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GRUP DE DISPOSITIUS FOTOVOLTAICS I OPTOELECTRÒNICS

Dye Sensitized Solar Cells

Outline

- Dye Sensitized Solar Cells.
- How?
- Why?
- Examples
- Conclusions

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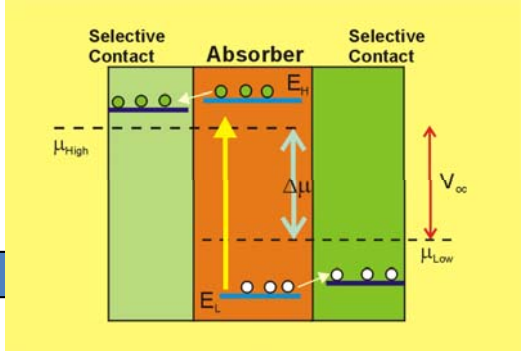
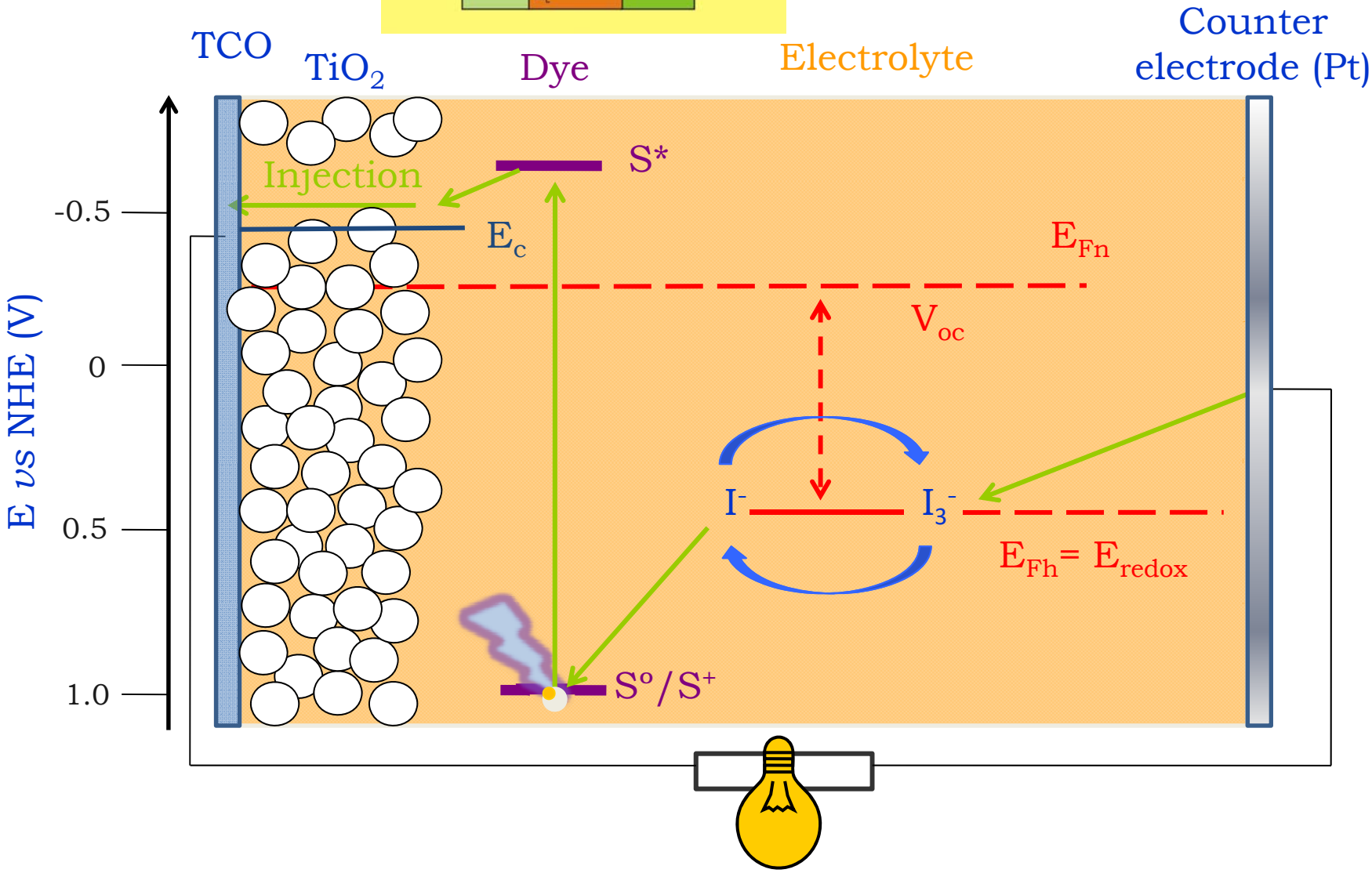
Dye Sensitized Solar Cells

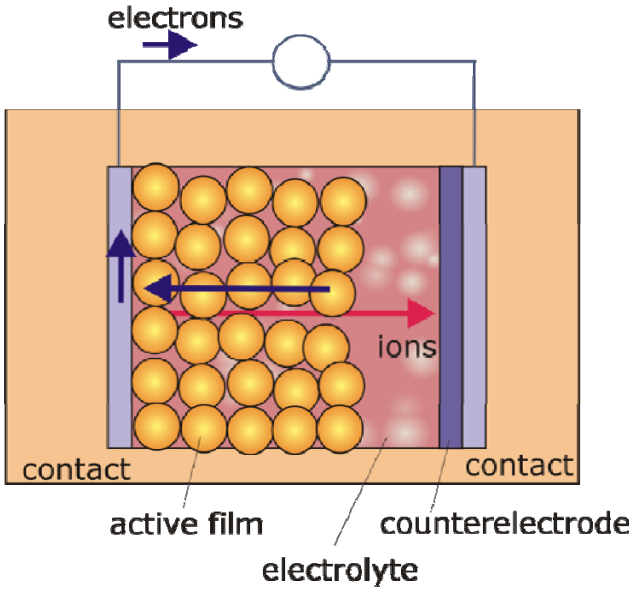
DSC Cartoon


Selective Contact
Absorber
Selective Contact
E_H
μ_{High}
$\Delta\mu$
V_{oc}
μ_{Low}
E_L


TCO
TiO_2
Dye
Electrolyte
Counter electrode (Pt)
E vs NHE (V)
-0.5
0
0.5
1.0
Injection
S*
E_c
E_{Fn}
V_{oc}
I^-
I_3^-
$E_{Fh} = E_{redox}$
S^o/S^+

Factors to Optimize

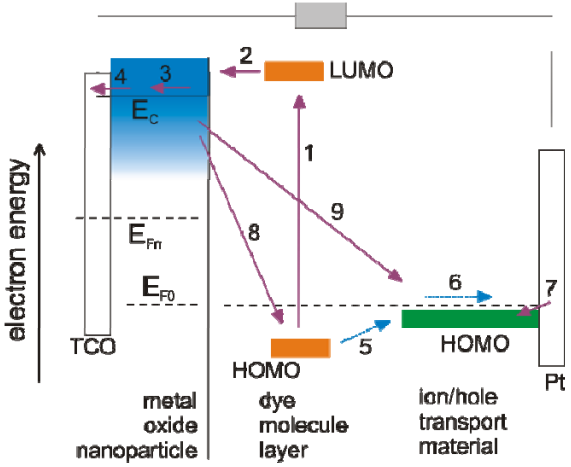
Light absorption



Carrier generation

Electron transport

Ion/hole transport



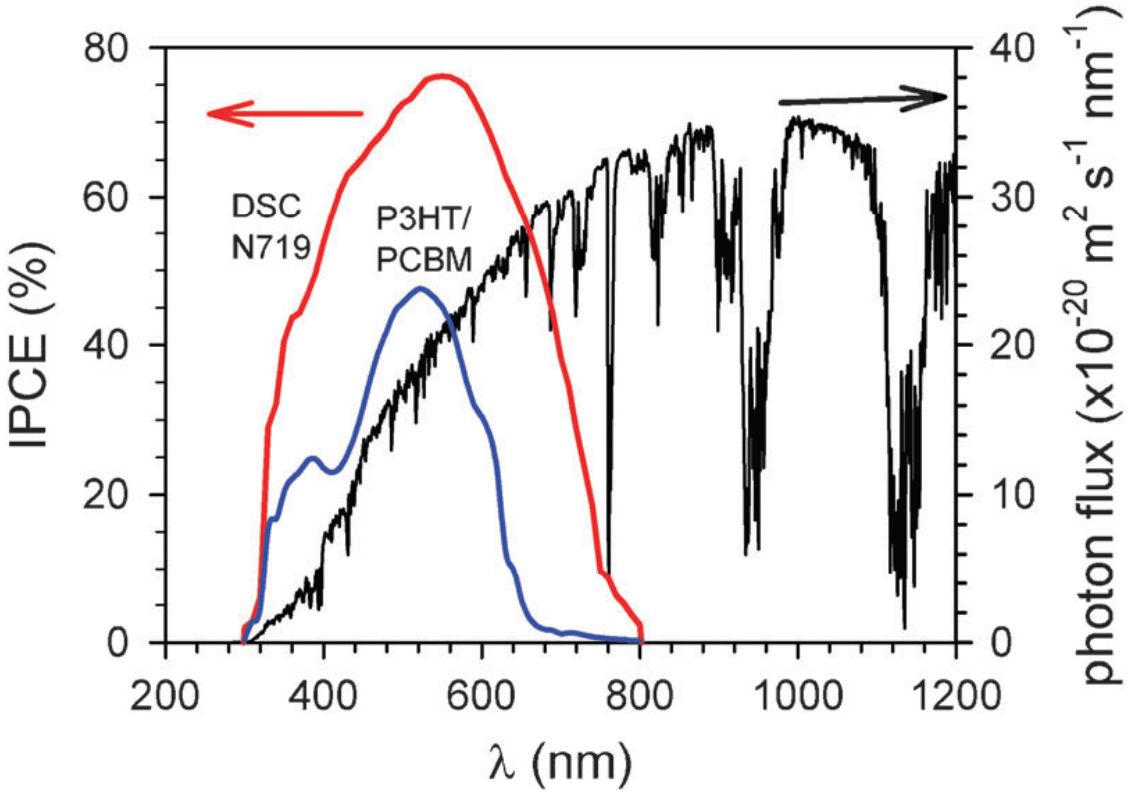
Recombination

CT at outer contacts

Series resistance

Photocurrent

$$j_{sc} = q\int_{\lambda_{\min}}^{\lambda_{\max}} \eta_{IPCE}\, \phi_{ph}^{source}(\lambda)\, d\lambda$$

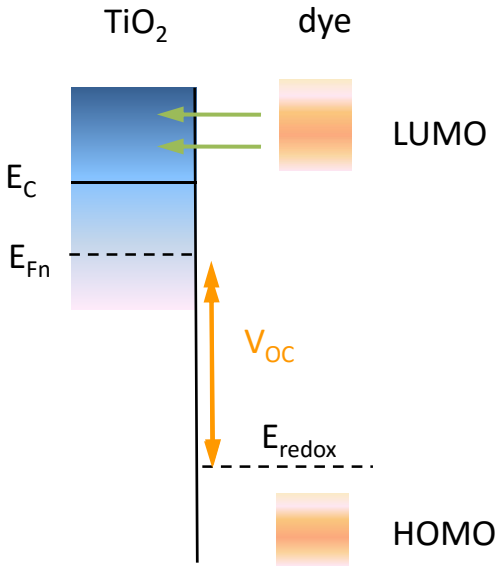


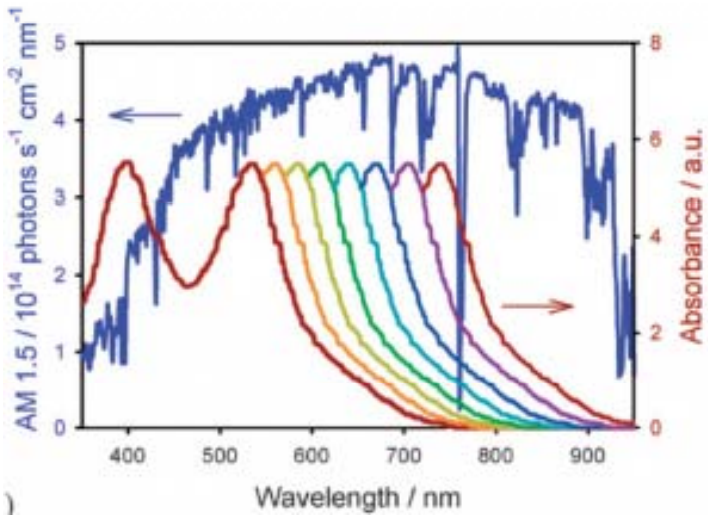
F. Fabregat-Santiago, G. Garcia-Belmonte, I. Mora-Seró and J. Bisquert, Phys. Chem. Chem. Phys., 2011, **13, 9083–9118**

Photocurrrent

Influence of energetics in photocurrent and photopotential

- The lower the LUMO of the dye the lesser the injection towards the TiO_2: current decreases



