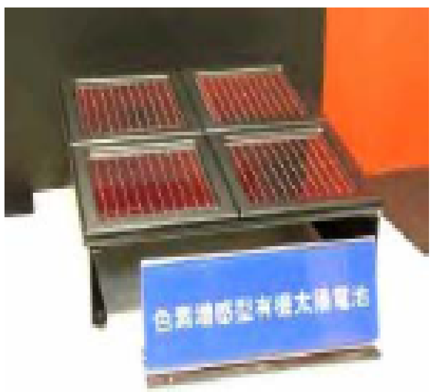
Topic : Dye Sensitised Solar Cells

By
Mr. A. V. Shinde

04/10/2018

Dye sensitised solar cells (DSSC's)



Dye Sensitised Nanocrystalline Metal Oxide Solar Cells

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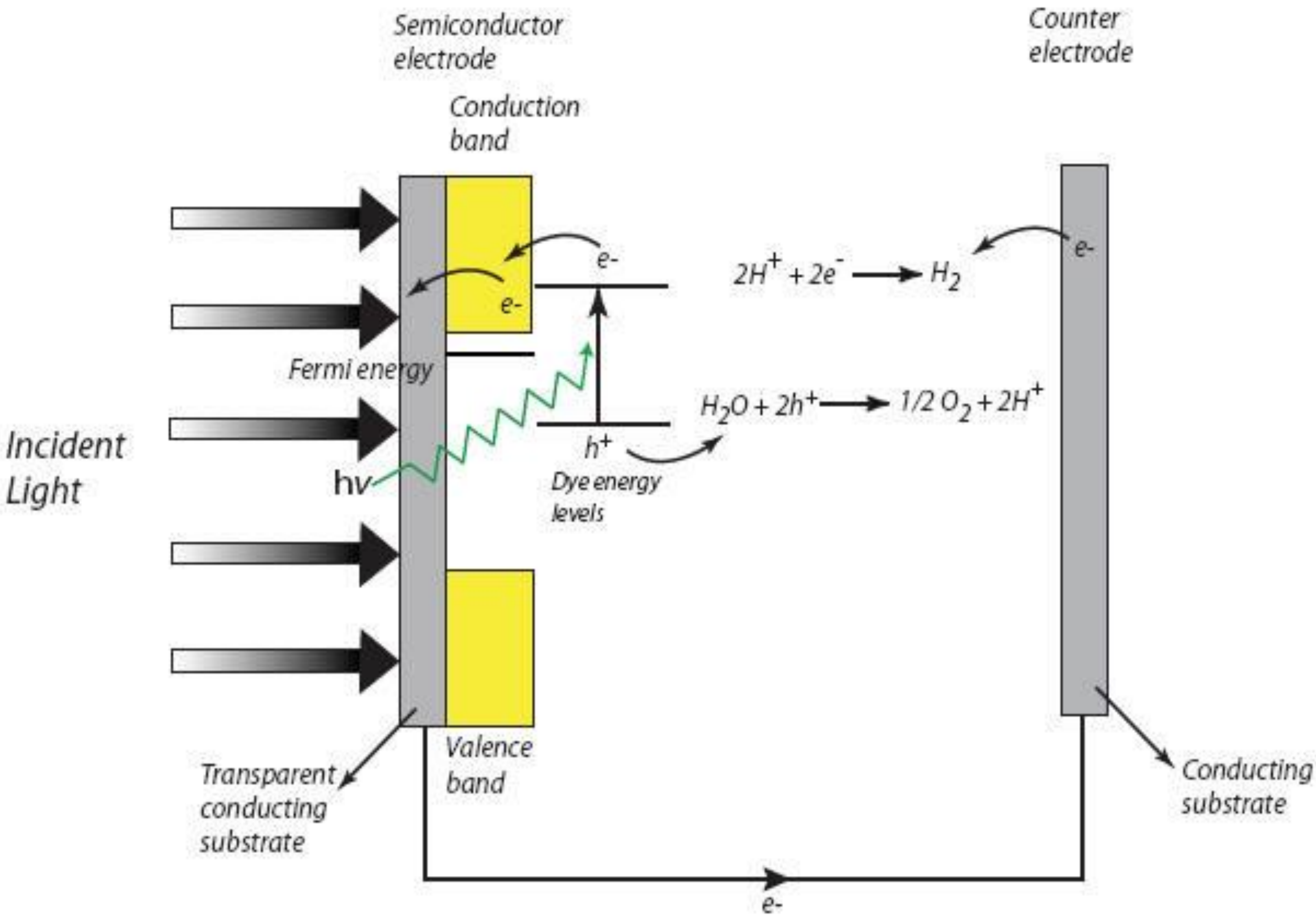
- First reported by Grätzel and coworkers 1991 (Nature, 353, 737-740)
- Solar to electric energy conversion efficiency up to 11 %
- Versatile function (flexible, translucent, coloured etc.)
- Low cost materials and processing
- Remarkably good photochemical stability (upto 10 year in accelerated trials)
- Rapidly expanding commercial development programme (especially in the Japan)



Semiconductor electrode
Conduction band
Counter electrode
e-
e-
e-
$2H^+ + 2e^- \rightarrow H_2$
Fermi energy
$H_2O + 2h^+ \rightarrow 1/2\ O_2 + 2H^+$
Incident Light
hv
h^+
Dye energy levels
Transparent conducting substrate
Valence band
Conducting substrate
e-

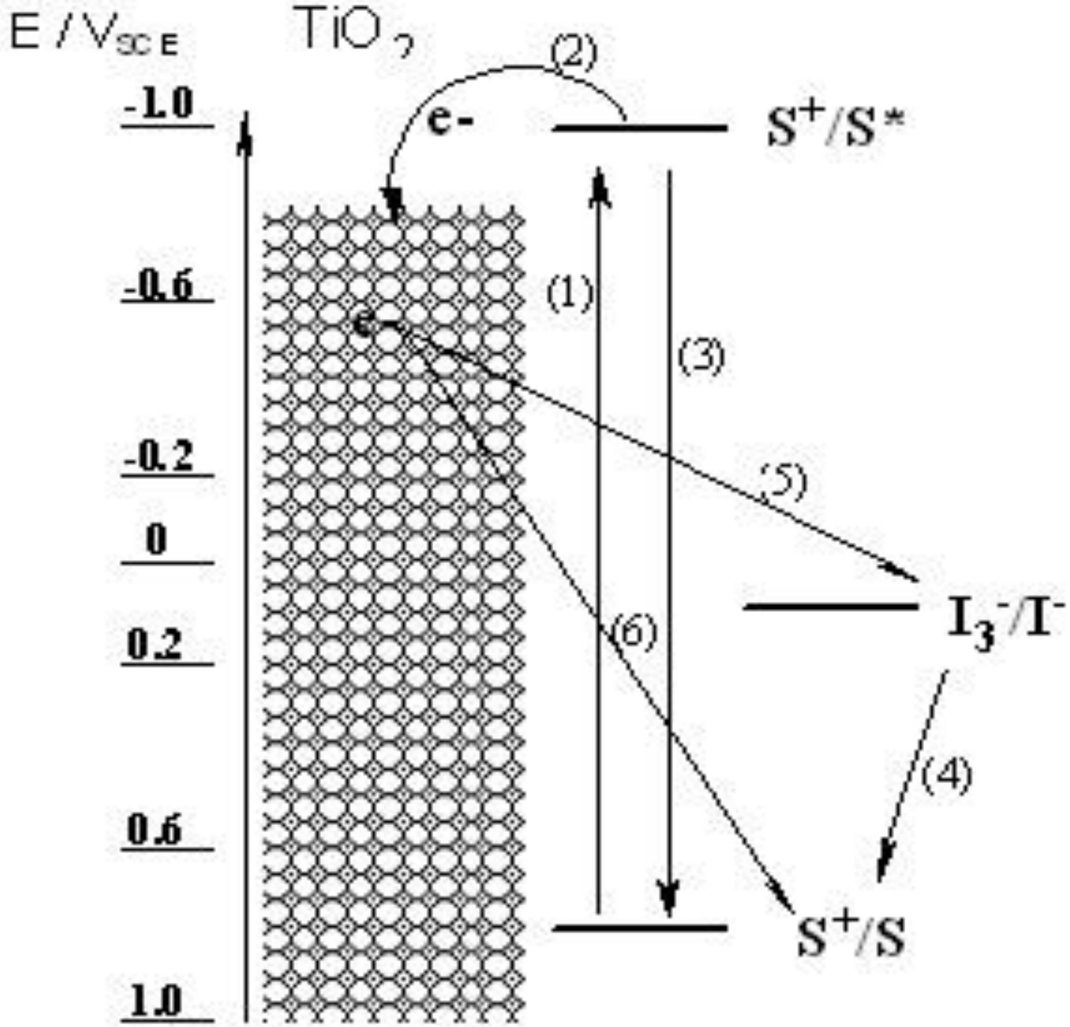


Fig.1. Energy level diagram of TiO_2 dye-sensitized solar cell. (1) Photon absorption, (2) electron injection, (3) deactivation reaction, (4) dye cation regeneration, (5) conduction band electron caption by redox mediator giving rise to dark current, (6) back electron transfer on dye cation.

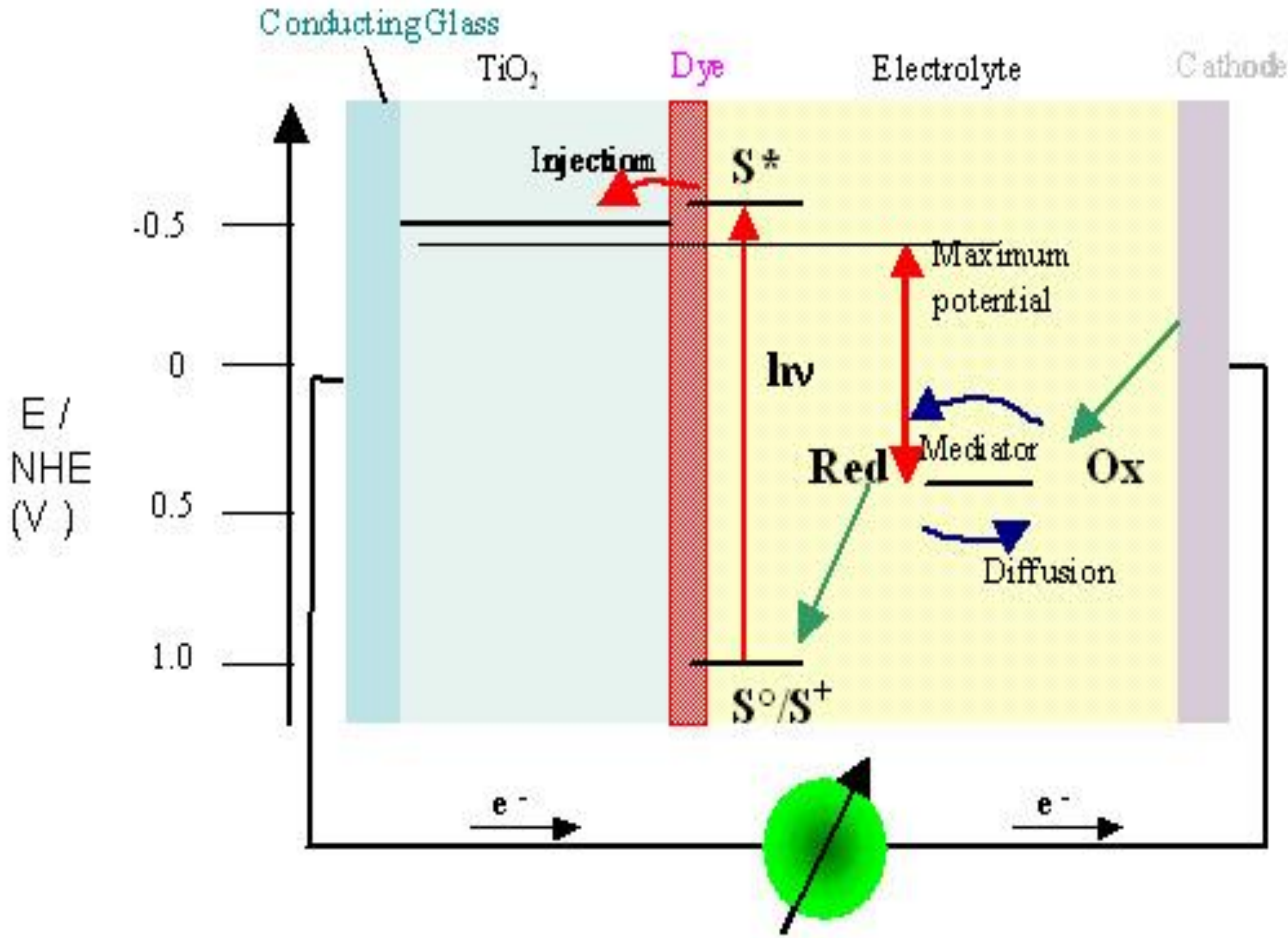
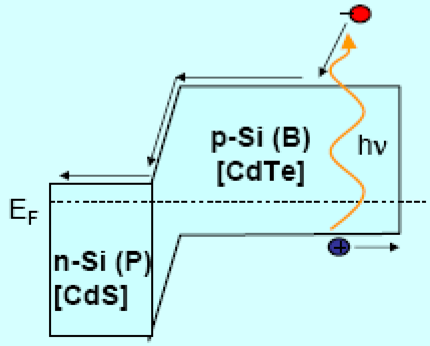
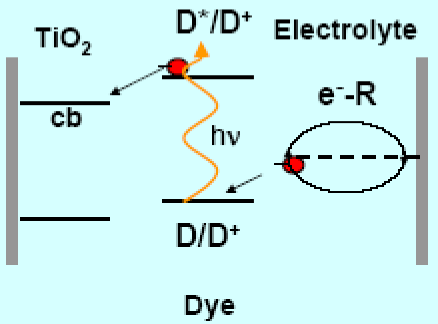


