Nanomaterials on energy applications

Advantages of nanomaterials

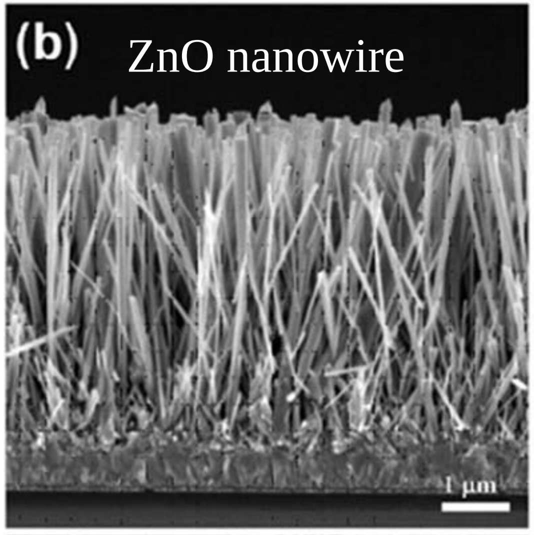
Very large difference in physical and chemical properties when the sizes of materials were down to nanoscale.

Advantages：

1. Large surface area

2. High reactivity

3. Lower cost

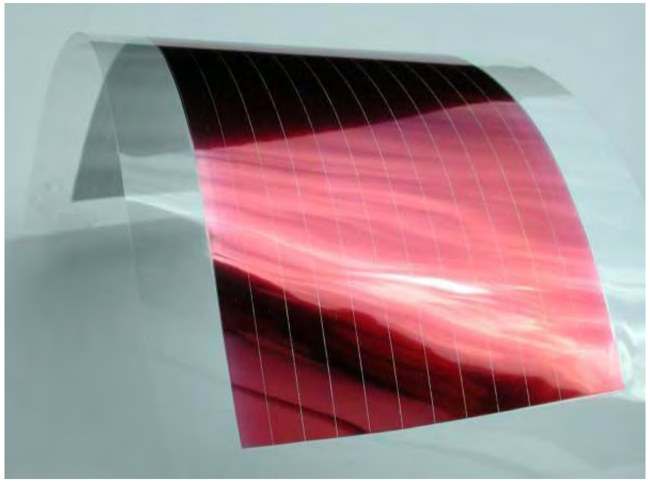