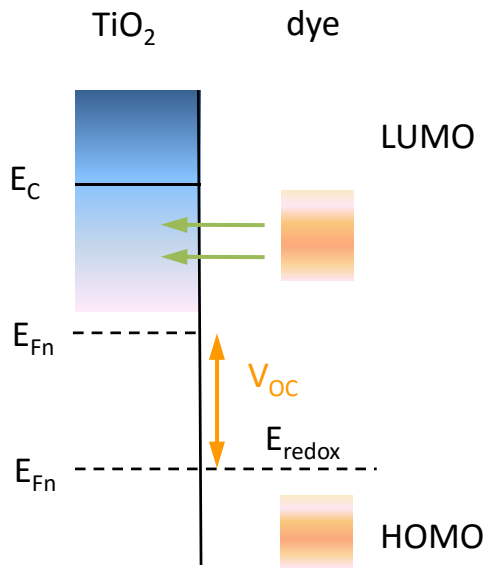


Photocurrent

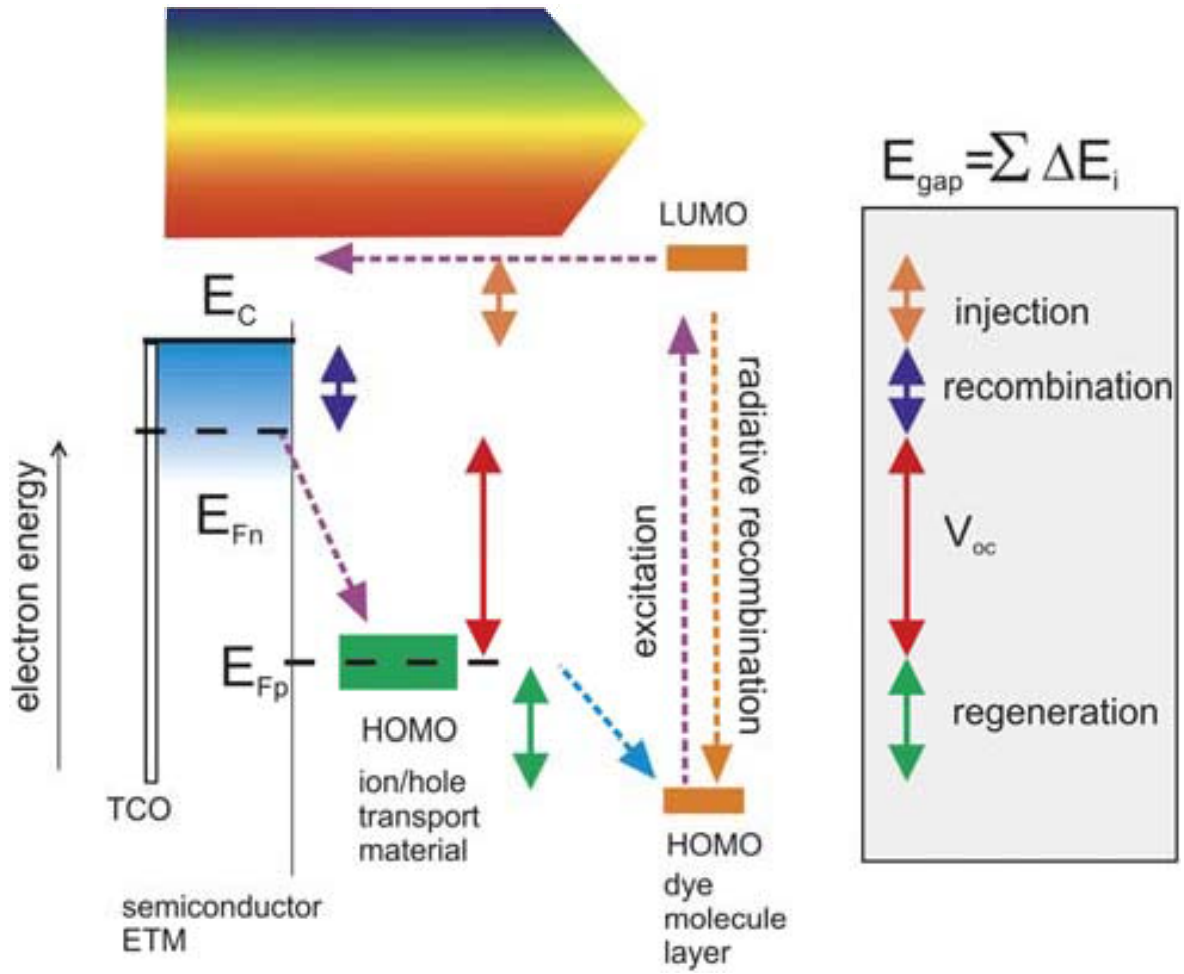
Influence of energetics in photocurrent and photopotential

Lowering the conduction band of TiO_2 is possible to recover the injection.

The cost is a loss in photopotential

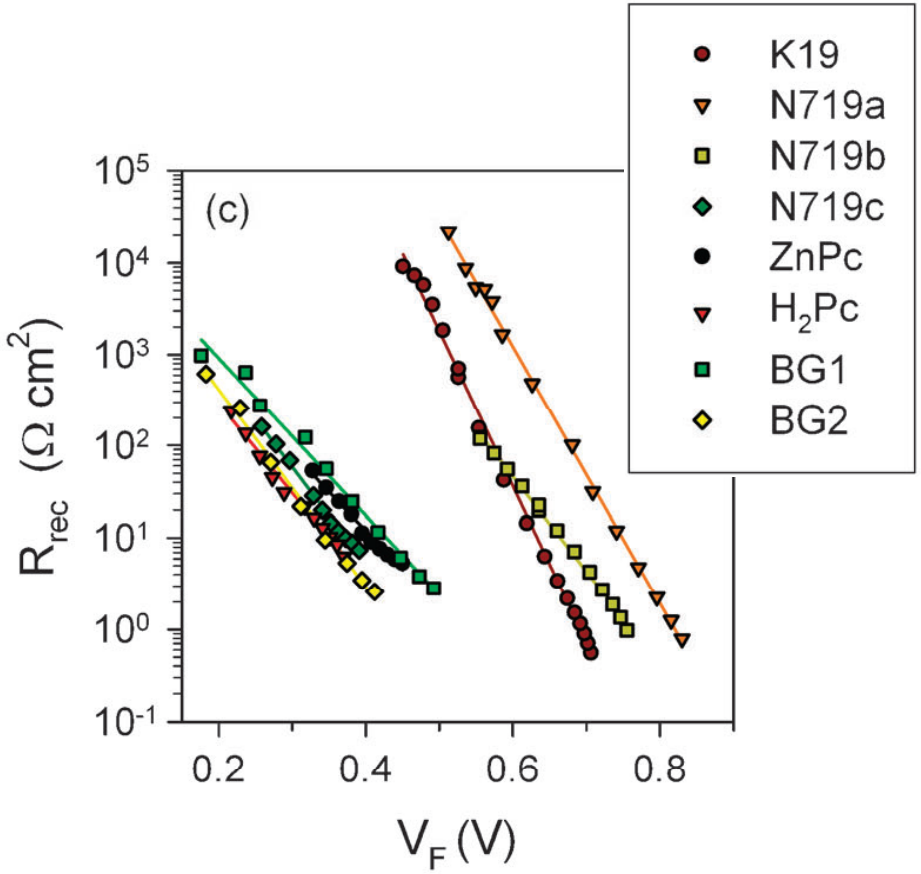


Photovoltage



E.M. Barea, J. Ortiz, F.J. Paya, F. Fernandez-Lazaro, F. Fabregat-Santiago, A. Sastre-Santos and J. Bisquert, **Energy Environ. Sci., 2010, 3, 1985–1994**

Recombination and V_{oc}



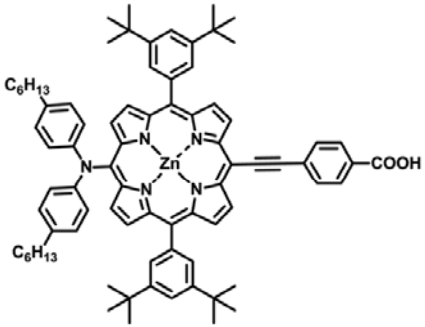
sample	Voc
K19	0.68
N719a	0.80
N719b	0.73
N719c	0.45
ZnPc	0.44
H_2Pc	0.35
BG1	0.45
BG2	0.39

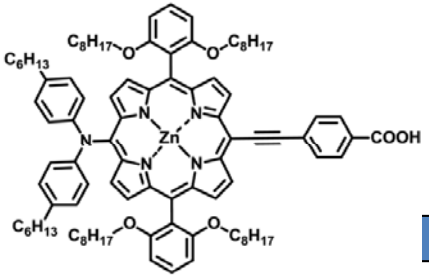
$$R_{rec} \approx R_0 \exp\left[-\beta \frac{qV_F}{k_B T}\right] \qquad with\ R_0[E_c, k]$$

Fabregat Santiago, et al. PCCP, **2011**, 13, 9083–9118

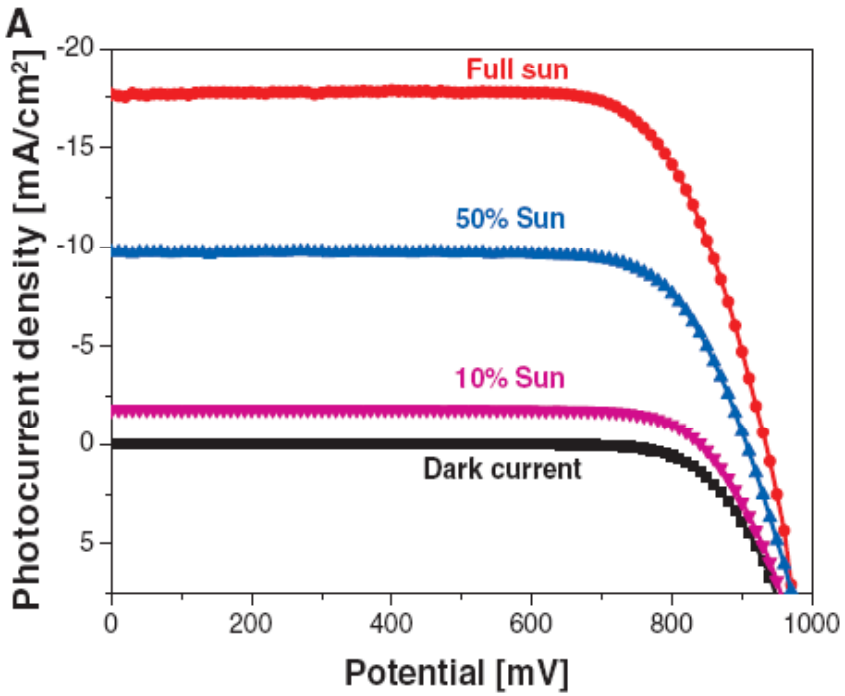
How?

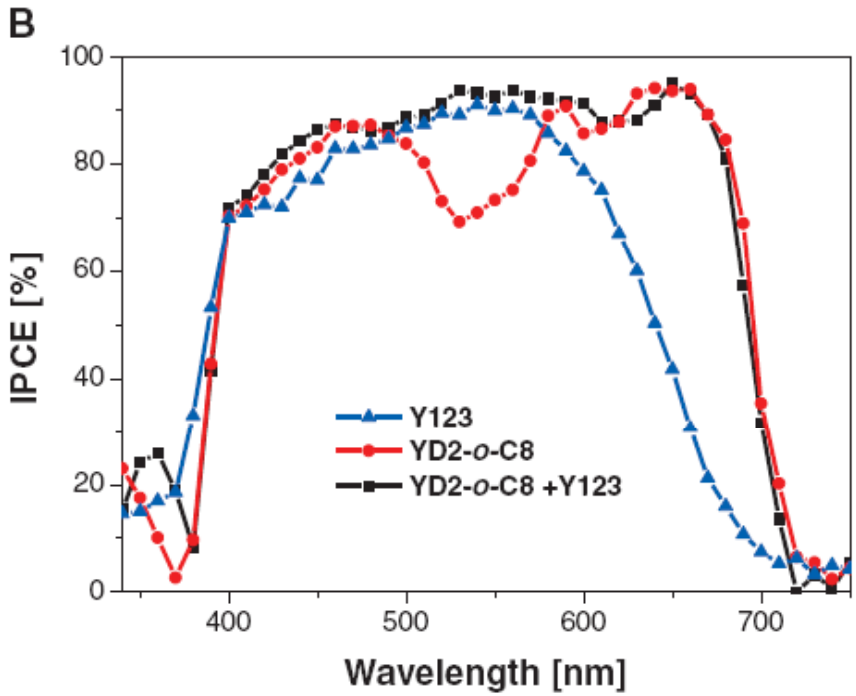
Record DSC





P_{in} (mW/cm^2)	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF	η (%)
9.4	1.83	840	0.79	13.0
50.8	9.72	910	0.76	13.1
99.5	17.66	935	0.74	12.3





Aswani Yella, *et al.* *Science* ***334, 629 (2011)***

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Dye solar cells

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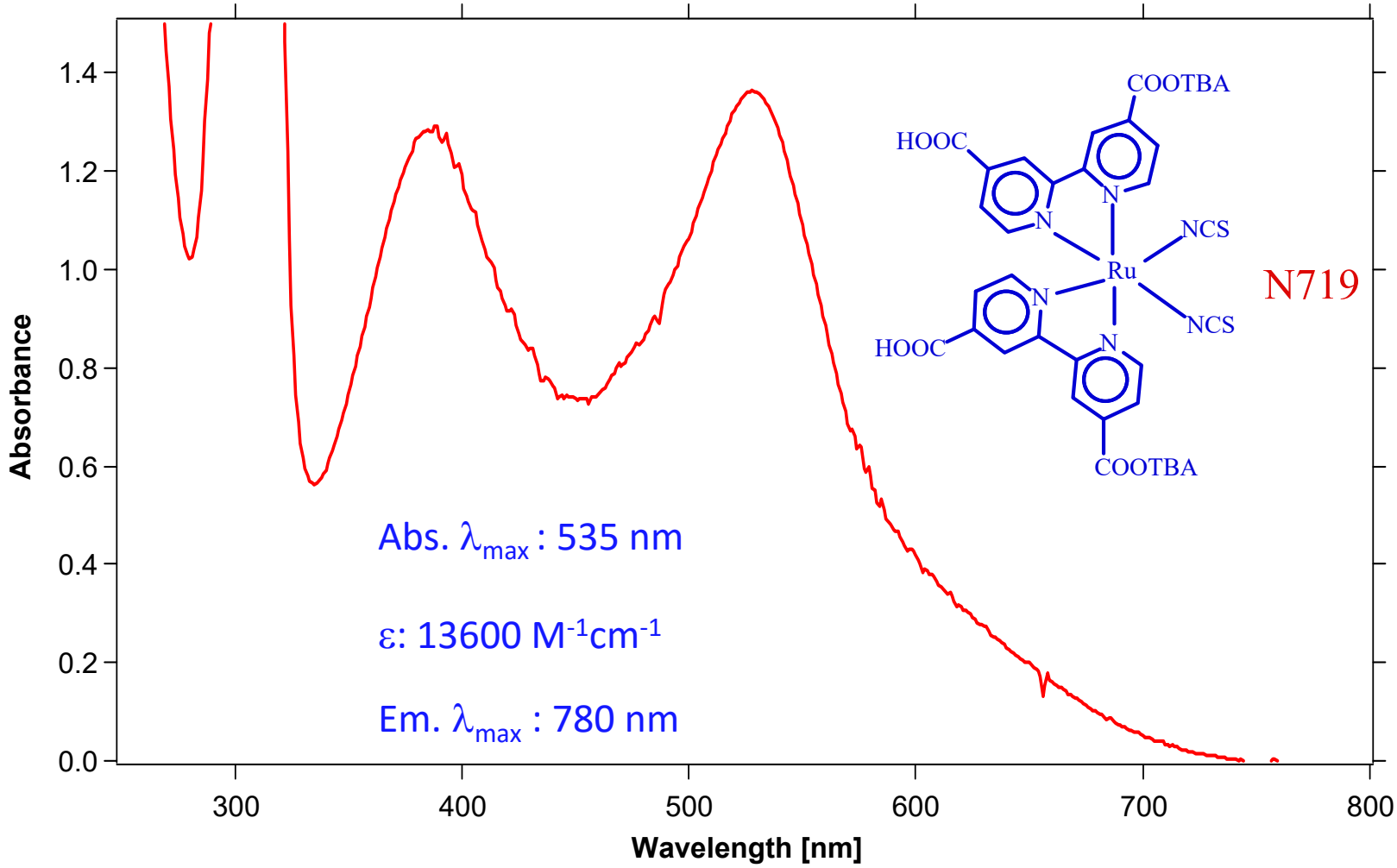
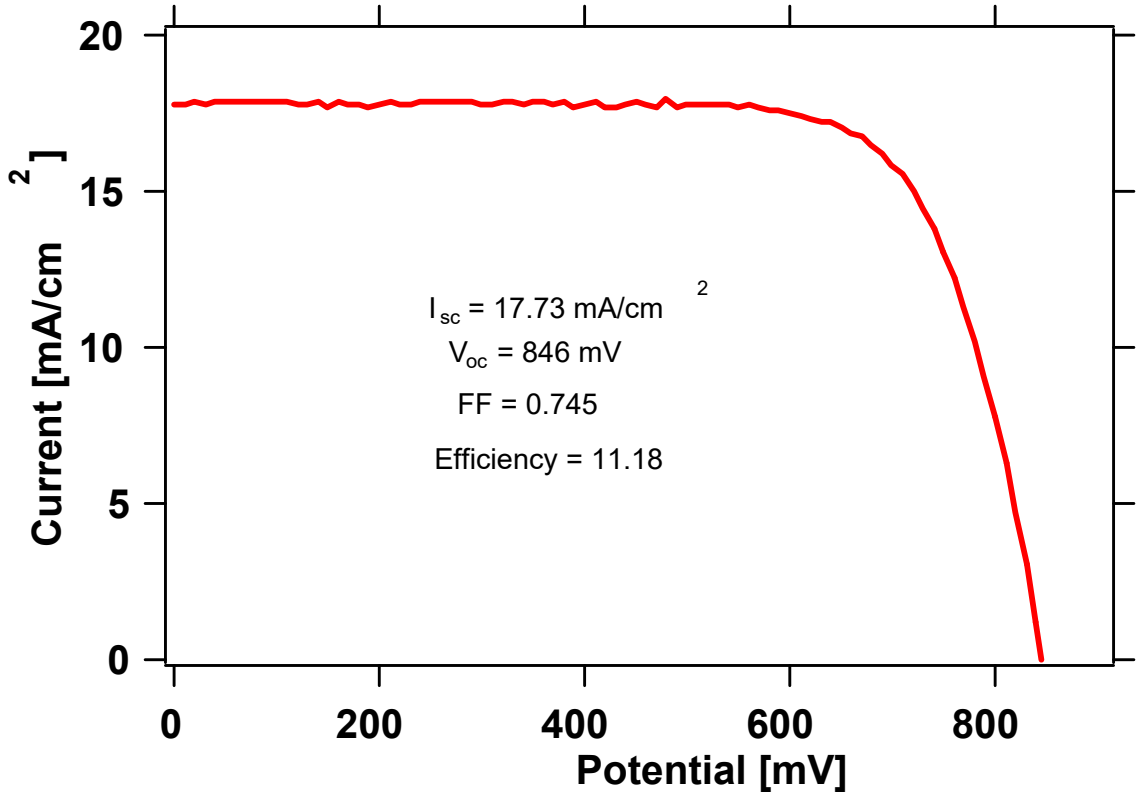


