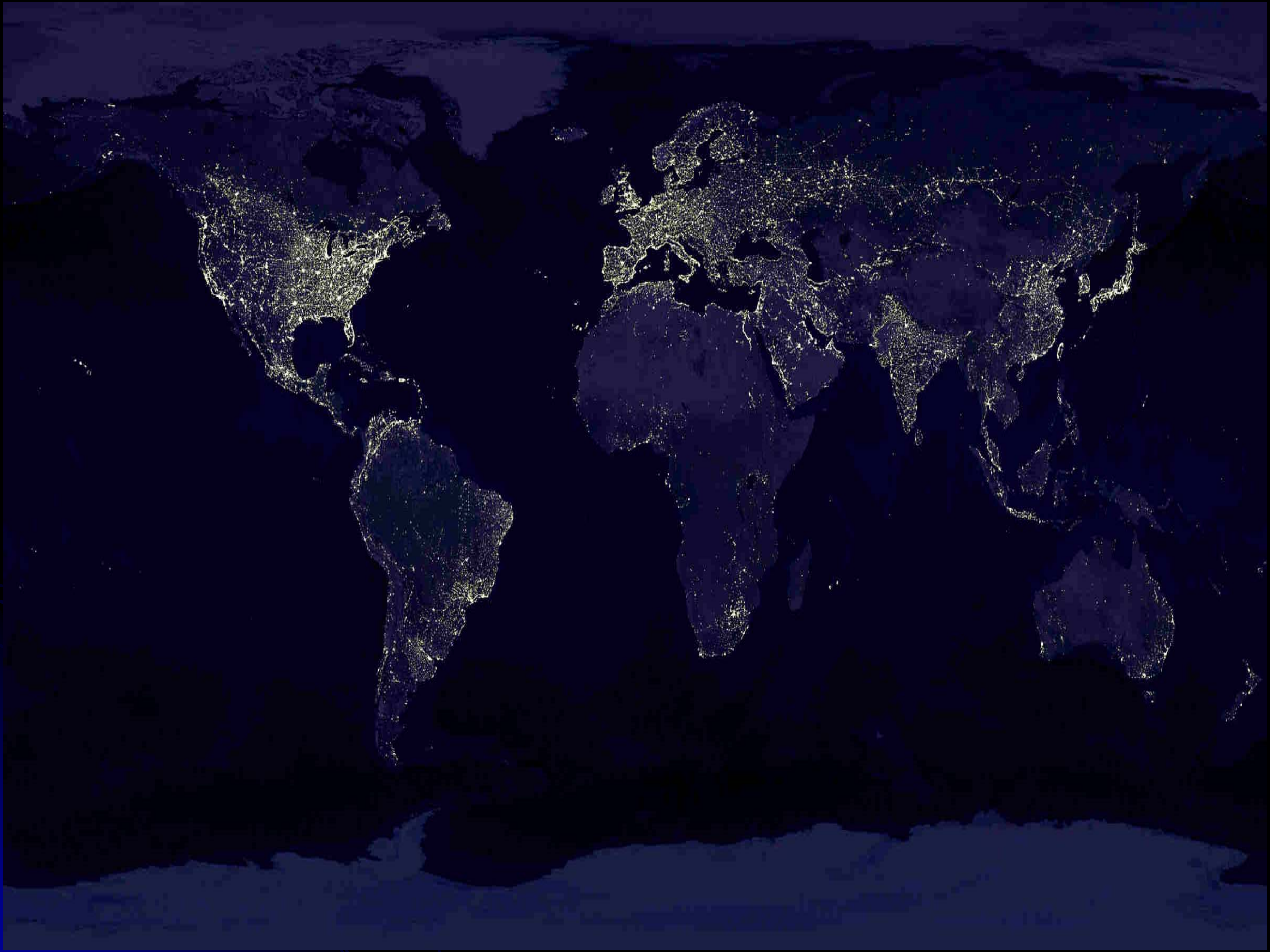
In the beginning God created the heaven and the earth. Genesis 1:1



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Modification of hydrophilicity by anion exchange

Energy Demand in near future

* Present: 12.8 TW
  2050년 : 28-35 TW

* Needs at least 16 TW
  Bio: 2 TW
  Wind: 2 TW
  Atomic: 8 TW (8000 power plant)
  Fossil: 2 TW

* Solar: 160,000 TW

Solar Energy

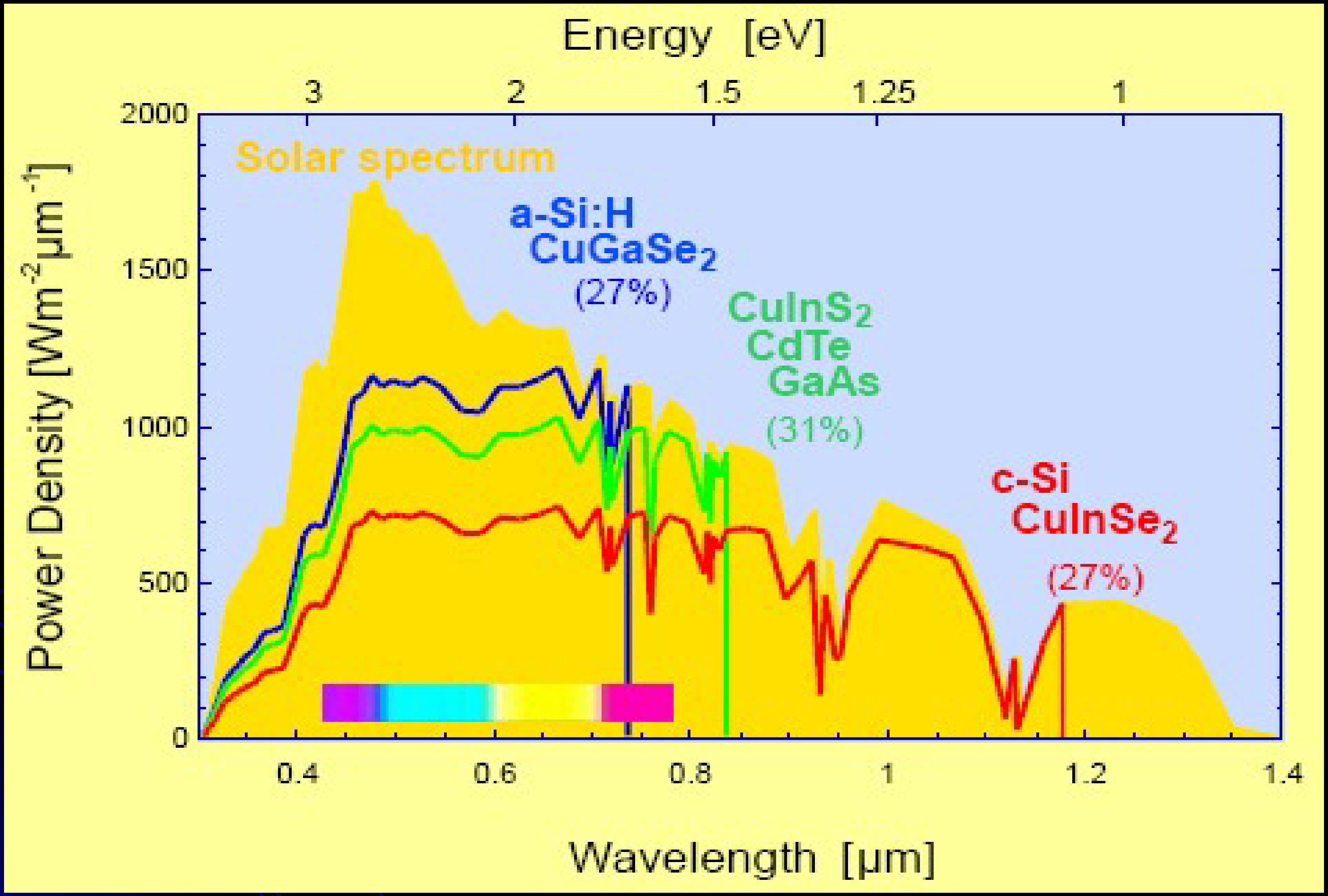
지구상 도달하는 태양에너지 15분 어치

: 인류 1년간 에너지 소모량

- 1년간 지구표면에 도달하는 태양에너지: 세계 전체 에너지 소비량의 2만배
  - 대기권외에 받는 태양에너지의 밀도; 1㎡ 당 1.35kw
  - 지구가 태양복사를 받는 단면적은 1.275 x 10^{14} ㎡
  - 지구가 받는 총에너지량: 1.73 x 10^{14} Kwh (1.48 x 10^{17} Kcal)

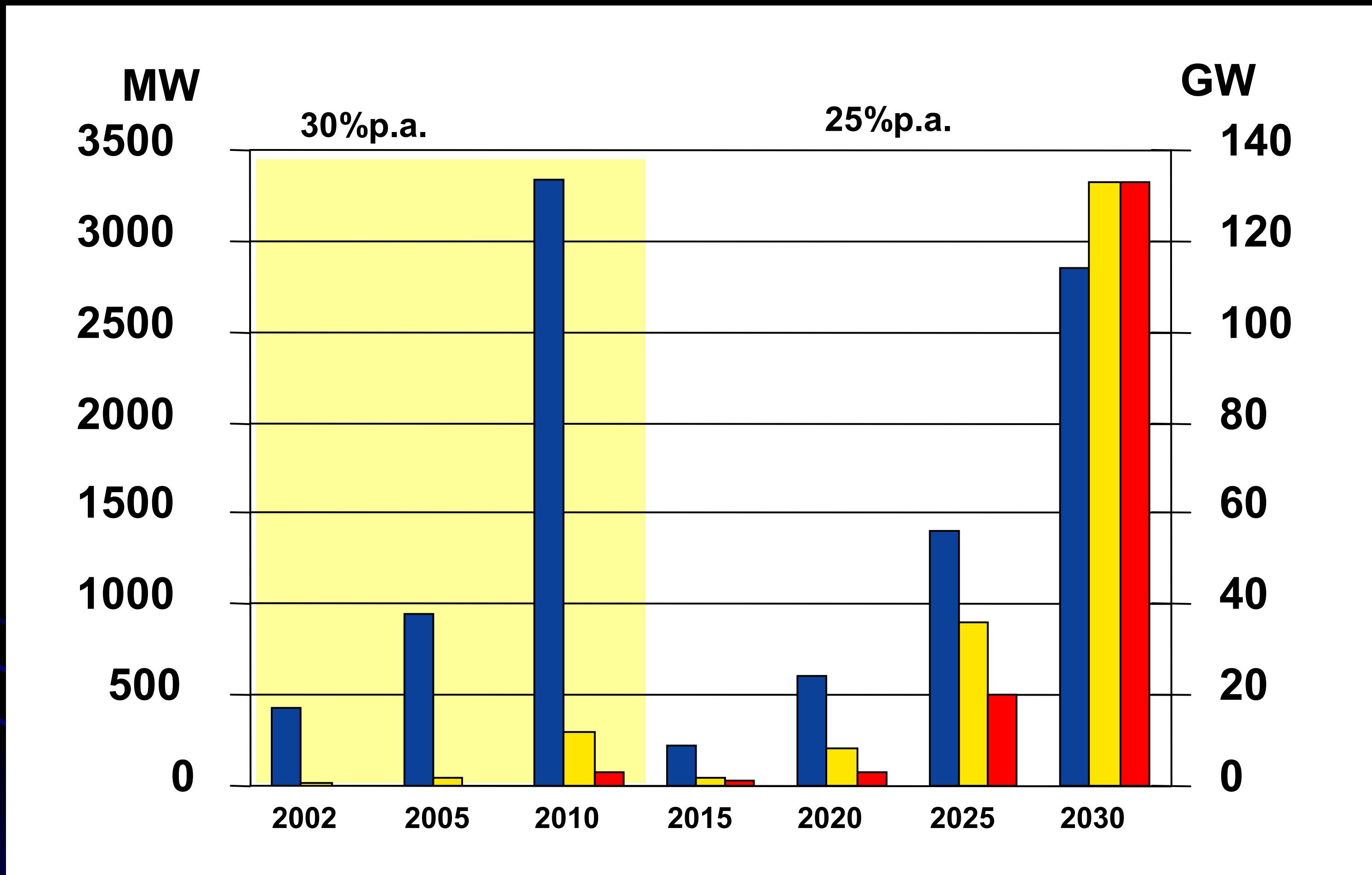
    30%는 직접 반사, 70%인 1.04 x 1017 Kcal가 지구에 도달

    우리나라의 평균일사량은 ㎡ 당 약 2,000 Kcal/day
- 무한정, 무공해
- 저밀도, 오직 낮에만....



