Nanostructured Materials for Decentralized Power Generation

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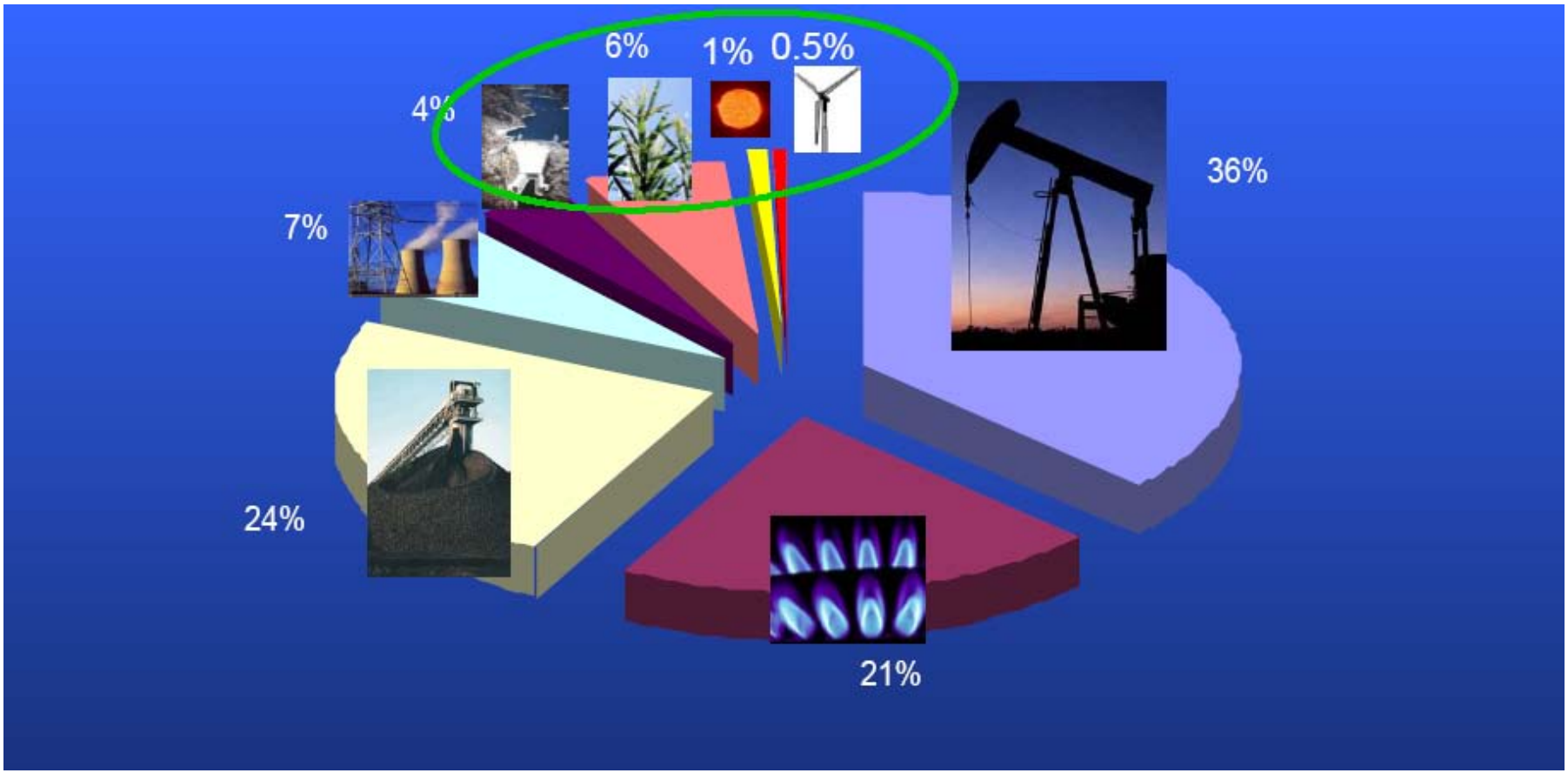
Outline

- Introduction
- Silicon-based Solar Cells
- Three Generations of Solar Cells
- Photocatalysis
- Artificial Photosynthesis
- Quantum Dots and Solar Cells
- Concluding Remarks

World Energy Consumption

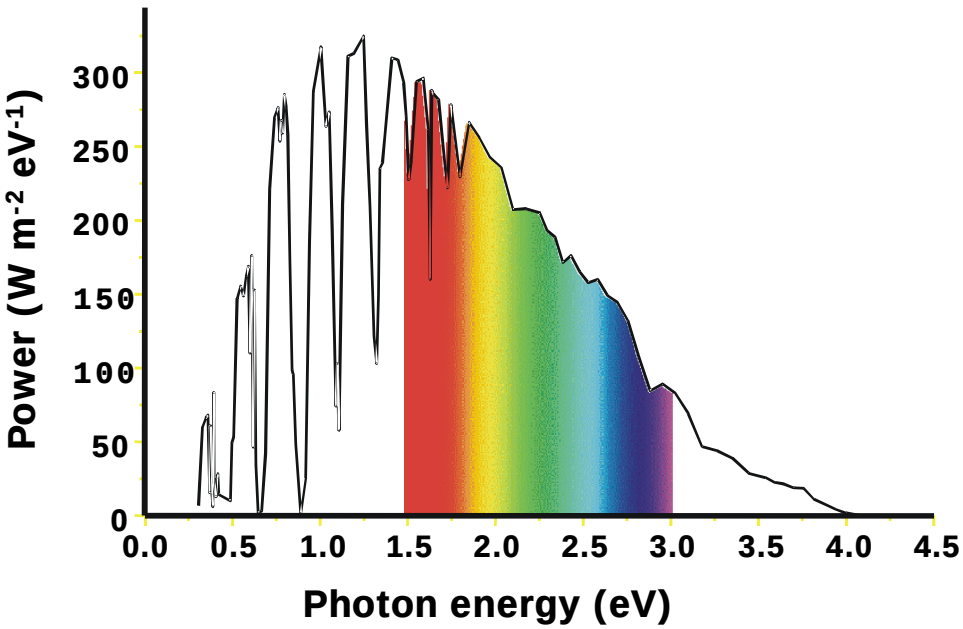


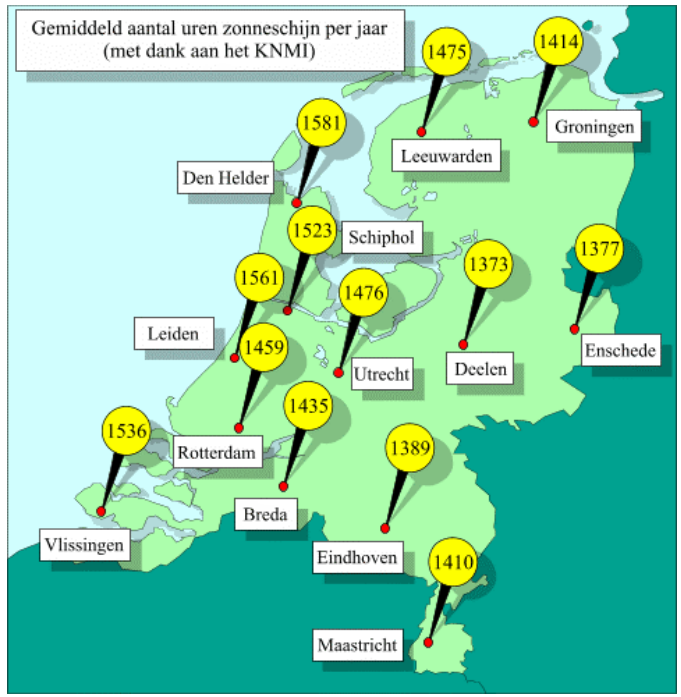
The most energies used are the **cheapest** and the **most polluting** ones.

