PHOTOCHEMICAL AND PHOTOVOLTAIC CELLS BASED ON NANOSTRUCTURED WIDE BANDGAP SEMICONDUCTORS

Yu Teng (Tony) Liang

MSE 395, Term Paper Presentation

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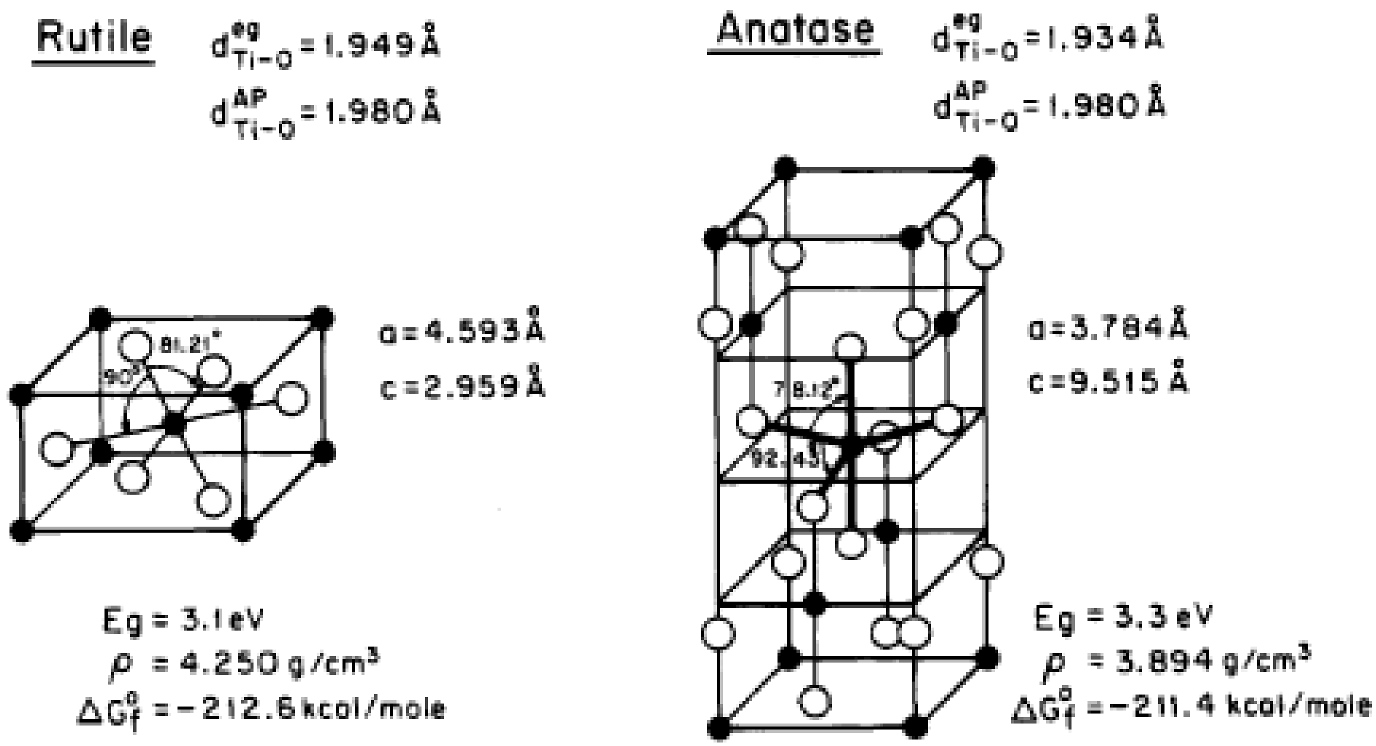
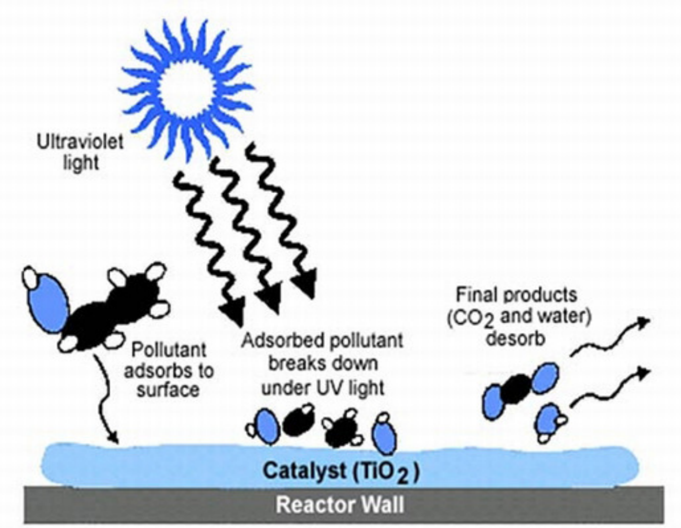
CRYSTAL STRUCTURE OF ANATASE AND RUTILE TiO_2