Energy [eV]
3
2
1.5
1.25
1
2000
1500
1000
500
0
Power Density [Wm-2µm-1]
Solar spectrum
a-Si:H
CuGaSe2
(27%)
CuInS2
CdTe
GaAs
(31%)
c-Si
CuInSe2
(27%)
0.4
0.6
0.8
1
1.2
1.4
Wavelength [µm]

Market Forecasting



- c-Si
- thin film
- New Concepts

2010년 360억불 시장예상
10년 내 현 반도체 시장 규모에 필적

Source: EPIA (2005.11)

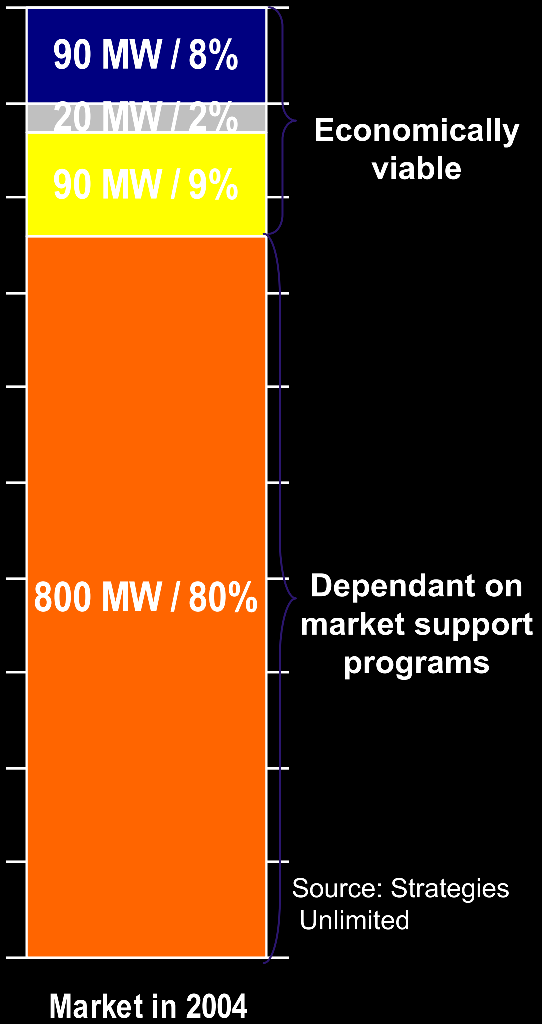
Solar cells Market

Off-Grid Industrial

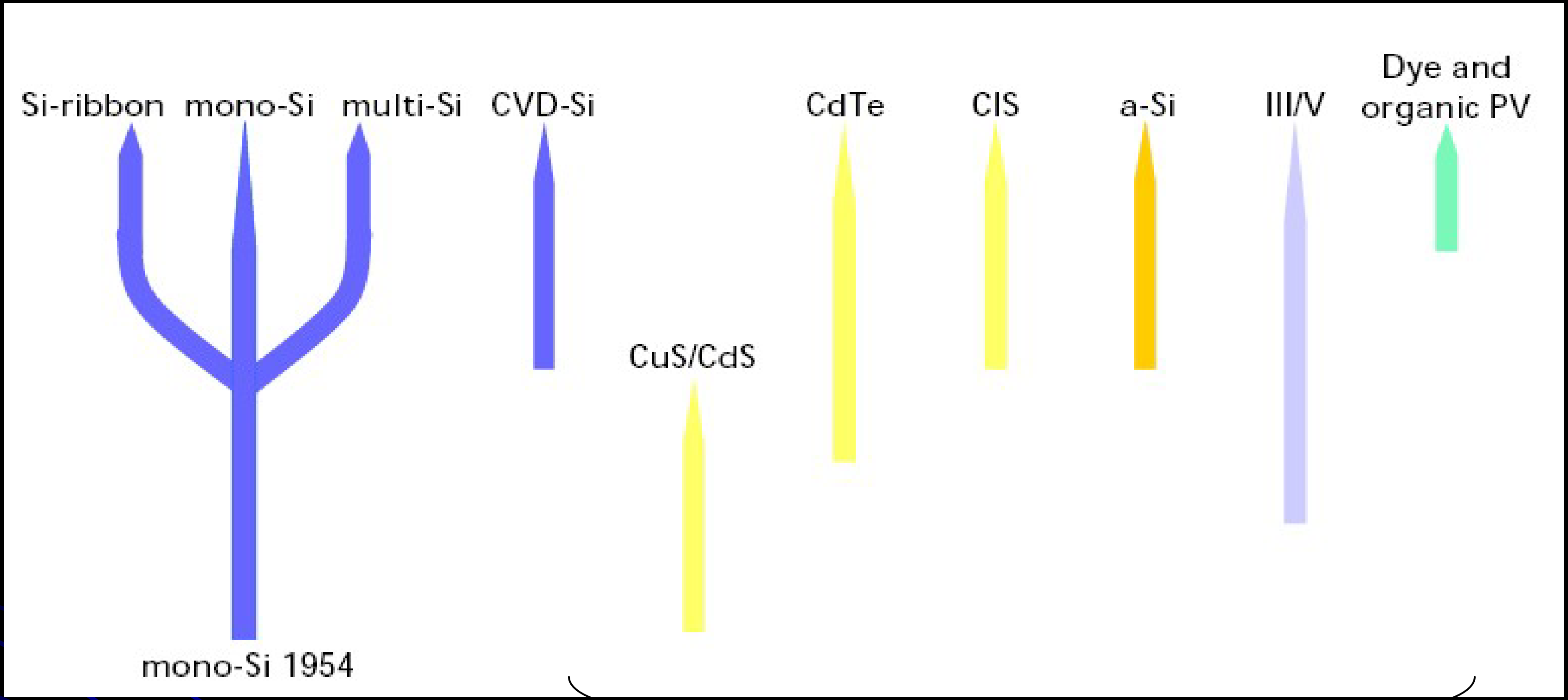
Consumer

Off-Grid Residential

On-Grid



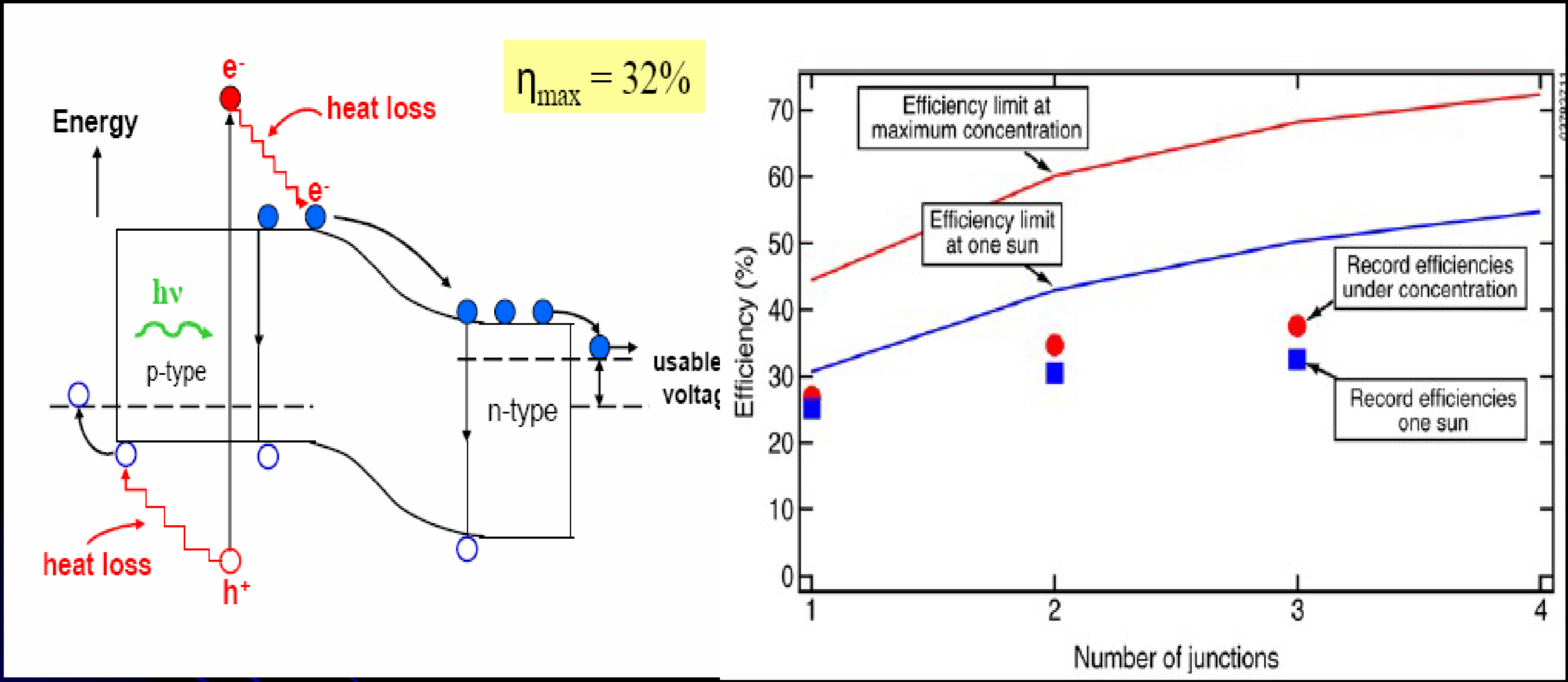
Solar cell technologies



Thin Film Solar Cell

Bell Telephone Laboratories crystalline Si cell reported in 1954
Bell cells and first solar module (6%)

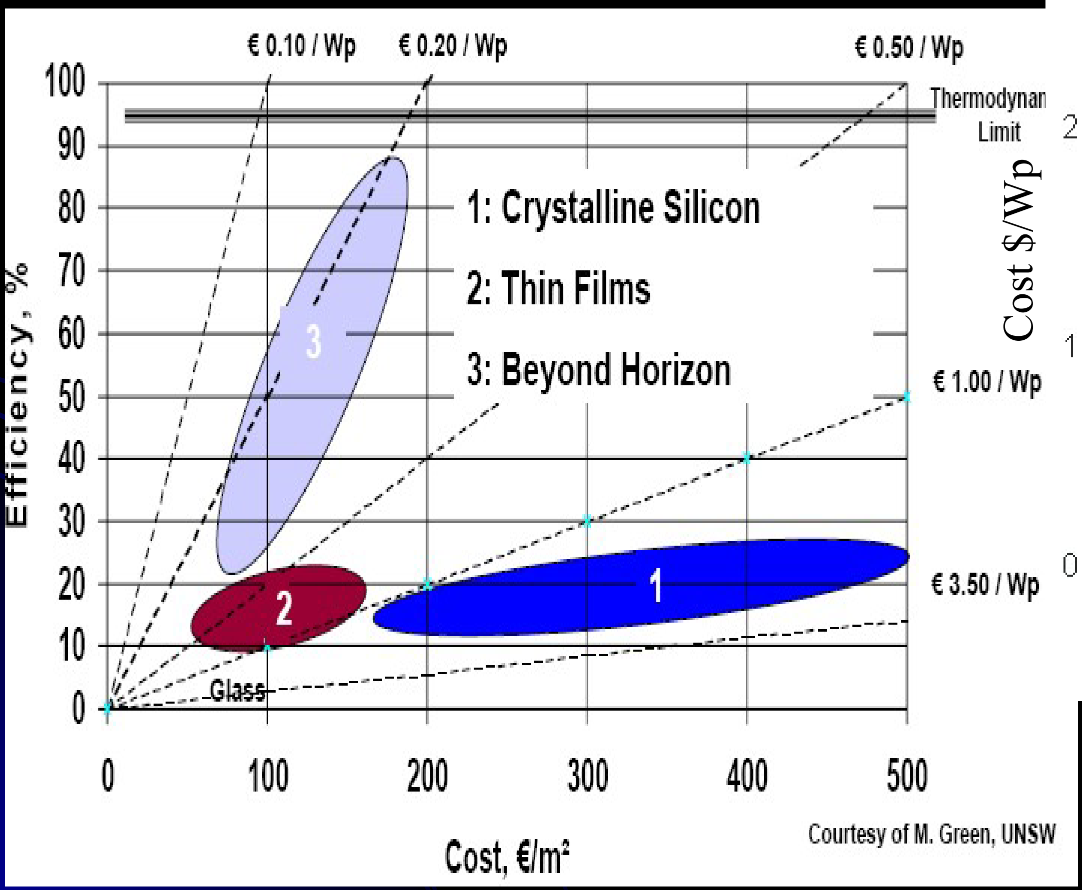
Limit of Efficiency

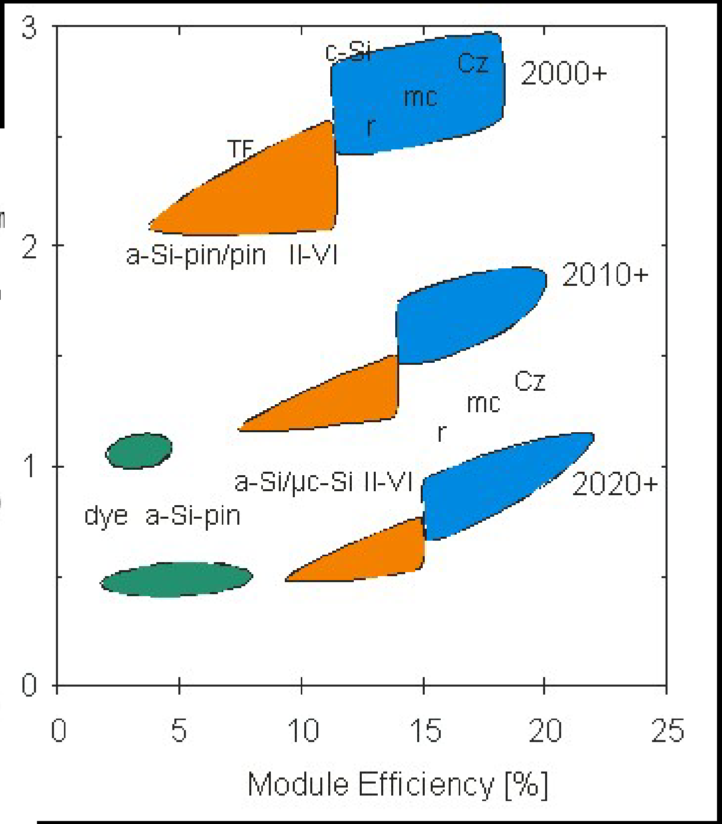


Jenny Nelson, The Physics of Solar Cells, 2003

태양전지의 종류에 관계 없이 P-N 접합 Single cell 의 이론적 효율 한계: 32 %
유기 태양전지의 경우 태양광의 흡수 정도를 고려해야 함
Tandem Cell 의 경우 이 이상 가능