Environmental Protection

Preventing dangerous climate change is as much a precondition for prosperity and public well-being as national security and public health!

Solar Irradiation





- sunlight power received by the earth is 120 x 10^{15} W
- AM 1.5 irradiation power density = 1000 W m^{-2}
- solar energy received is 5 x 10^{6} EJ / year (EJ = 10^{18} J)
- total energy demand in 2003 is 400 EJ / year
- mankind needs 20 x 10^{6} Wh per person per year = 1 hour of sunlight per year!!!

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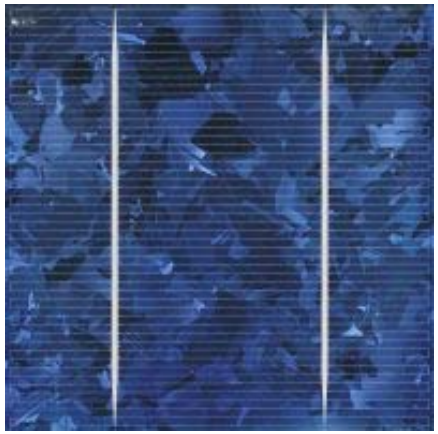
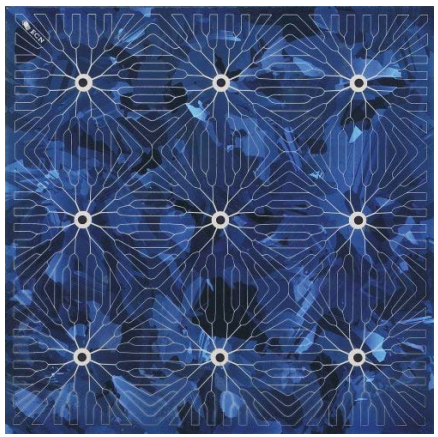
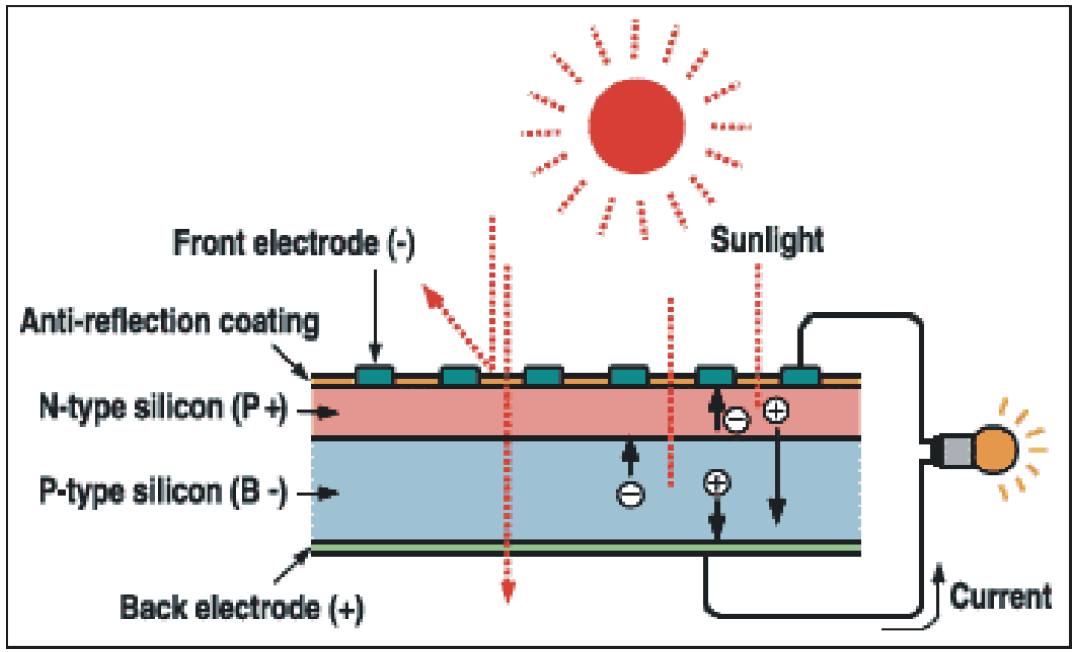
First Generation Solar Cells



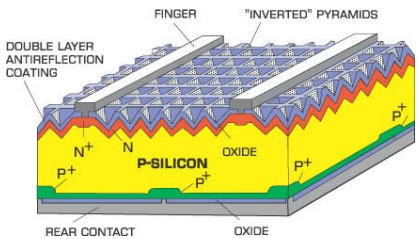




- Crystalline silicon wafers
- 0.3 mm thick
- 99.9999 % pure material
- 15 % conversion efficiency
- too expensive