Dye solar cells

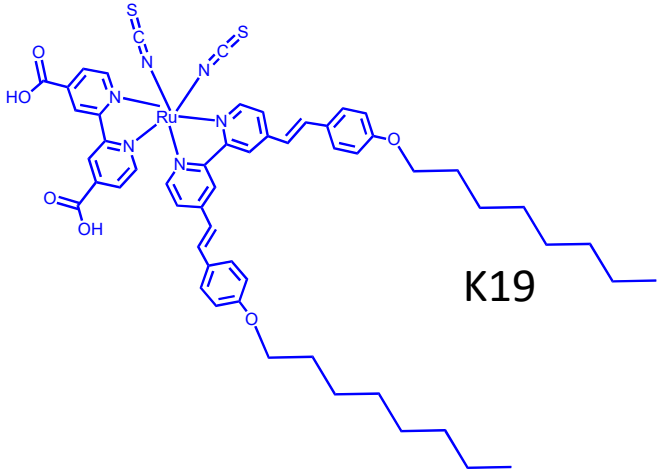
11.2 % efficiency

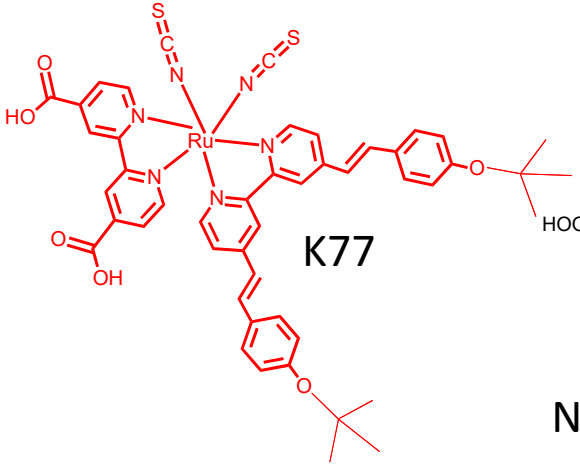


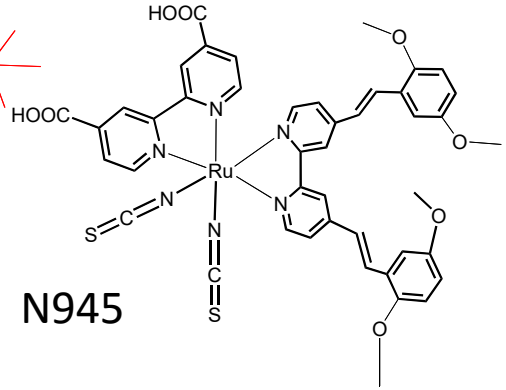
Nazeeruddin, Mohammad K.; De Angelis, Filippo; Fantacci, Simona; Selloni, Annabella; Viscardi, Guido; Liska, Paul; Ito, Seigo; Takeru, Bessho; Graetzel, Michael. JACS, 127, 16835, 2005.

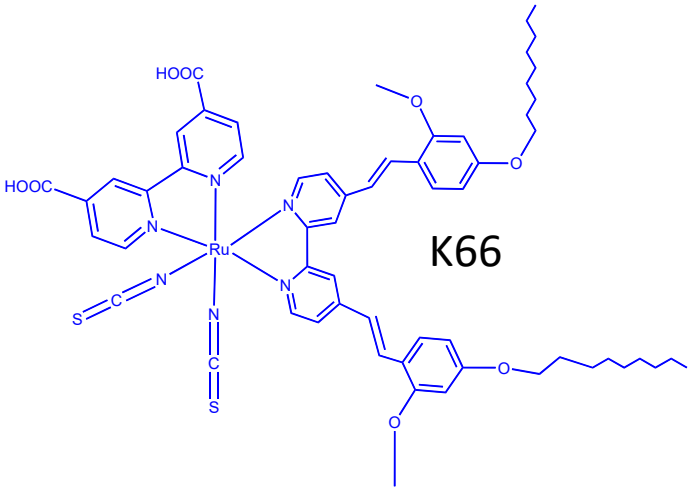
Dye solar cells

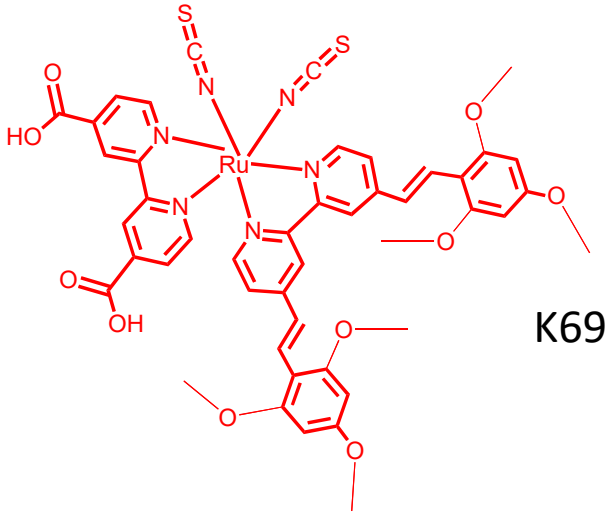
Sensitizers with π-extended donor ligands







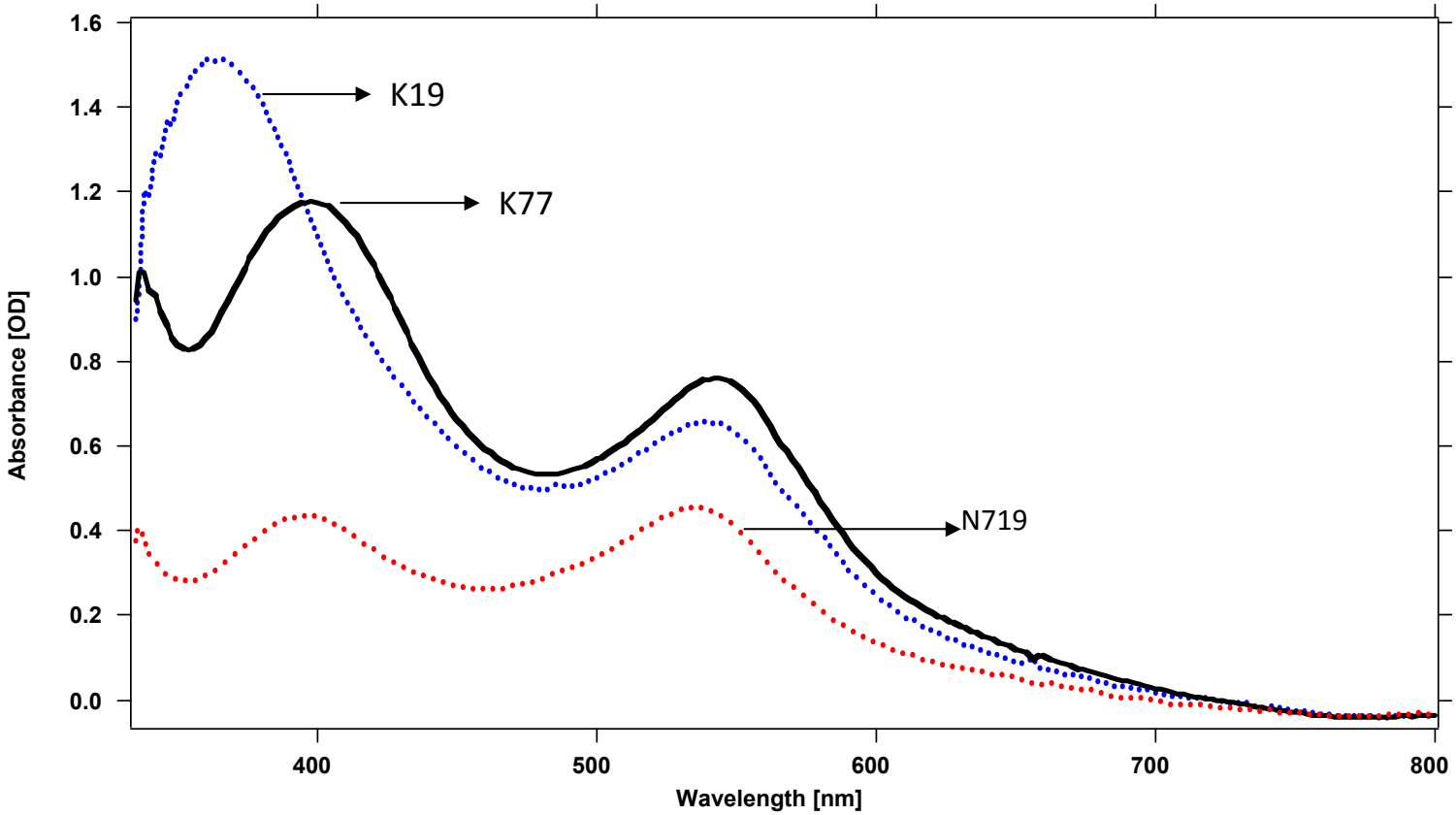




Inorg. Chem. 45, 787-797, 2006.

Dye solar cells

UV-Vis spectra of N719 (red), K19 (blue) and K77 (black)



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Dye solar cells

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THE JOURNAL OF PHYSICAL CHEMISTRY C

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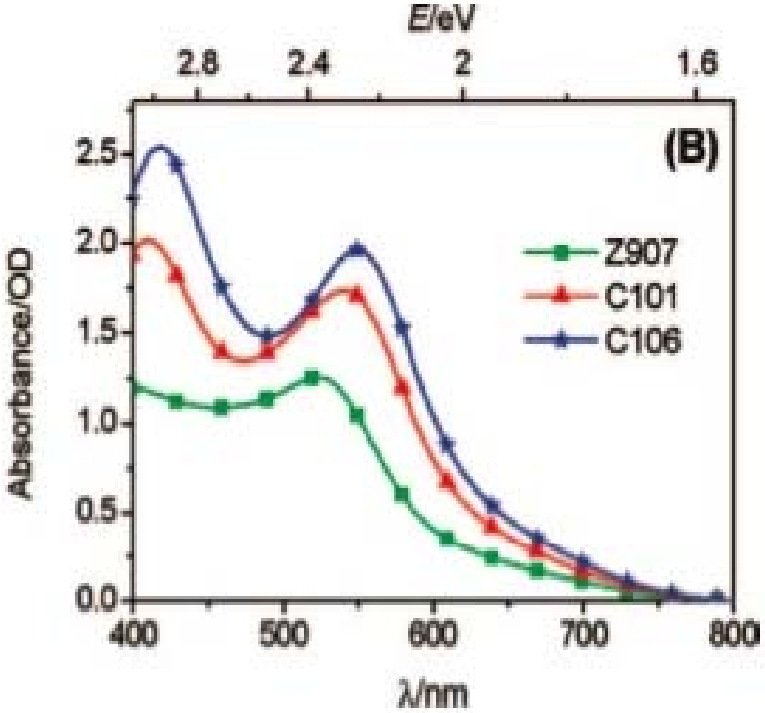
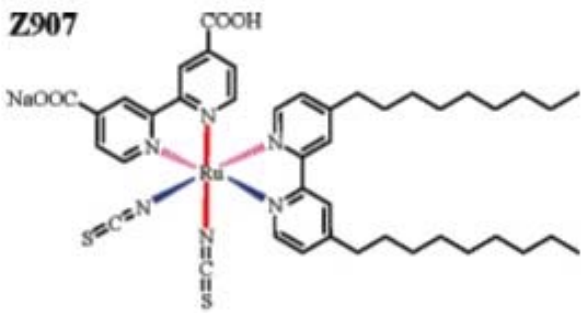
Article

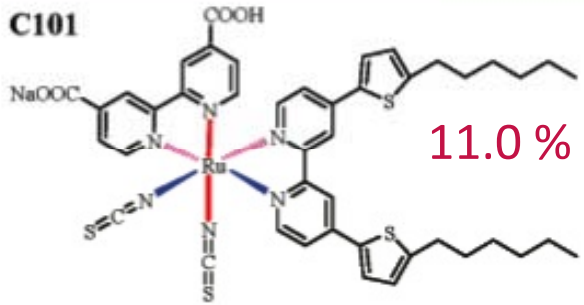
Dye-Sensitized Solar Cells with a High Absorptivity Ruthenium Sensitizer Featuring a 2-(Hexylthio)thiophene Conjugated Bipyridine