Generation of Solar cells

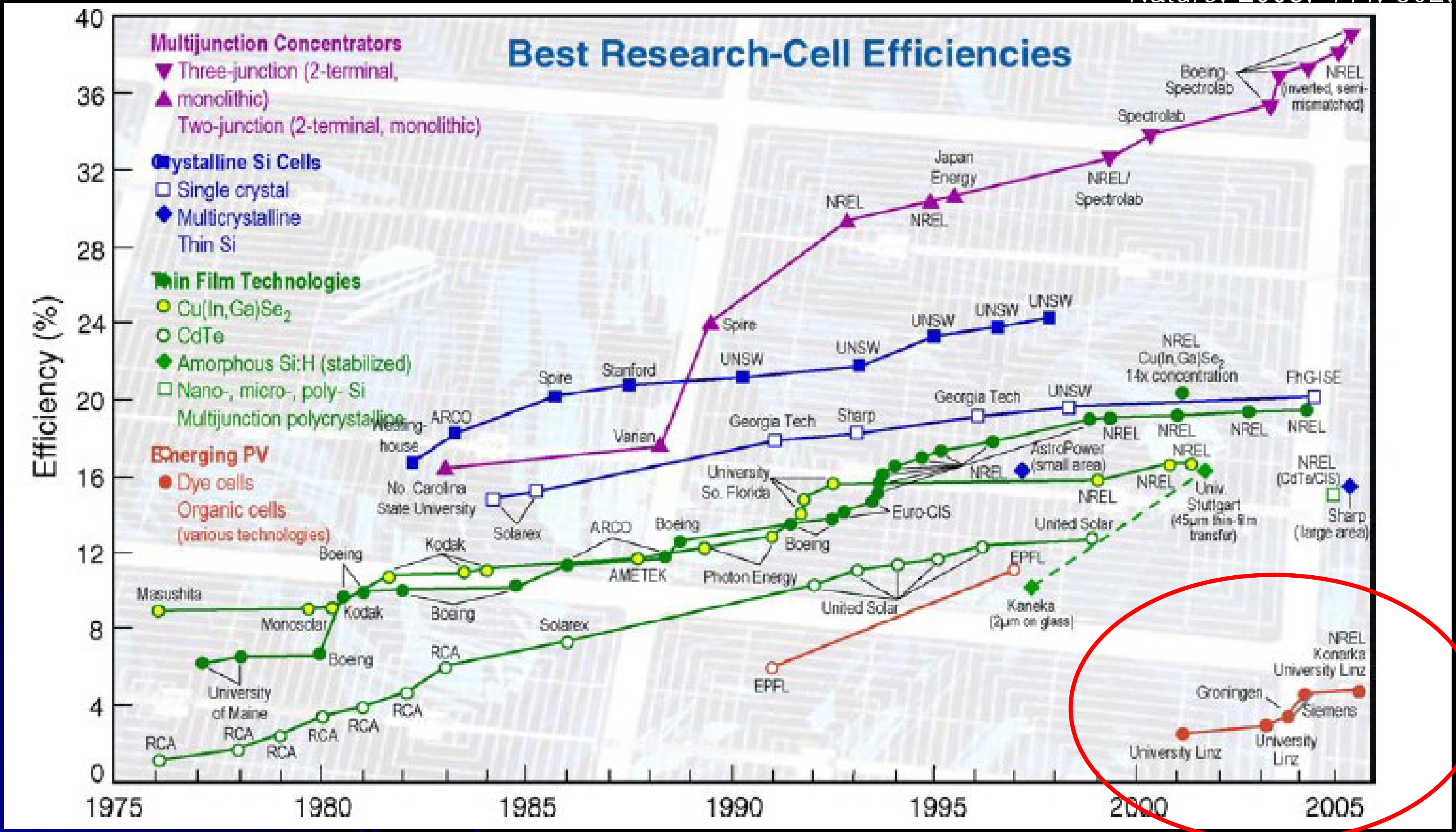




Source: Schott Solar

Best Solar cell

Spectrolab. 40.7%
Nature, 2006, *444*, 802.



Source: NREL

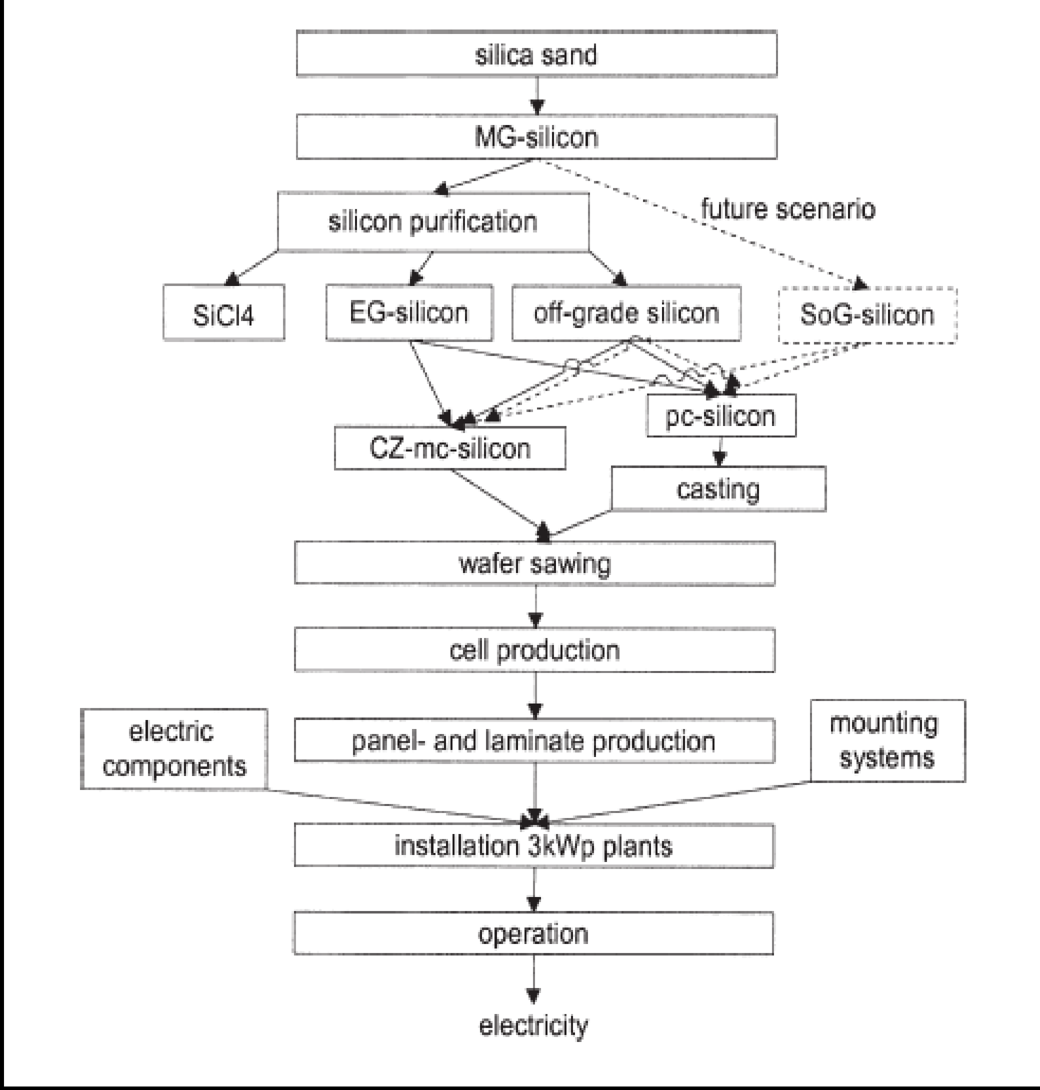
Drawbacks of Si-based Solar Cells

- Environmental Problems

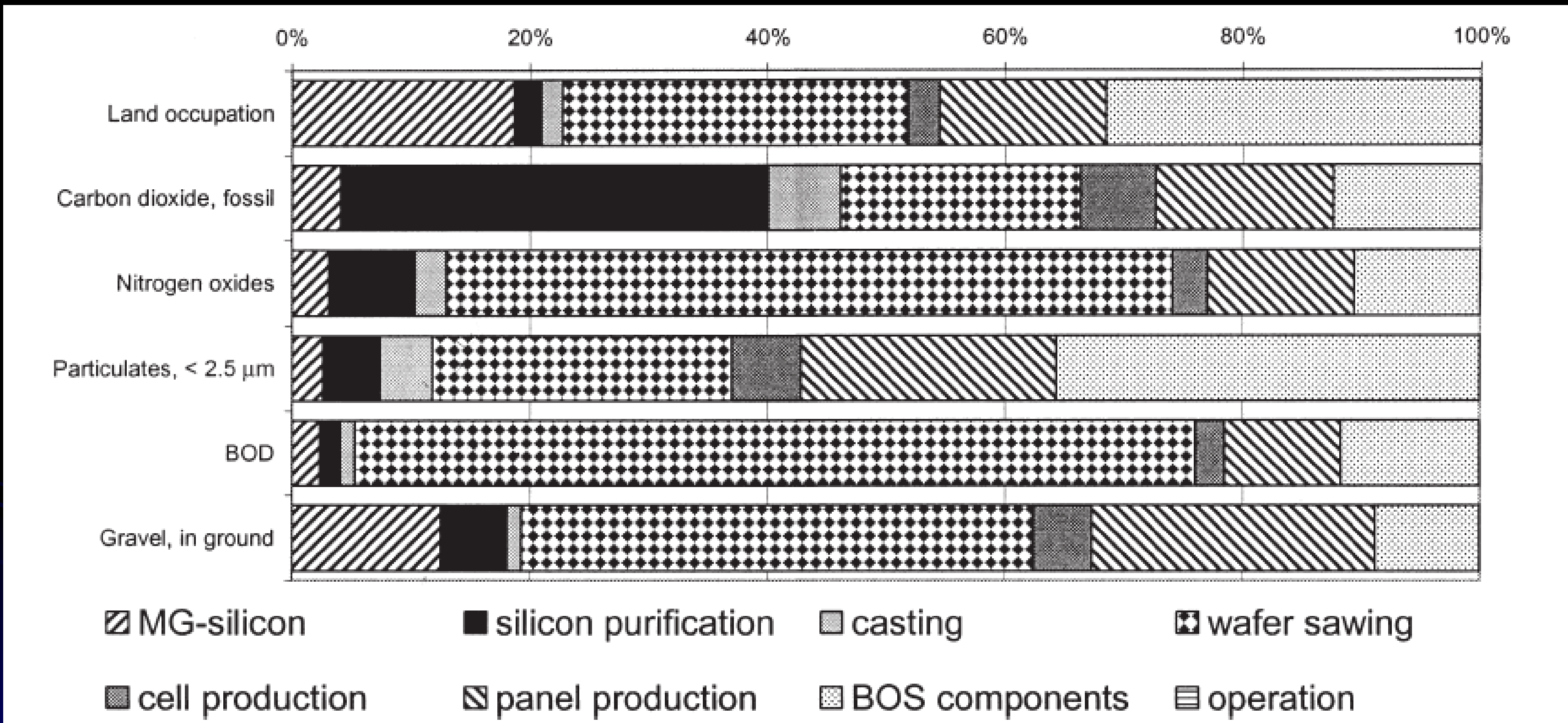
✓ High production cost

✓ High energy intensive process

✓ Instability of Si supply

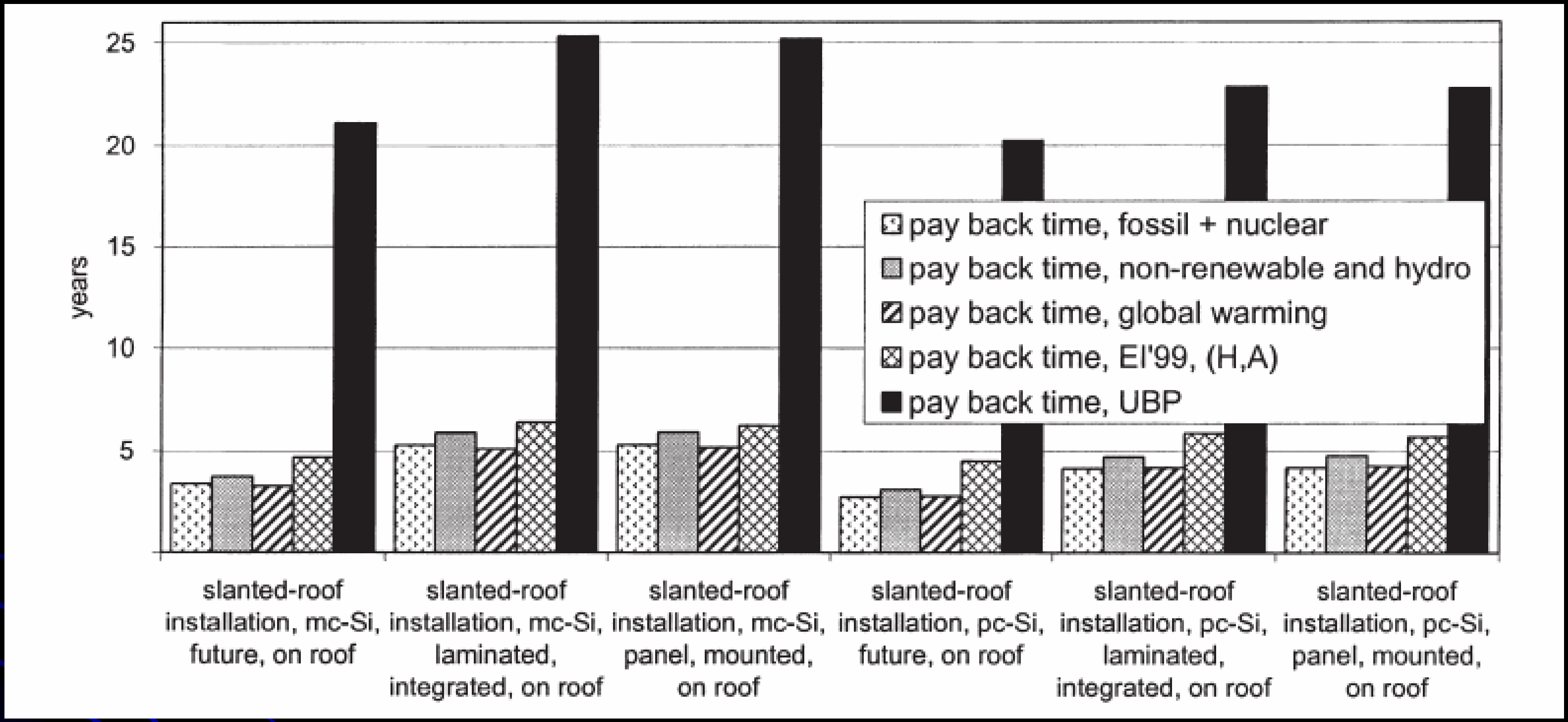


실리콘 태양전지의 생산 과정의 공해배출 물질



"Life Cycle Assesment of Photovoltaic System"
Progress in Photovoltaics: Research and Application 2005, *13*, 429.