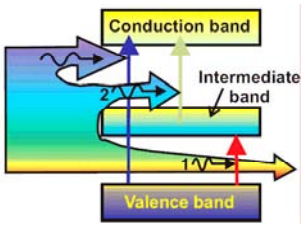
Three generations of solar cells

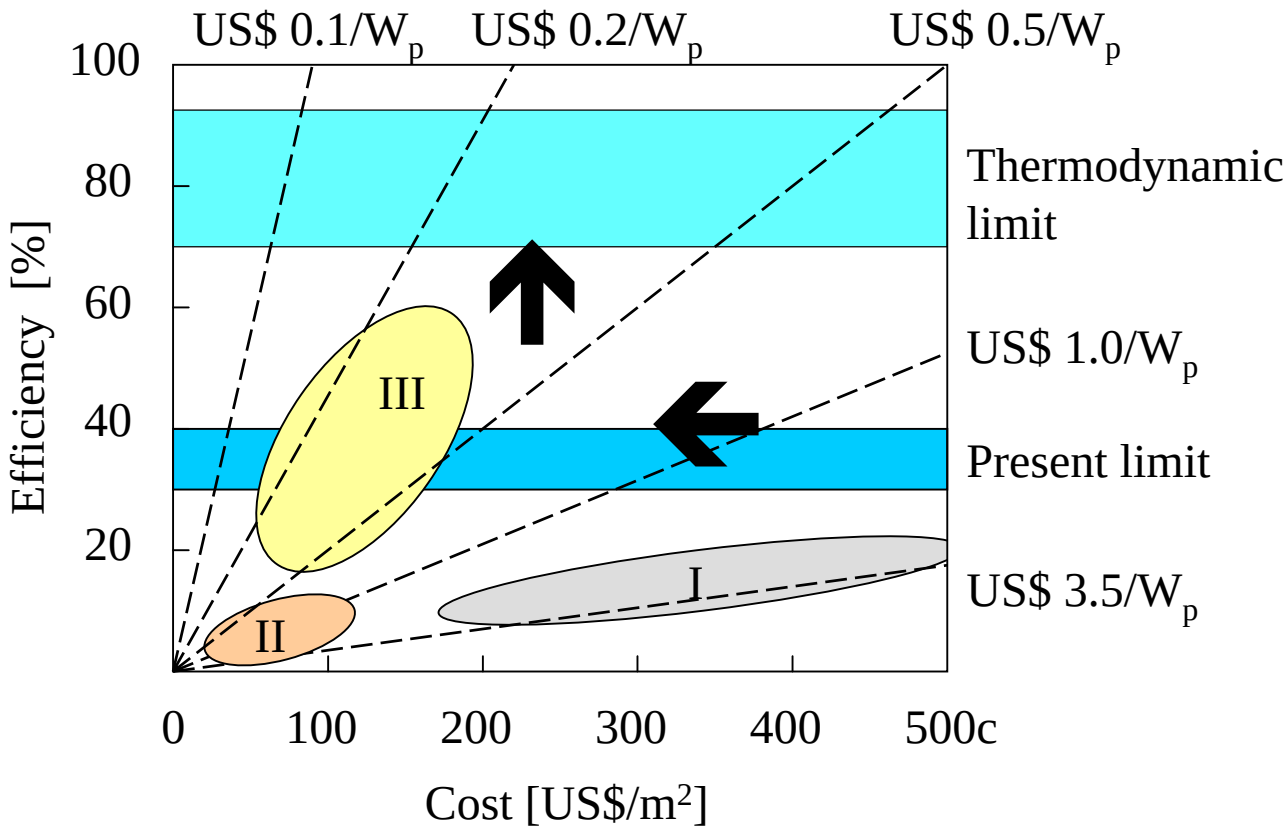
I. Wafer based Si



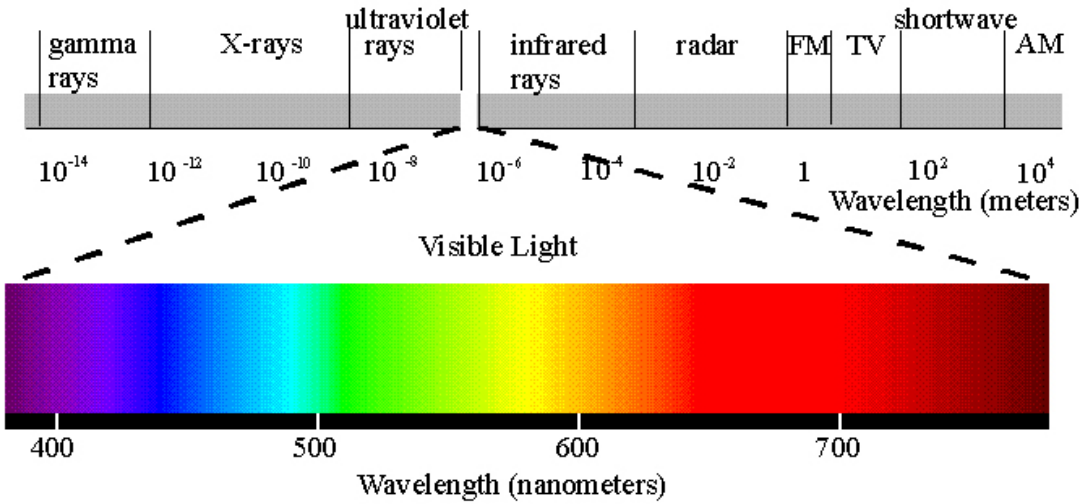
II. Thin films

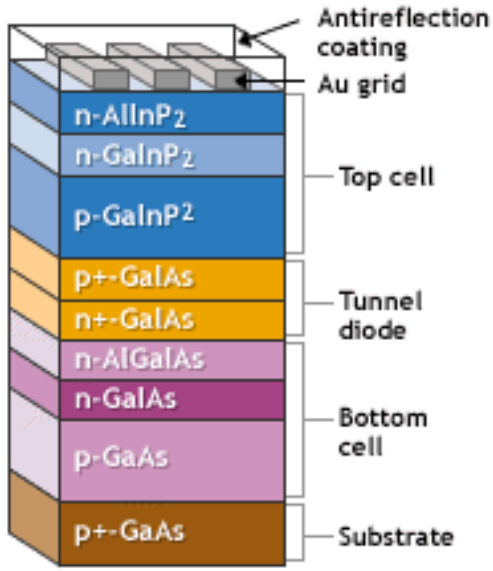
III. Cheap and efficient





High efficiency solar cells





Optimal use is made of solar energy when for every wavelength a dedicated solar cell is available.

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The Power of Light

At room temperature, the average energy of an electron is 0.025 eV

One green light photon has an energy of 2.5 eV *at room temperature!*

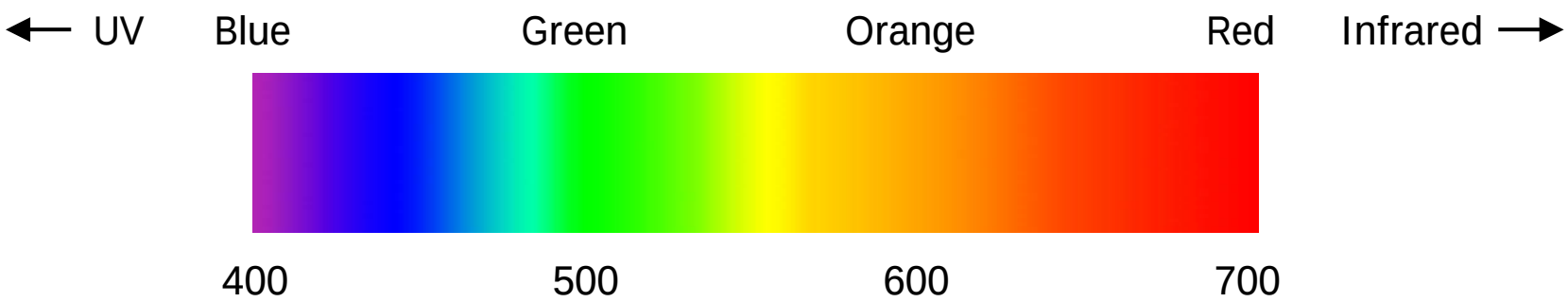

Photo-catalysis: using light to drive chemical reactions

Photo-Catalysts need to be cheap...