Yiming Cao, Yu Bai, Qingjiang Yu, Yueming Cheng, Shi Liu, Dong Shi, Feifei Gao, and Peng Wang

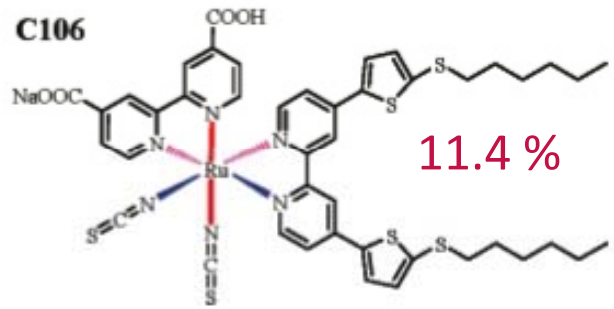
J. Phys. Chem. C, **Article ASAP** • DOI: 10.1021/jp9006872 • Publication Date (Web): 25 March 2009







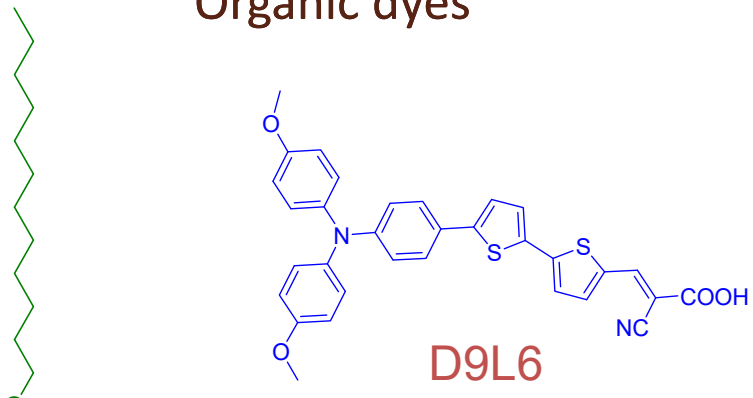
11.0 %



11.4 %

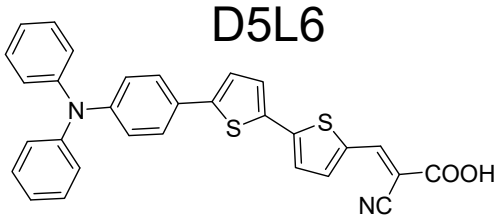
Dye solar cells

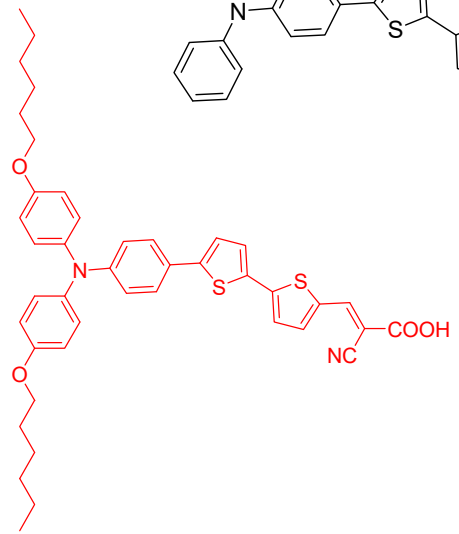
Organic dyes



D9L6

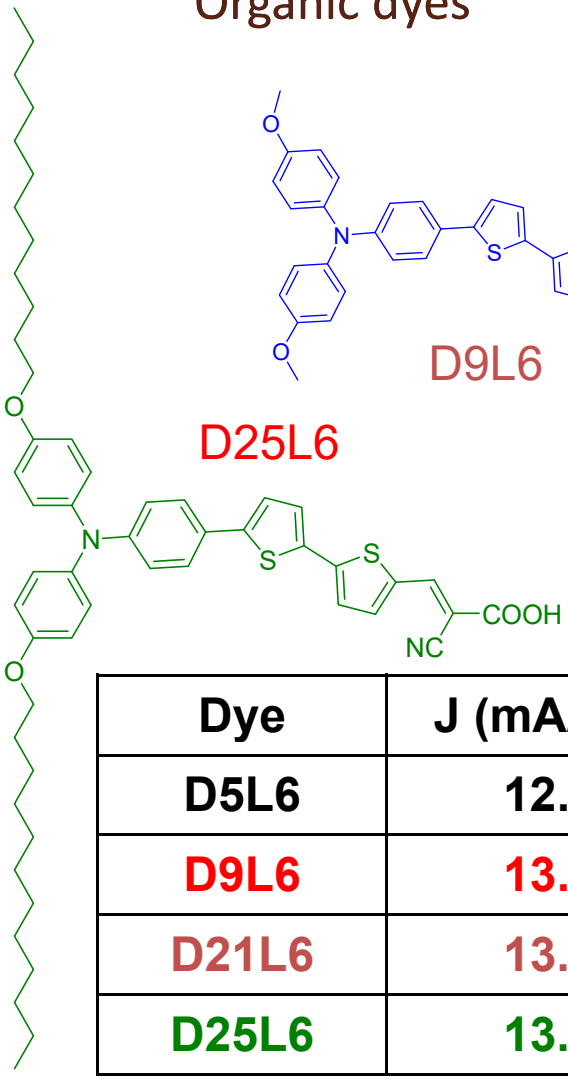
D5L6





D21L6

D25L6



Dye	J (mA/cm2)	V (mV)	FF	efficiency
D5L6	12.50	685	0.74	6.29
D9L6	13.36	641	0.70	6.08
D21L6	13.70	733	0.72	7.25
D25L6	13.73	745	0.69	7.05

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Dye solar cells

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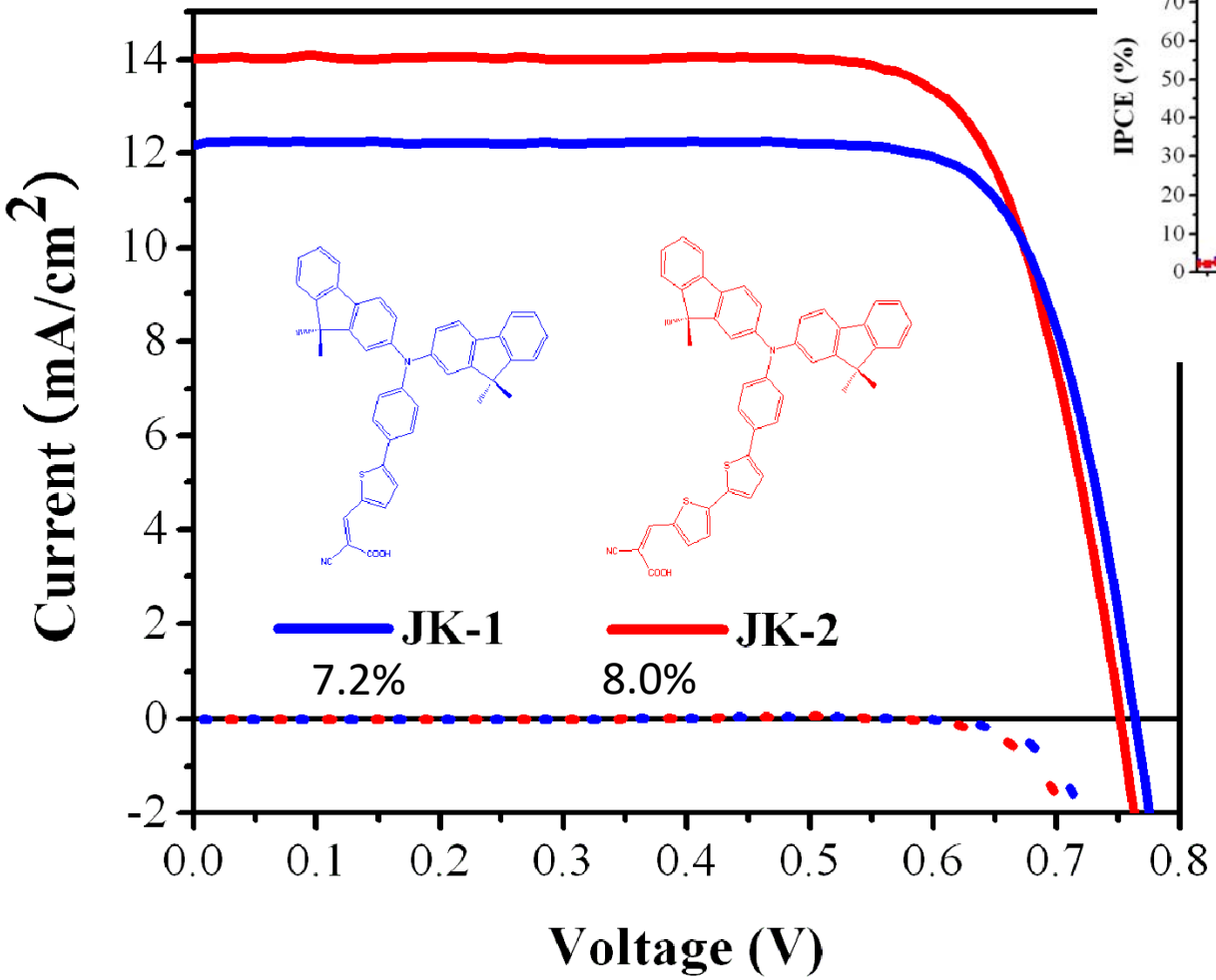
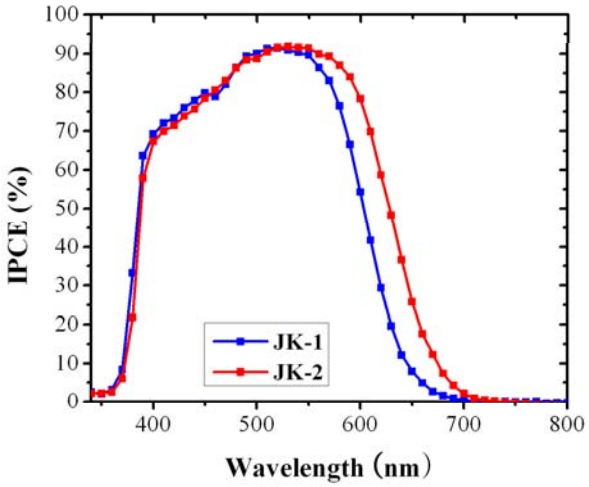
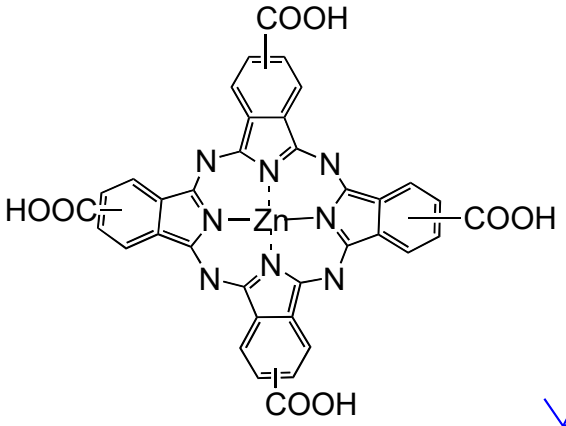
Organic dyes