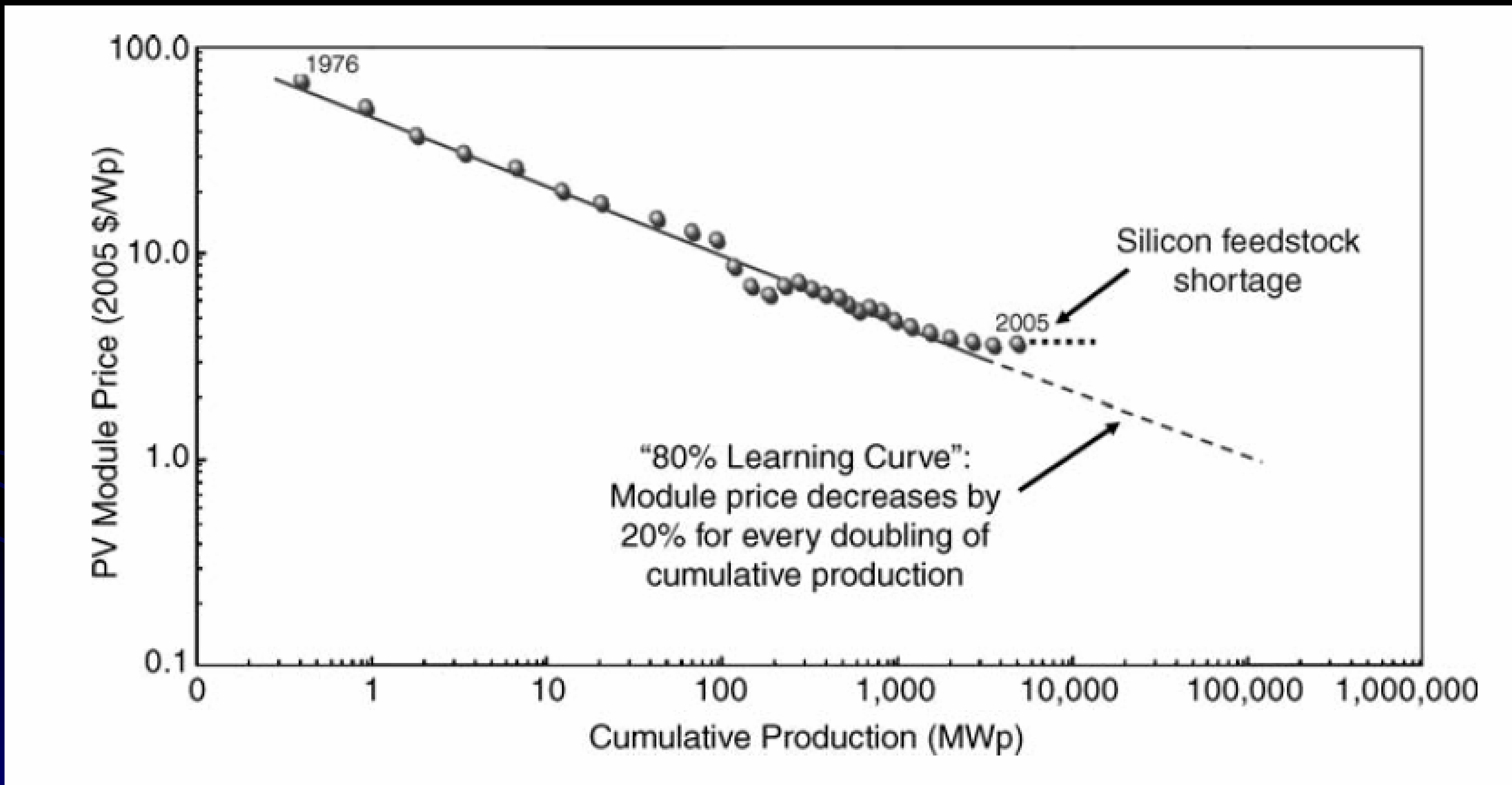
Payback Time of Si-based Solar Cells



Energy and Environmental Payback Time of 3 kWp Si Solar Cells

"Life Cycle Assesment of Silicon Photovoltaic System"
Progress in photovoltaics: Research and Application 2005, *13*, 429.

Photovoltaic module price/Wp vs. cumulative production



A. Slaoui et at. *MRS* 2007, *32*, 211

New Types of Solar Cell

Thin Film Inorganic Solar Cells

NanoSolar Co./California/USA

CIGS (Copper-indium-gallium-sulfide) based-thin film solar cells

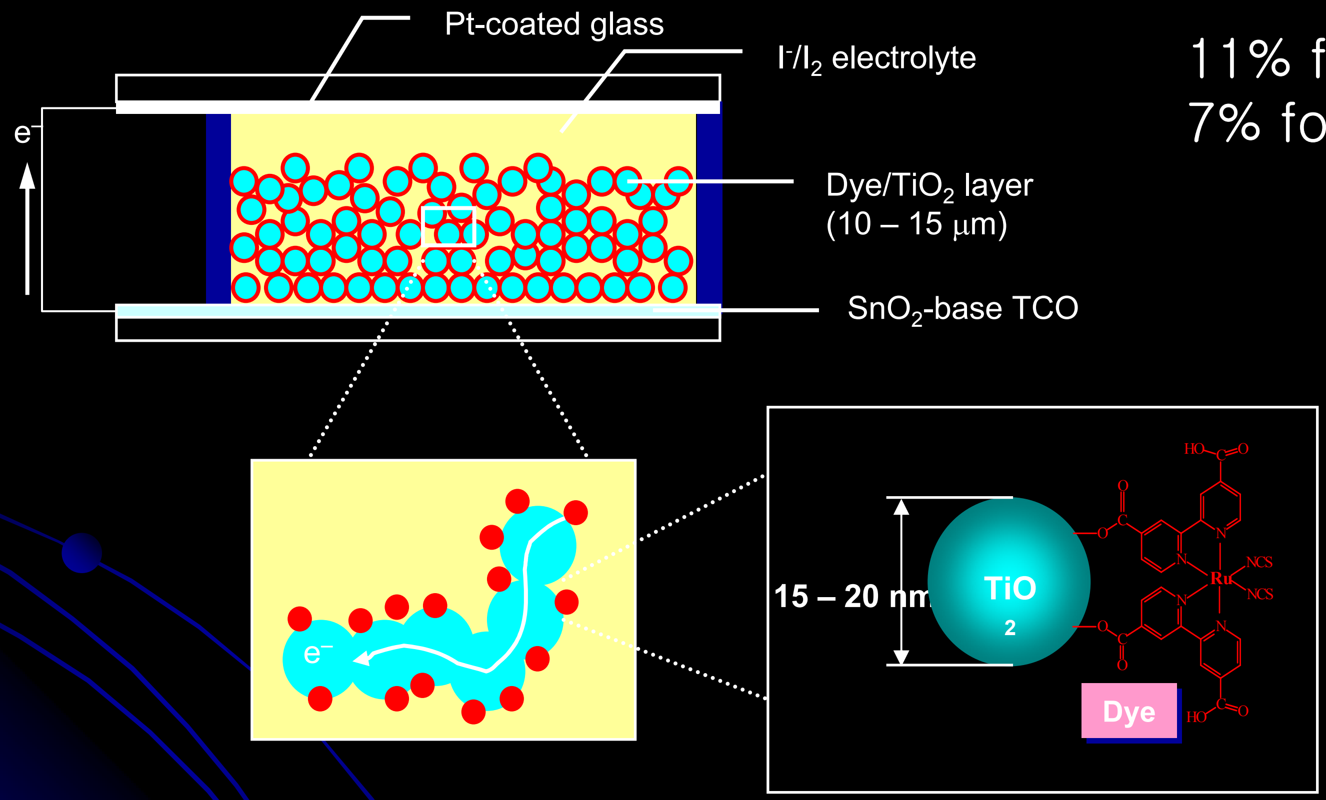
- **Production capacity: 430 MW/year**
- **Production cost: 10-20% of silicon solar cell**
- **Roll to Roll process: 3 mile solar cell/polymer roll**

- **Construction cost for 400 MW :**
  - **1 billion dollars for silicon solar cells**
  - **0.1 billion dollars for thin film solar cells**

- **0.1 billion investment from Google and others**

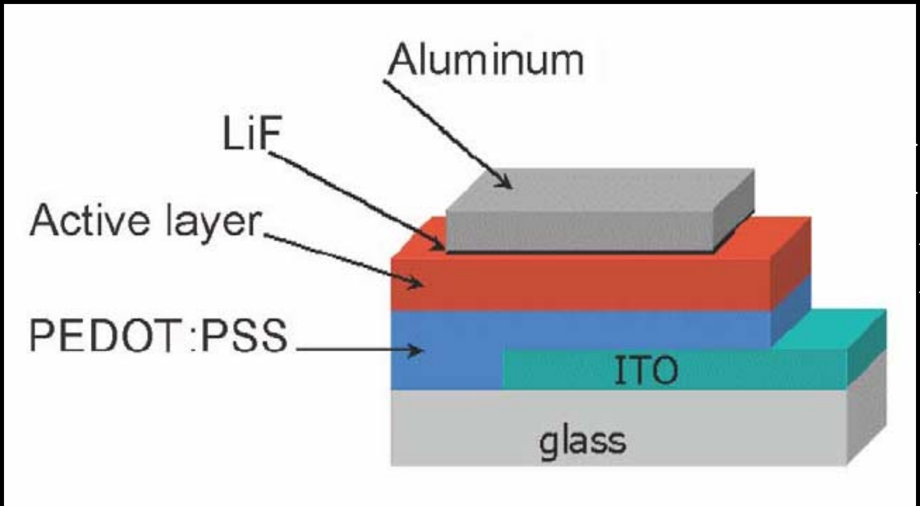
전자신문 **2006**년 **6**월 **23**일

Nano-Size TiO_2 based Dye-sensitized Solar Cell



11% for dot cell
7% for panels

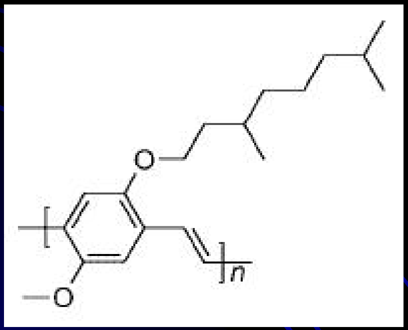
Organic Solar Cells

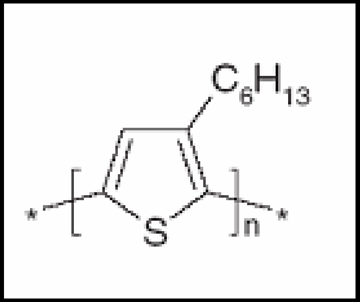


100~300 nm
0.1~1 nm
50~400 nm
30~100 nm

Total device thickness < 1 μm
(except ITO substrate)

p-type : conducting polymer





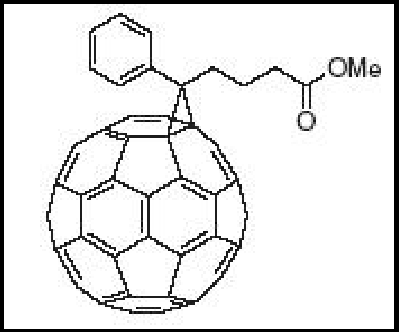
MDMO−PPV

$\mu_h = 5 \times 10^{-7}$ cm/Vs

P3HT

$\mu_h = \sim 0.1$ cm/Vs

n-type : nano particle



PCBM

$\mu_e = 2 \times 10^{-3}$ cm/Vs

2. Hybrid solar cells

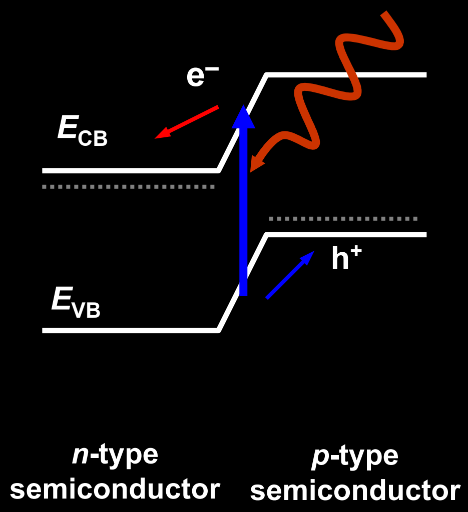
Definition

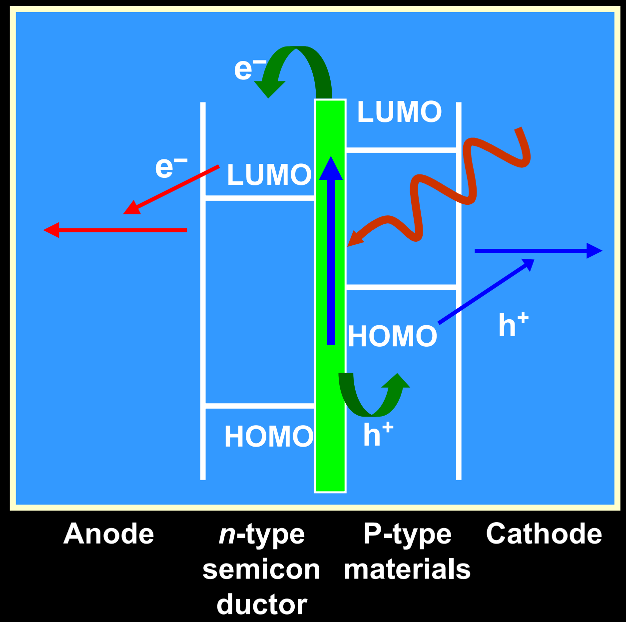
Liquid phase synthesis of inorganic semiconductors