***Figure 2**: Schematic diagram of a dye sensitised solar cell.*

Silicon Photovoltaic Cells

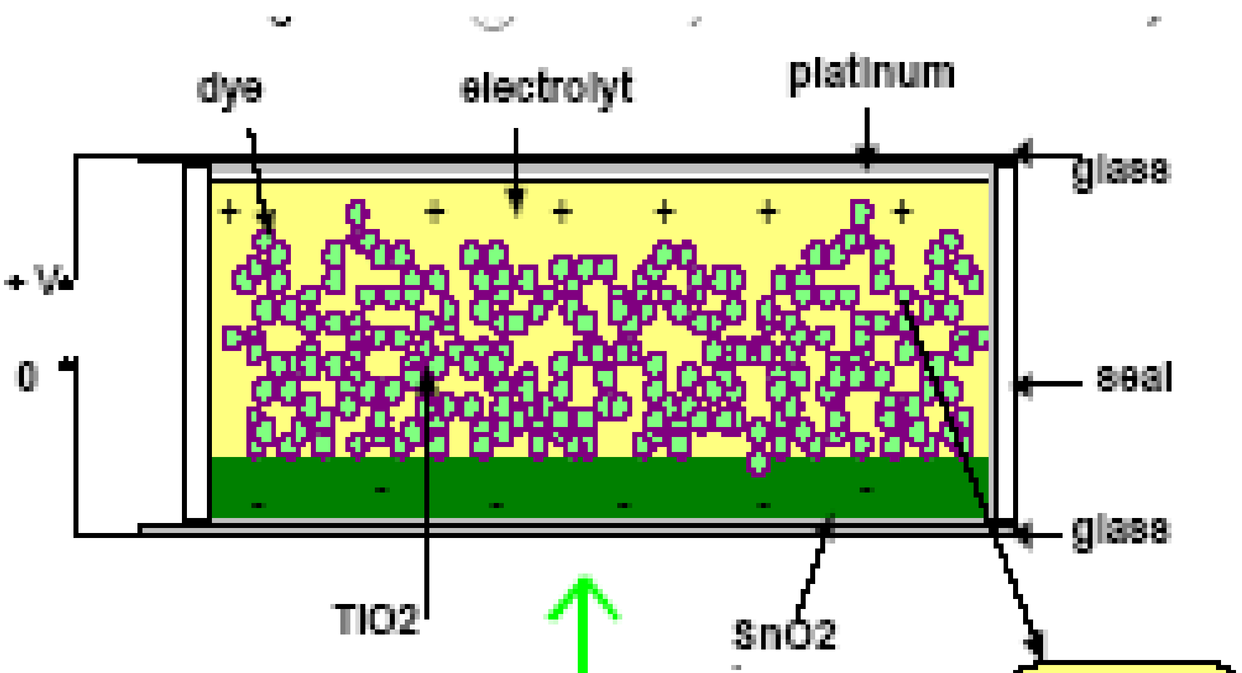
Dye Solar Cells





Charge separation by electric field within a p- and n-doped semiconductor material (Si, II-VI, a-Si: H)

Charge separation by kinetic competition like in photosynthesis



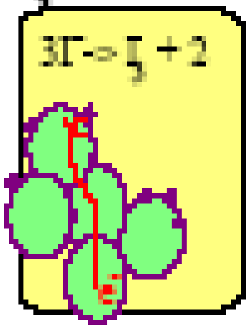
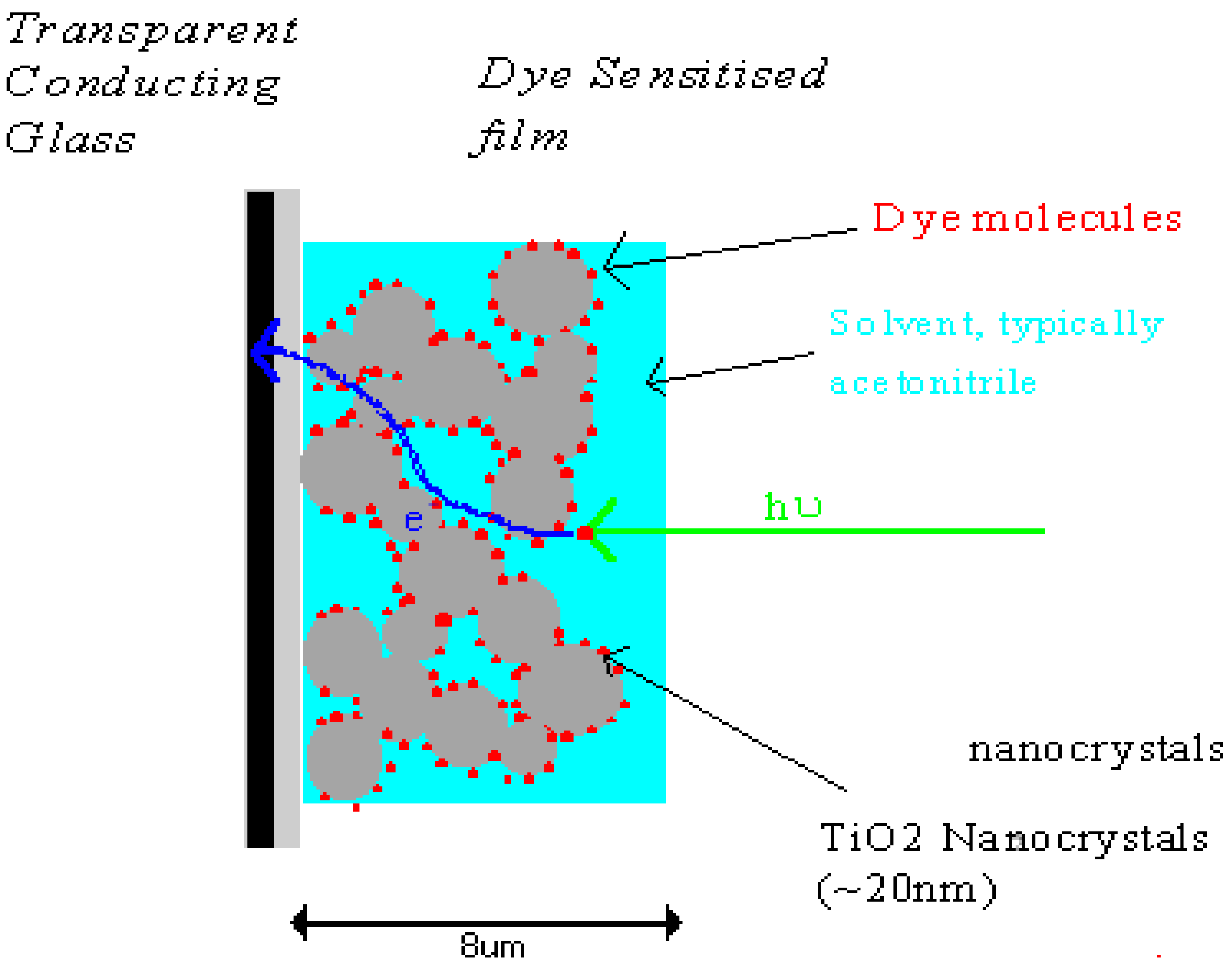
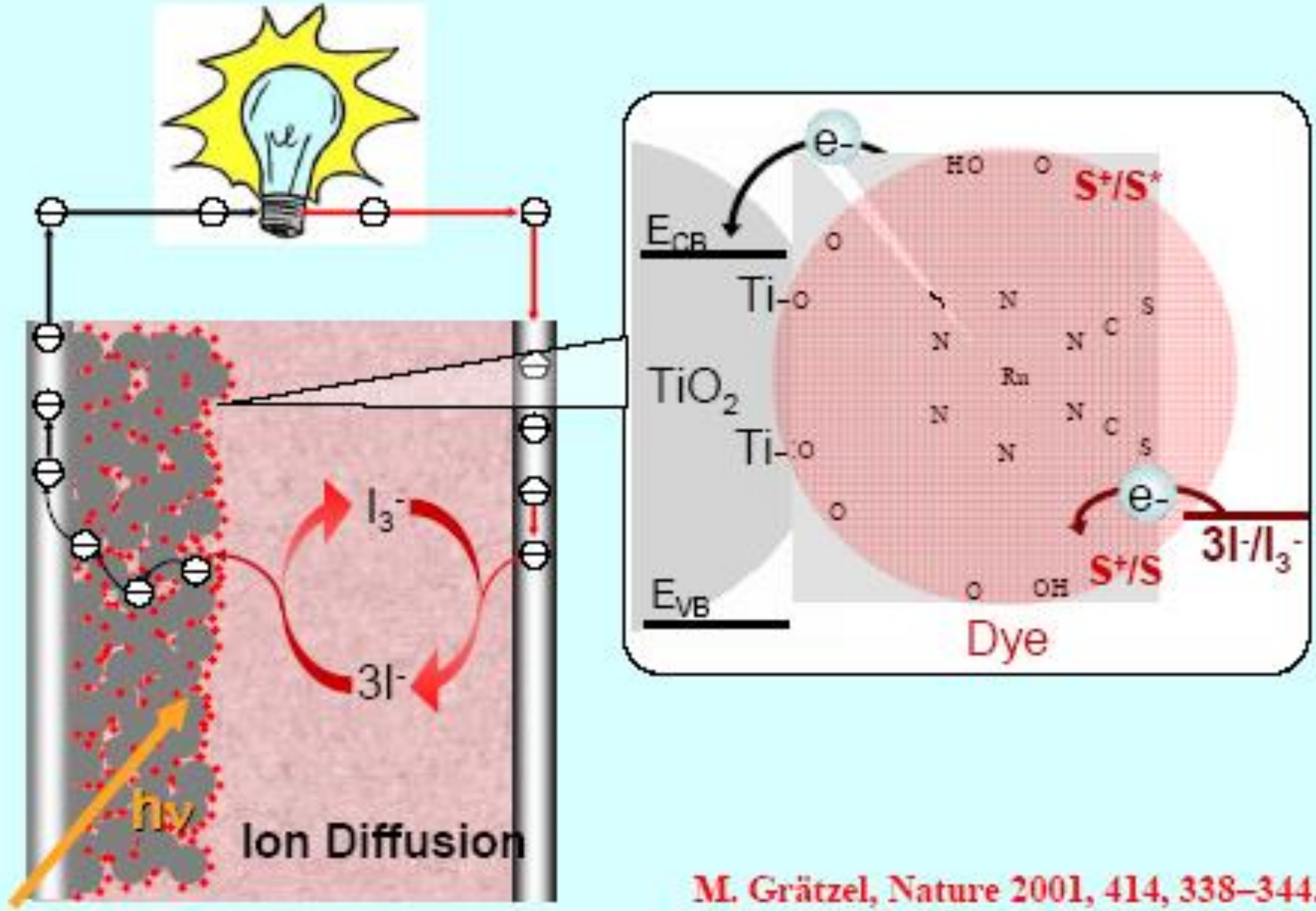


Figure 1. Schematic of arrangement of dye sensitised PV cell. Electron conduction to the conducting glass contact proceeds through the TiO_2, whilst hole conduction by the liquid electrolyte proceeds through the pores of the TiO_2 film.