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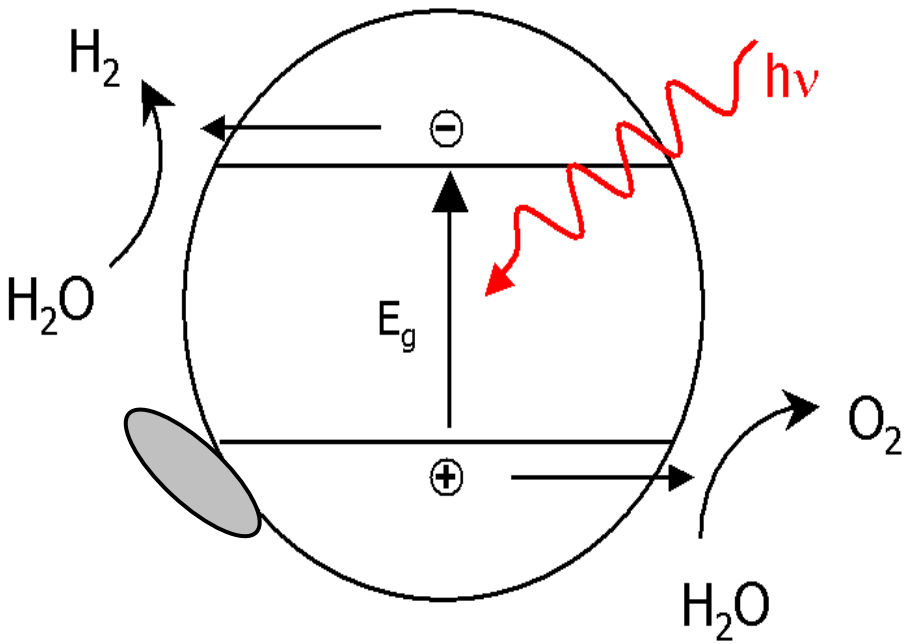
Photo-Catalysis with Semiconductors



Efficiencies < 2%

1 photon
=
100-300 kJ/mole!

Applications:

- Hydrogen production
- Solar-to-fuel (e.g. CO_2 to MeOH)
- NO_x remediation
- Waste-water purification
- Selective oxidation of hydrocarbons (e.g. cyclohexane → cyclohexanone)

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Photo-catalytically Active Pavement

DeNOx pavement

- Based on TiO_2 photocatalyst
- NO_x is converted into nitrates (HNO_3)
- Rain removes nitrates (re-activation of catalyst surface)
- 50 m^2 neutralises *annual* NO_x exhaust of one car

Test locations:

- Marathon road, Vlaardingen
- Antwerp (Belgium)

Developed in ’79 by Mitsubishi
First test in Japan in 1997
Dutch company: Struyk Verwo

$$TiO_2 + NO(g) + light \xrightarrow{O_2, H_2O} HNO_3$$

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Air Purification – The Japanese Way!