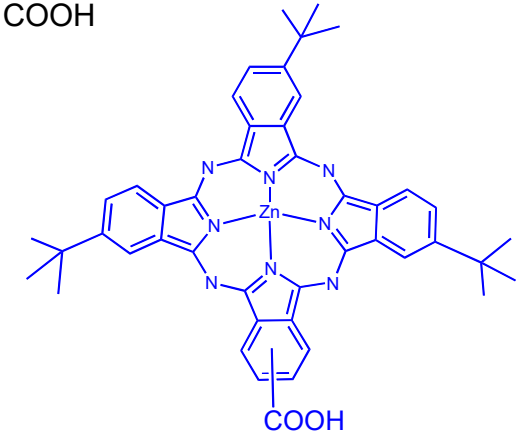


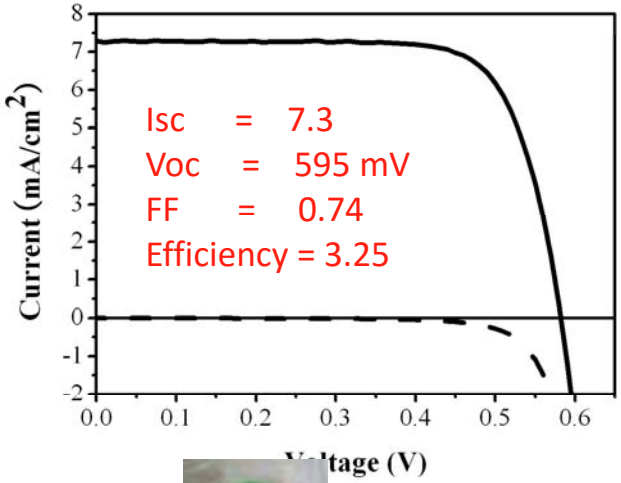


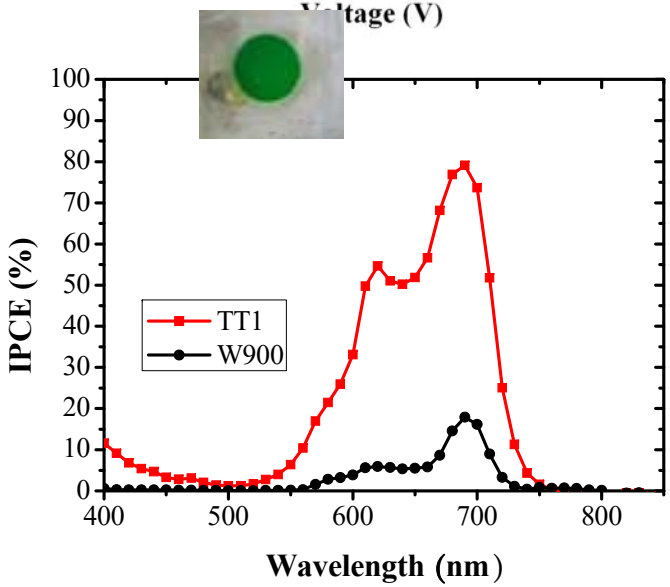
Dye solar cells

Phthalocyanines





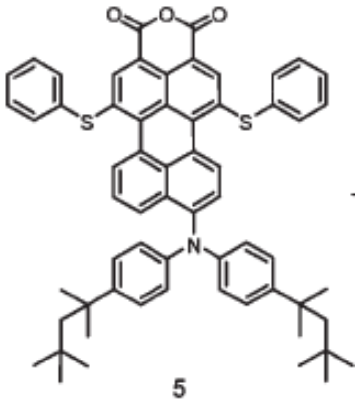


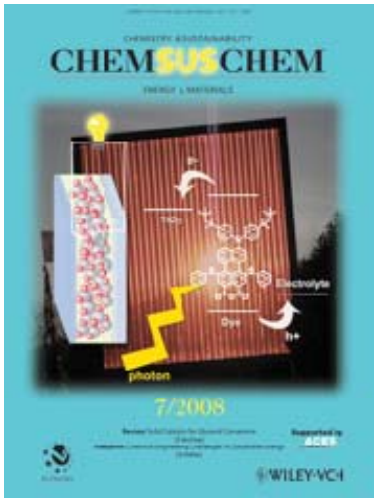


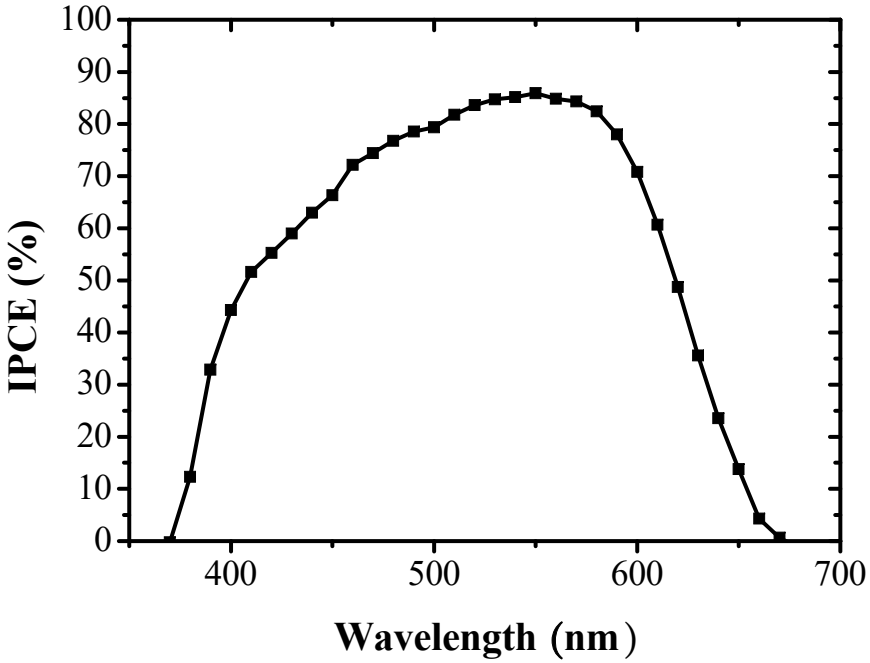
ANGEWANDTE CHEMIE-INTERNATIONAL EDITION Volume: 46, 373-376, 2007

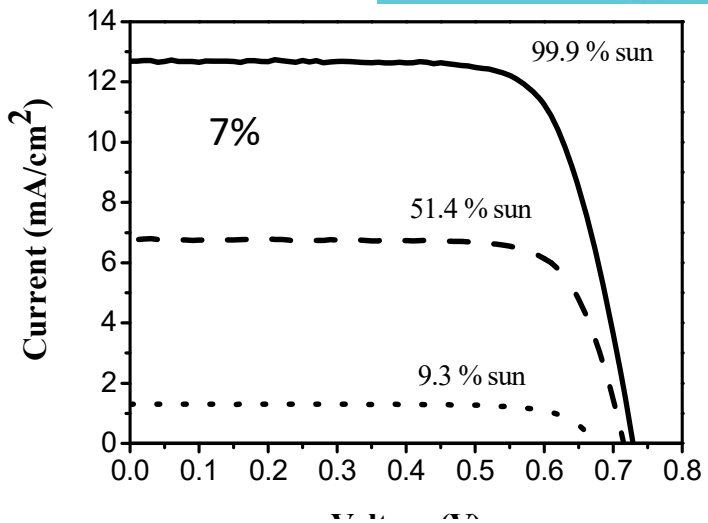
Dye solar cells

Perylenes





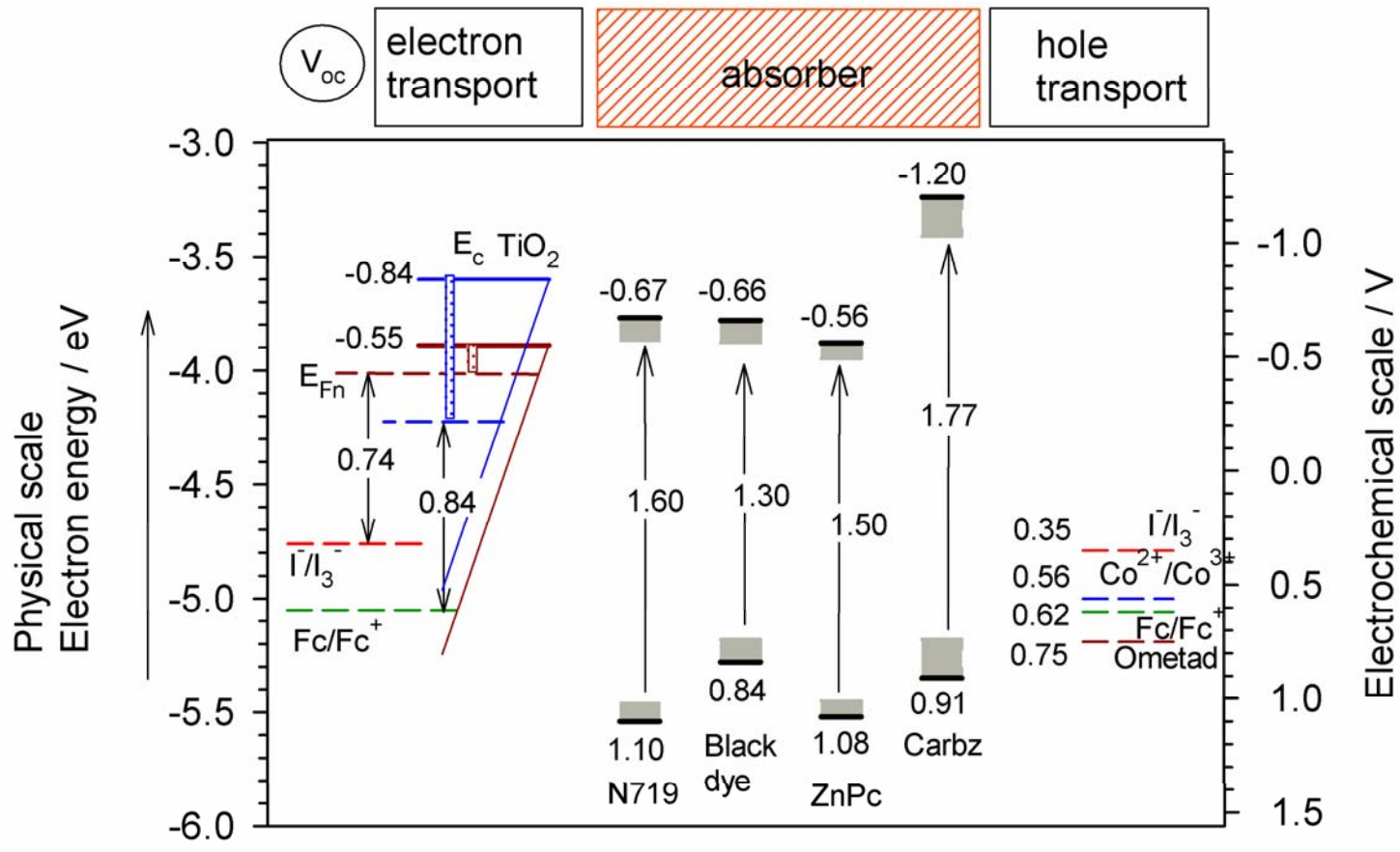




C. Li et al., *ChemSusChem*, 2008, *1*, 615

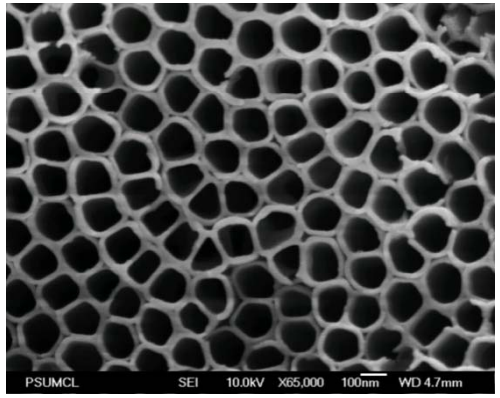
Dye solar cells

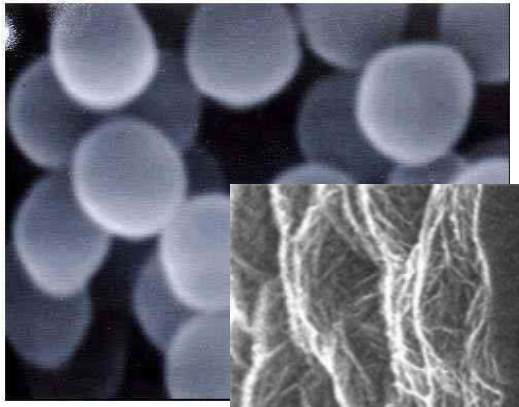
Redox role

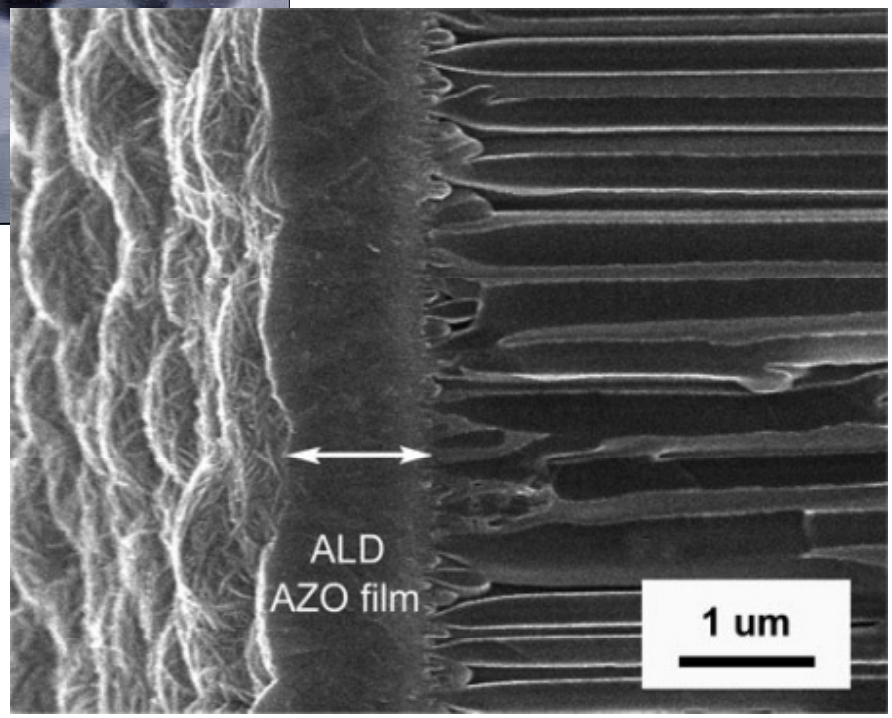


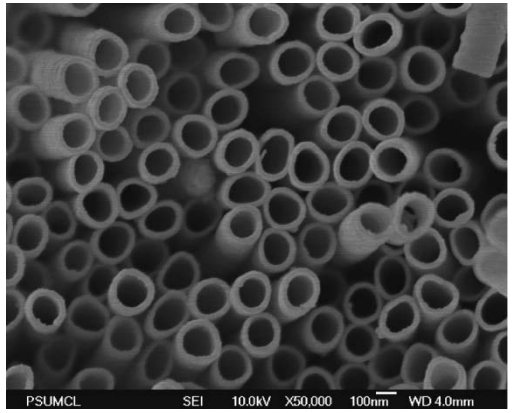
Dye solar cells

Cèl·lules solars de colorant (dye solar cell): nanoestructures







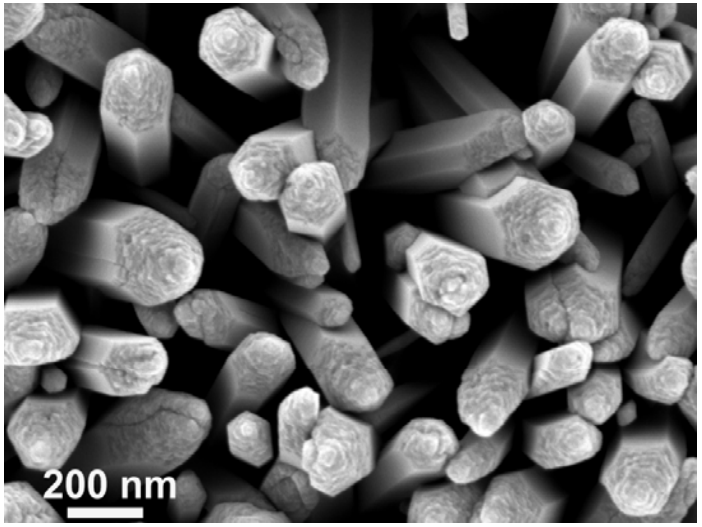


Nanotubs de TiO_2

Nanotubs de ZnO

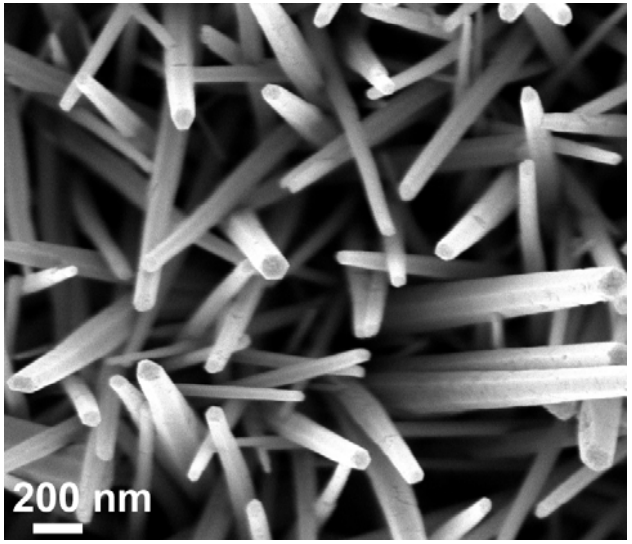
Dye solar cells

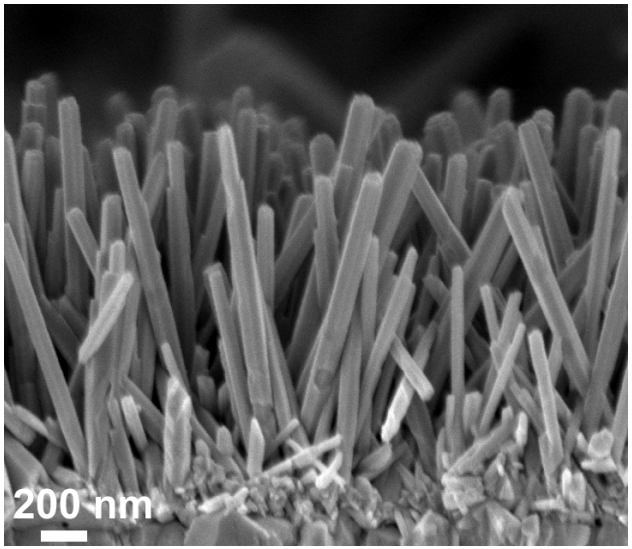
ZnO Nanorods



Electrodeposited nanorods

d = 30 - 300 nm
L = 100 nm – >1 μm
S/S_g = 5 - 30





Why?