- Fujishima and Honda discovered TiO2 photocatalysis in 1972

Linsebigler, et al., Photocatalysis on TiO2 Surfaces: Principles, Mechanisms, and Selected Results. *Chemical Review*, 1195, 95, 735-758.

TiO_2 AS PHOTOCATALYSTS

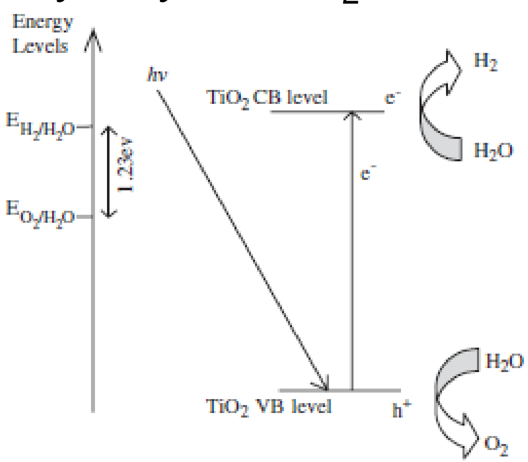


- 3.0-3.4eV band gap and absorbance in UV
- Oxidative:
  - Air urification
  - Waste water treatment
  - Anti-fogging, anti-bacterial, and self-cleaning surfaces
- Redox:
  - Hydrolysis, solar hydrogen generation
- Reductive:
  - Reduction of CO_2 into hydrocarbonsp

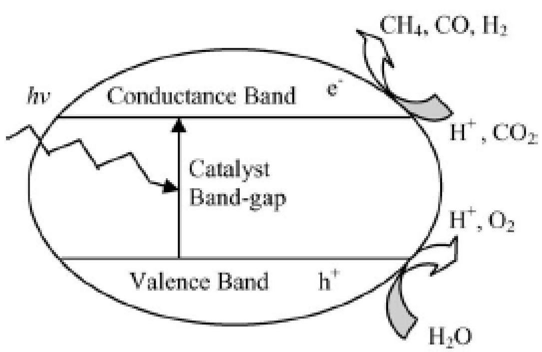
Nanoprotect Inc., http://www.nanoprotect.co.uk/photocatalyst.html

ELECTROCHEMICAL POTENTIAL AND PROPOSED REACTION MECHANISMS

Hydrolysis of H_2O:



Photoreduction of CO_2:



Proposed Photoreductive Mechanism:

$$TiO_2 + h\nu \rightarrow (h^+ + e^-)$$

$$\begin{cases} H_2O + h^+ \xrightarrow[TiO_2]{} \cdot OH + H^+ \\ \cdot OH + H_2O + 3h^+ \xrightarrow[TiO_2]{} O_2 + 3H^+ \end{cases}$$

$$2H_2O + 4h^+ \xrightarrow[TiO_2]{} O_2 + 4H^+$$

$$\begin{cases} CO_2 \xrightarrow[TiO_2]{} CO + \frac{1}{2}O_2 \\ CO \xrightarrow[TiO_2]{} \cdot C + \frac{1}{2}O_2 \end{cases}$$

$$CO_2 \xrightarrow[TiO_2]{} \cdot C + O_2$$

Resulting,

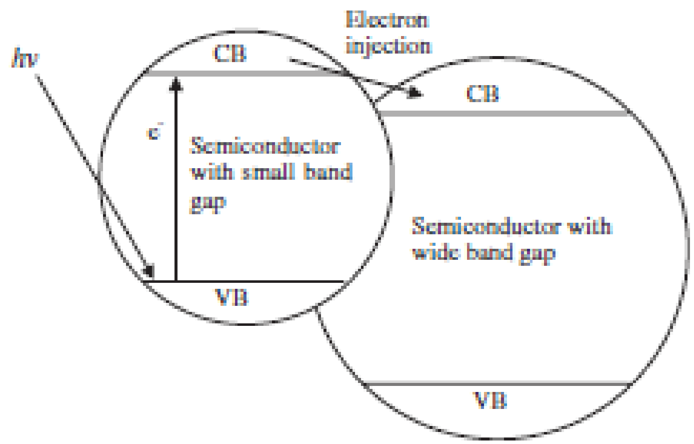
$$\cdot C + 4H^+ + 4e^- \xrightarrow[TiO_2]{} CH_4$$