The photosynthesis of plants

CO_2

O_2

H_2O

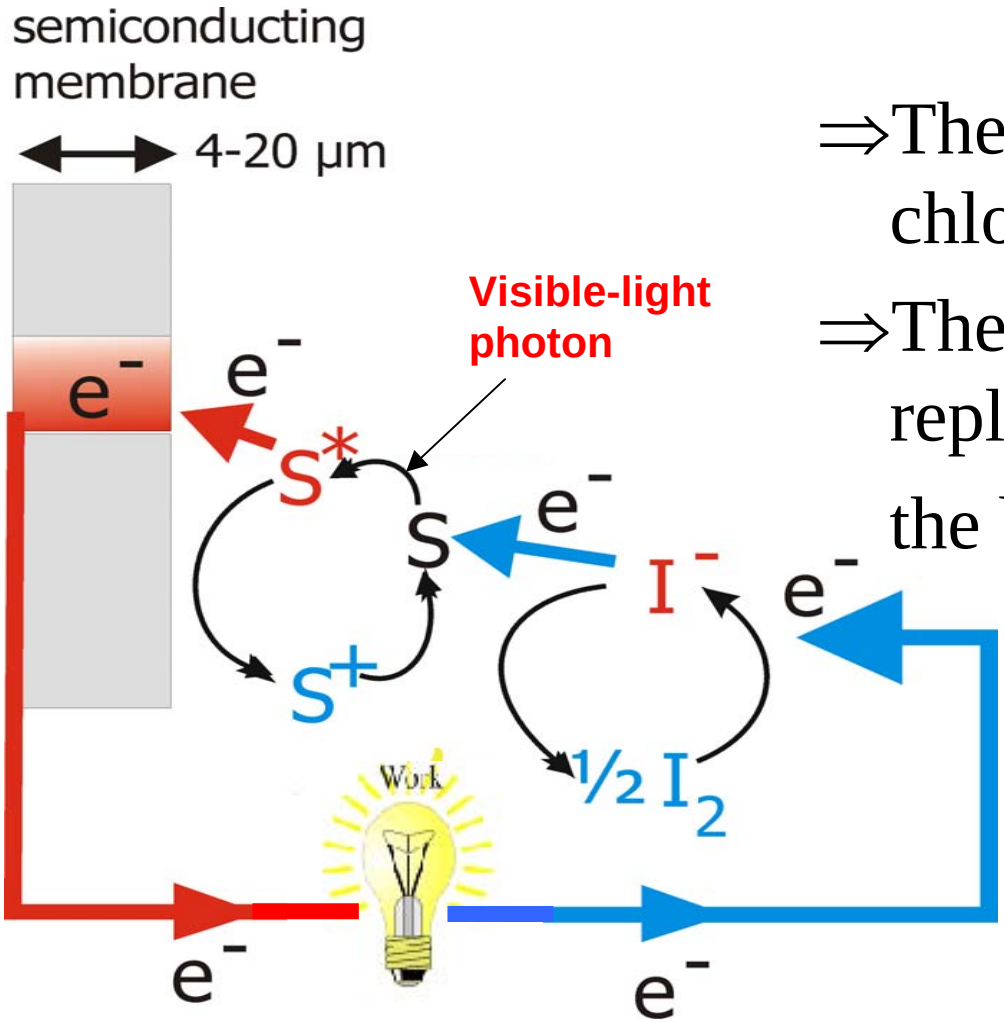
sugar

respiration of plants and animals

combustion

wood, coal, oil, gas

Artificial Photosynthesis

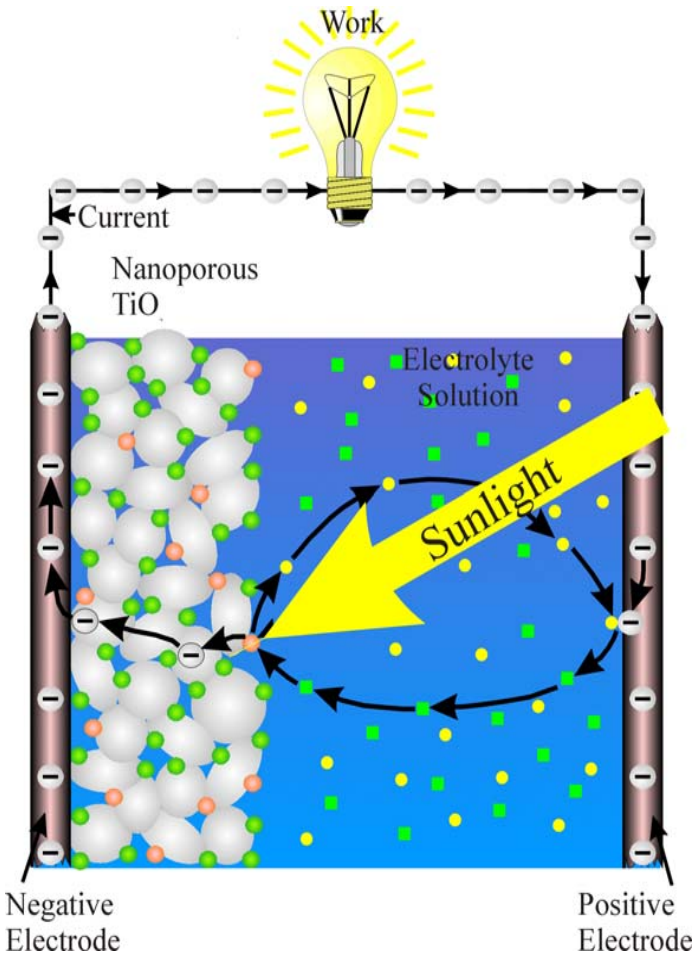


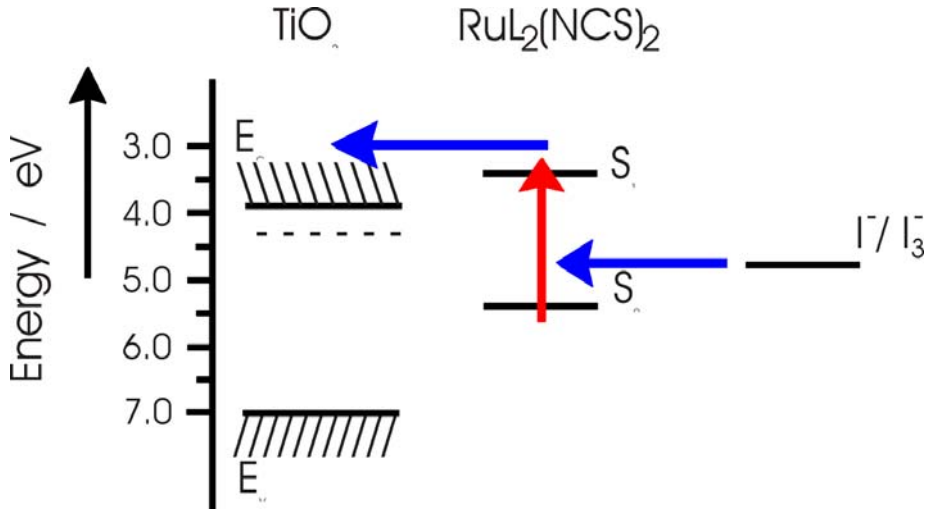
⇒The sensitizer S replaces chlorophyll

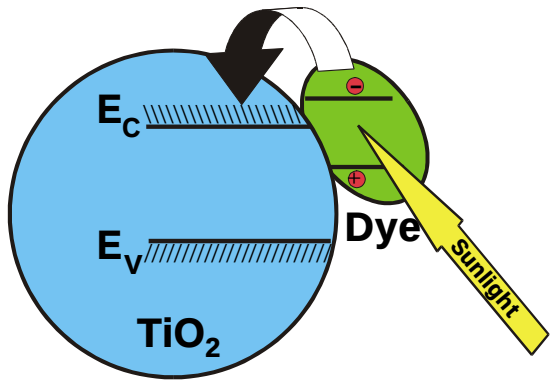
⇒The semiconducting membrane replaces

the biological membrane

Dye-sensitized solar cells







B. O'Regan and M. Grätzel, Nature 353 (1991) 737
U. Bach, ..., and, M. Grätzel, Nature 395 (1998) 583

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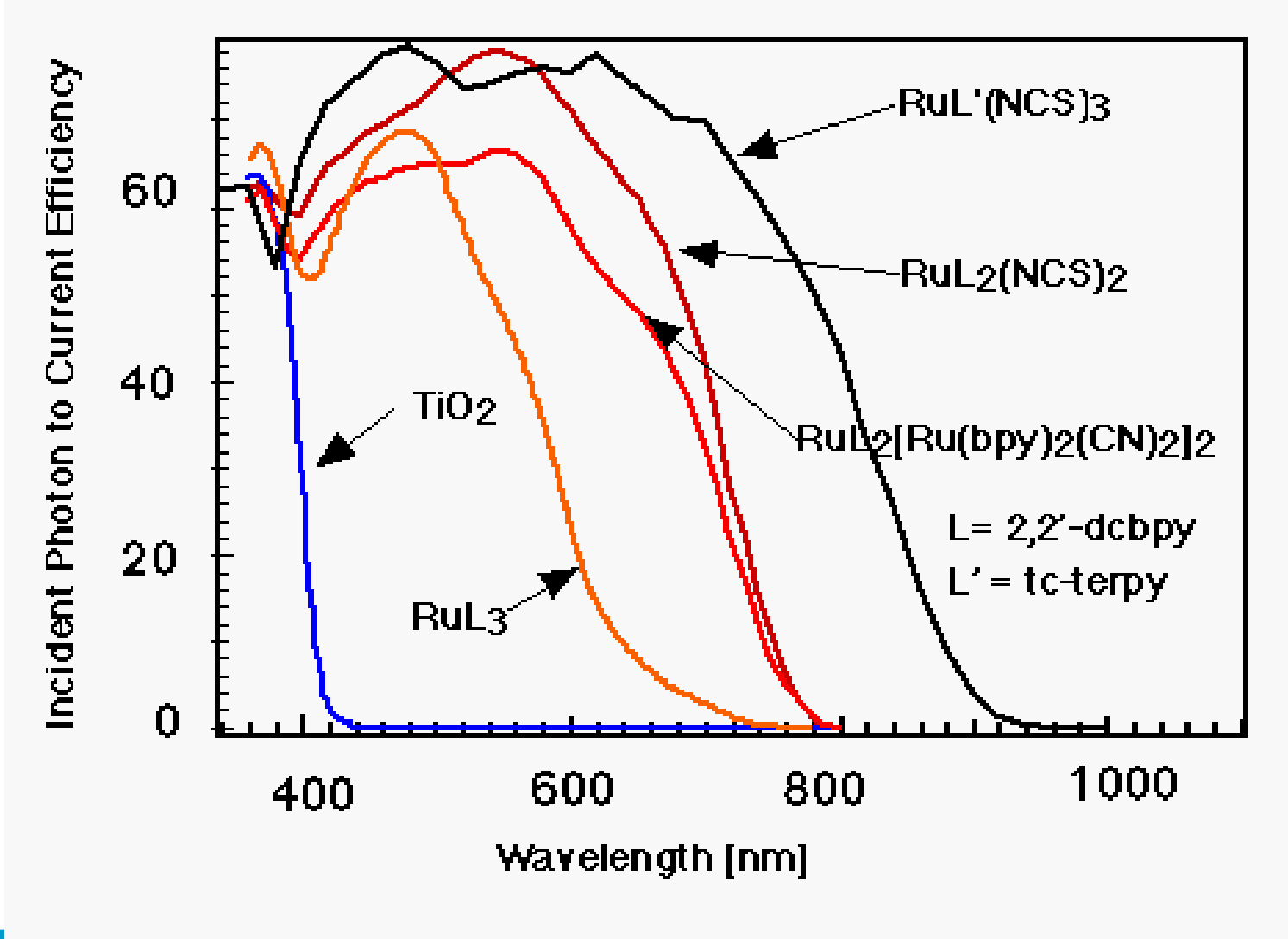
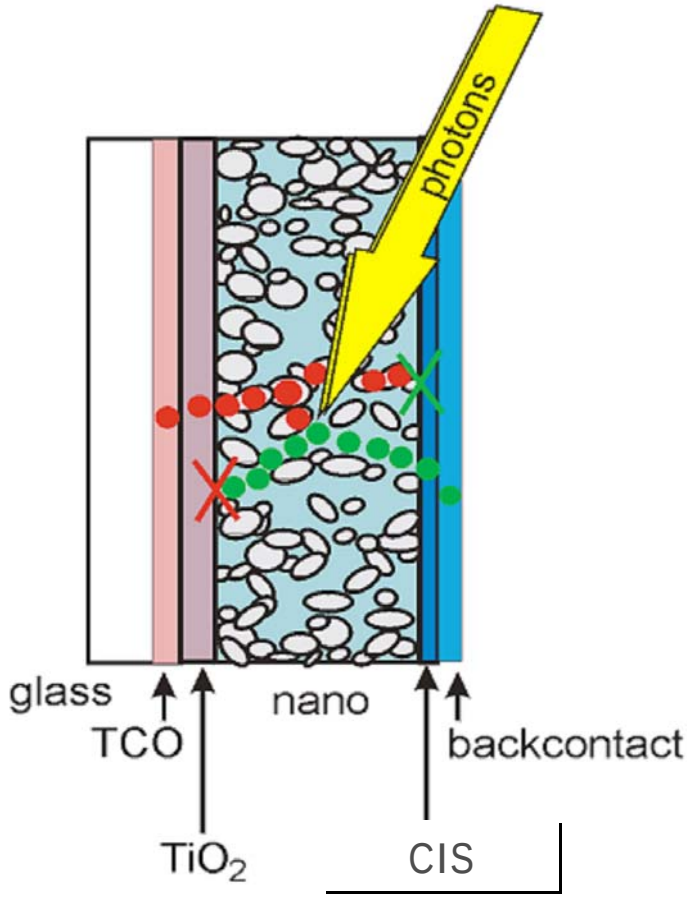
Optical absorption of titania - development of sensitizing dyes.