Transparent
Conducting
Glass
Dye Sensitised
film
Dye molecules
Solvent, typically
acetonitrile
hυ
e
nanocrystals
TiO2 Nanocrystals
(~20nm)
8um

Sensitized mesoscopic heterojuntions

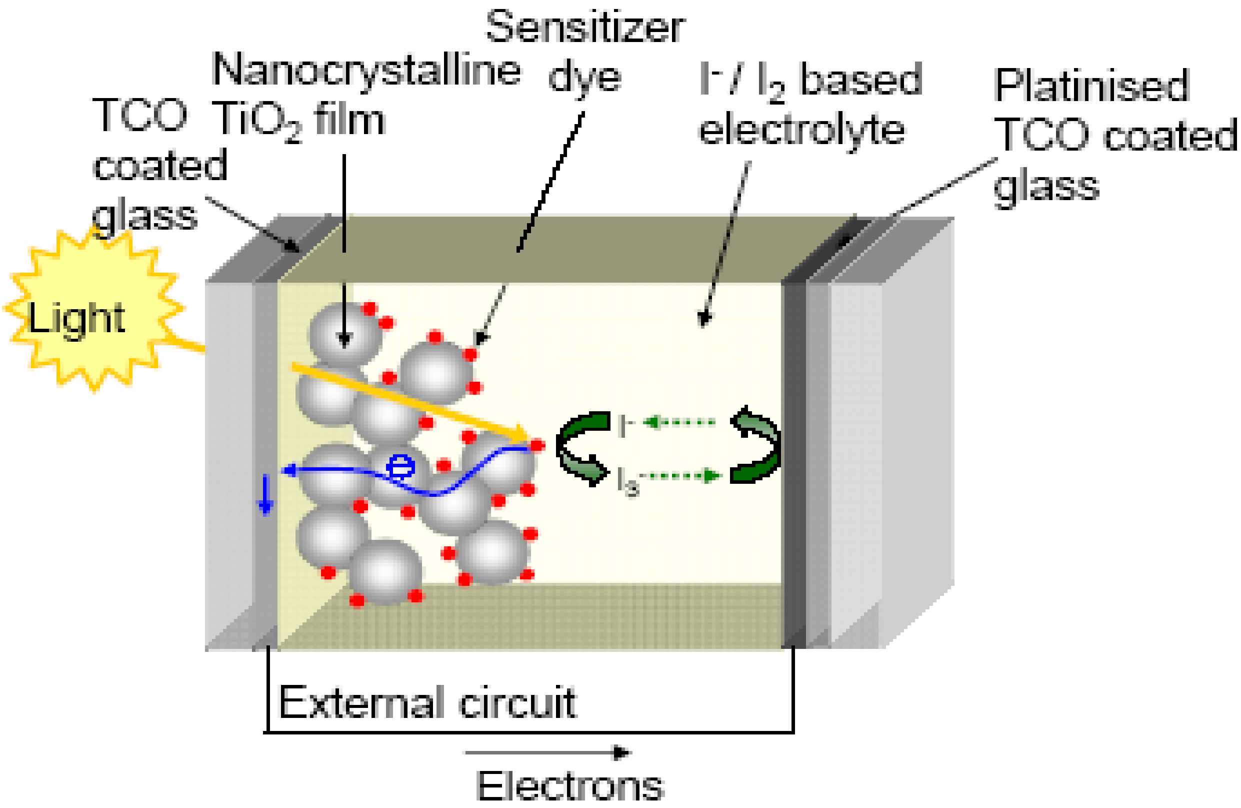


M. Grätzel, Nature 2001, 414, 338–344.

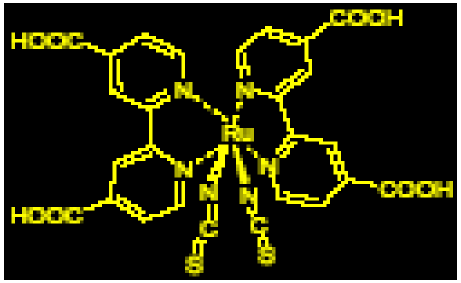
B. O'Regan, M. Grätzel, Nature 1991, 353, 737–740

- Sensitiser dye adsorbed to surface of TiO_2 nanocrystals
- High roughness of nanoporous films allows for high surface coverage of dye.
- Sensitiser dye: cis-$(NCS)_2$ bis(carboxy-2,2'-bipyridine) ruthenium(II)
- Incident monochromatic photon to current conversion efficiency(IPCE) ~100% between 510 and 570nm

How they work



Dye = $Ru(dcbpy)_2(NCS)_2$



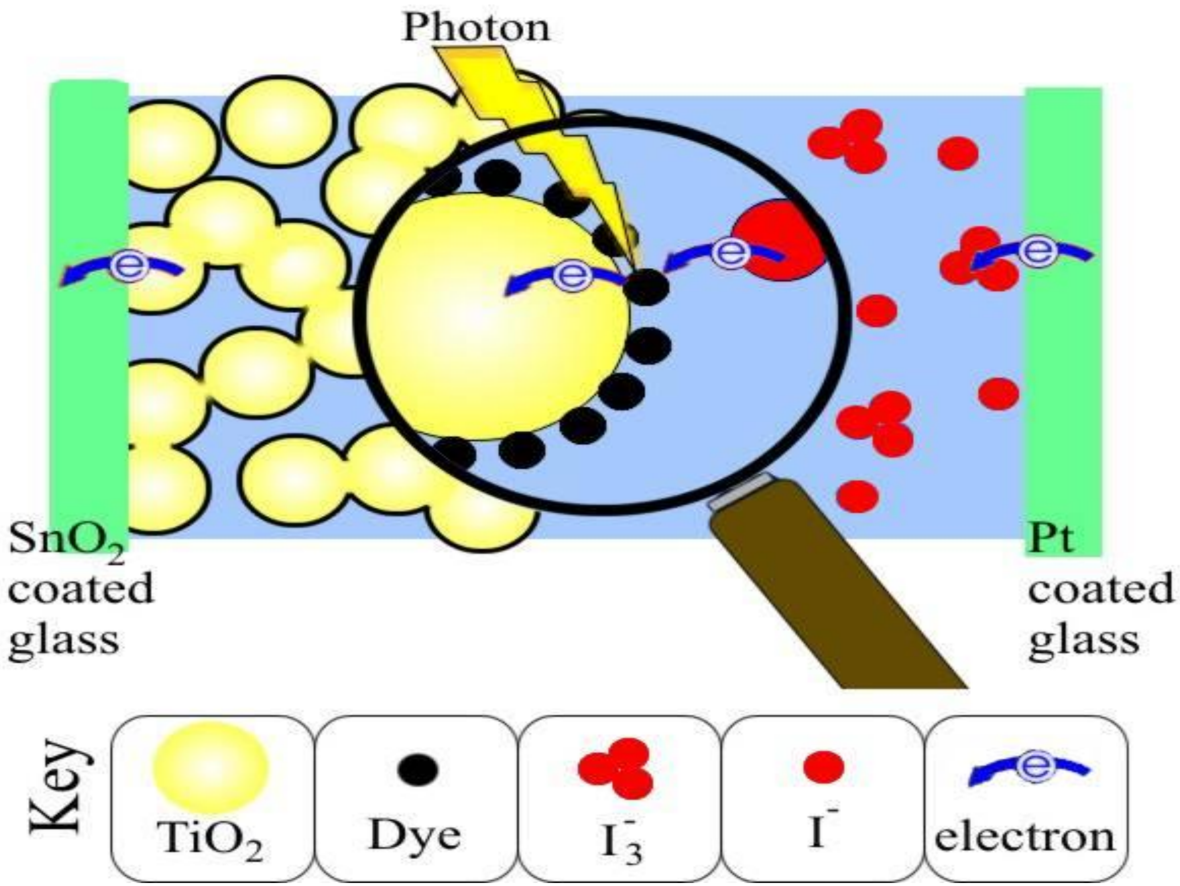


Fig 2: schematic diagram of a dye sensitised solar cell

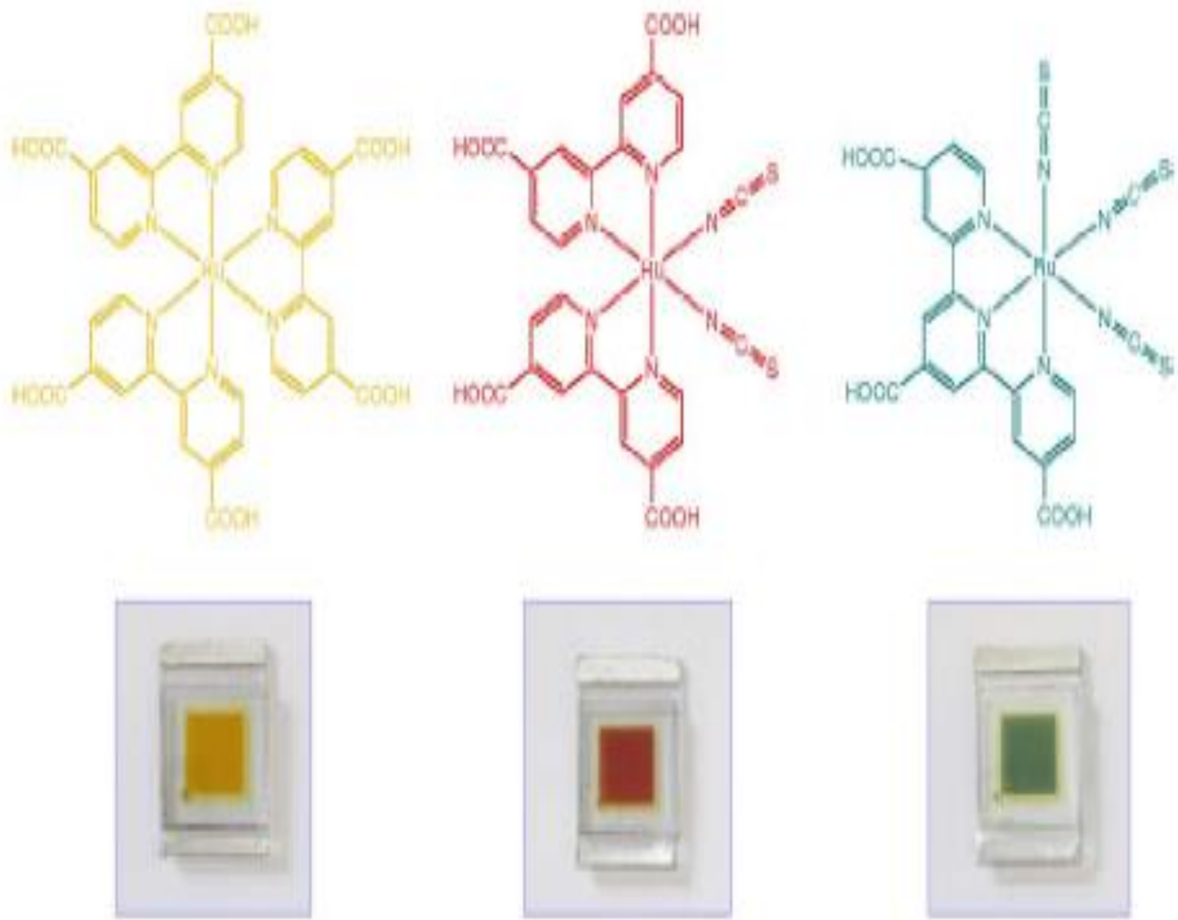
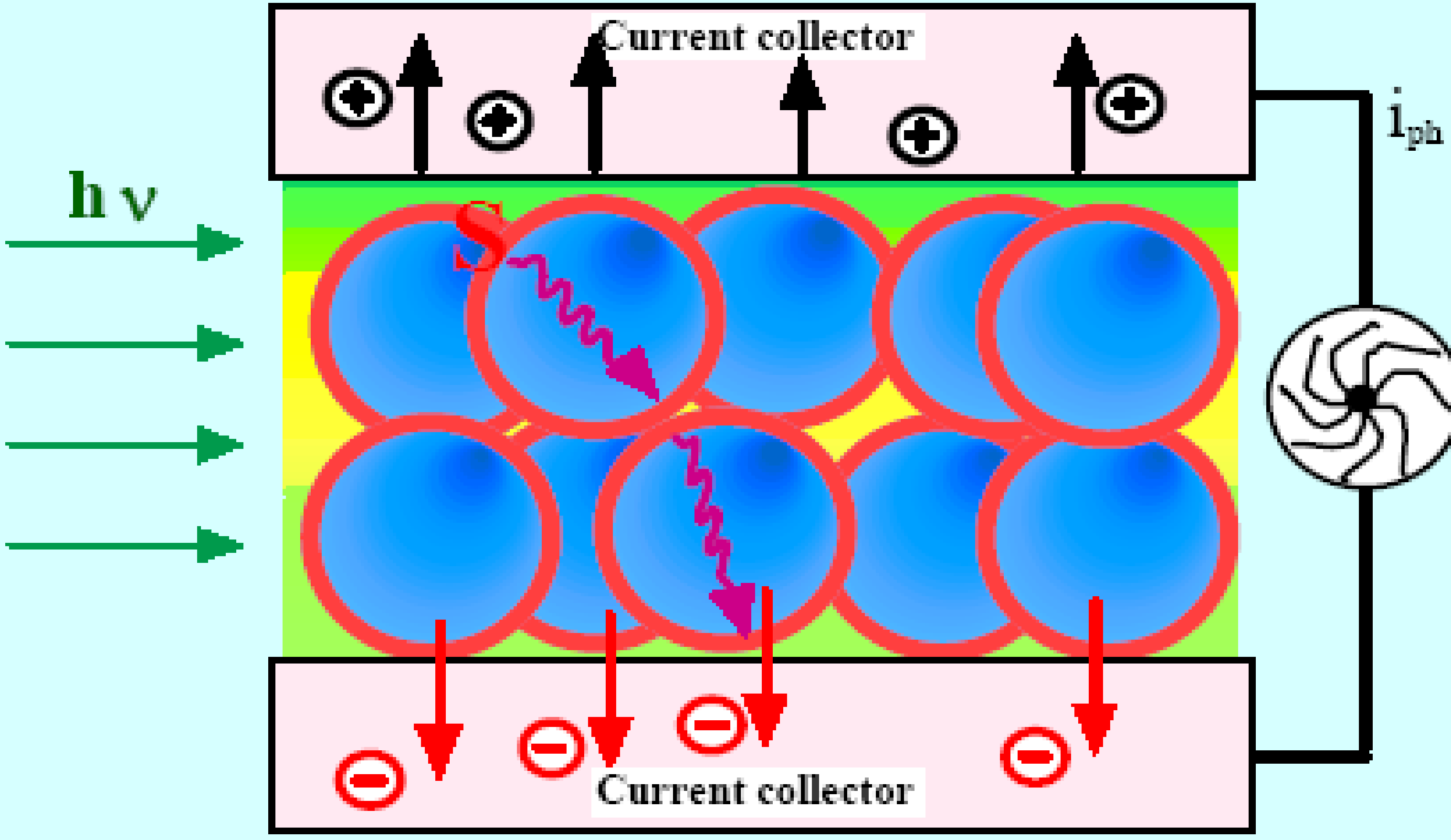