$$2H^+ + 2e^- \xrightarrow[TiO_2]{} H_2$$

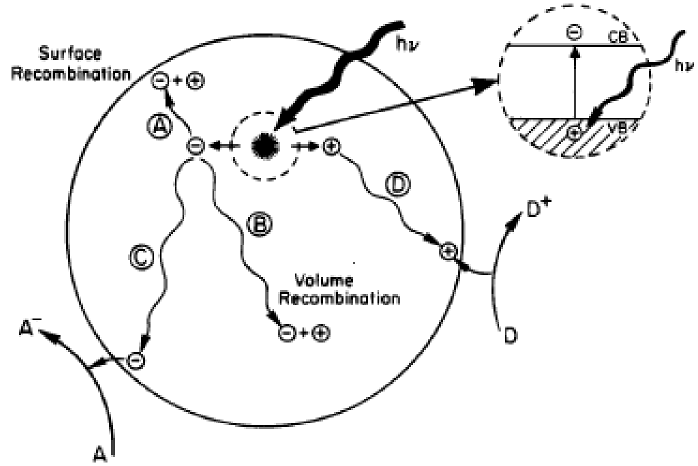
Top Left: Ni, et al., A Review and Recent Developments in Photocatalytic Water-Splitting. *Renewable and Sustainable Energy Reviews*. 2007, 11, 401-425.
Bottom Left: and Right: Tan, et al. Photocatalytic reduction of carbon dioxide into gaseous hydrocarbon using TiO2 pellets. *Catalysis Today*, 2006, 115, 269-273.

SCHEMES FOR CATALYTIC ENHANCEMENT OF TiO_2 MEMBRANES

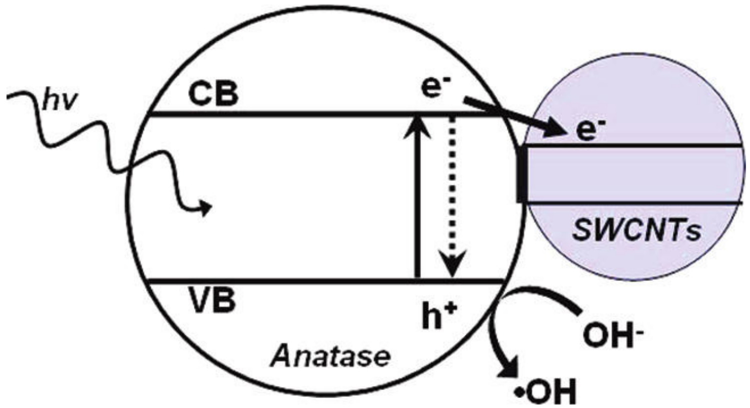
Semiconductor Composite:



Catalytic Efficiency Hindered by Recombination:



Metallic/Nanotube Composites:



Left: Linsebigler, et al., Photocatalysis on TiO2 Surfaces: Principles, Mechanisms, and Selected Results. *Chemical Review*, 1995, 95, 735-758.
Bottom Right: Yao, Y., et al., Photoreactive TiO2/Carbon Nanotube Composites: Synthesis and Reactivity. *Environmental Science & Technology, 2008.,* 42: 4952-4957.
Top Right: Ni, et al., A Review and Recent Developments in Photocatalytic Water-Splitting. *Renewable and Sustainable Energy Reviews*. 2007, 11, 401-425.