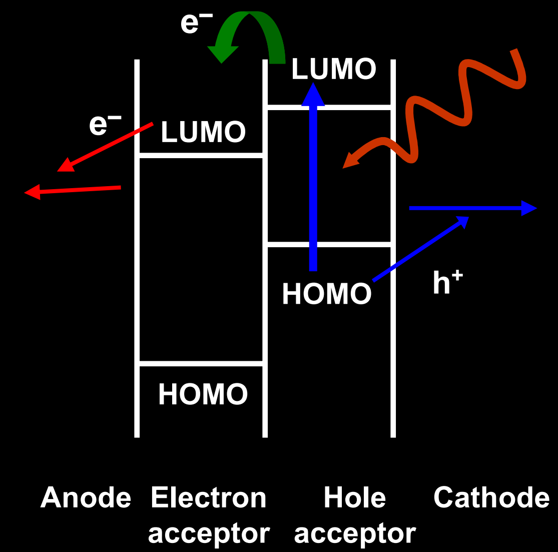
Water-soluble polymers for the interfacial contact

Modification of hydrophilicity by anion exchange

New Types of Solar Cells







Inorganic cells

Hybrid solar cells

Organic cells

Fast carriers mobility
Long life time
High production cost
Brittle

→ ←

Inorganic *n* + Organic *p*

ETA Cell
Dye-sensitized Solar Cells

Low Production Cost
Flexible
Tunable color
Light weight
Slow carrier mobility
Short life time

Liquid-phase preparation of inorganic semiconductors

- Nanocrystalline TiO_2/ZnO by layer-by-layer deposition
- $Cd(OH)_2$ of n-type and $HgCr_2S_4$ of p-type by layer-by-layer deposition
- CdO nanowires, TiO_2, ZnO by chemical bath deposition
- CdSe nanowires by electrodeposition

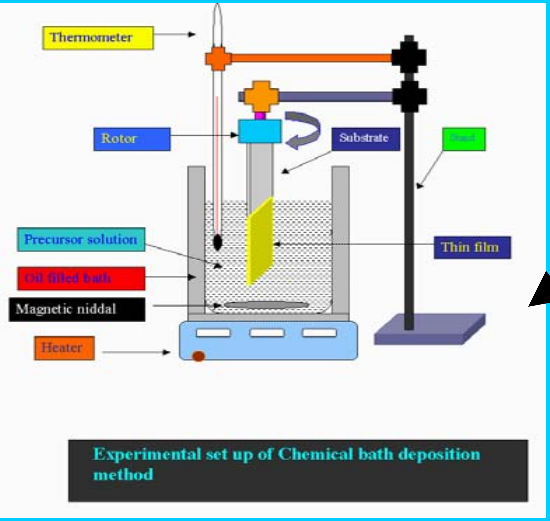
Gas-phase thin-films preparation methods

Vacuum evaporation	Gas Phase	Sputtering
Resistive heating Flash evaporation Electron beam evaporation Laser evaporation Arc evaporation Radio frequency (RF) heating	Chemical vapor deposition Laser chemical vapor deposition Photo chemical vapor deposition Plasma-enhanced chemical vapor deposition Metal -organochemical vapor deposition	Glow discharge DC sputtering Triode sputtering Getter sputtering Radio frequency (RF) sputtering Magnetron sputtering Face target sputtering Ion beam sputtering AC sputtering

Liquid-phase thin-films preparation methods

Chemical bath deposition
Layer-by-Layer deposition (LbL)
Spray pyrolysis
Electrodeposition
Electroless deposition
Anodization
Liquid phase epitaxy
Sol gel process
Langmuir-Boldgett (LB) technique

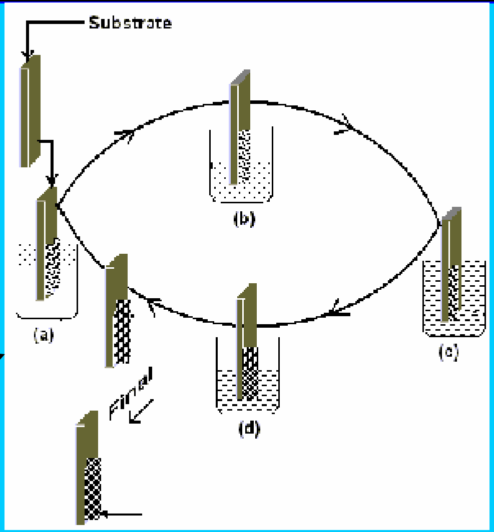
Inexpensive chemical deposition methods



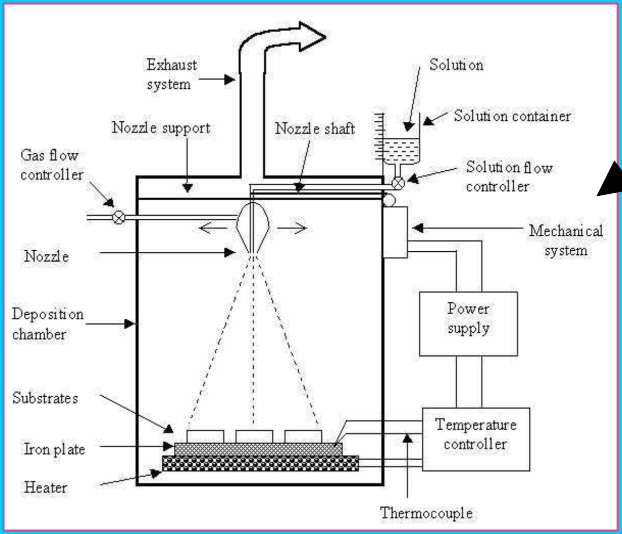
Experimental set up of Chemical bath deposition method

CBD

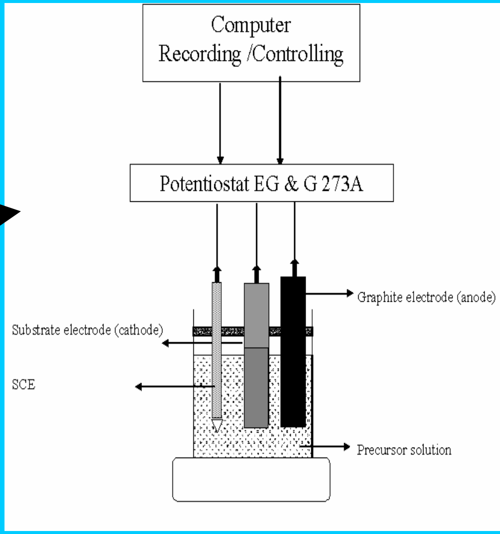
LbL



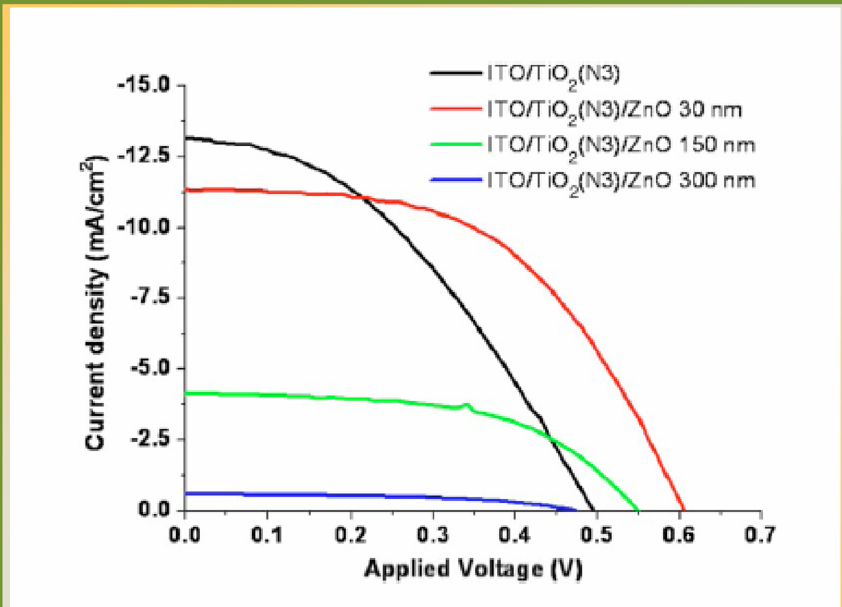
SPRAY



ED



Nanocrystalline TiO_2/ZnO by layer-by-layer deposition



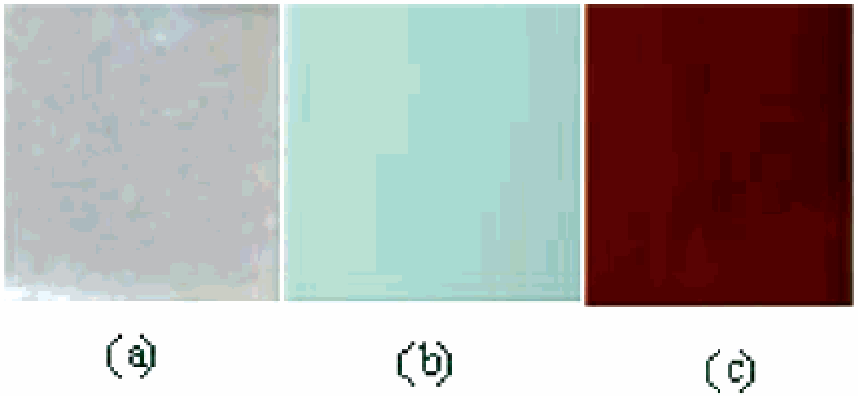


Figure 1. Photoimages of the surfaces of (a) TiO_2, (b) TiO_2/ZnO, and (c) TiO_2/ZnO with N3 dye. The images were taken under a white light source.

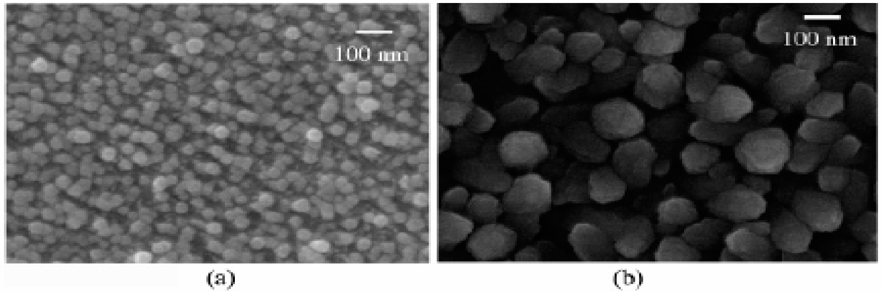


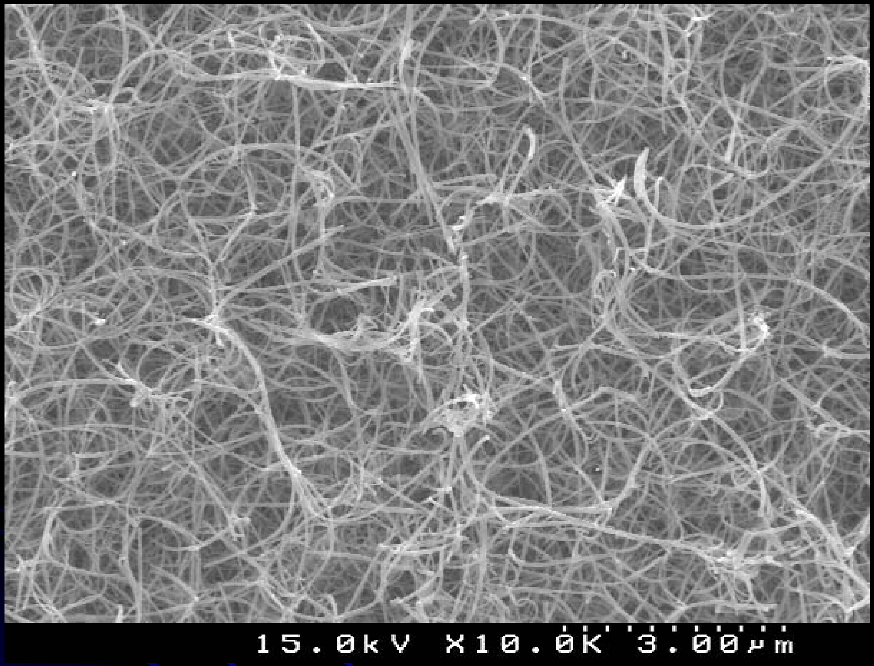
Figure 3. SEM images of (a) the as-deposited TiO_2 thin film and (b) with TiO_2/ZnO thin film deposition. The images were recorded at different magnification due to the differences between the structure of the TiO_2 and ZnO samples.

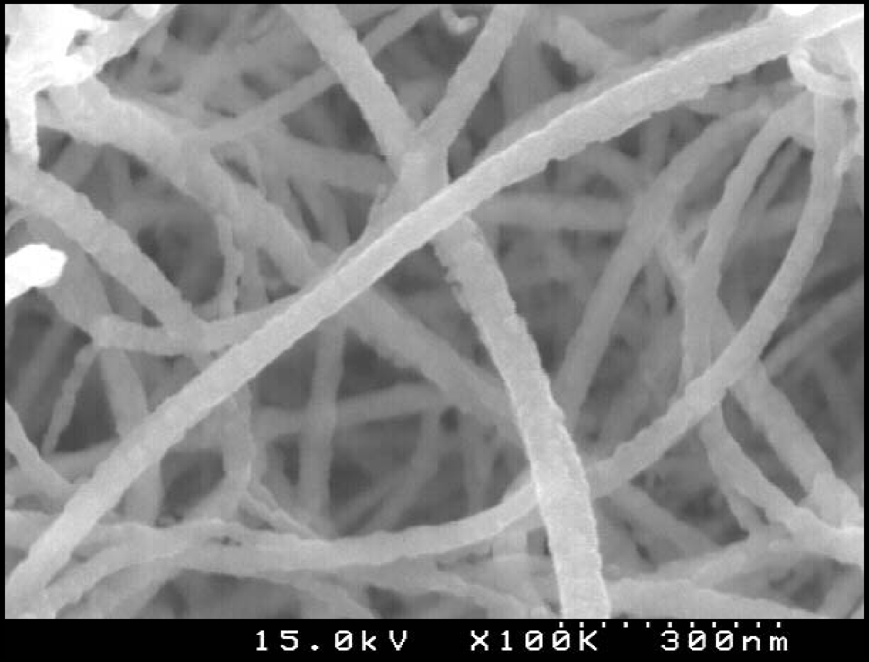
TABLE I. DSSCs performance of TiO_2 (N3) and ZnO coated TiO_2 (N3) electrodes under the light intensity of 80 mW/cm^2.