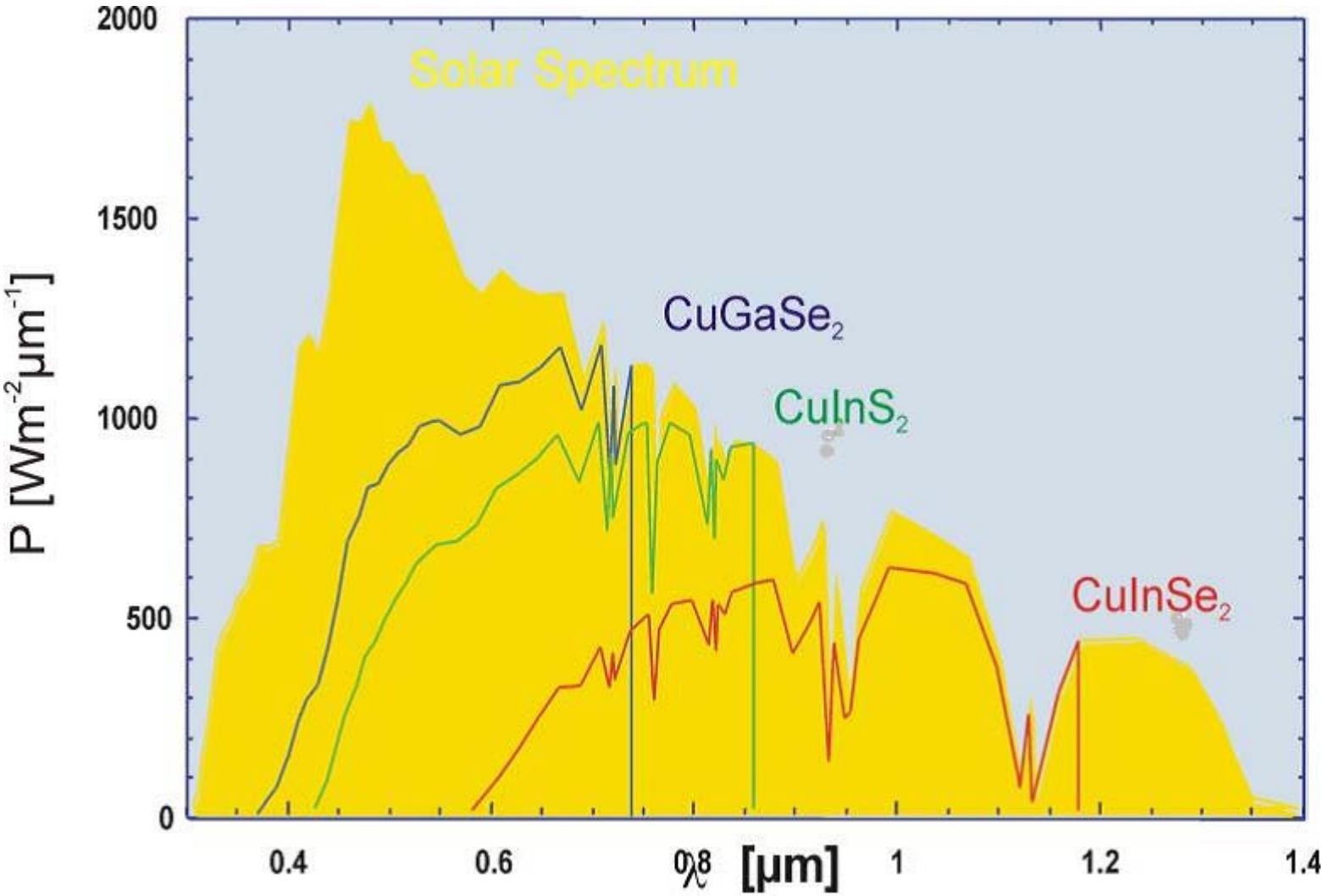
Courtesy of Greatcell Solar, Switzerland