DYE-SENSITIZED SOLAR CELLS

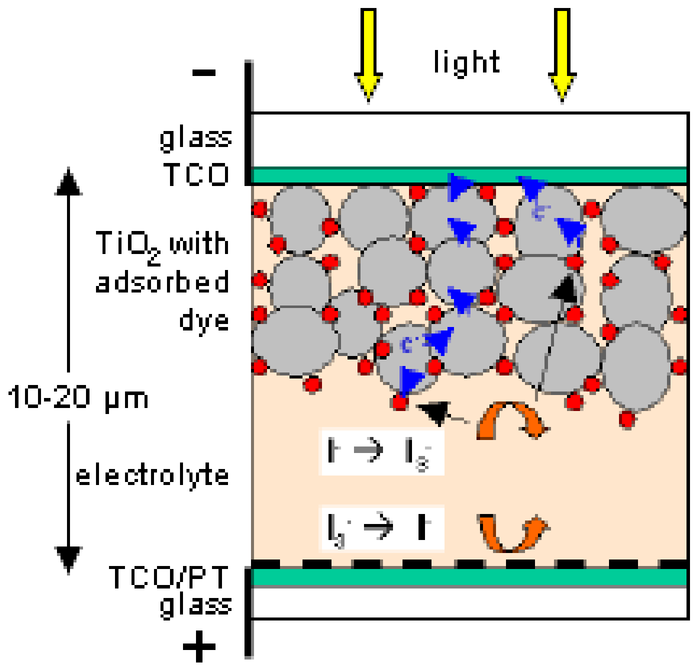


Fig. 1: Schema of dye-sensitezed solar cell

- Lower materials (dye, TiO_2) cost than traditional silicon and thin film photovoltaics
- Efficiency above 10% have been demonstrated
- Can be made flexible using flexible substrates and thin electrodes

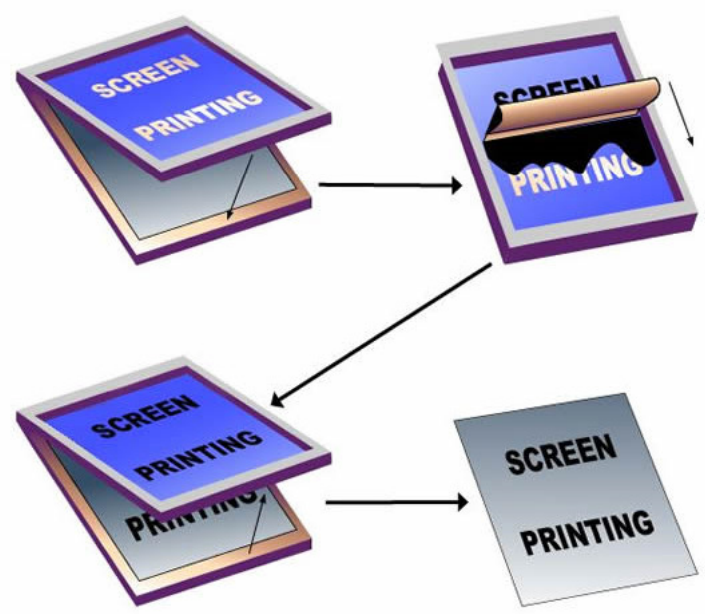
Open Loop Dye Sensitized Solar Cells: http://www.loop.ph/bin/view/Openloop/DyeSensitizedSolarCells

MANUFACTURE OF THIN FILM AND DYE-SENSITIZED SOLAR CELLS

Roll to Roll CIGS Processing:

CIGS Panel Geometry:

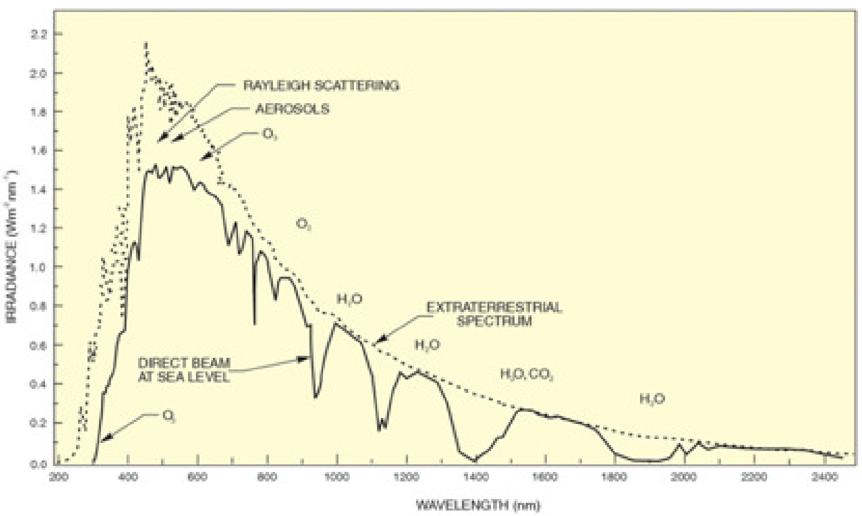
Dye Sensitized Solar Cell Electrodes are Screen Printed:



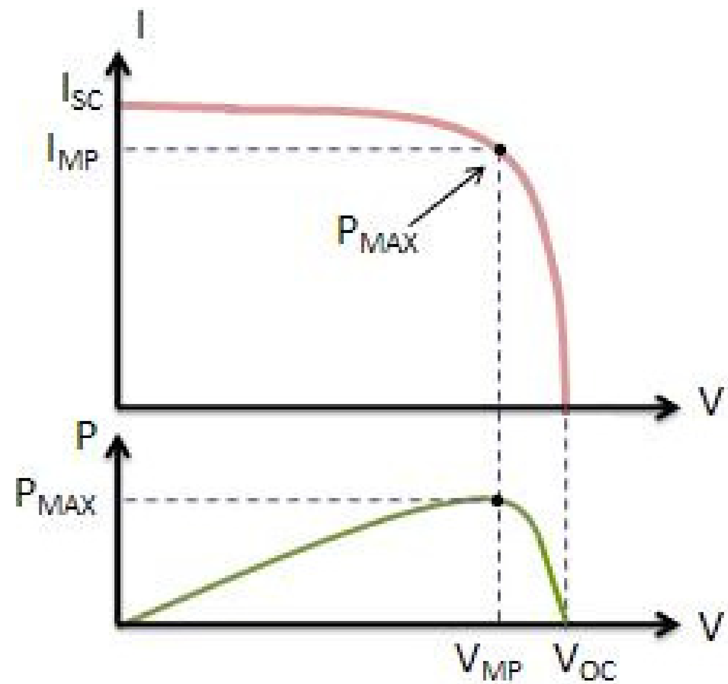
Top Left: Nanosolar Inc., http://www.nanosolar.com
Bottom Left: Solyndra, Inc., http://www.solyndra.com
Right: International Paper Knowledge Center: http://glossary.ippaper.com

Photovoltaic Testing and Efficiency Determination

Extraterrestrial and Atmospheric Solar Spectrum:



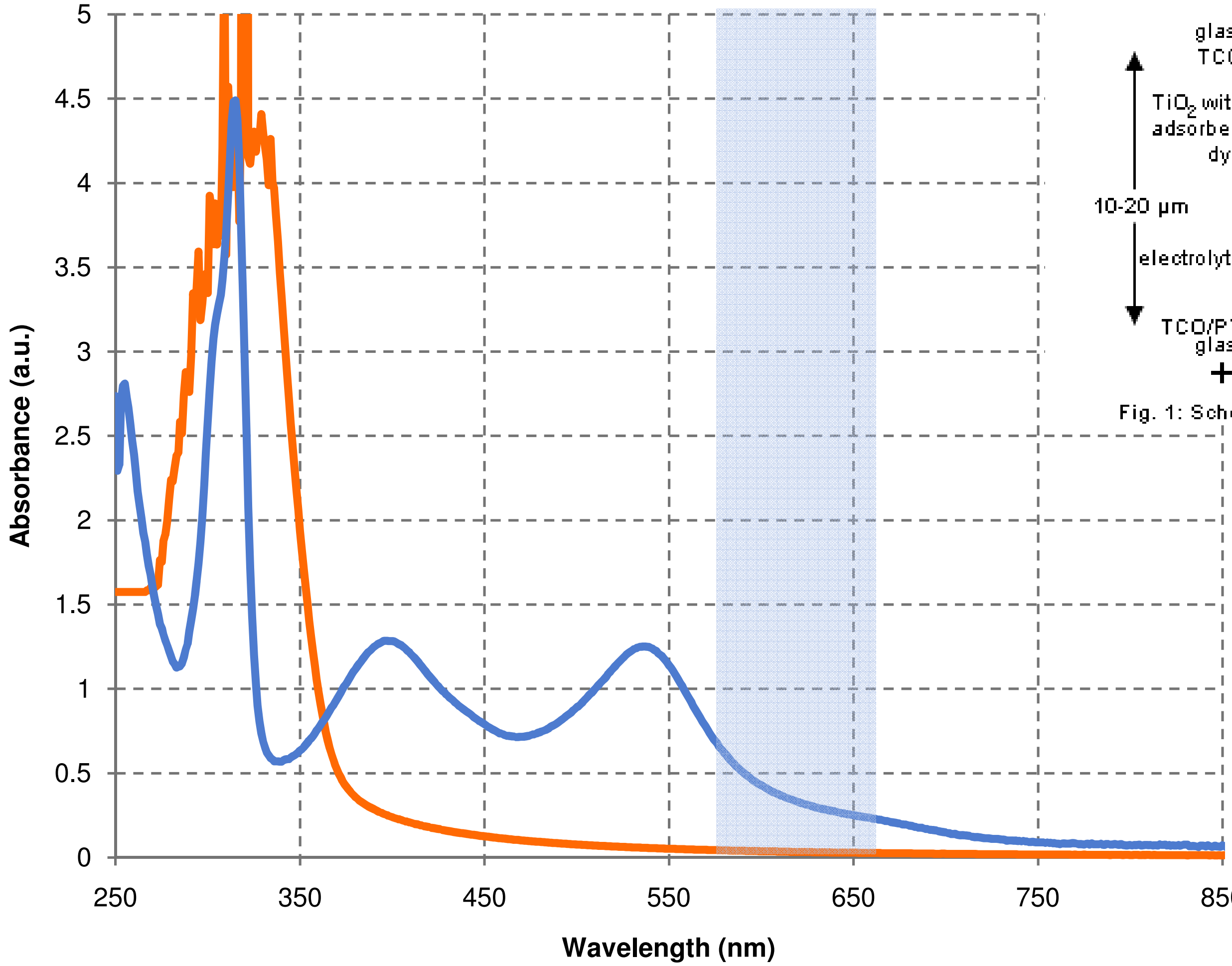
I-V Curves and Efficiency Extraction:



- Dye-sensitized solar cells are colored depending on the dye absorbance

Top Left: Newport Corp., http://www.newport.com
Bottom Left: Solaronix, Inc., http://www.solaronix.com
Right: National Instruments Corp., http://www.ni.com.

Optical Absorbance of Dye-Sensitized Cell Components



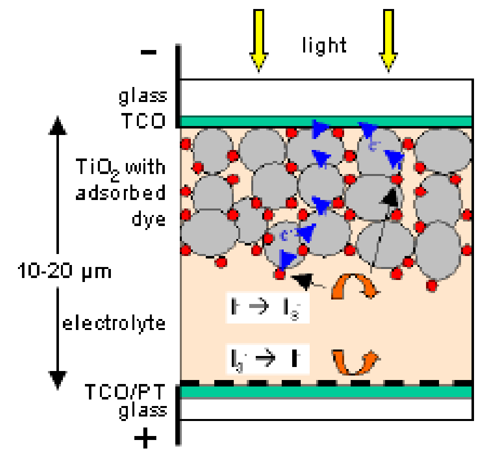
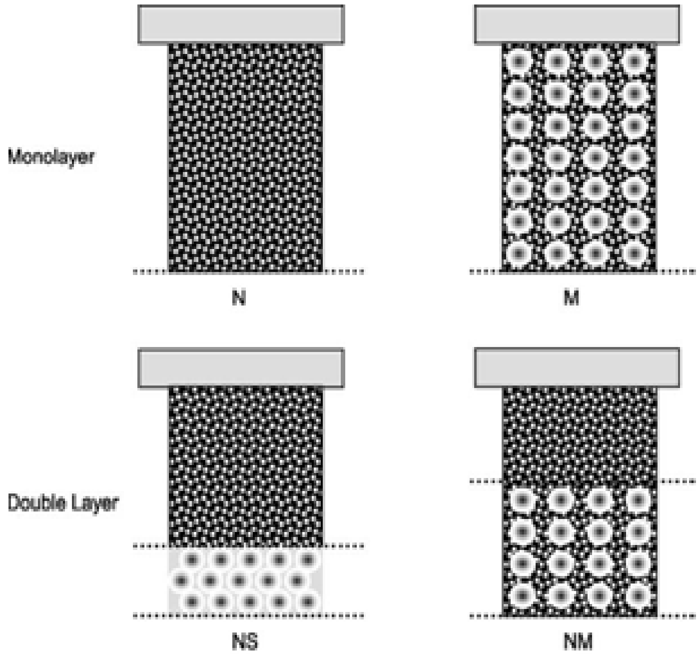