Fig. 6. The structure of the ruthenium sensitizers RuL_3 (yellow) cis-$RuL_2(NCS)_2$ (red) and $RuL'(NCS)_3$ (green) where L = 2,2′-bipyridyl-4,4′-dicarboxylic acid and L′ = 2,2′,2″-terpyridyl-4,4,′4″-tricarboxylic acid. The lower part of the picture shows nanocrystalline TiO_2 films loaded with a monolayer of the respective sensitizer. The film thickness is 6 μm. (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

Light Induced Charge Separation in nanocrystalline Films



B. O'Regan, M. Grätzel, Nature 1991, 353, 737–740

Dye sensitized nanocrystals show quantitative conversion of the photons into electric current

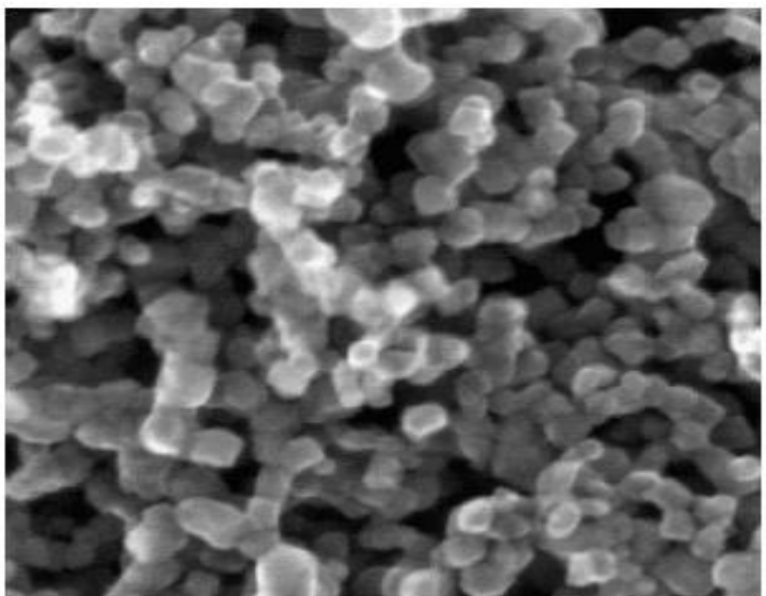
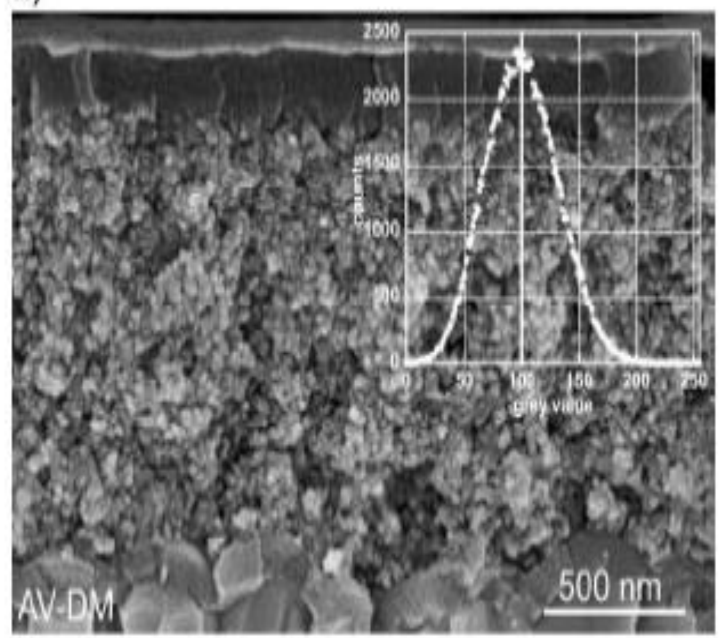


Fig. 2. Scanning electron microscope picture of a nanocrystalline TiO_2 (anatase) film used in the dye-sensitized solar cell (DSC).

a)



b)

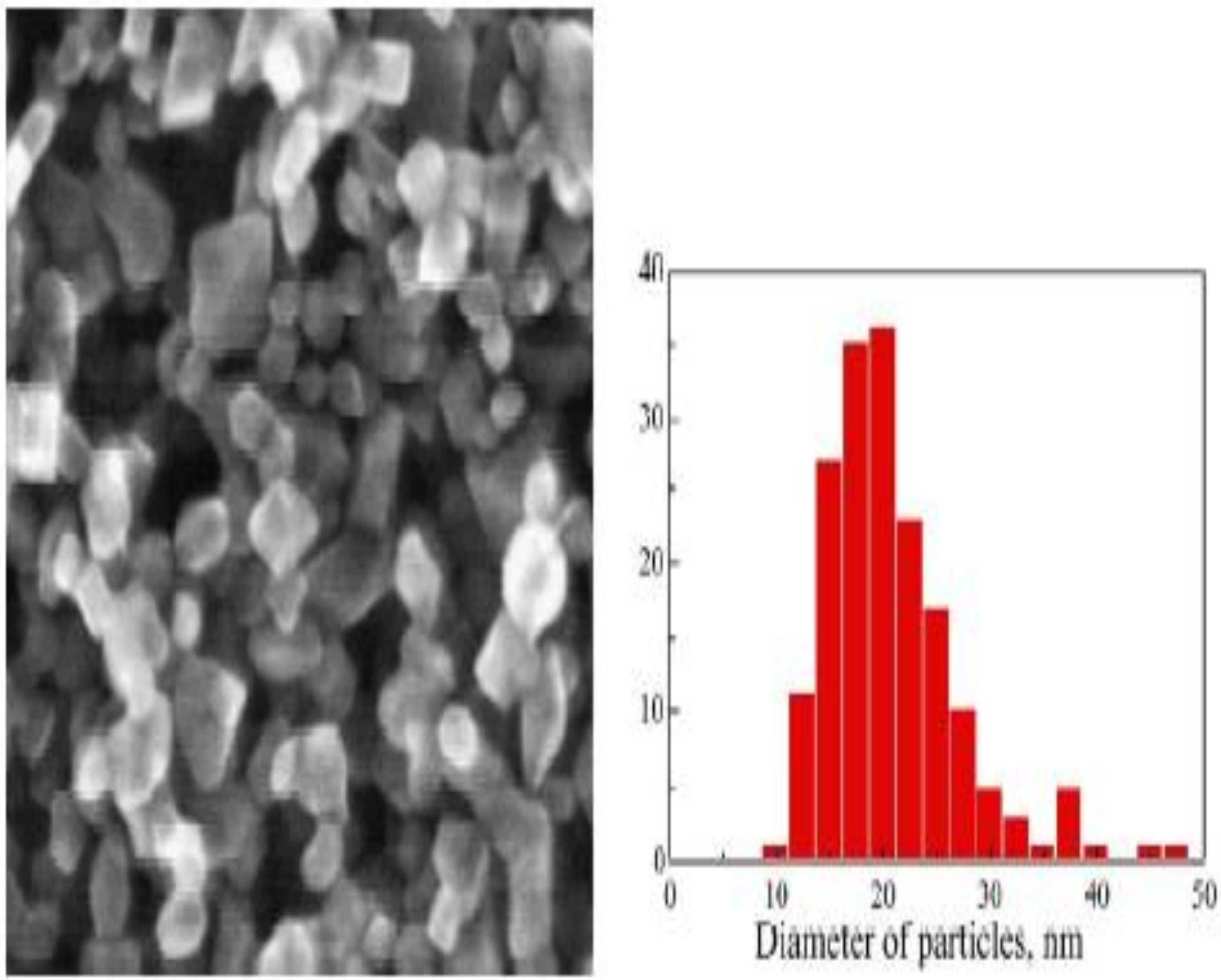
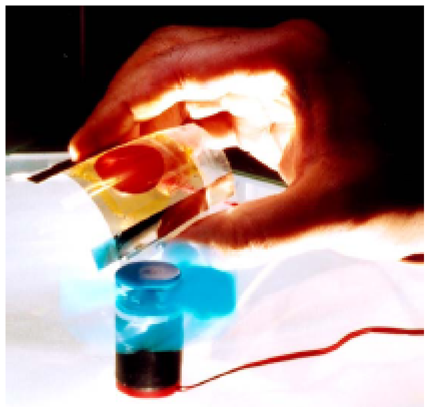
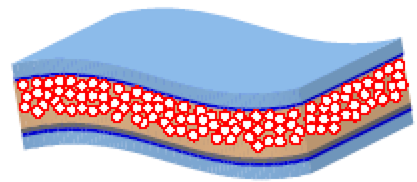


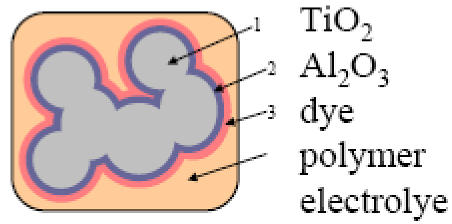
Fig. 4. Scanning electron micrograph and particle size distribution for a TiO_2 anatase colloid prepared at 230 °C, which has given optimal photovoltaic performance so far.