Wu, J. J., et al., Appl. Phys. Lett. 2007, 91, 093117

Nanomaterials on energy applications

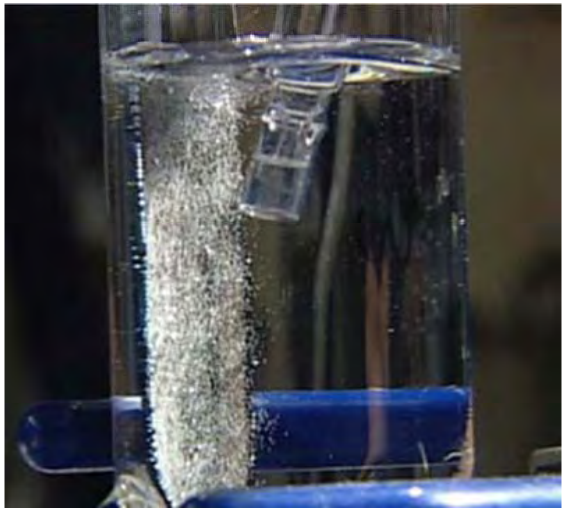
Fuel Cell

Solar cell



http://www.chenyo.com/sitebuilder/page2.php?view=preview&image=17&category=3

Water Splitting

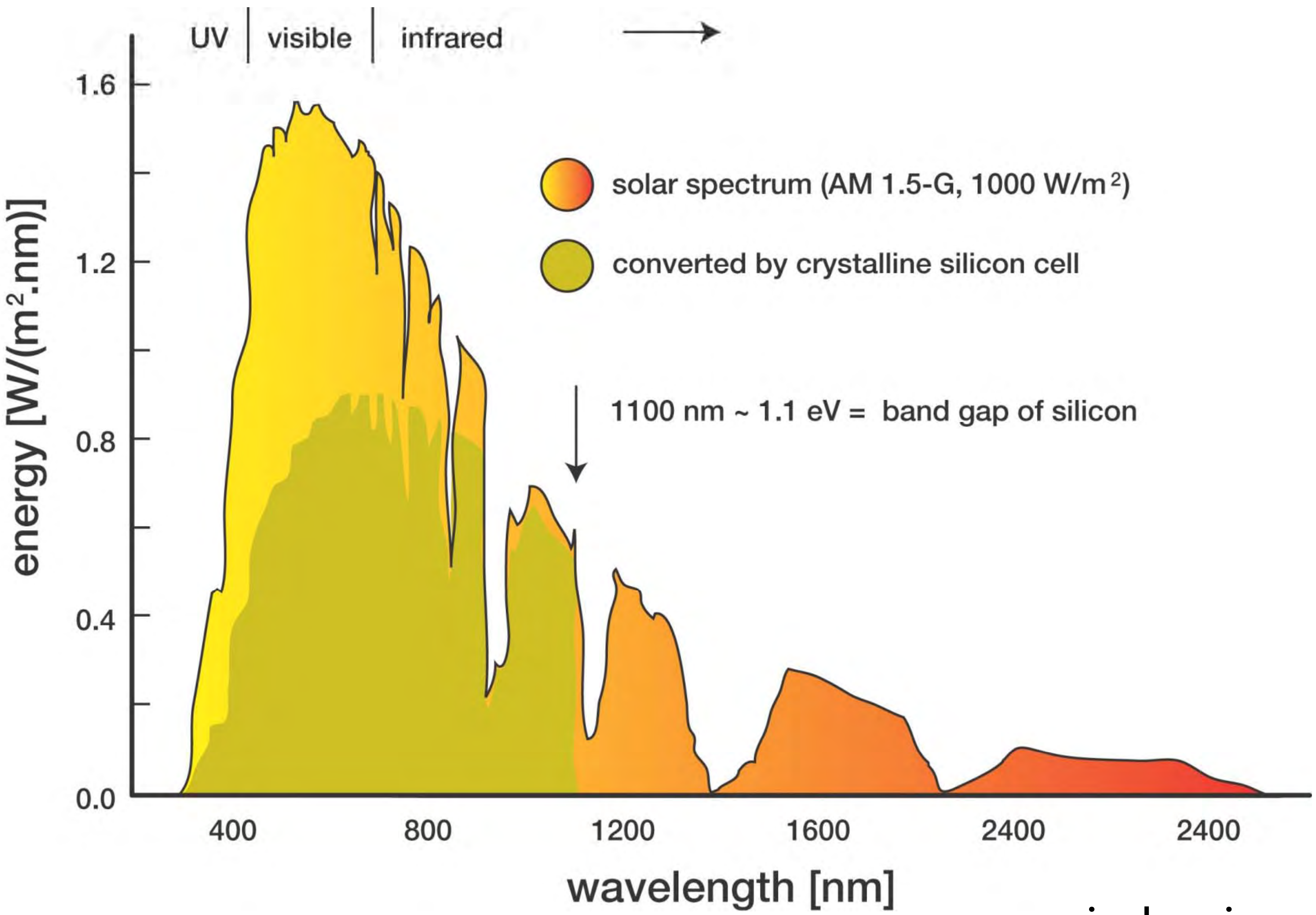


News Release issued by MIT News Office on July 31, 2008)