Fig. 1: Schema of dye-sensitezed solar cell

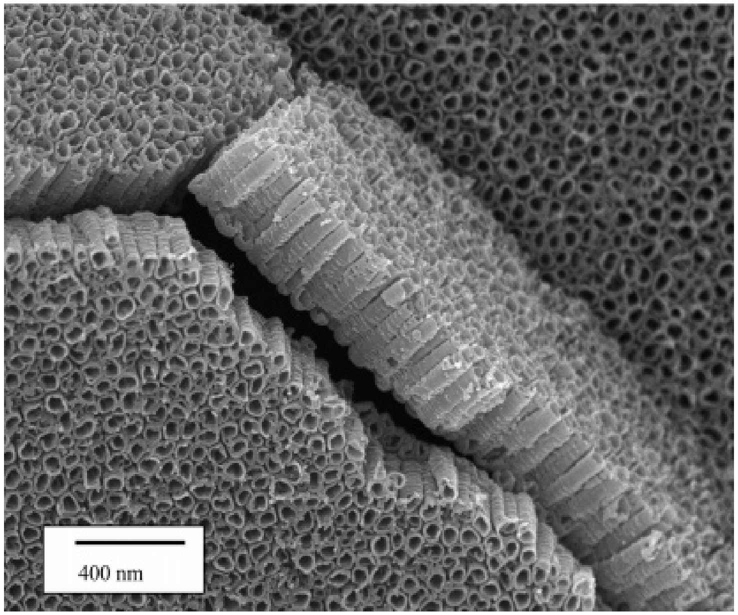
Open Loop Dye Sensitized Solar Cells: http://www.loop.ph/bin/view/Openloop/DyeSensitizedSolarCells

SCHEMES FOR IMPROVING ELECTRON TRANSPORT IN TiO_2

Back reflecting unabsorbed low wavelength light:



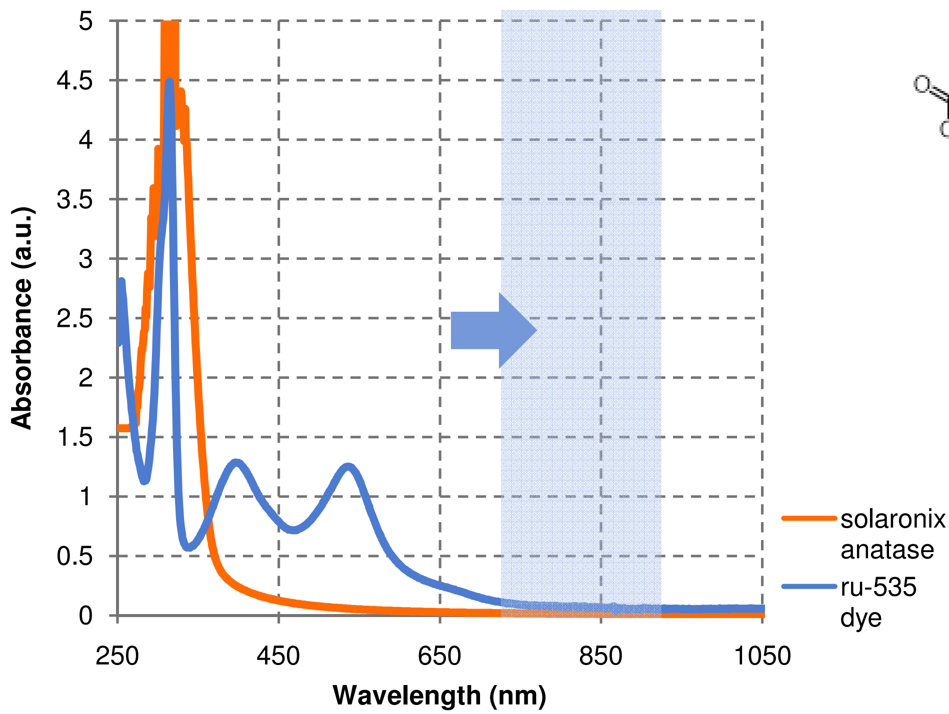
One dimensional electron transport confinement:

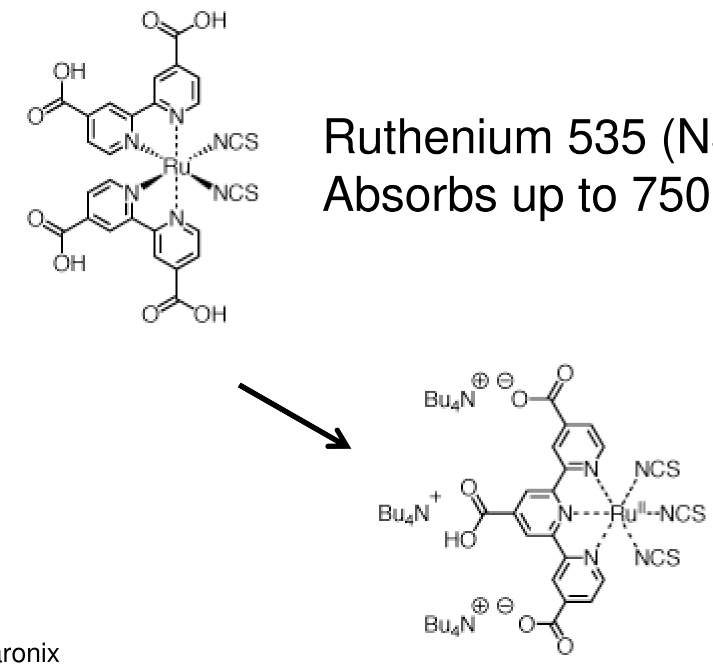


Left: Wang, et al., Significant Influence of TiO2 Photoelectrode Morphology on the Energy Conversion Efficiency. *Coordination Chemistry Reviews*, 2004, 1381-1389.
Right: Mor, et al., Use of Highly-ordered TiO2 Nanotube Arrays in Dye-sensitized Solar Cells, *Nano Letters*, 2006, 6, 215-218.

DEVELOPMENT OF STABLE "BLACK" DYES

Increase Near IR Absorbance:



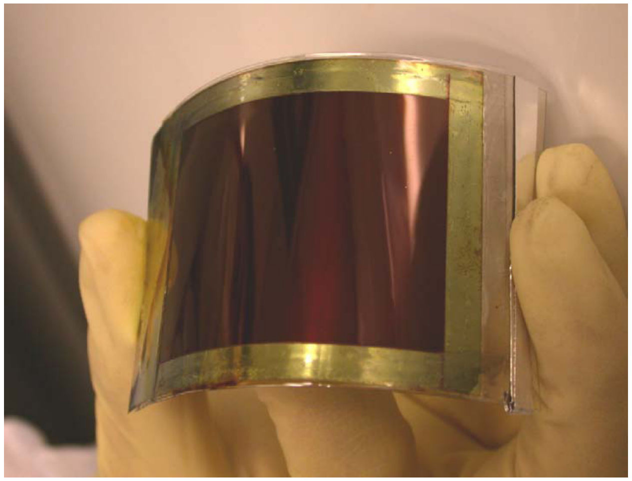


Ruthenium 535 (N3):
Absorbs up to 750nm

Ruthenium 620-1H3TBA:
Absorbs up to 920nm

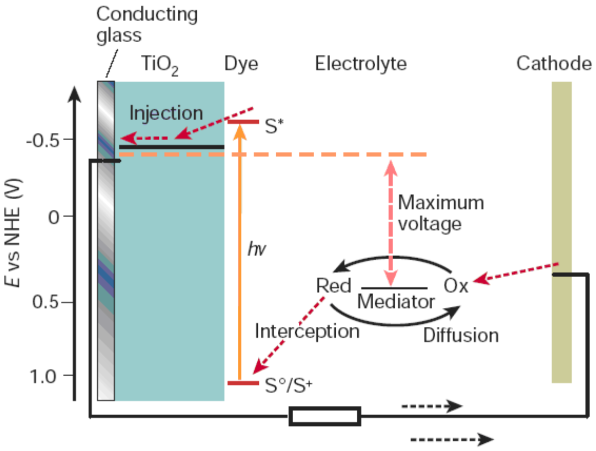
Solaronix Inc., http://www.solaronix.com

Flexible Substrate Incorporation and Electrolyte Sealing



- Flexible substrates available for Electrode Deposition:
  - Stainless Steel (2.4%)
  - ITO coated PET
- Device Lifetimes not proven

- Molten salt electrolytes with efficiency up to 8.2%
- Suffers from decreased open cell voltage and decreased flux



Top: Kang, et al., A 4.2% Efficient Dye-sensitized TiO2 solar cell using stainless steel substrate. *Solar Energy Materials and Solar Cells*, 2006, 90, 574-581.
Bottom: Bach, Monash University, Chemistry Department, http://www.chem.monash.edu.au/staff/bach/research.html