Solid state DSSC's on plastic substrates



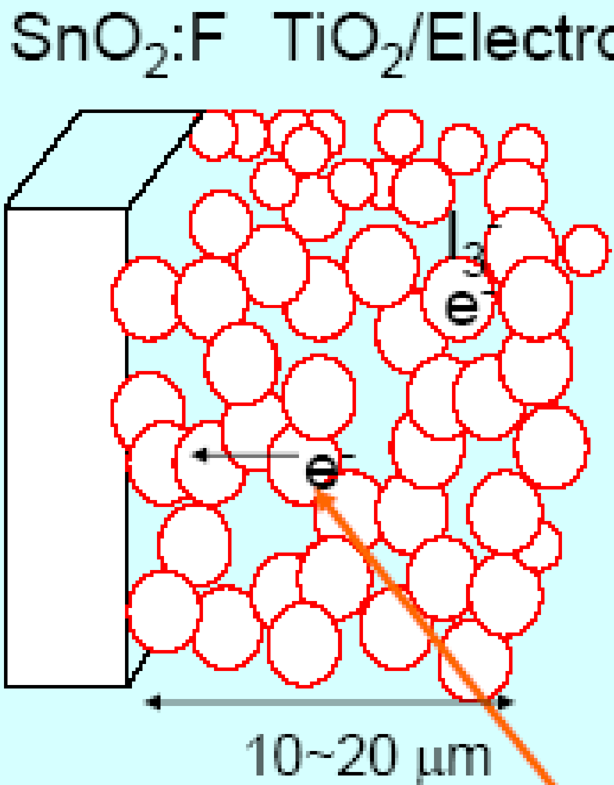
Haque et al. Chem Comm 2003





4 component inorganic/organic nanocomposite

Electron Transport: Diffusion and Electron Lifetime

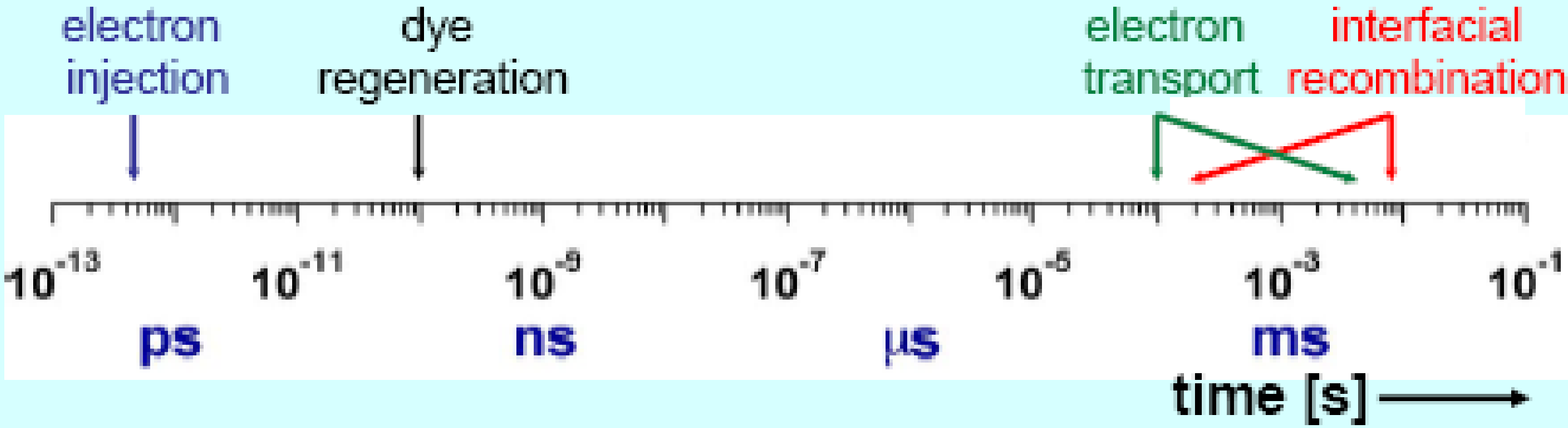


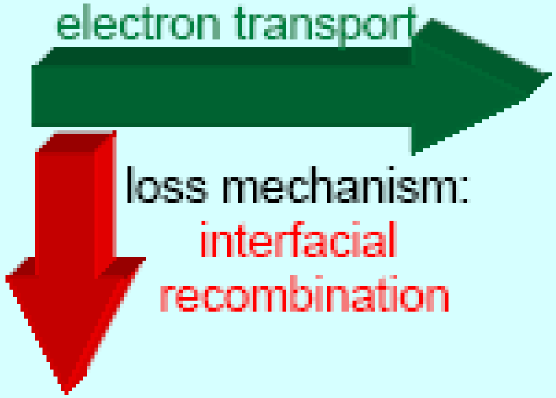
$$L = \sqrt{D\tau}$$

Electrons should travel to the SnO_2 before charge recombination occurs

Diffusion length should exceed the thickness of the mesocopic TiO_2 film

Dynamic Competition





Competition ⇒

Electron diffusion length

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

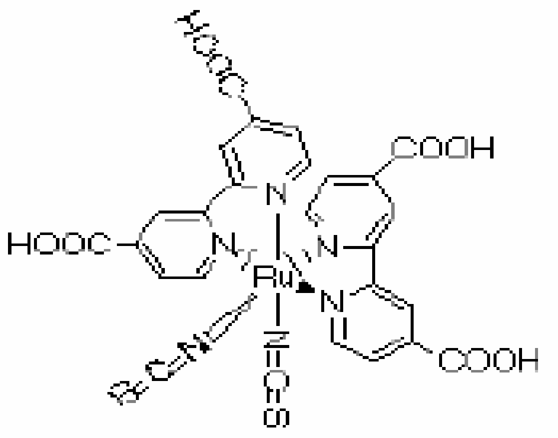
τ_n: electron lifetime
D_n: electron diffusion coefficient

The two dilemmas of light harvesting by surface immobilized molecular absorbers

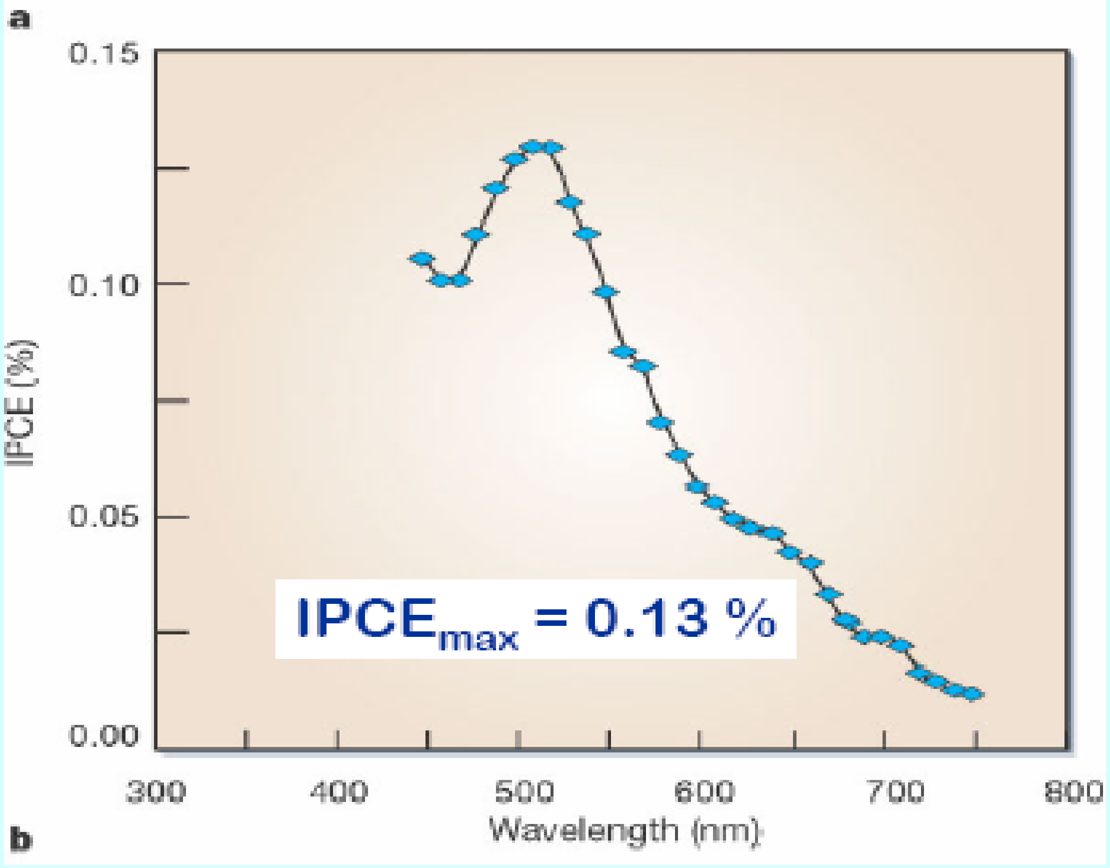
1. A monolayer of dye on a flat surface absorbs at most a few percent of light because it occupies an area that is much larger than its optical cross section

2. Compact semiconductor films need to be n-doped to conduct electrons. Energy transfer quenching of the excited sensitizer by the electrons in the semiconductor leads to conversion of light to heat reducing photovoltaic conversion efficiency.

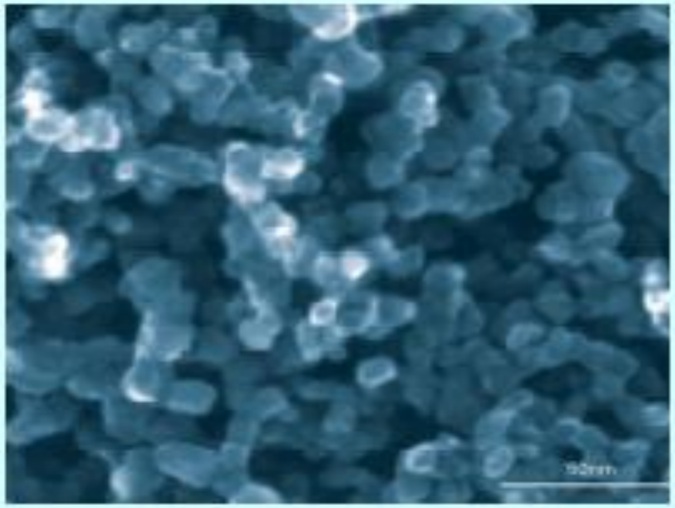
Incident photon to electron conversion efficiency (IPCE) of a dye-sensitized TiO_2 (101) single crystal PEC solar cell

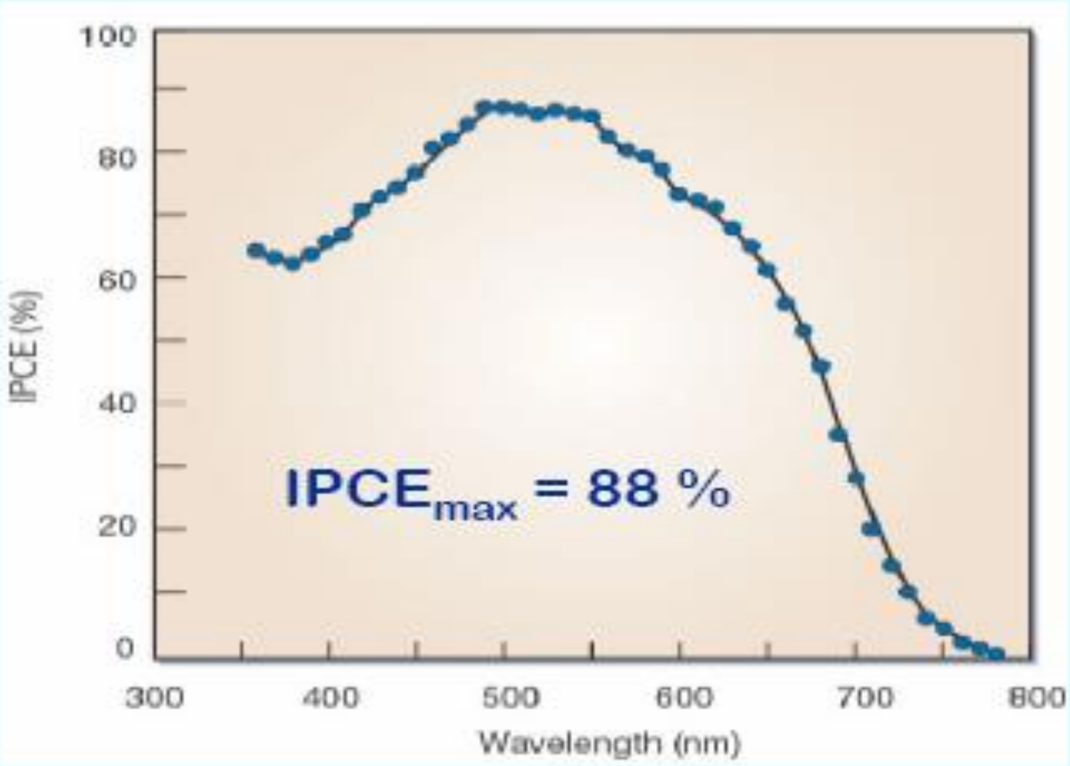


$[Ru(dc\text{-}bpyH_2)_2(NCS)_2]$

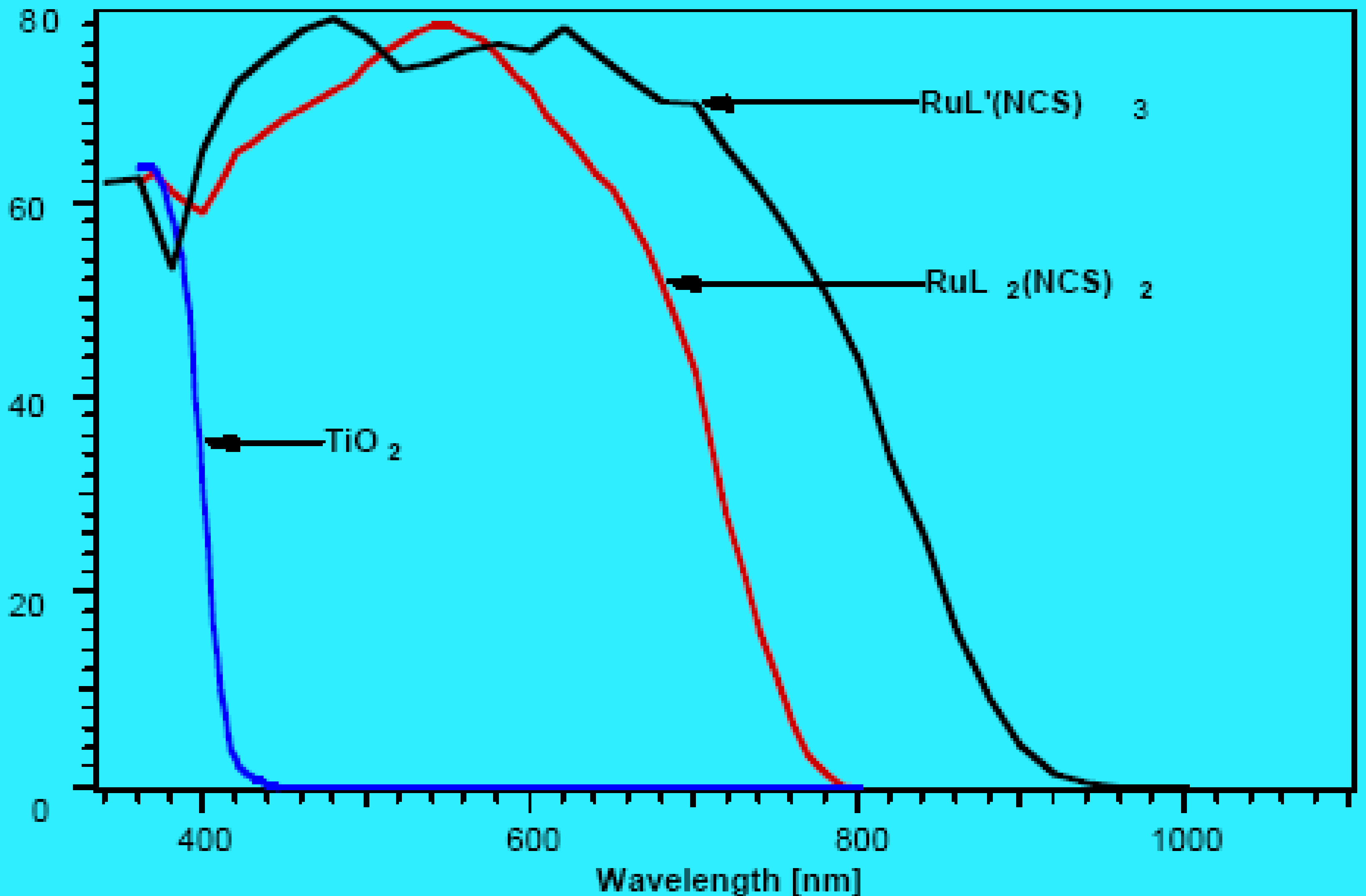


Incident photon to current conversion efficiency of a dye-sensitized solar cell based on a mesoscopic TiO_2 electrode