Why Sensitized Solar Cells?

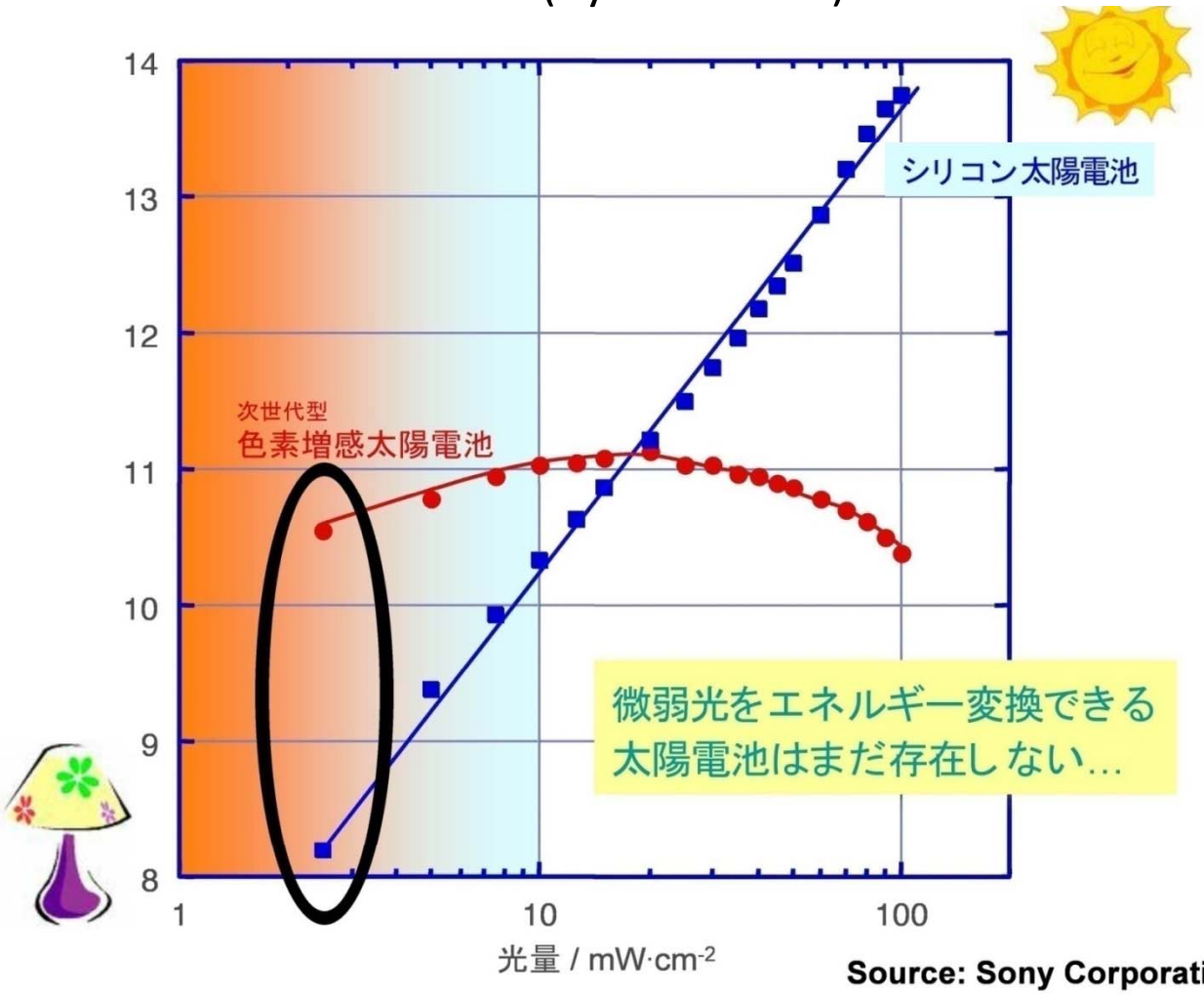
- Environmentally friendly
- Readily available raw materials
- Operating voltage not dependent on light level or orientation
- Better performance in normal solar conditions
- Power all day every day - delivers kWh/SqM (not Watt peak)
- Long term stability of technnology
- Can be directly integrated into products
- Only solar cell technology that can be transparent and bifacial
- Looks good – many colours and effects
- Low cost manufacture – low embodied energy

Dye solar cells

Integració en façanes i cobertures:

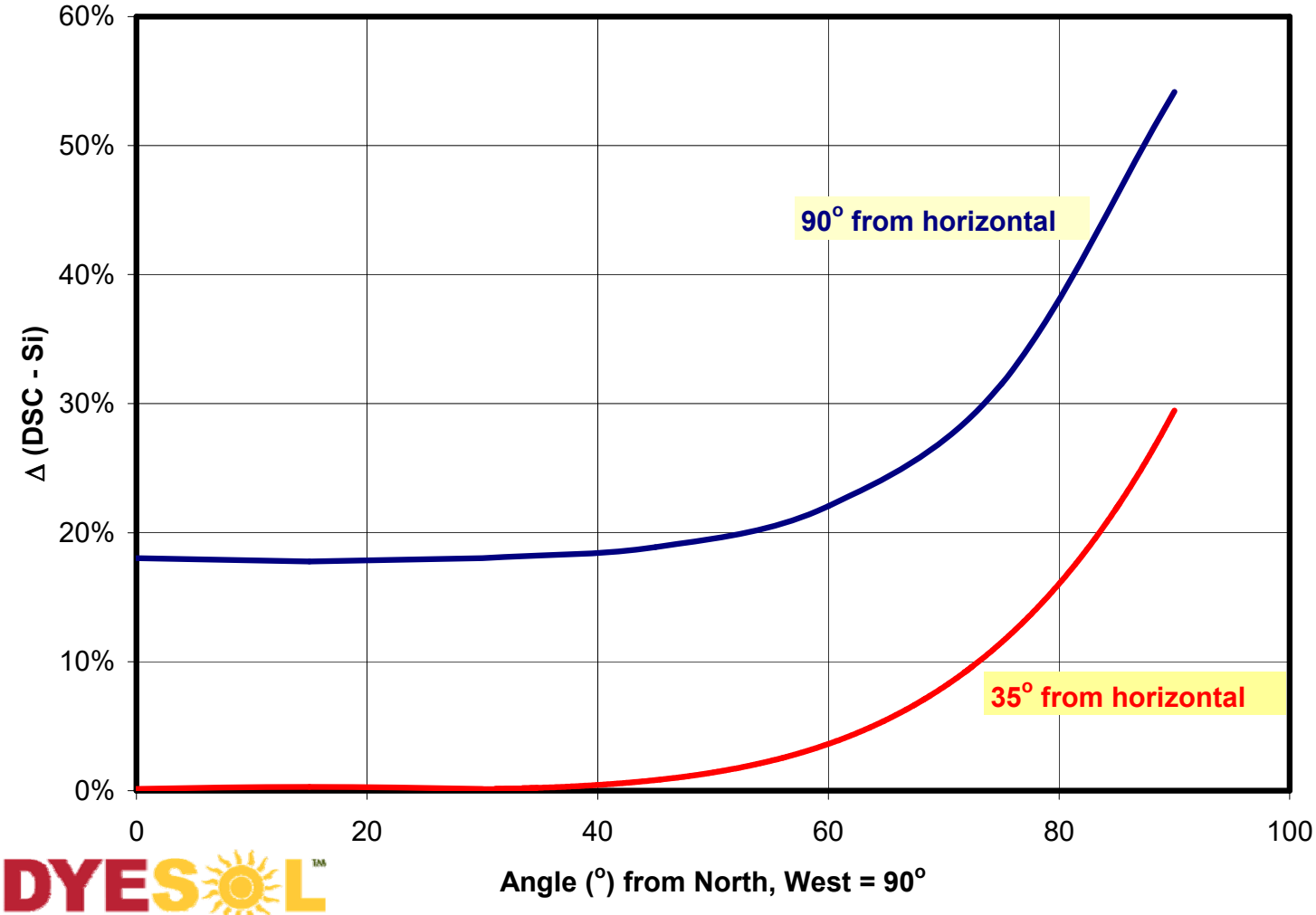
Dye solar cells

Cèl·lules solars de colorant (dye solar cell)



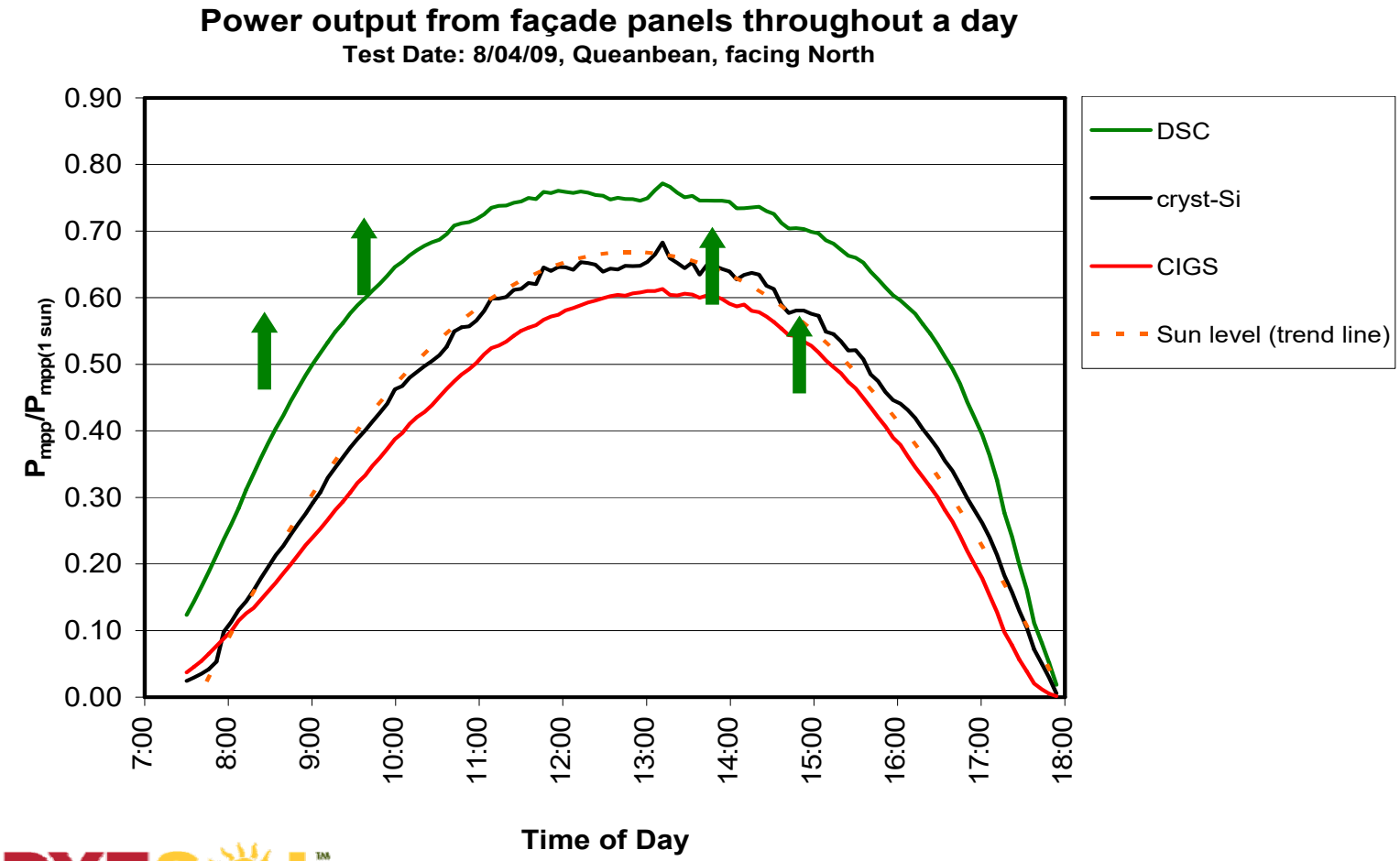
Source: Sony Corporation (2007)

Less Sensitive to the Angle of Incidence (I)



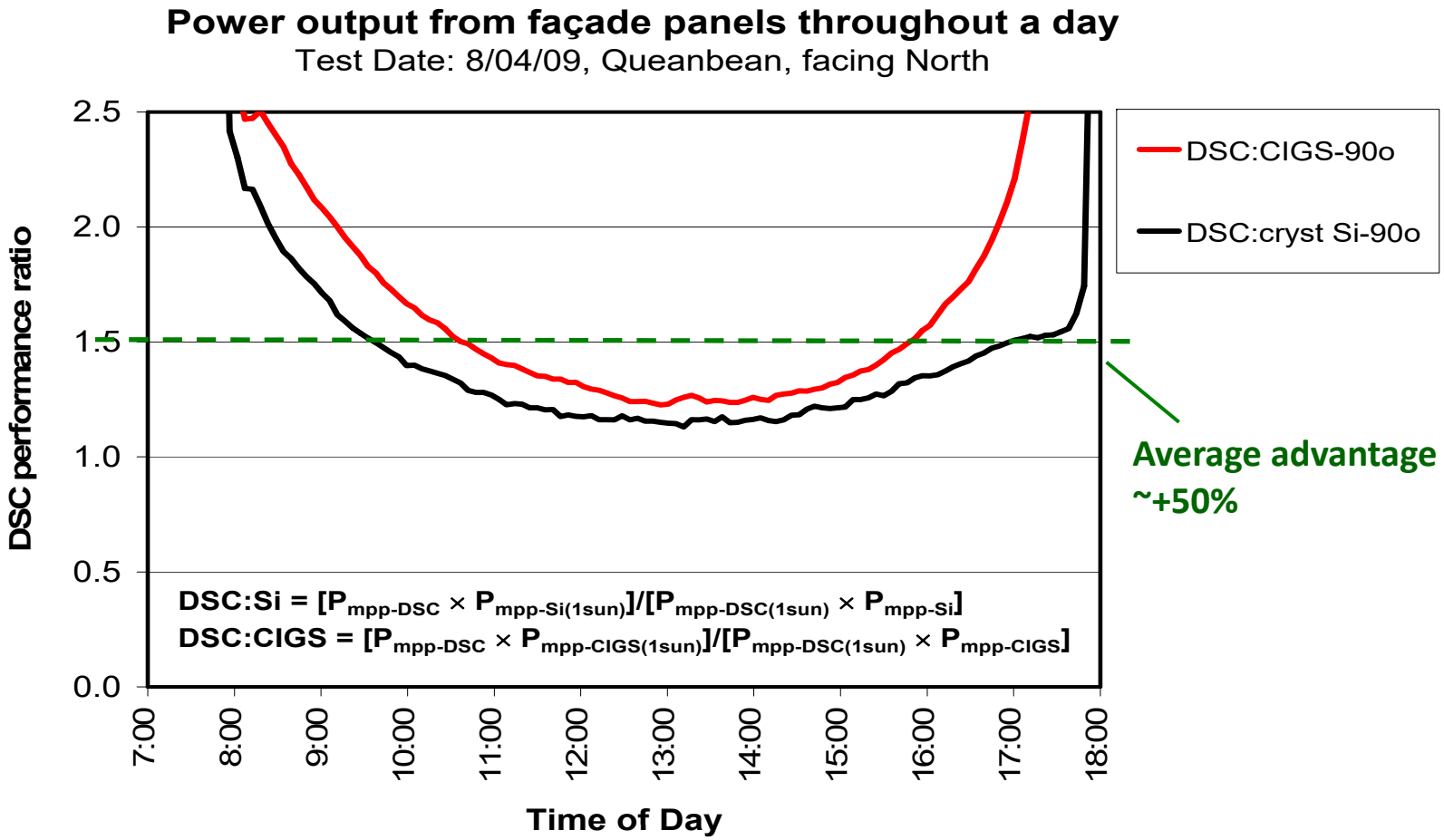
Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Less Sensitive to the Angle of Incidence (II)



Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Less Sensitive to the Angle of Incidence (III)



Courtesy: DYESOL GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

GRUP DE DISPOSITIUS FOTOVOLTAICS I OPTOELECTRÒNICS

Dye solar cells

UNIVERSITAT JAUME•I

Objectives: beat CIGS & Si monocristalline

Producció del 200 % de l'energia consumida

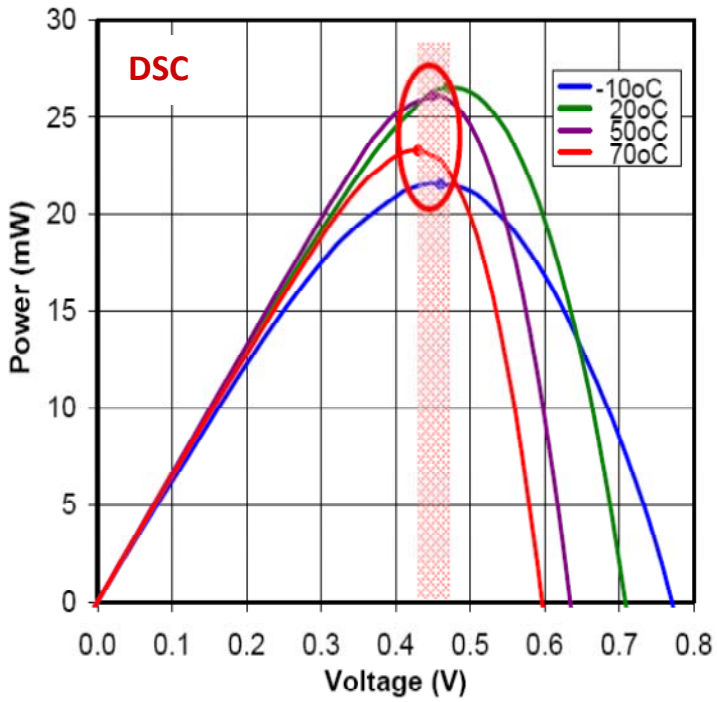
Solar decathlon: http://www.sdeurope.org

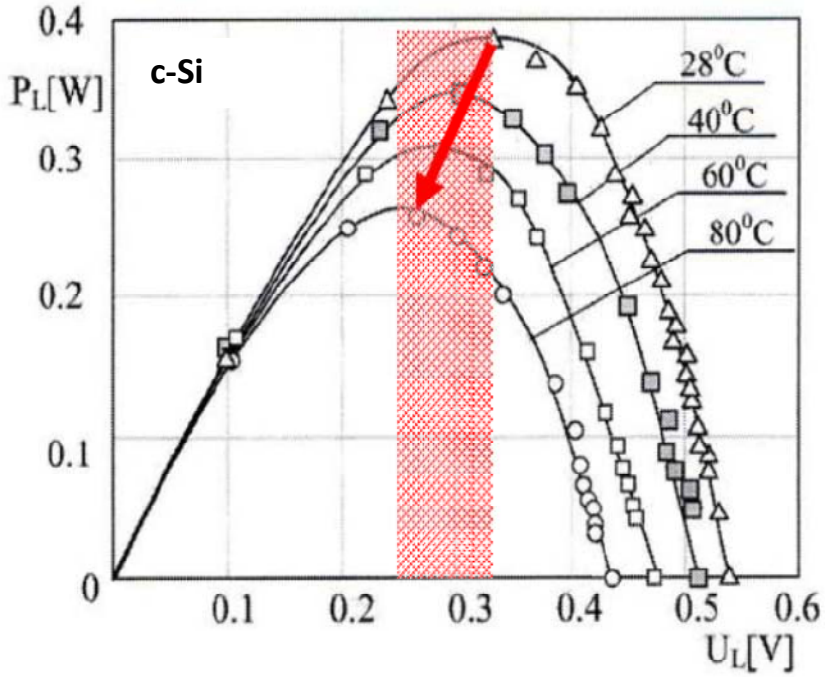
Facades


The Toyota Dream House
AISIN - Japan
DSC
made by
AISIN -SEIKI
http://www.toyota.co.jp/jp/news/04/Dec/nt04_1204.html


DSSC Façade System
at the CSIRO Energy Centre
Newcastle, Australia - DYESOL

Better Relative Performance at High Temperature



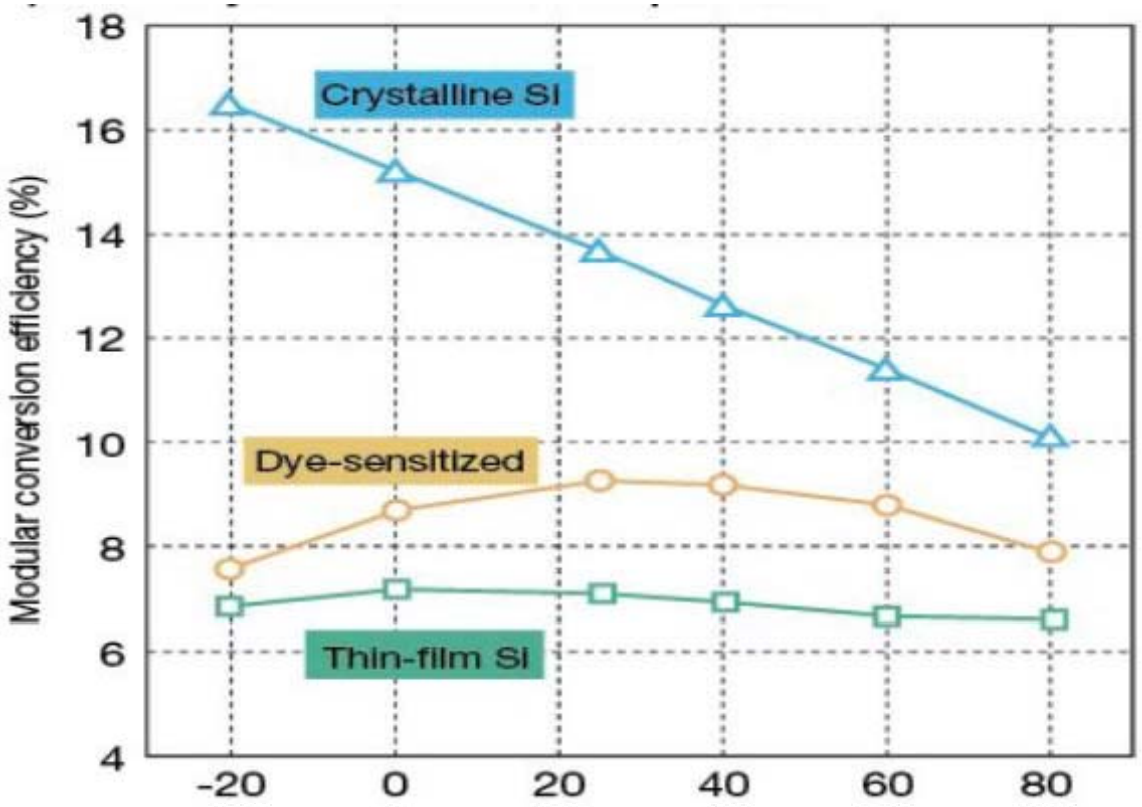


Temperature increase	P_{mpp} drop for DSC	P_{mpp} drop for c-Si
From 20° to 50°C	5%	19.5%
From 20° to 70°C	15%	32.5%

Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

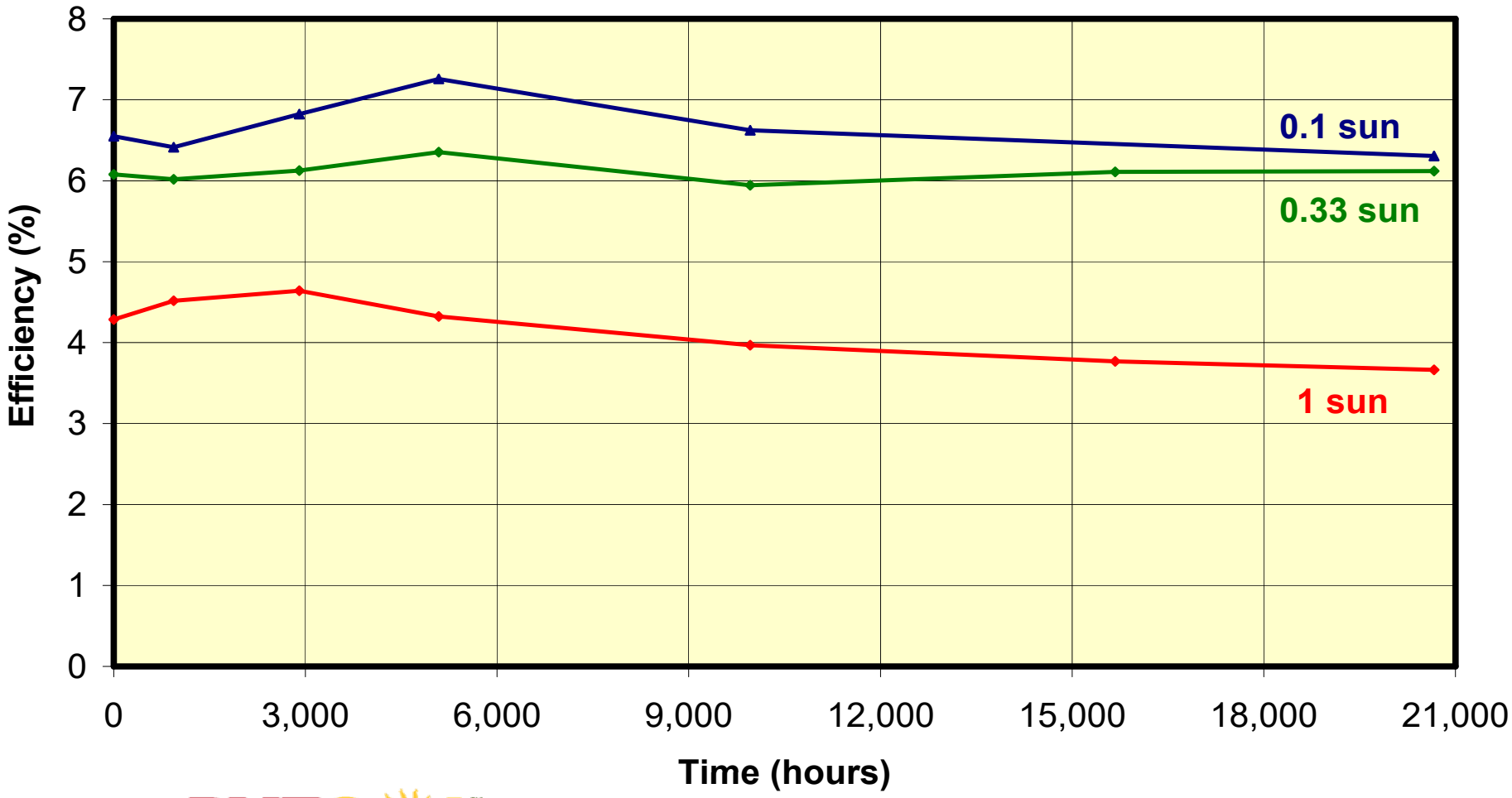
Dye solar cells

Cèl·lules solars de colorant (dye solar cell)



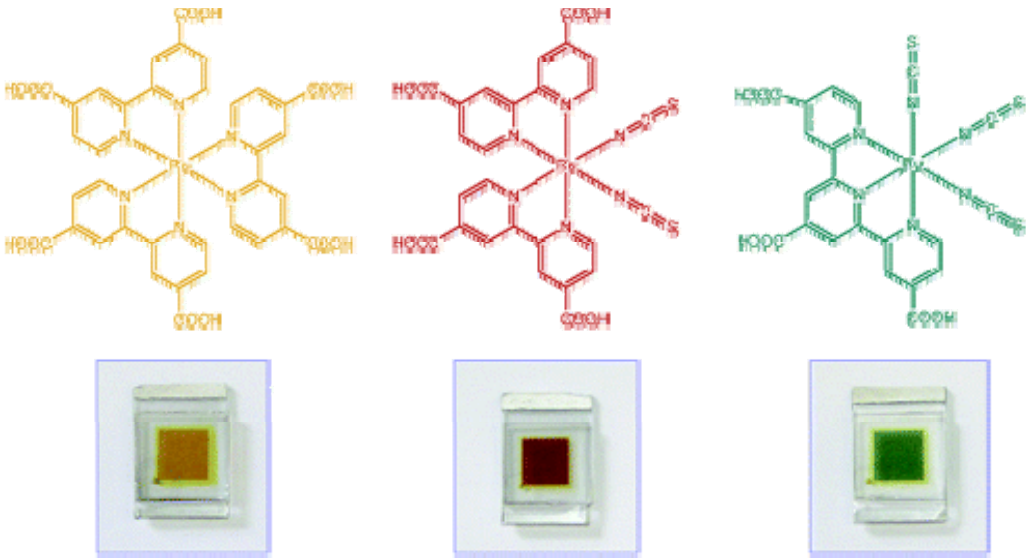
Font: *Tetsuo Nozawa,* Nikkei Electronics Asia (July 2008), Data from Sony

Long Term Stability



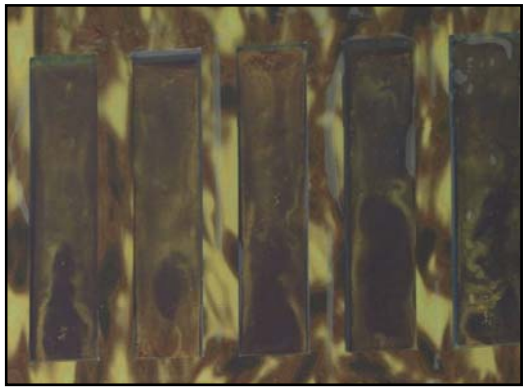
Courtesy: DYESOL GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Versatility (I)