Electrode	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	η (%)
TiO_2 (N3)	0.49	13.2	0.40	3.31
TiO_2(N3)/ZnO (30 nm)	0.62	11.7	0.52	4.51
TiO_2(N3)/ZnO (60 nm)	0.59	4.51	0.55	2.50
TiO_2(N3)/ZnO (150 nm)	0.54	4.14	0.55	1.59
TiO_2(N3)/ZnO (300 nm)	0.47	0.61	0.51	0.18

J. Phys. Chem. B **2005**, *109*, 24254.
Appl. Phys. Lett. 2006, 89, 253512
Electrochimica Acta **2005**, *50*, 2453

CdO nanowires by chemical bath deposition (CBD)

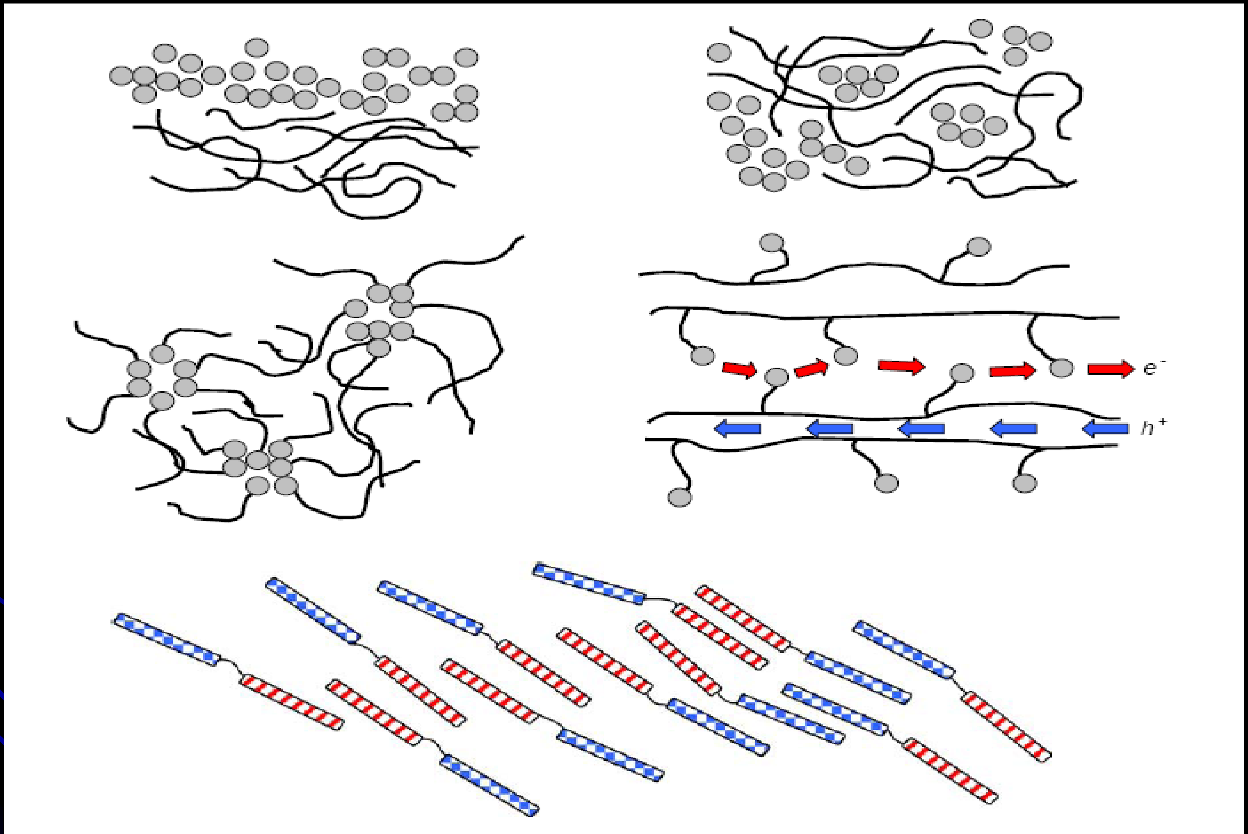




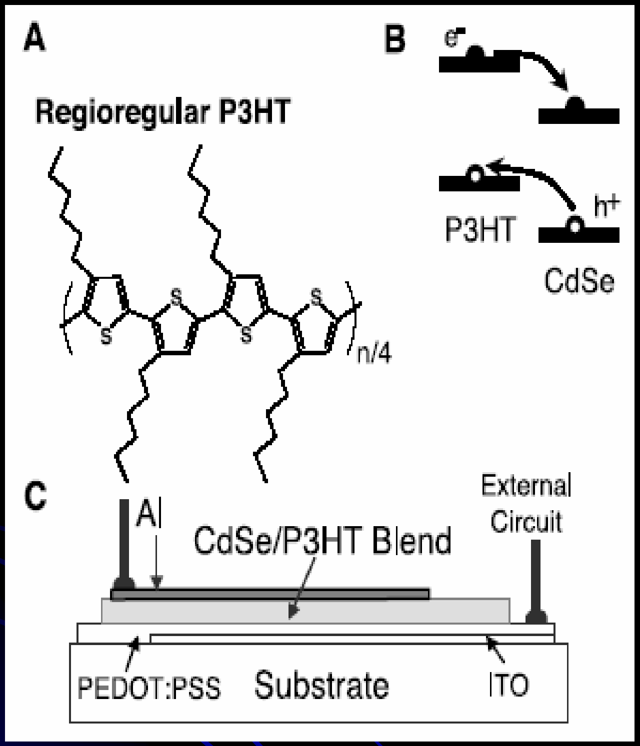
Energy conversion efficiency: ~1% under 80 mW/cm^2

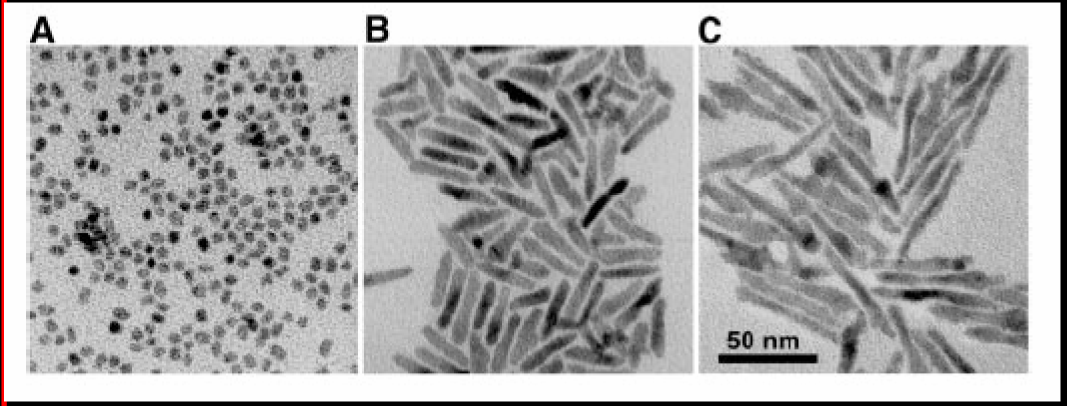
Solar Energy 80 (2006) 185
J. Photochem. Photobio. A in press

Different morphologies of heterojunction cells.



Hybrid Solar Cells with Quantum Dots

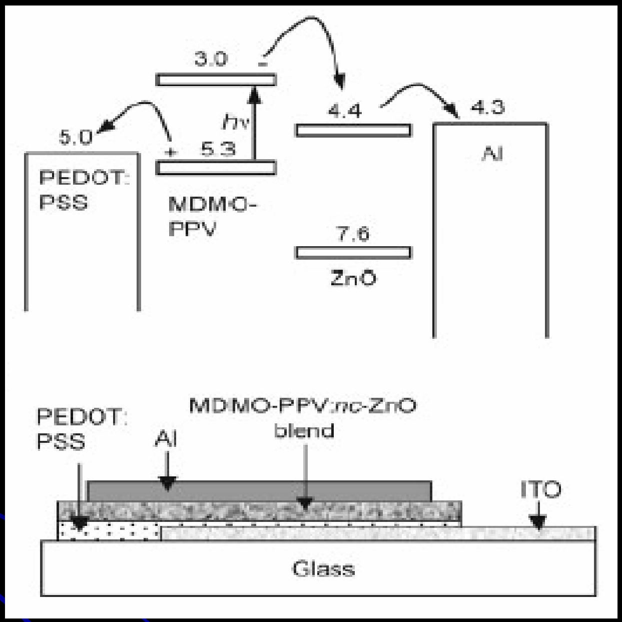


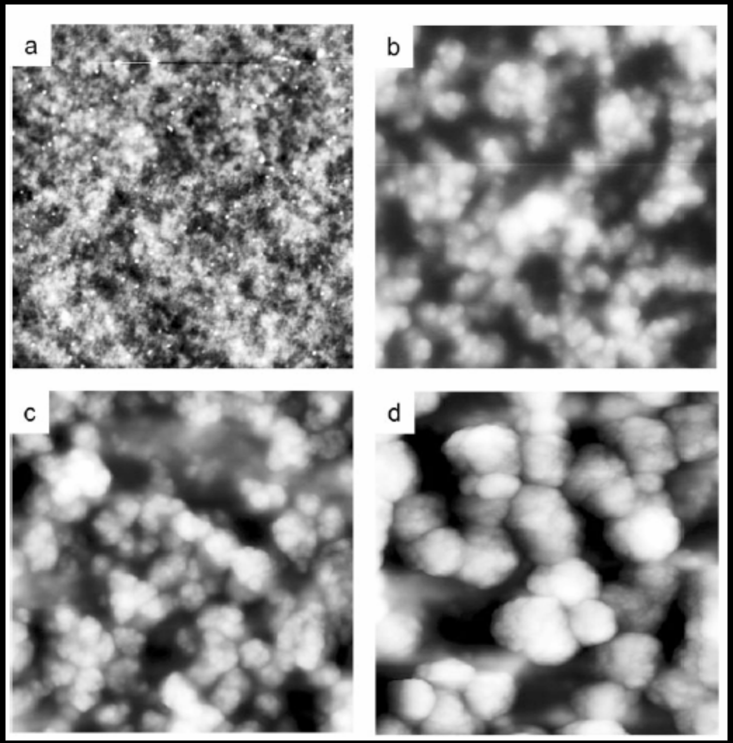


Eff = 1.7 %

✓ **A. P. Alivisatos** *et. al. Science* **2002,** ***295*****, 2425**
✓ **A. P. Alivisatos** *et. al. Adv. Mater.* **1999,** ***11*****, 923**

ZnO nanoparticles bending in P3HT polymers





***Eff* = 0.92 %**

✓ **R. A. J. Janssen** *et. al. Adv. Funct. Mater*. **2004, *16*, 1009.**
✓ **R. A. J. Janssen** *et. al Adv. Funct. Mater.* **2006, *16*, 1112.**

Infiltrating semiconducting polymers into mesophorous films

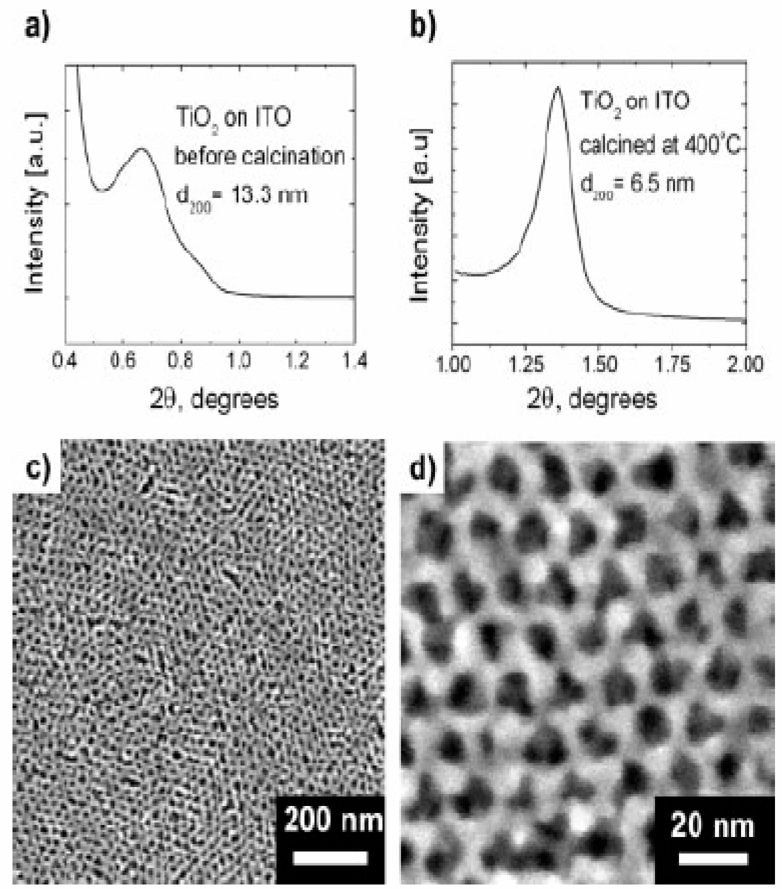


Fig. 1. Mesoporous titania characterization. X-ray diffraction patterns of mesoporous titania before (a) and after (b) calcination at 400 °C, and HRSEM images of calcined mesoporous titania at two different magnifications (c,d). Pores with 3-fold rotational symmetry are shown in (d).