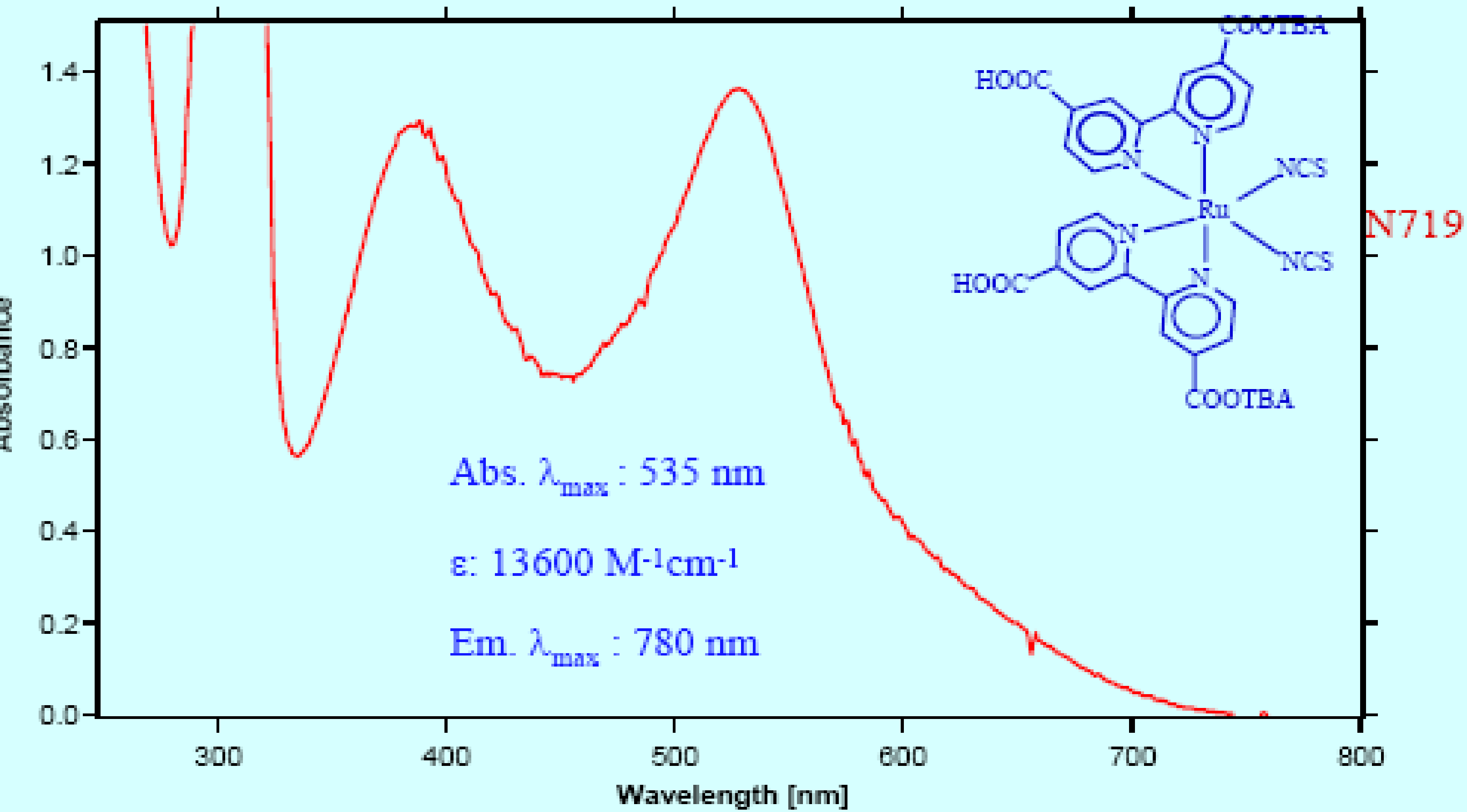
Photocurrent action spectrum of different ruthenium complexes attached to nanocrystalline TiO2 films



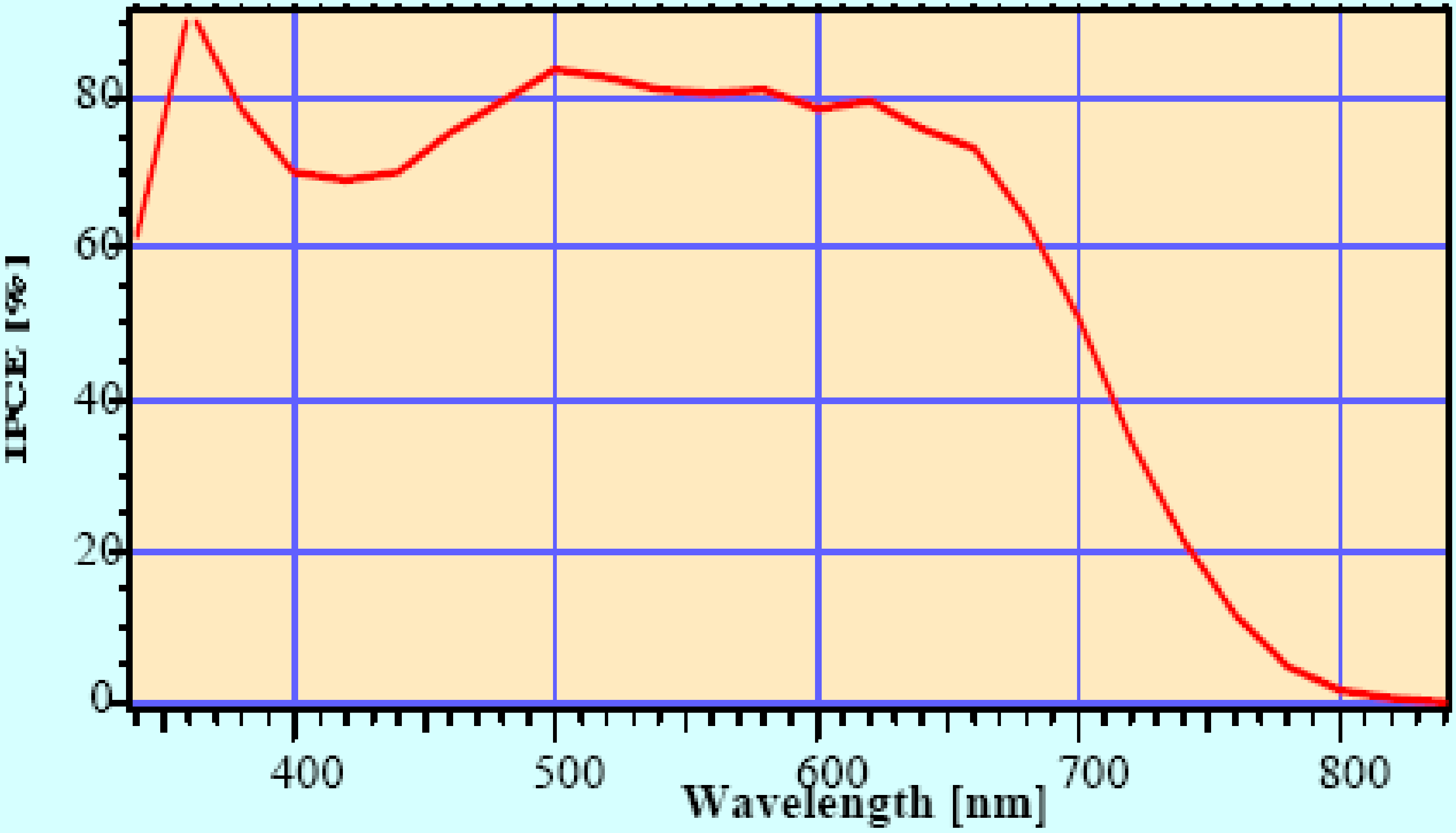
L = 4,4'-COOH-2,2'-bipyridine

L' = 4,4',4"-COOH-2,2':6',2"-terpyridine

Absorption Spectra of N719 Sensitizer

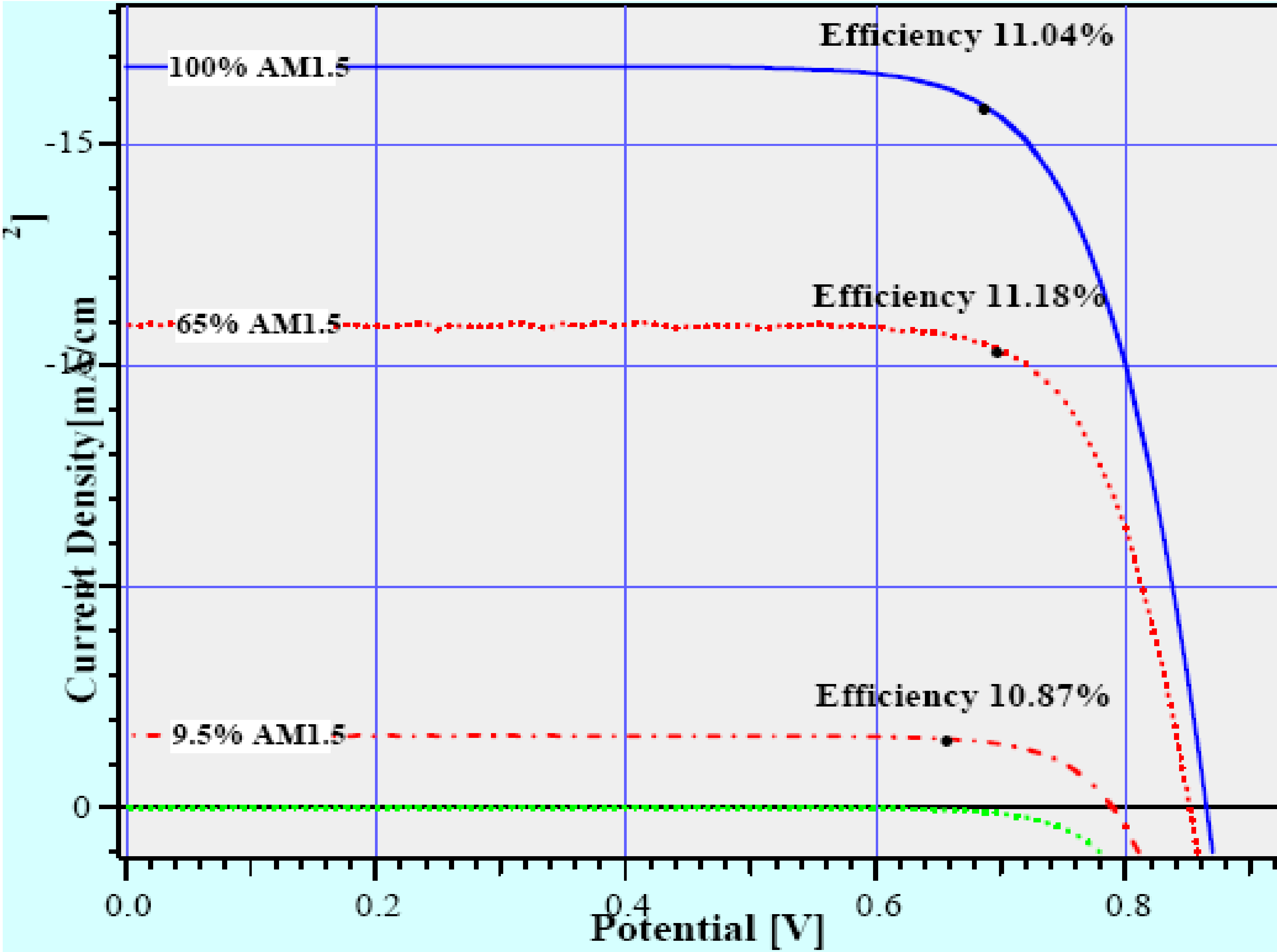


Photocurrent action spectrum obtained with the N719 dye attached to 16 + 4 μm nanocrystalline TiO_2 film.