Requirements for 3D Solar Cells

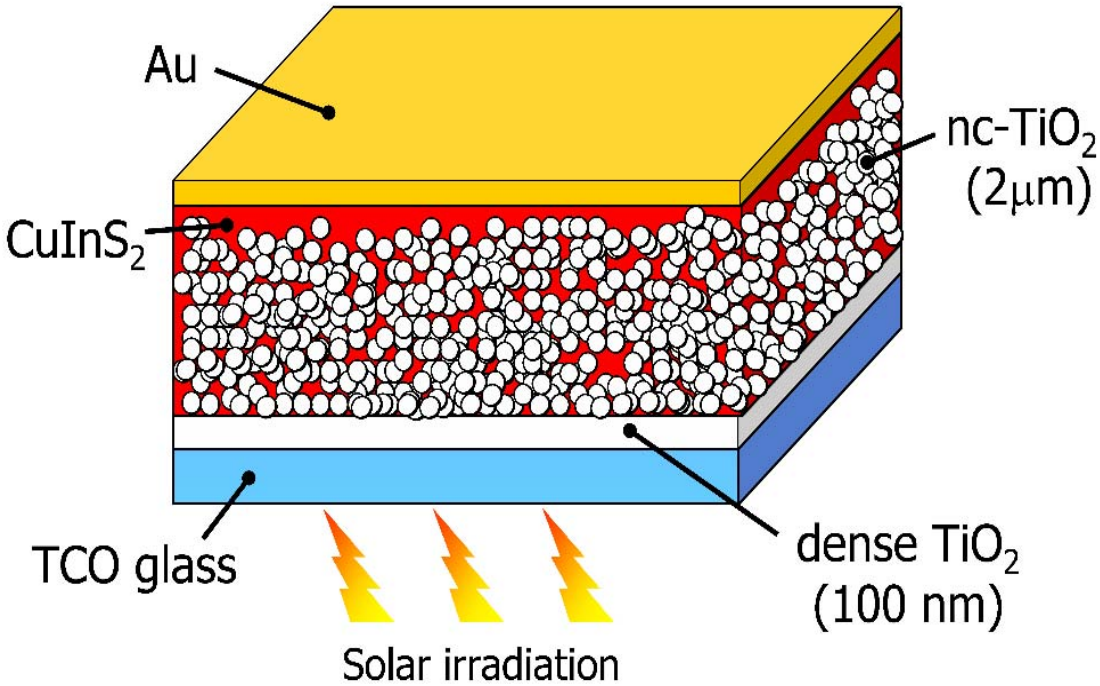
1. Percolation of electrons and holes
2. Selective contacts
3. No electrical shunts (pinholes)
4. Stoichiometric TiO_2
5. p-type $CuInS_2$ (CIS)
6. Intimate contact
7. Complete filling of pores
8. Buffer layer



Spectral Response



3D Delft Solar Cell

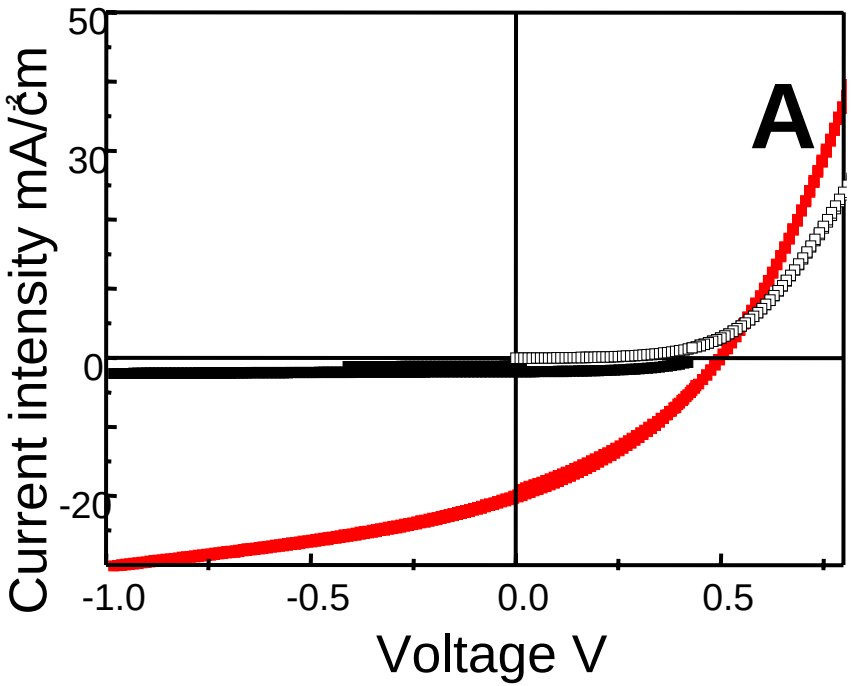


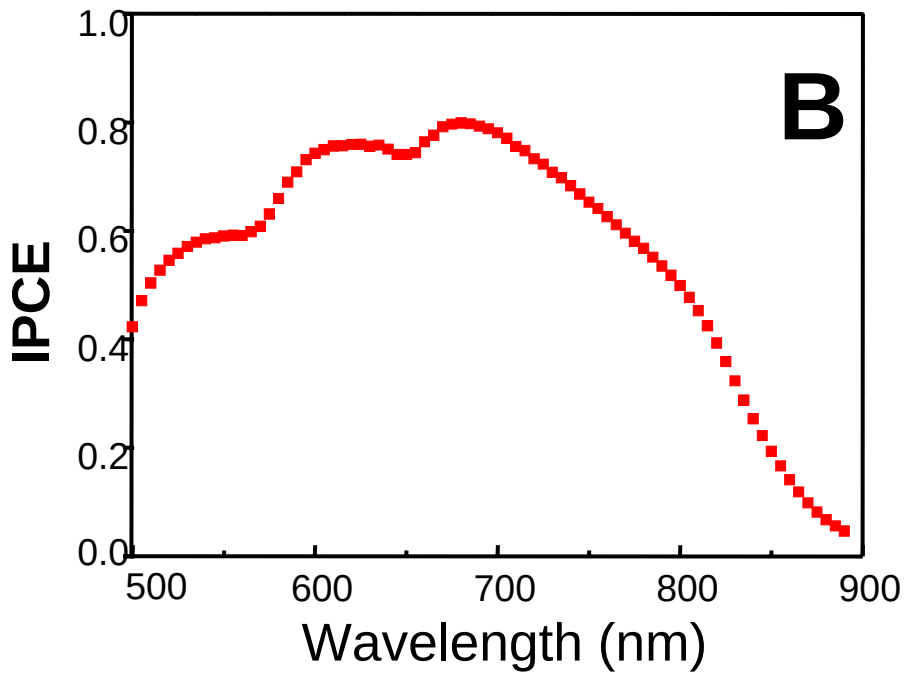
1 percolation of electrons and holes
2 selective contacts
3 no electrical shunts (pinholes)
4 stoichiometric TiO_2
5 p-type $CuInS_2$
6 buffer layer
7 intimate contact
8 complete filling of pores

M. Nanu, J. Schoonman, and A. Goossens, Advanced Materials 16 (2004) 453
M. Nanu, J. Schoonman, and A. Goossens, Adv. Func. Mat. 15 (2005) 95