Spin coating and high temperature treatment 100-200 °C, 1 min – 48 hr

Only 33% of the total volume of the film can be filled with a semiconducting polymer

***Eff* = 0.13 %**

✓ **M. D. McGehee,** *Adv. Funct. Mater.* **2003,** *13*, 301.

Infiltration and in-situ polymerization

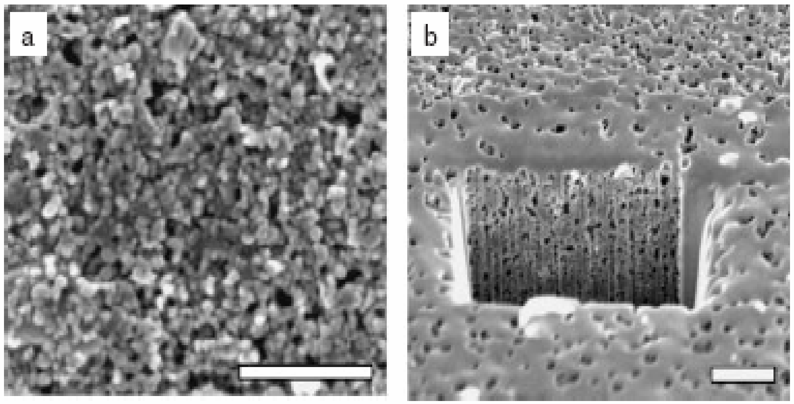
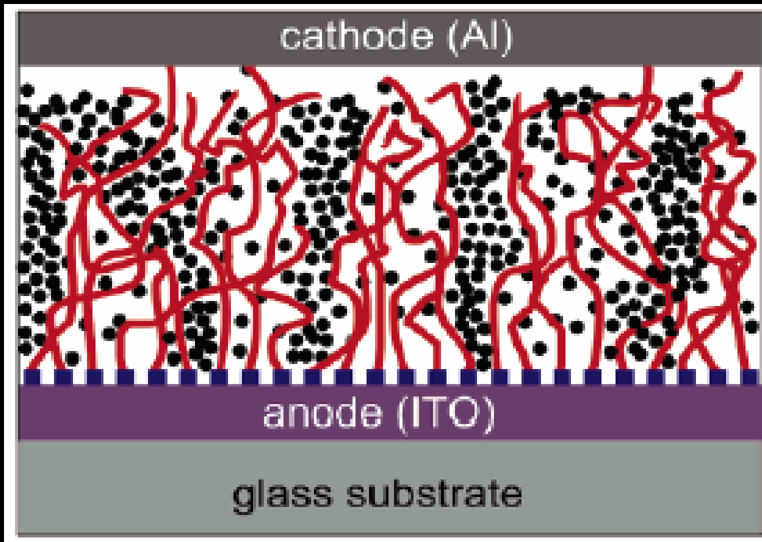
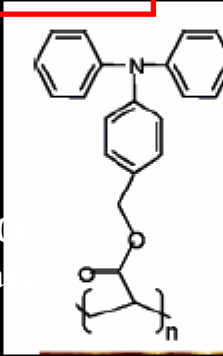


Figure 1. SEM image of a random nanocrystalline TiO_2 film created by spin-coating. a) Top view and b) angled view of a cross-section. The scale bars represent 500 nm.





Conversion Efficiency 0.06-0.16%

Quantum efficiencies 50%

Random nanocrystalline TiO_2 network
A very low incorporation of polymer (0.5%)

✓ **A. J. Heeger** *et. al. Adv. Funct. Mater.* **2004, *15*, 677.**

Nanocrystalline CdSe spin-coated on IT
PTPAA brush grown from an ITO surfa

✓**R. H. Friend et al.** ***Nano Lett.*** **2005, *5*, 1653.**

Role of linkage groups and their hydrophilicity

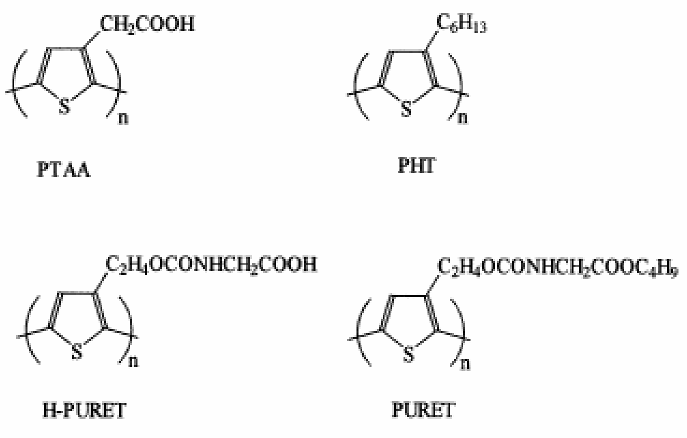


Figure 1. Structures of polythiophenes considered in this study.

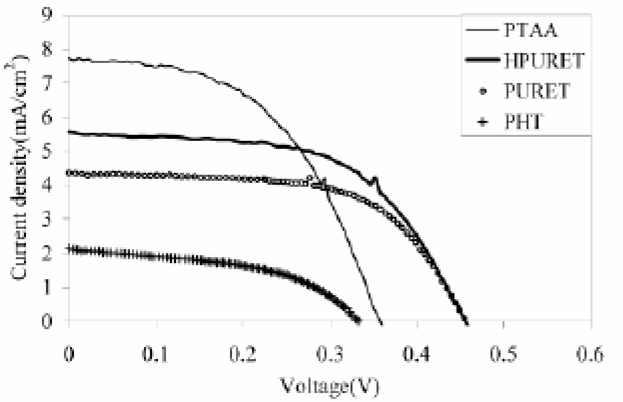


Figure 3. *I–V* characteristics of polythiophen

***Eff* = 1.5 %**

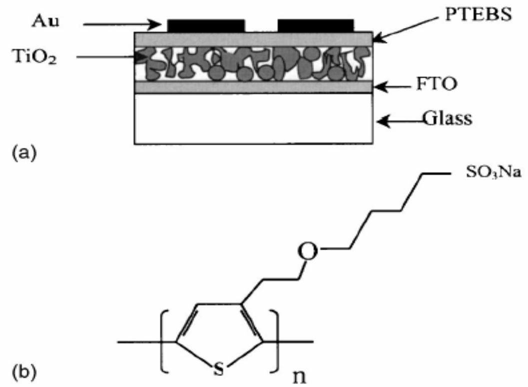


FIG. 1. (a) Schematic of glass/FTO/TiO$_2$/polymer/Au solar cells; (b) chemical structure of the water-soluble polythiophene (sodium poly[2-(3-thienyl)-ethoxy-4-butylsulfonate]).

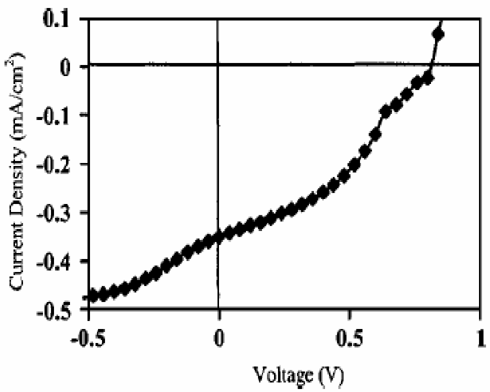


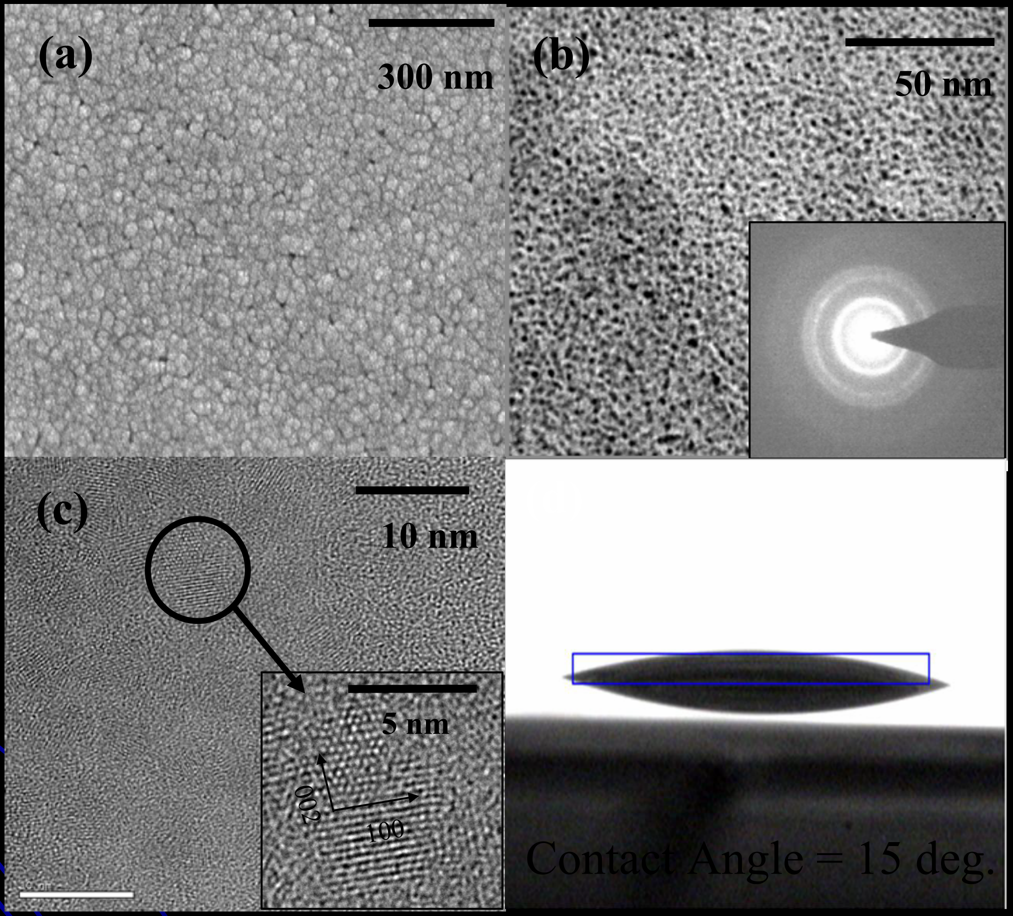
FIG. 2. Linear *J–V* curve in the fourth quadrant under 80 mW/cm^2 AM1.5 illumination.

***Eff* = 0.13 %**

✓**J. Kumar** *et. al*, *Nano L*

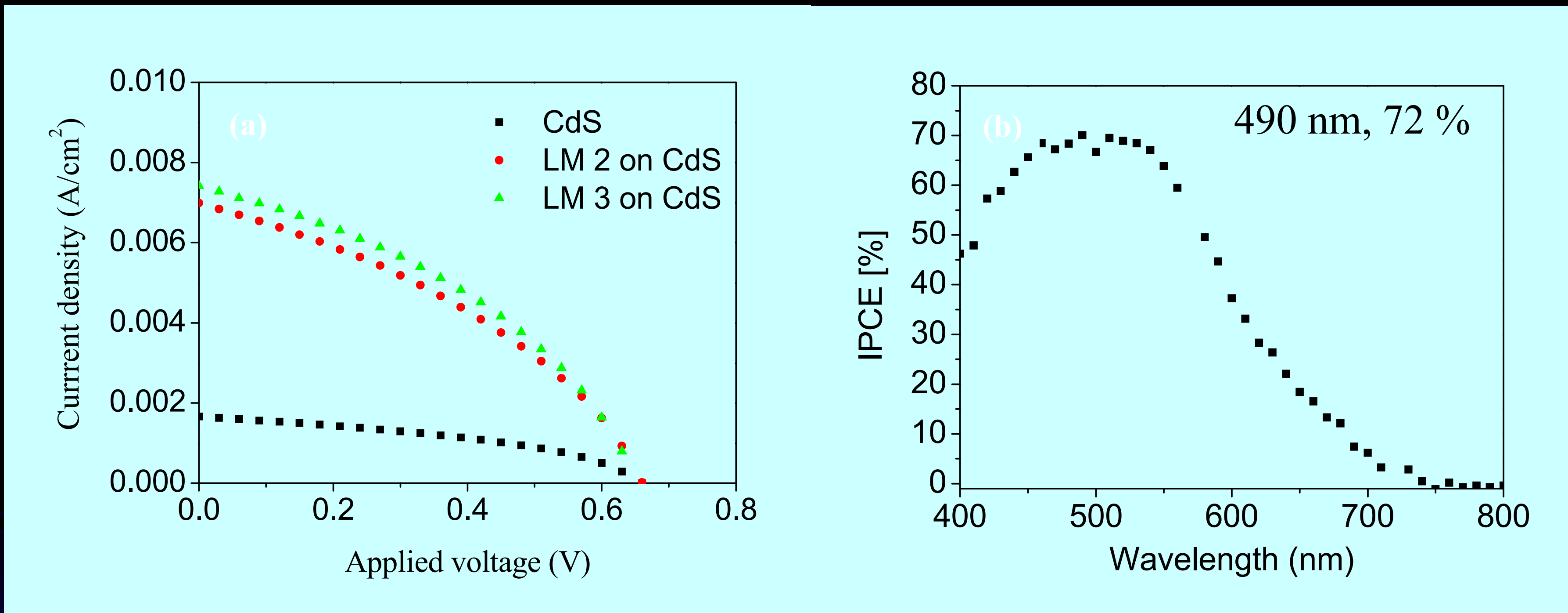
✓ **J. T. McLeskey, Jr.** , *Appl. Phys. Lett.* **2005**, ***86***,**153501**.