Plug into the Sun

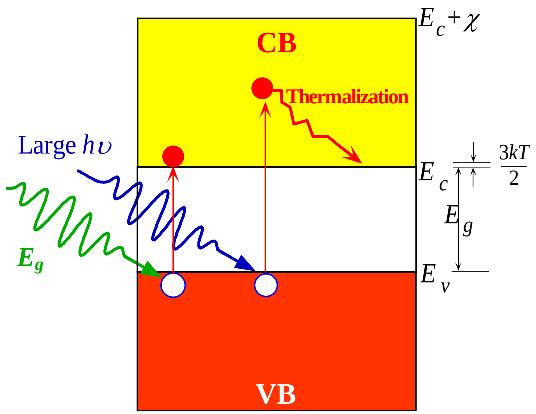
Dye Sensitizer Solar Cell

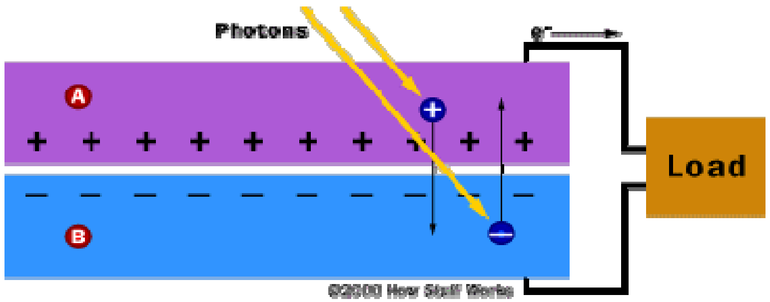
Solar spectrum

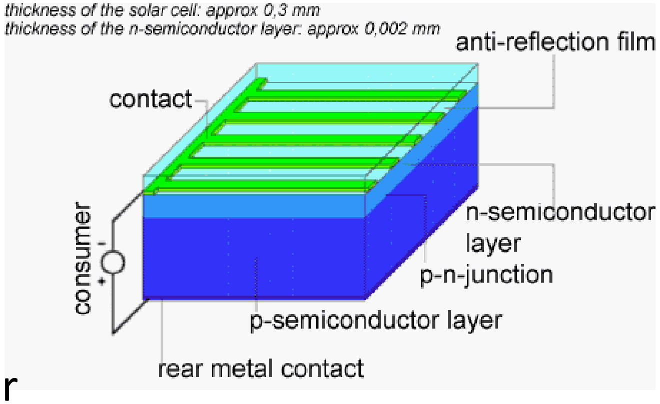


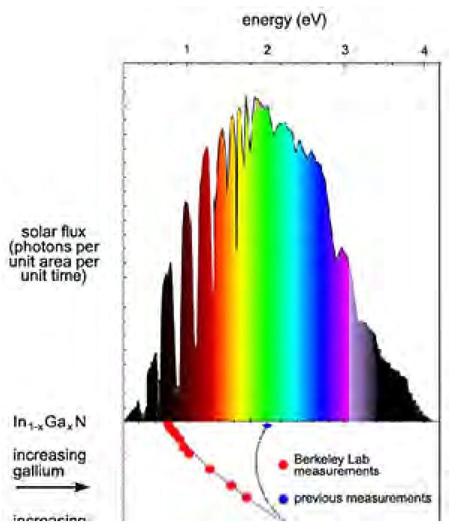
www.vicphycsics.org

How dose photons be converted to electrons?









1. Absorption
2. Electron(-) and hole(+) pair (transport)
3. Current-voltage (Electricity)

Very simple device architecture compared to IC !