$CuInS_2$ | nc-TiO_2 3D solar cell

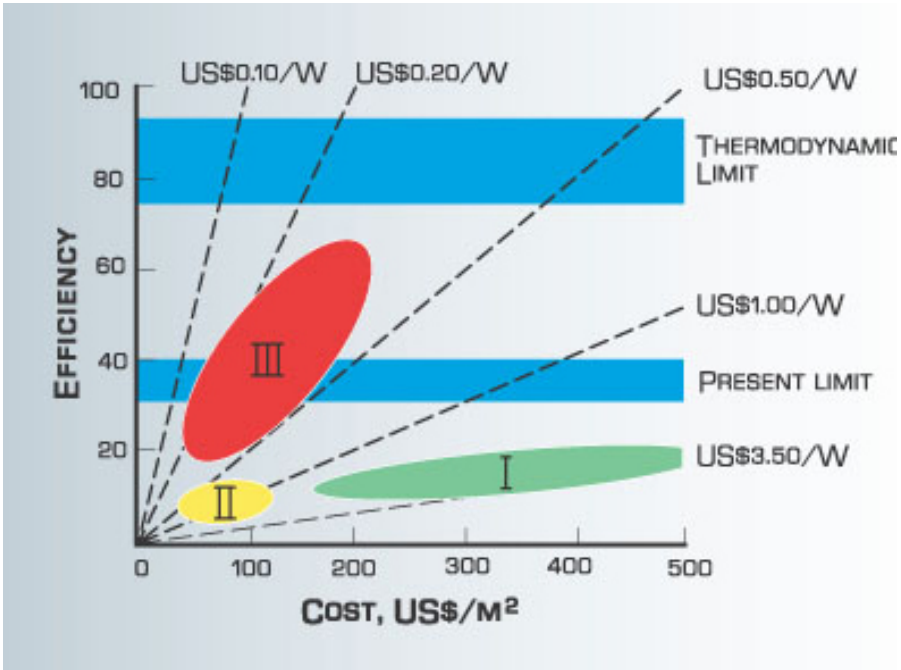
SnO2:F/TiO2/In2S3/CuInS2/Au

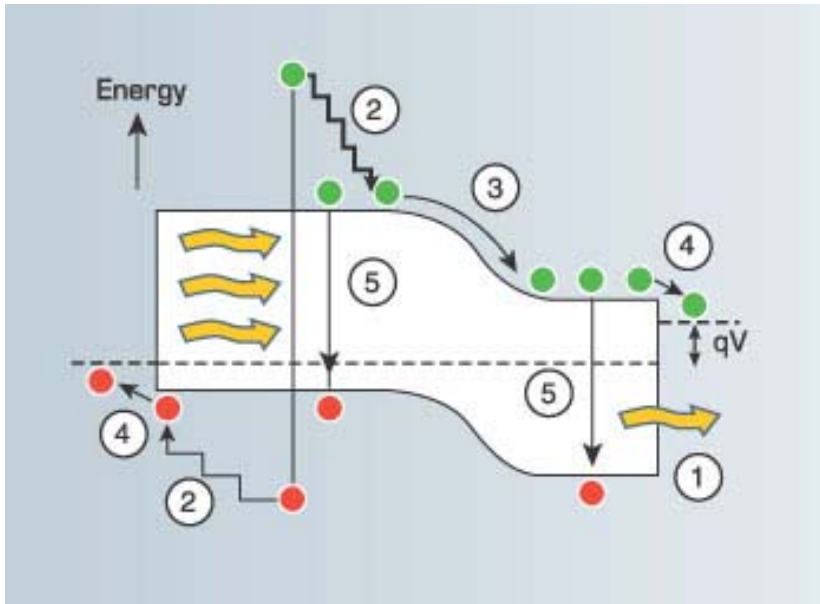




V_{OC} = 0.52V, I_{SC} = 19 mA/cm^{-2}, fill factor = 0.45
Overall energy conversion efficiency about 6 %

Third generation solar cells

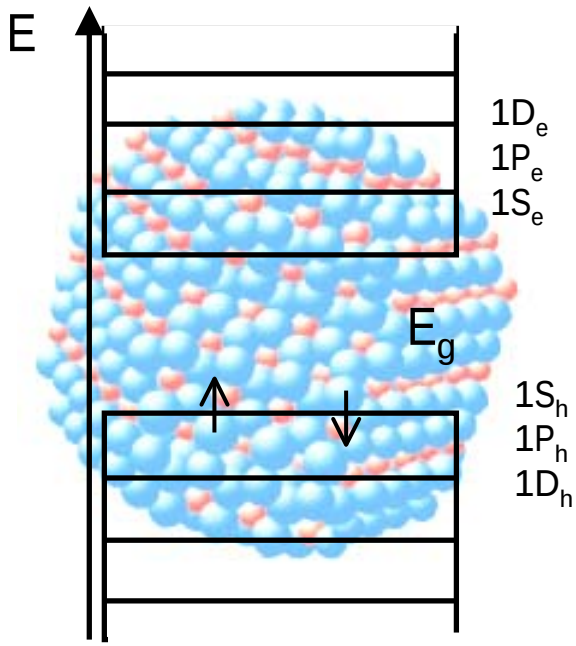


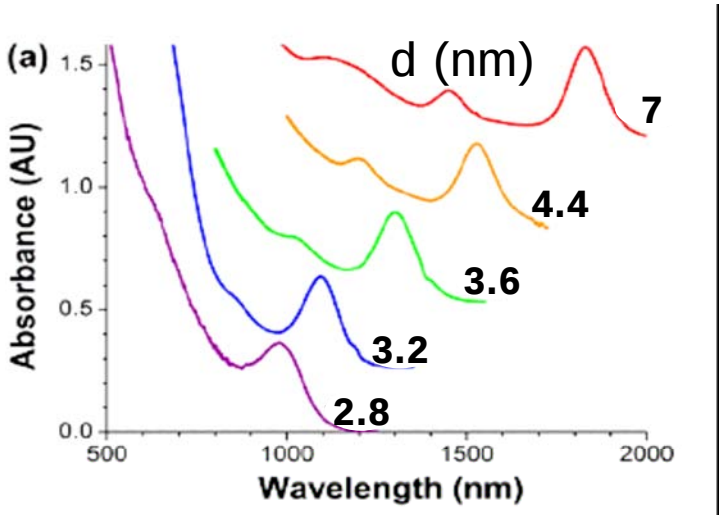


First generation: efficiency 15% at $3.5 /Wp
Second generation: efficiency 7-10% at $1 /Wp
Third generation: efficiency 30-60% at $0.35 /Wp

LOSS FACTORS
25%: non-absorbing infra red
25%: thermolization
25%: carrier transport

Quantum confinement in Q-dots





*Richard D. Schaller, et.al. PRL **95,** 196401 (2005)*

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Concluding Remarks

- Decentralized Solar Energy Conversion is a Materials Problem
- Nano-sized Materials contribute to the Development of Innovative Devices
- Quantum Dots are the Future.