Preparation of CdS nanoparticles on ITO by CBD



✓ Nanocrystalline CdS film on ITO; (a) SEM, (b) TEM (inset: SAED), (c) high-resolution TEM (inset: magnified image) and (d) water contact angle

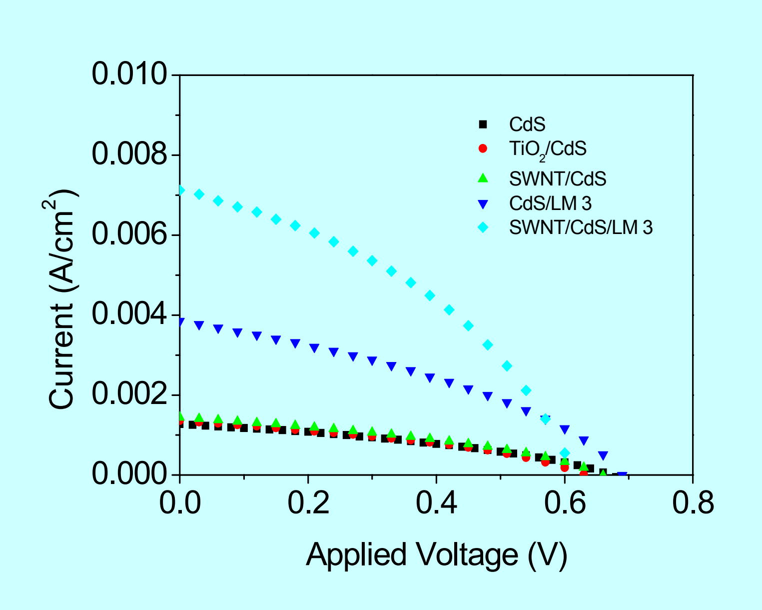
J-V curves of hybrid polymer solar cells on CdS/ITO in the presence of $I^-/I_3^-/CH_3CN$

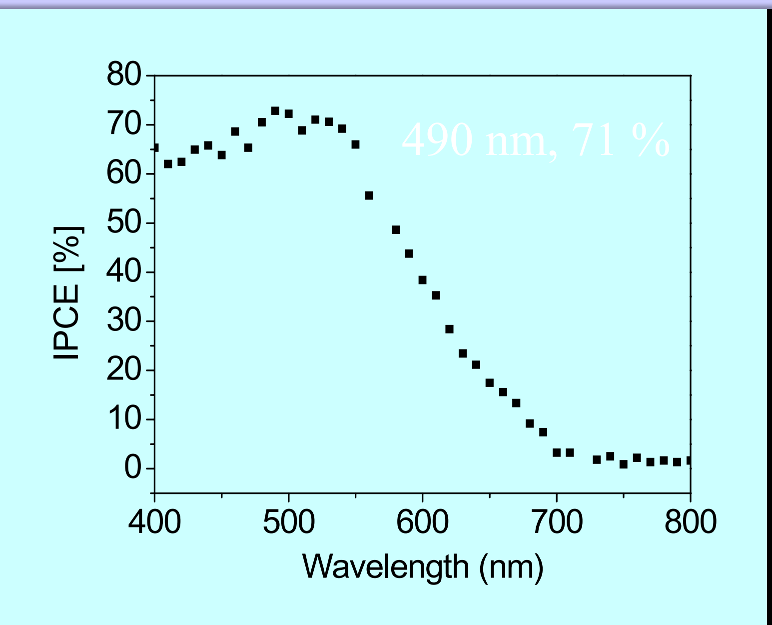


	Voc (V)	*Jsc* (mA/cm²)	*FF*	*Eff* (%)
CdS	0.66	1.66	0.42	0.57
CdS/LM 2	0.66	6.99	0.37	2.15
CdS/LM 3	0.65	7.42	0.39	2.37

In the presence of TiO2 layers as a hole blocking layer

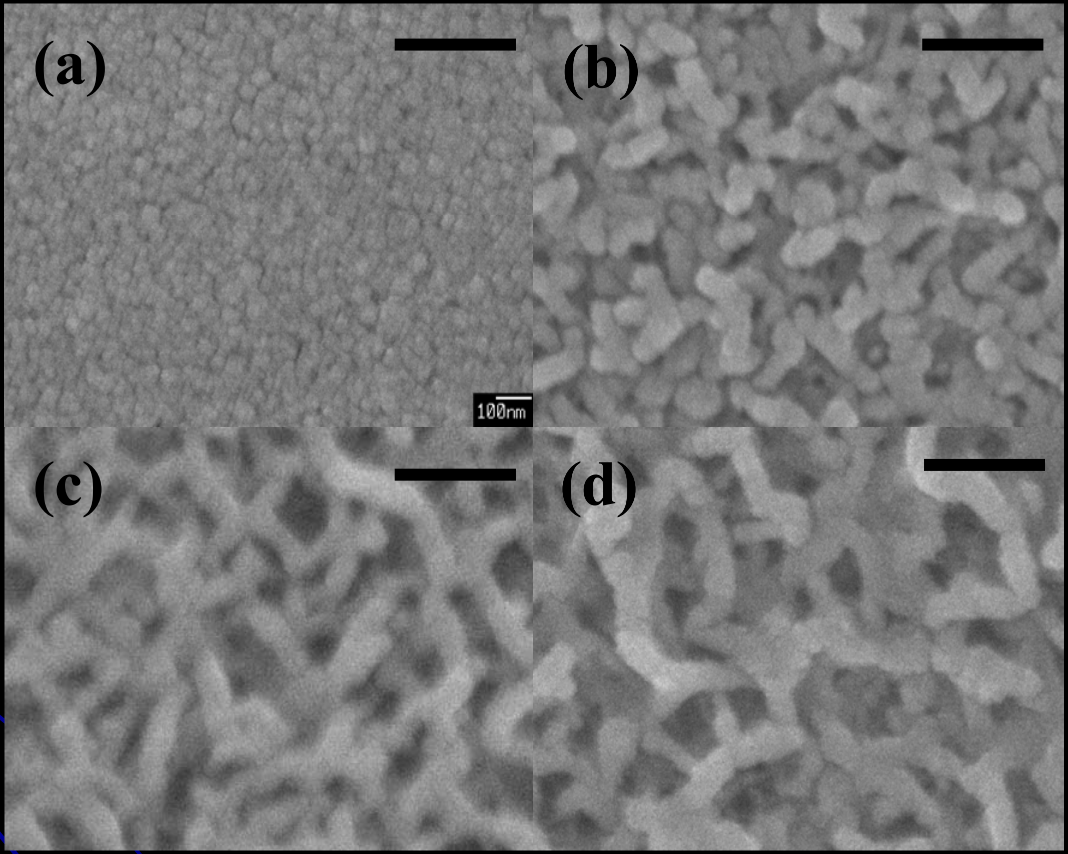
J-V curves of hybrid polymer solar cells on SWNTs/CdS/ITO





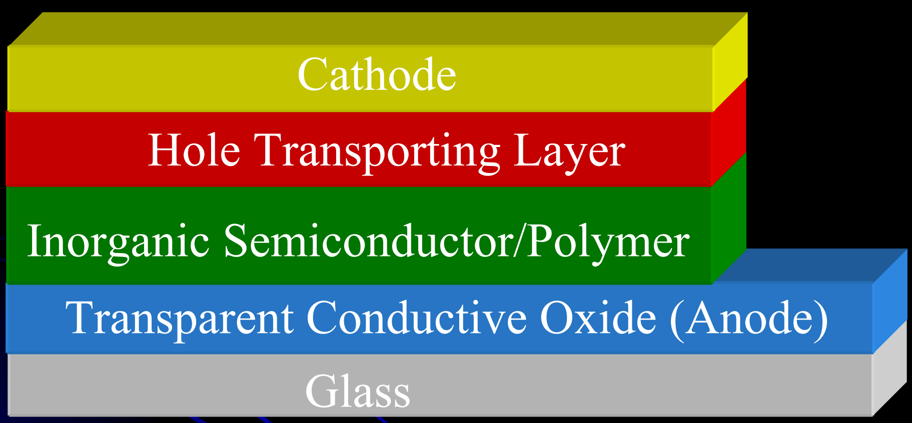
CdSe	Voc (V)	Jsc (mA/cm^2)	FF	Eff (%)
CdS	0.68	1.27	0.36	0.39
TiO_2/CdS	0.63	1.36	0.37	0.40
SWNT/CdS	0.66	1.44	0.37	0.44
CdS/LM 3	0.69	3.85	0.37	1.22
TiO_2/CdS/LM 3	0.65	7.42	0.39	2.37
SWNT/CdS/LM 3	0.63	7.12	0.39	2.19

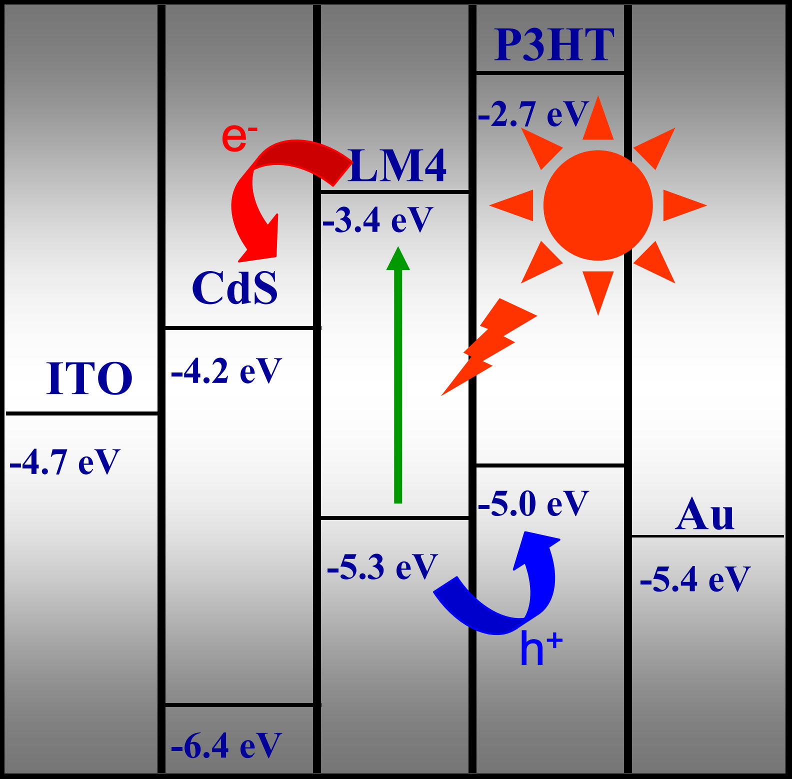
Preparation of Macaroni-Shaped In_2S_3 nanorods



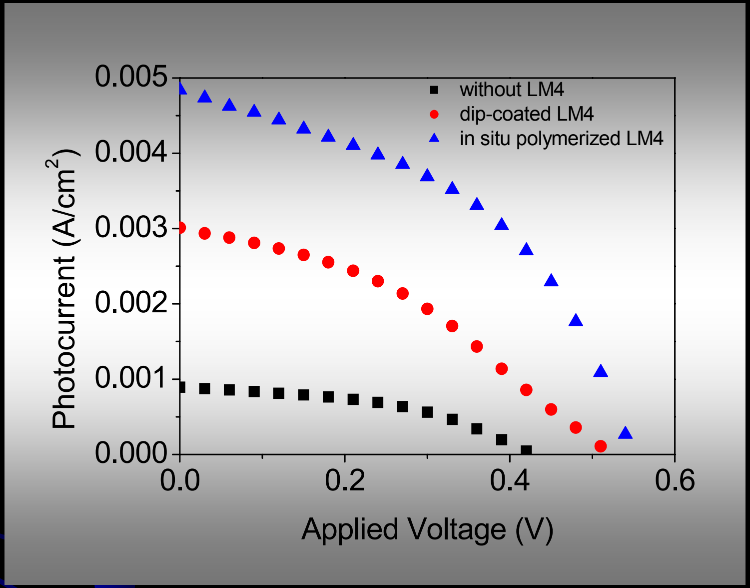
SEM image (scale bar : 300 nm) of In_2S_3 film on ITO; prepared by the addition of 0.1 M HCl (a) 0 vol %, (b) 2 vol %, (c) 4 vol % and (d) 6 vol %.

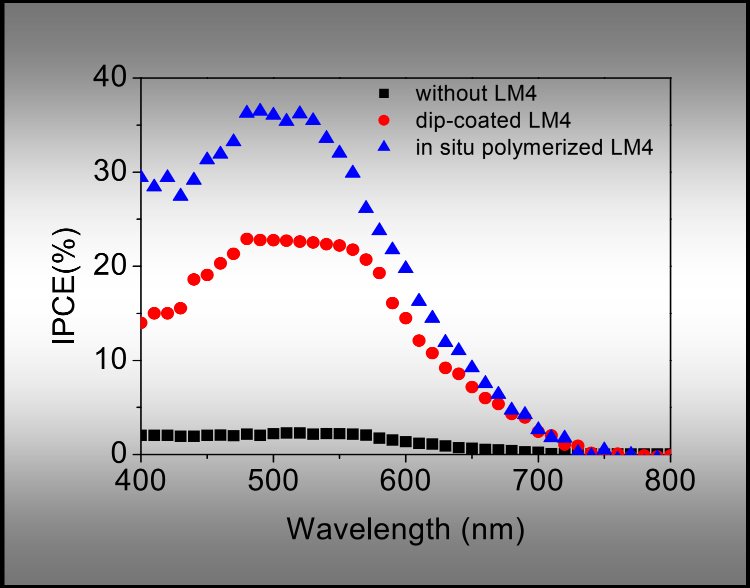
Hybrid solar cells with P3HT as a hole transporting materials





I-V characteristic of hybrid solar cell





ITO/CdS/LM4/P3HT/Au	*Voc* (V)	*Jsc* (mA/cm^2)	*FF*	*Eff* (%)
without LM4	0.43	0.89	0.44	0.17
dip-coated LM4	0.52	3.01	0.37	0.58
in situ polymerized LM4	0.54	4.84	0.45	1.19

Summary

- ✓ **Interfacial contact in hybrid solar cells was optimized using water-soluble polymer photosensitizers**
- ✓ **Water-soluble, acetylene-based polymer photosensitizers was developed and its surface hydrophilicity was modified by anion exchange method**
- ✓ **Fabrication of electrochemical solar cells with acetylene-based polymer**

  - A power conversion efficiency of 2.37%
- ✓ **Solid-state hybrid solar cells with hydrophilicity control**

  - A power conversion efficiency of 1.19%

Members

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