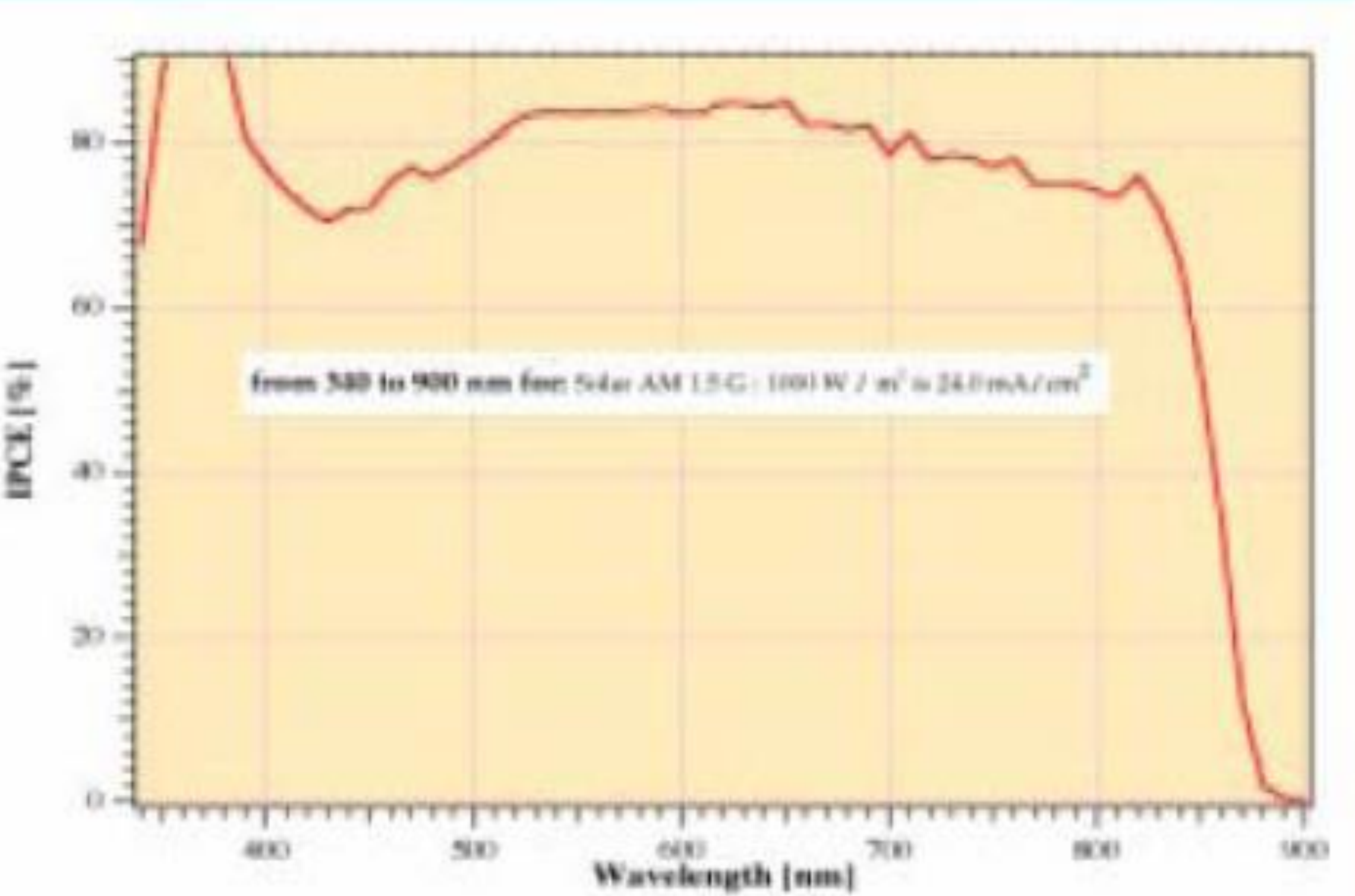


IPCE = 83%

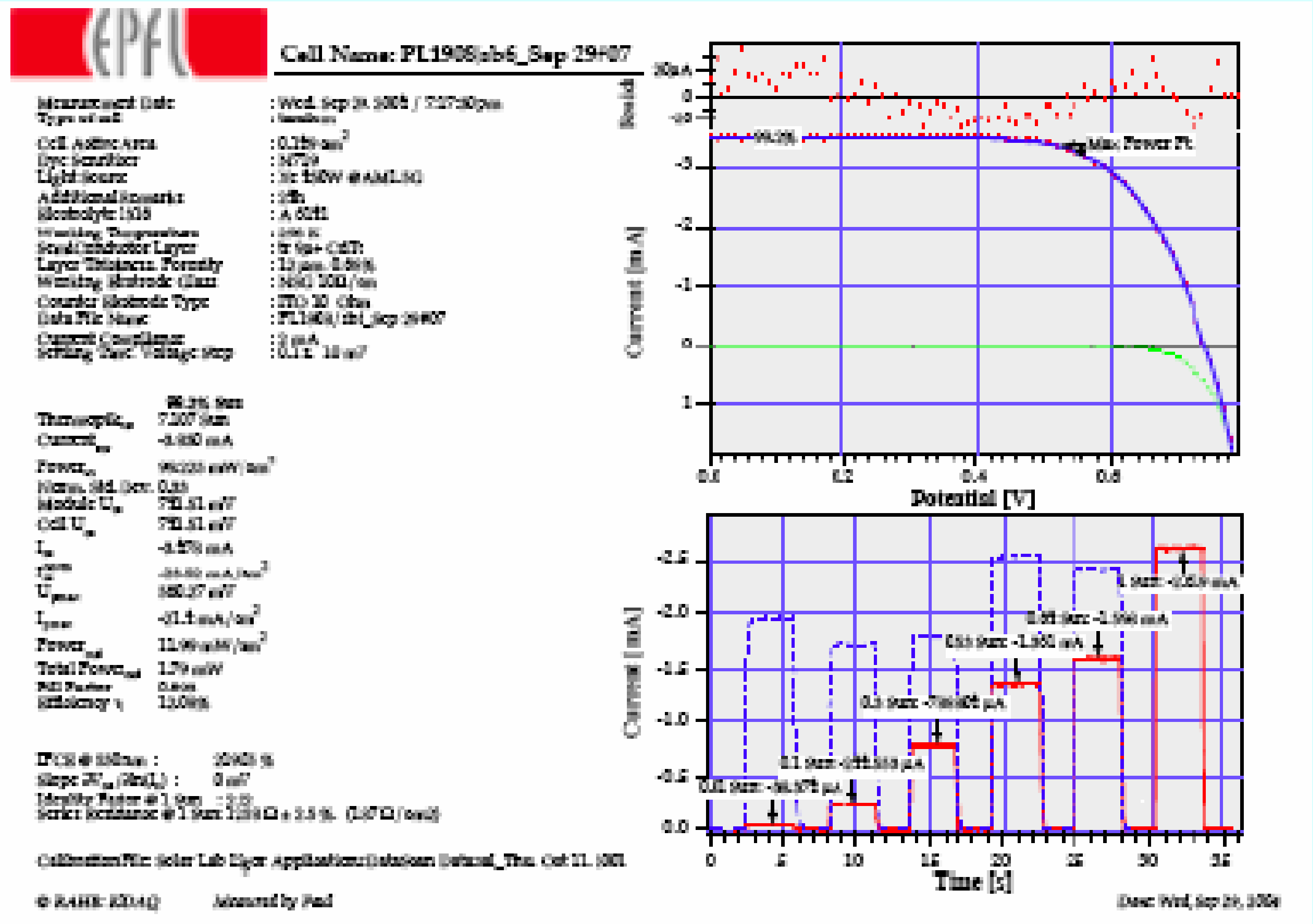
AM1.5 (1000 W/mcm^2) current = 16.9 mA/cm^2



Efficiency 11.04%
100% AM1.5
Efficiency 11.18%
65% AM1.5
Efficiency 10.87%
9.5% AM1.5
-15
0
0.0
0.2
0.4
0.6
0.8
Potential [V]
Current Density [mA/cm2]



IPCE [%]
0
20
40
60
80
400
500
600
700
800
900
Wavelength [nm]



New record conversion efficiency of 12.04 %

STABILITY

Requirements for outdoor use according to international PV standards applied to single crystal silicon but so far not to thin film PV cells

UV plus heat (55-60 C): 1000 hours

Accelerated thermal test at 85 C: 1000 h

Humidity test and temperature cycling (sealing issues)

Advantages *vs.* Silicon Cells

- Low cost and ease of production
- Performance increases with temperature narrowing the efficiency gap
- Bifacial configuration - advantage for diffuse light and albedo
- Efficiency less sensitive to angle of incidence
- Transparency for power windows
- Color can be varied by selection of the dye, invisible PV-cells based on near-IR sensitizers are feasable
- Low energy content (for silicon this is 5 GJ/m2 !), payback time is only a few months as compared to years for silicon.
- Outperforms amorphous Si

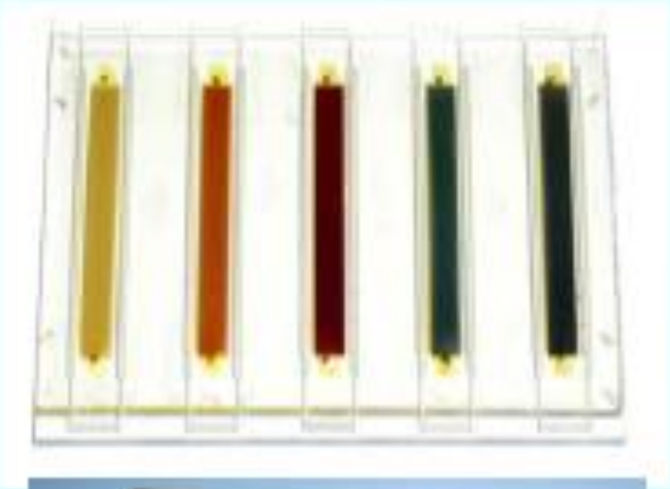
Emerging and new applications call for:

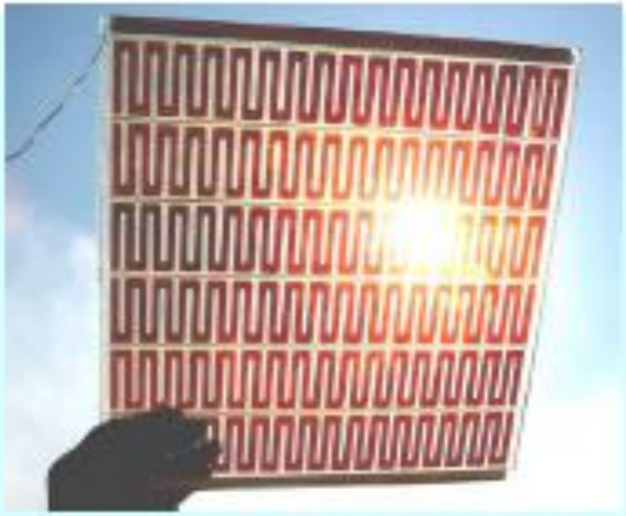
- colour
- flexibility
- light weight
- easy of integration
- many more

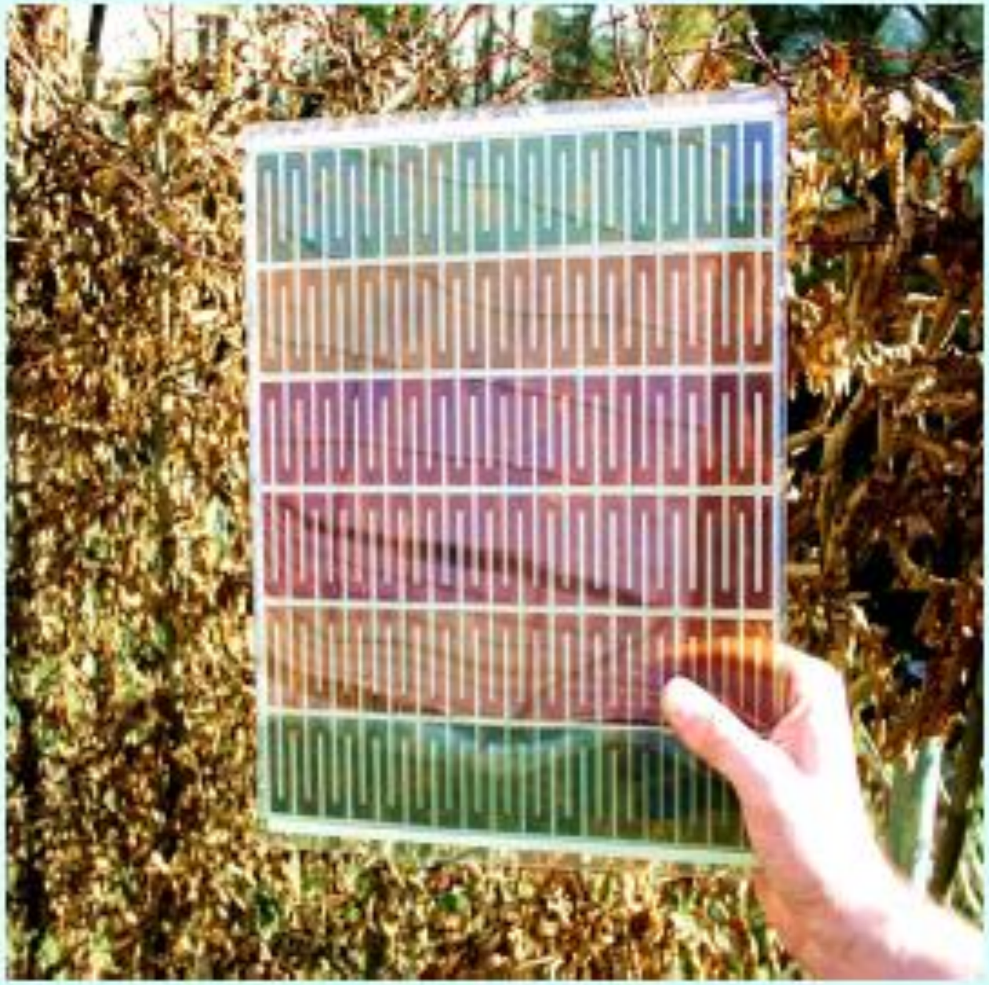
... further development and new technologies in order to meet optimally the customer demands and needs

