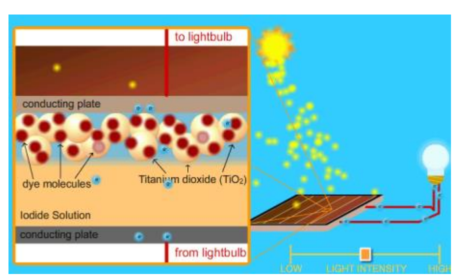
How does a dye-sensitized solar cell work?

- Light with high enough energy excites electrons in dye molecules
- Excited electrons infused into semiconducting TiO_2, transported out of cell
- Positive "holes" left in dye molecules
- Separation of excited electrons and "holes" creates a voltage

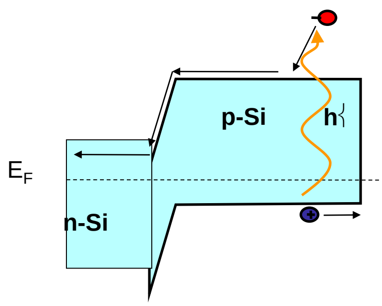


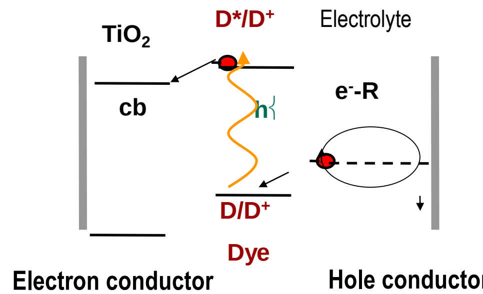
Source: http://www.compadre.org/portal/items/detail.cfm?ID=12726

Dye sensitized solar cells separate light absorption from carrier transport

p-n junction photovoltaic cells

dye sensited solar cells DSC





Charge separation by electric field at the p-n junction

Charge separation by kinetic competition as in photosynthesis

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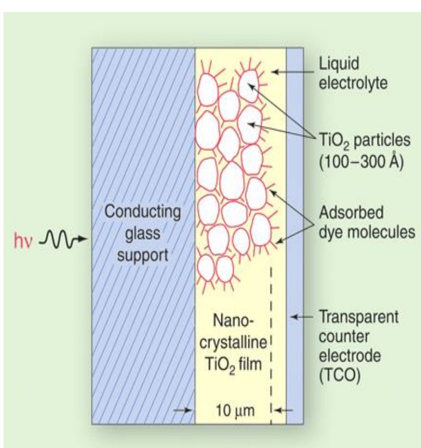
Design of solid state dye-sensitized solar cells



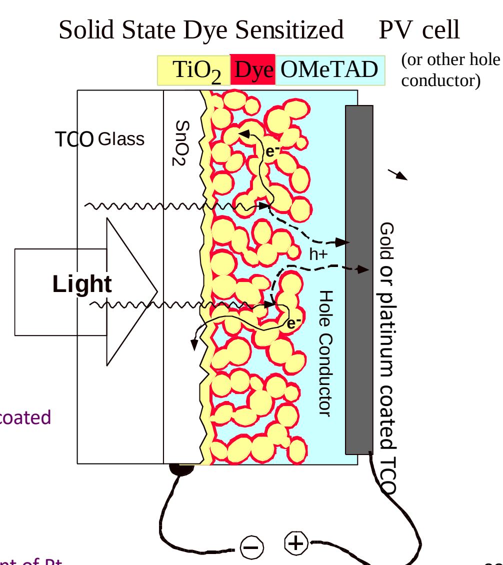
Conducting electrode conducting glass support coated with conducting oxide.

Nano structured dye-sensitized TiO_2 film

Liquid electrolyte

Counter electrode

coated with conducting oxide with small amount of Pt



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