Versatility (II)

- Large palette of coloration
- Patterns



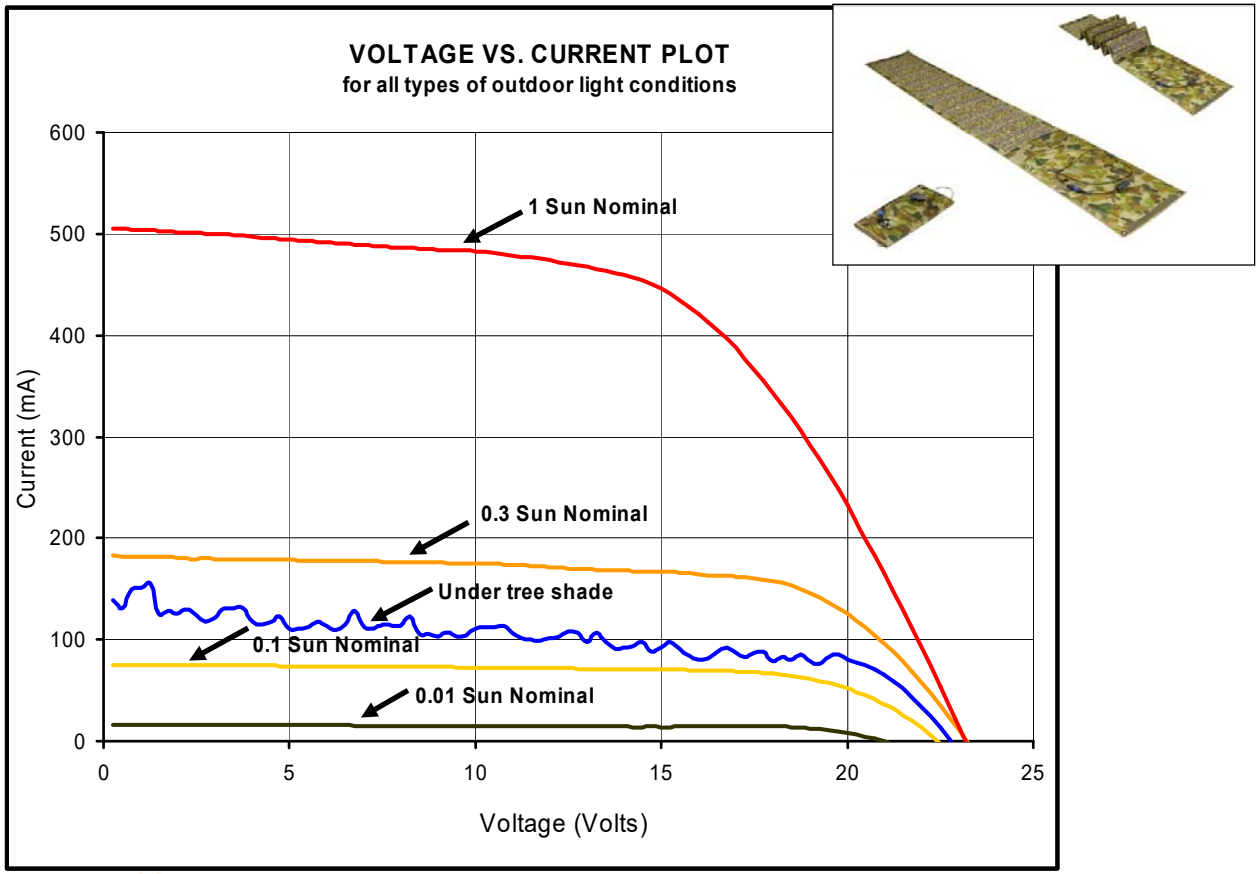
Courtesy: DYESOL GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Flexible Substrates (I)

Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Flexible Substrates (II)

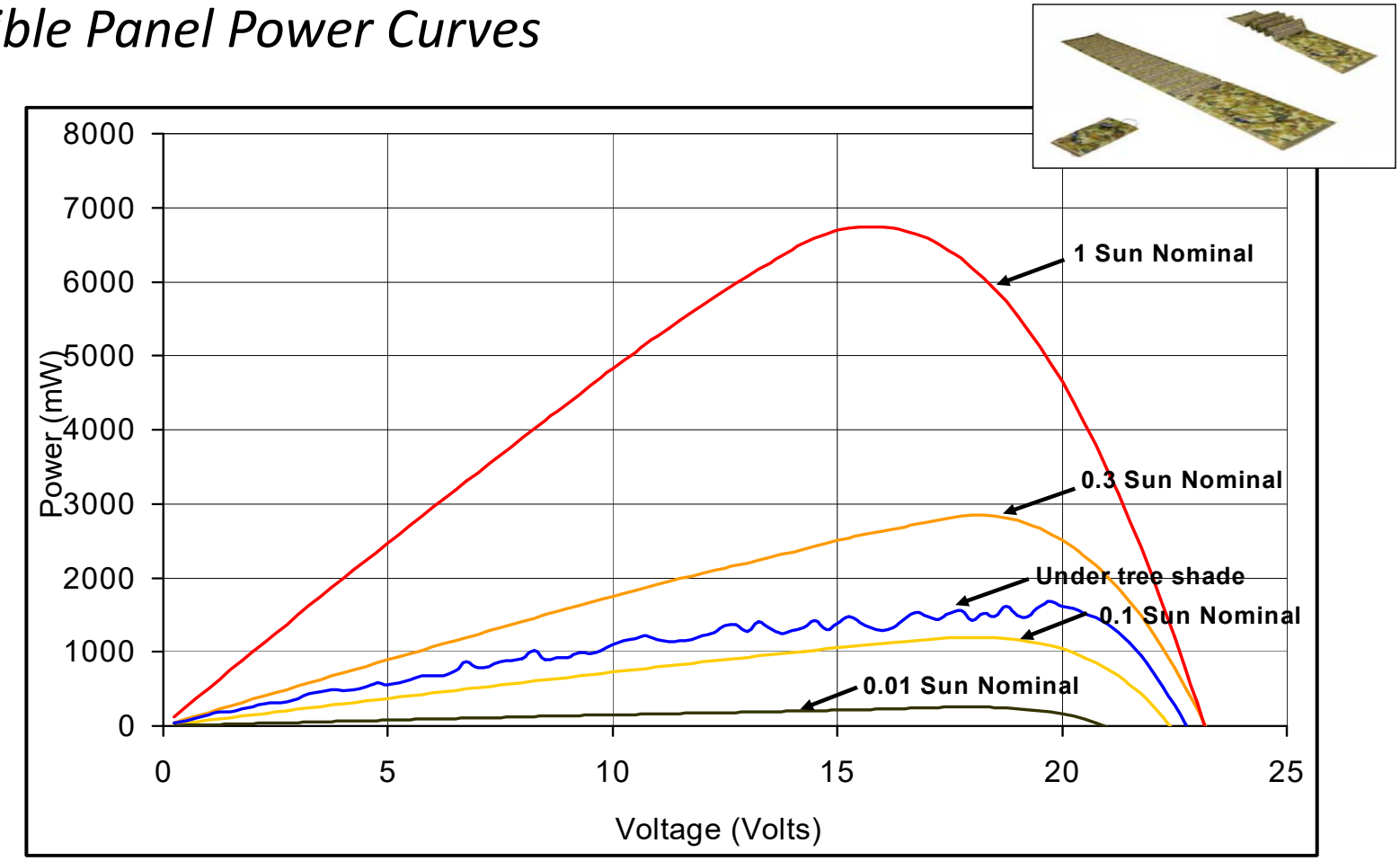
- *Flexible Panel I-V Curves*



Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Flexible Substrates (III)

- *Flexible Panel Power Curves*



Courtesy: DYESOL GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

Flexible Substrates (IV)

- *Can you see the panel?*

Courtesy: DYESOL™ GROUP of COMPANIES Global Leaders in Dye Solar Cell Technology

G24I

G24I builds 120 MeW capacity plant for flexible DSC production in Wales

Adran Menter, Arloesi a Rhwyd
Department for Enterprise Inno
and Networks

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

Tuesday, 17th October 2

WORLD-LEADING SOLAR TECHNOLOGY FIRM TO INVEST IN WALES

A multi-million pound investment into a unique world-leading renewable energy technology is to create up to 300 jobs in South Wales, it was announced today **(Tuesday, 17th October 2006).**

G24 Innovations Ltd (G24i), a new UK registered company (whose major shareholder is Renewable Capital LP of the United States), is to manufacture dye sensitised solar cells – one of the latest, lightest, most efficient and least costly solar technologies in the world – at a 187,000 sq ft facility at Wentloog Park, Cardiff and plans to begin manufacturing early in 2007.

G24i's new cells will have potential application in a wide range of products although the initial market is expected to be for mobile consumer led products such as mobile phone chargers, smart textiles (incorporating the technology into fabrics), emergency and homeland security applications, MP3 players, laptop computers and handheld game consoles.

The company also believes there is an opportunity to integrate the cells in building products that can meet part of a building's energy requirements and further reduce carbon emissions.

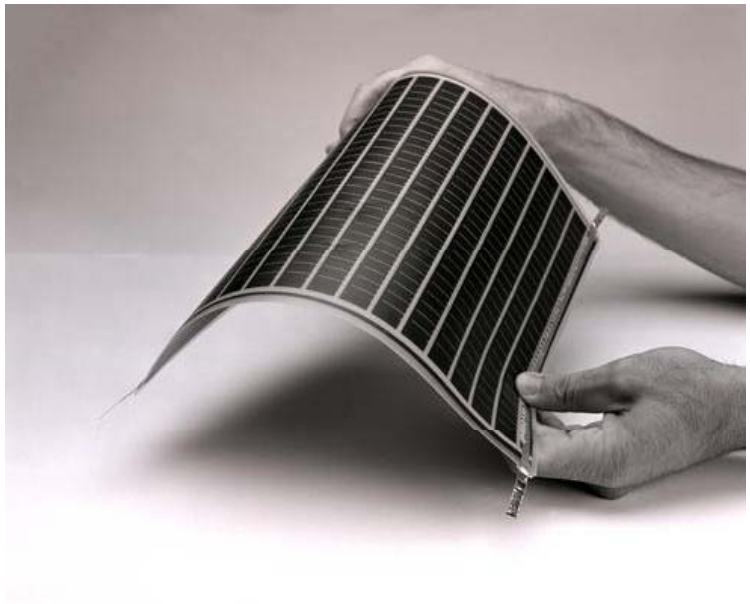
ddion News

Founders of G24I: Ed Stevenson and Robert Hertzberg (64th speaker of Californian State Assembly)

G24I facility

The G24I plant in Cardiff has started production on June 21 (solstice),2007

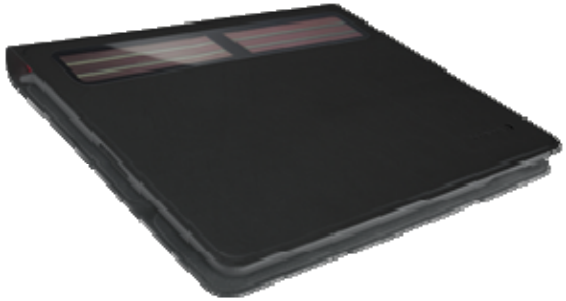
G24I product



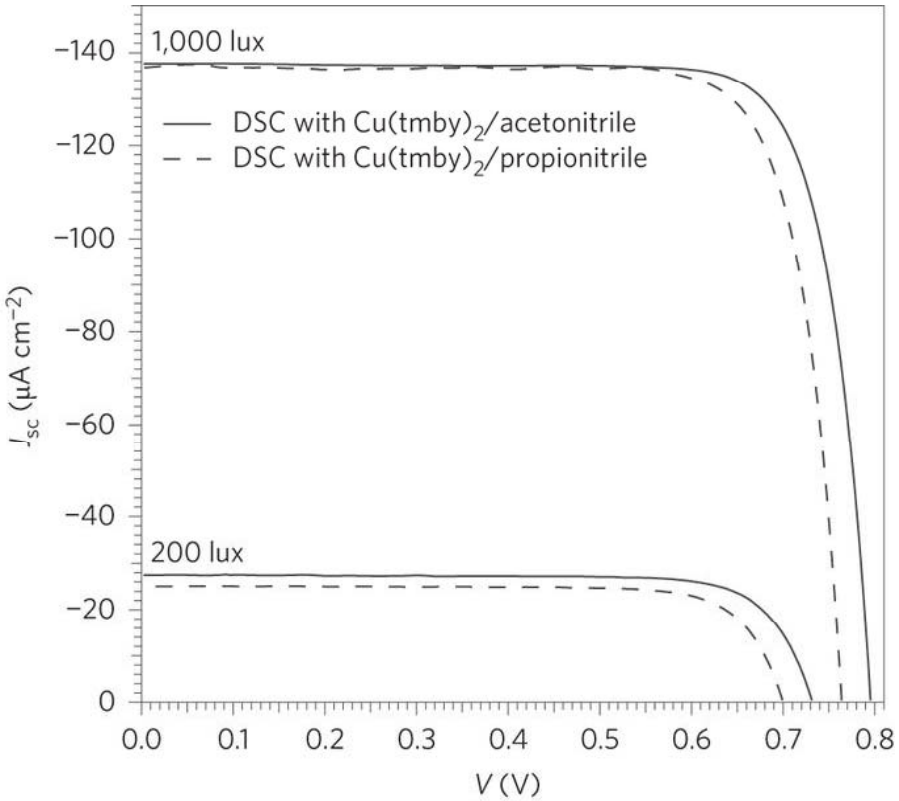
G24I product

The first G24I product is a light weight flexible power supply for mobile telephones

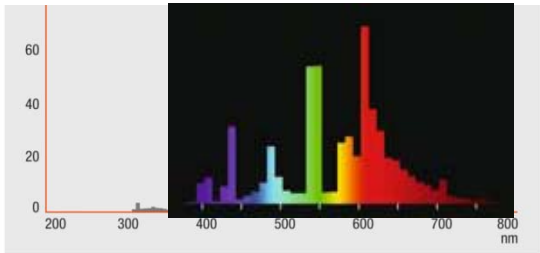
G24I + logitech product



Dye cells strike back



Up to 28.9% efficient under indoor illumination (Osram 930 warm-white fluorescent light tube)



Freitag, M. et al. A. Dye-sensitized solar cells for efficient power generation under ambient lighting. *Nature Photonics* ***2017, 11, 372.***

Conclusions

- Solar Energy is the energy source with higher potentiality to solve the energy problem.
- A full exploitation of solar energy needs the development of cheaper devices in order to attend the grid parity.
- Different technologies have been used for photovoltaic applications. Nanotechnology has the potential for the development of a 3rd generation of solar cells cheaper and more efficient.

Conclusions

- Sensitized solar cells are a good example of a new paradigm in solar cell configuration separating the light absorption from the charge transport processes, allowing relax the quality requirements of materials.

- Sensitized solar cells present a series of interesting advantages for the development of photovoltaic devices: High design freedom, flexibility, versatility…