Courtesy Dr. Winfried Hoffman, CEO, RWE, SCHOTT Solar GmbH

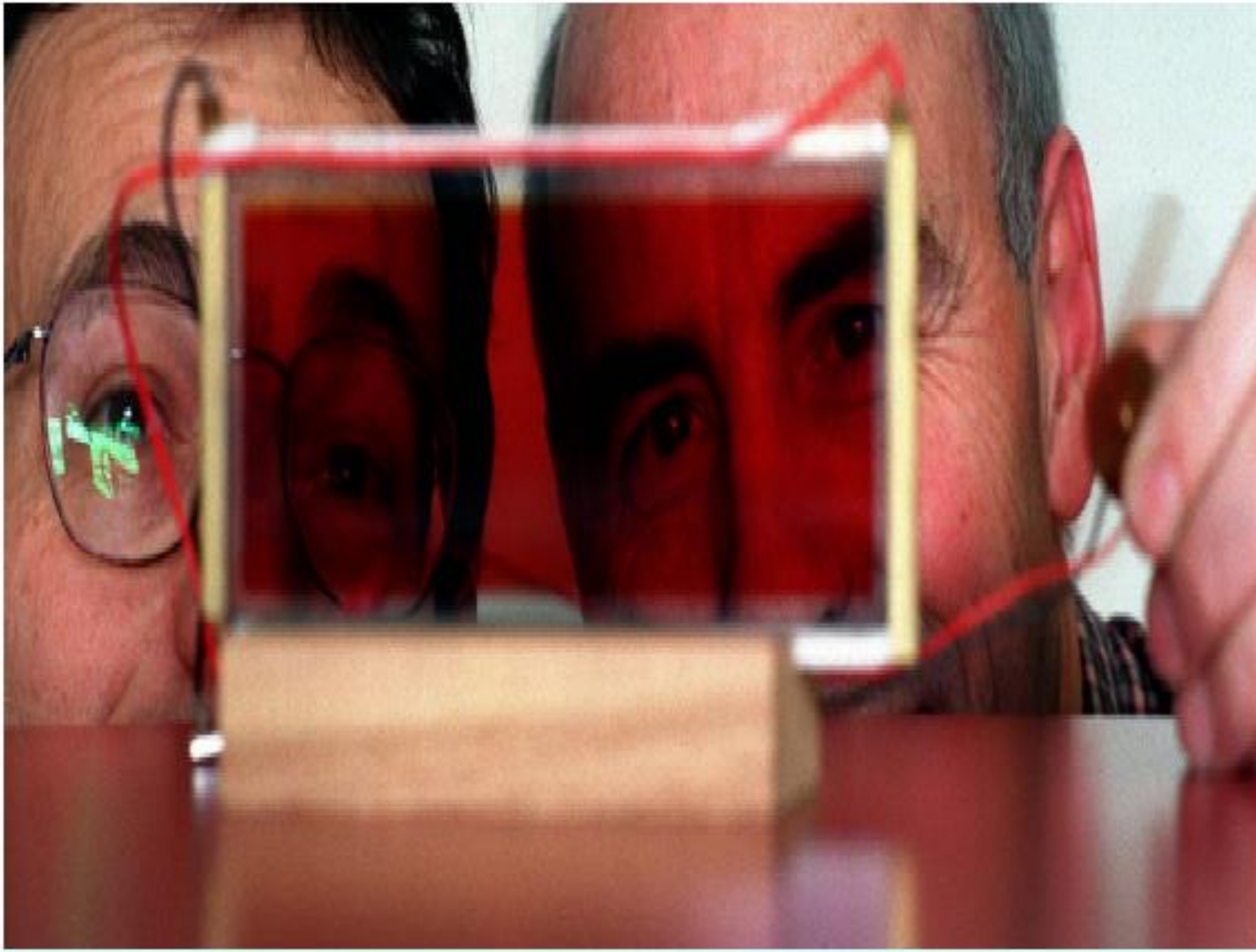
Various colours in a series-connected dye solar cell modules

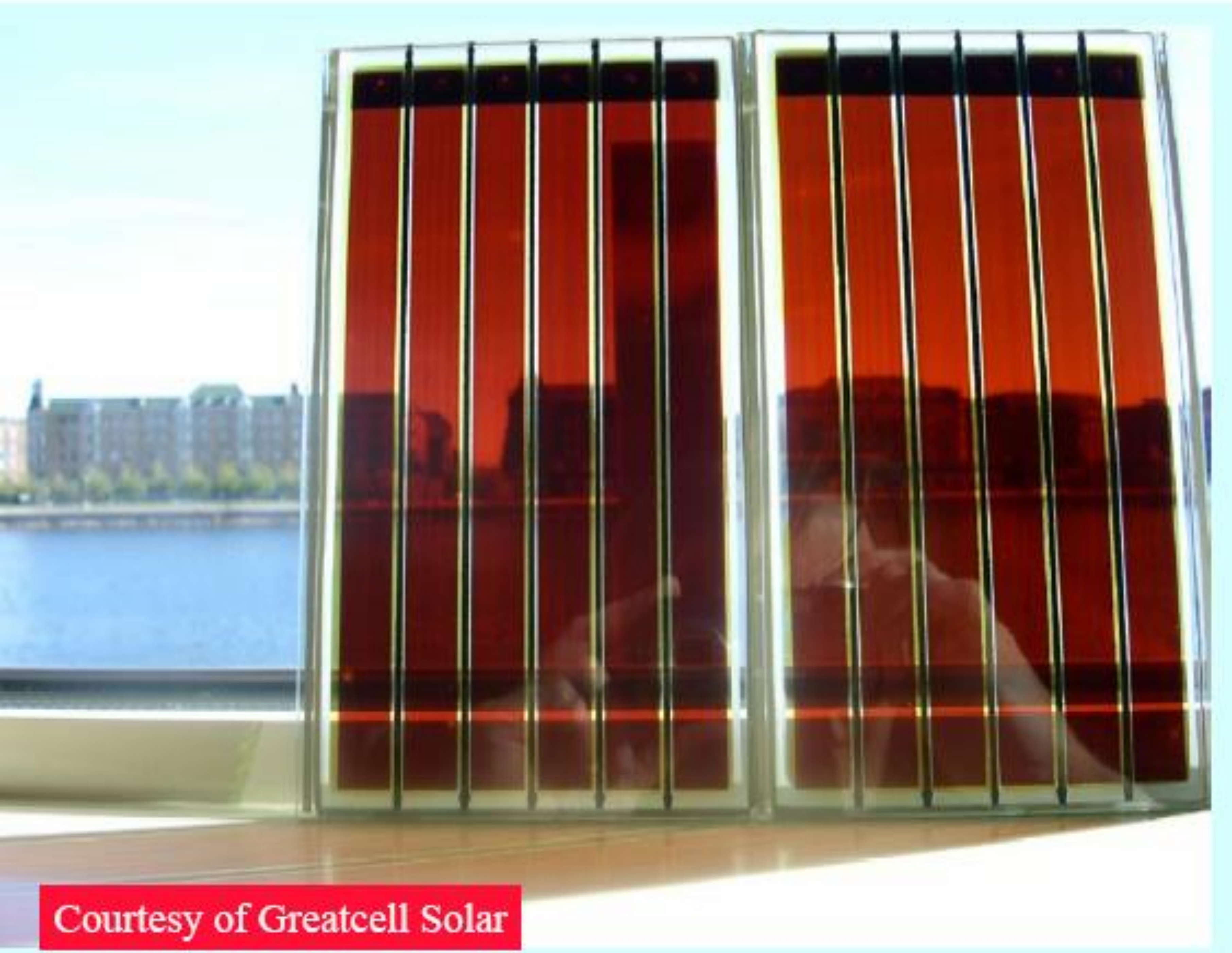






Courtesy Dr. Winfried Hoffman, CEO, RWE, SCHOTT Solar GmbH




Courtesy of Greatcell Solar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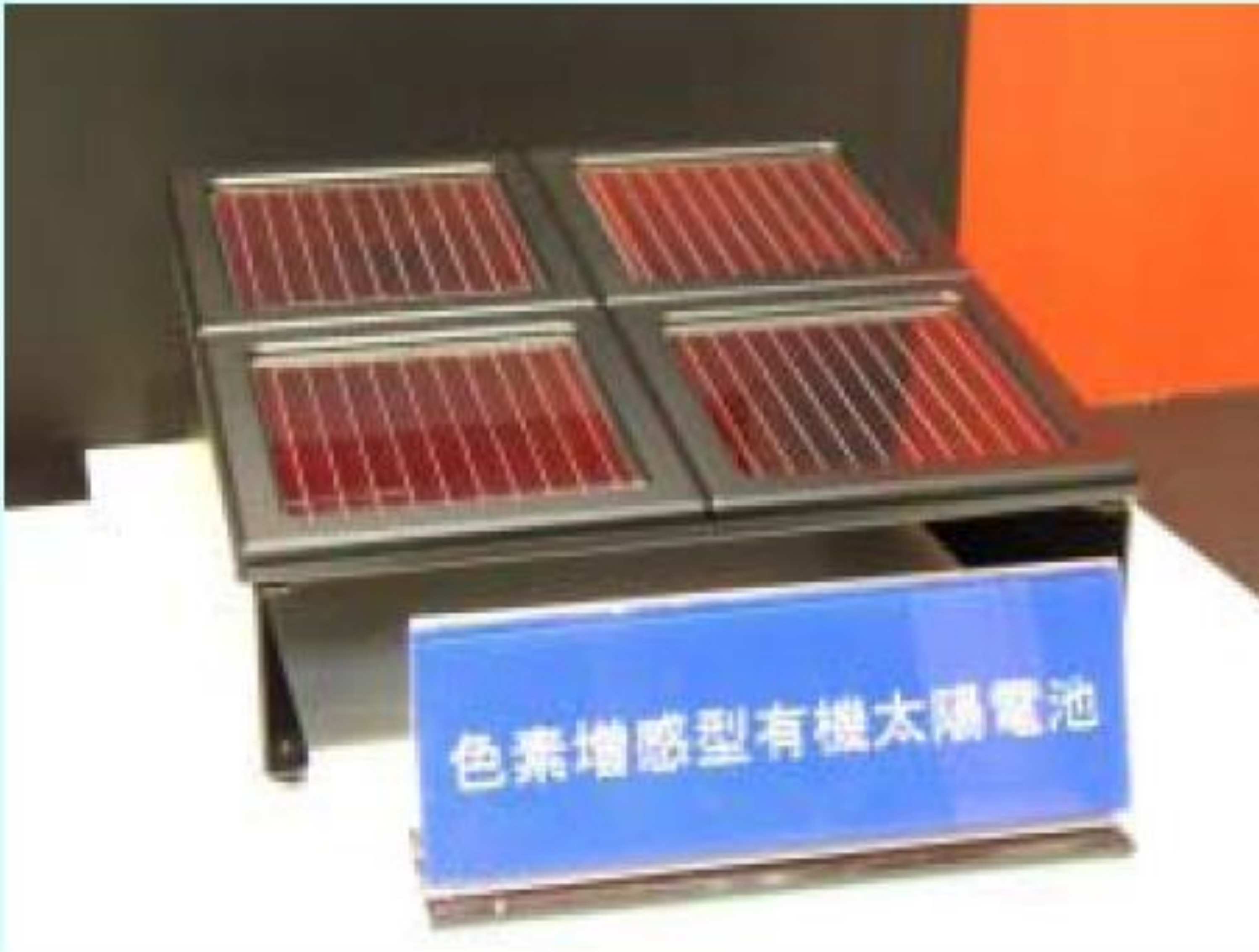

Hitachi's new dye sensitized cell achieves 9.3 percent efficiency

THANK YOU