Solar cell generations

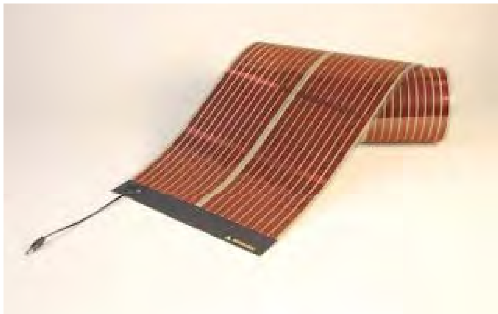
1st generation
Si based solar cell

www.en.wikipedia.org

2nd generation
Thin film solar cell

www.pinheng-technology.com

3rd generation
Organic solar cell



www.pinheng-technology.com

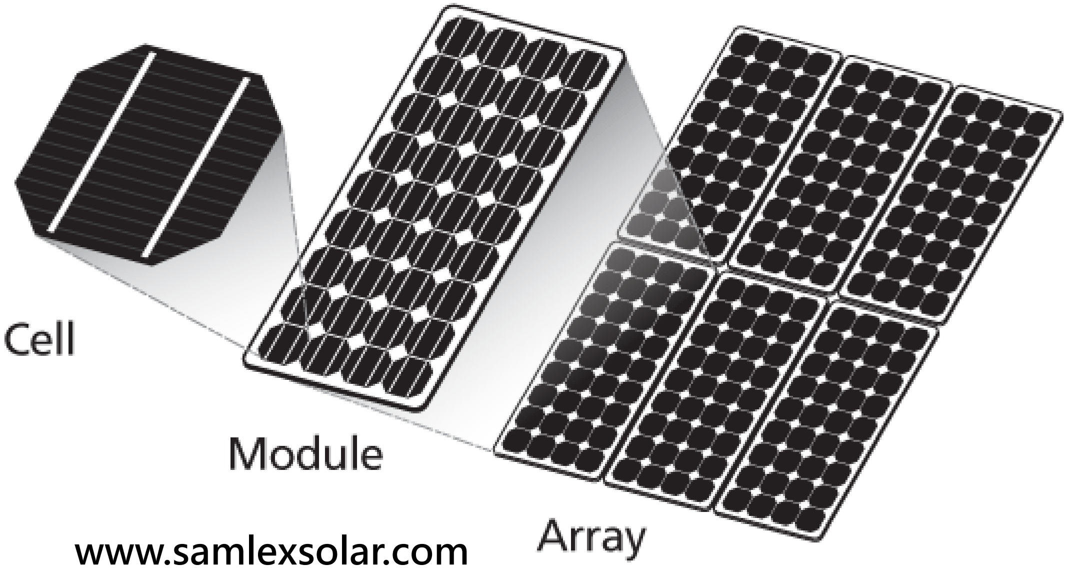
1st generation : **Si based solar cell**

Silicon mineral

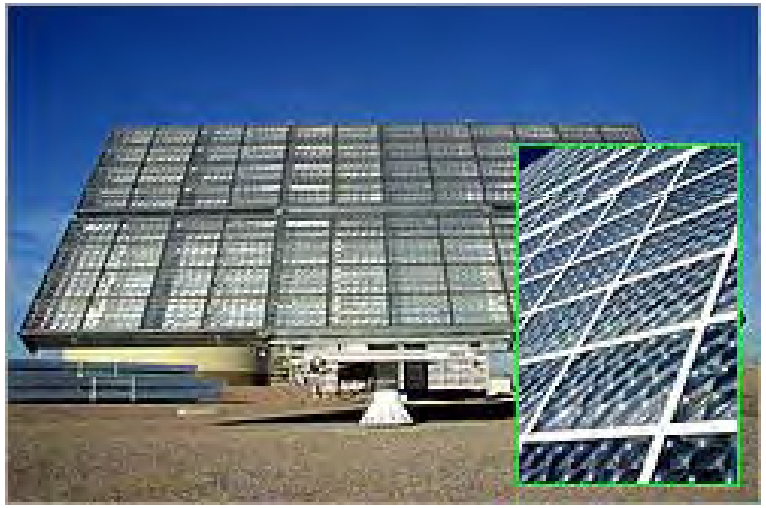
Photo by Enricoros

Si ingots and wafers

Shanghai Panmeng Technology Material Co., Ltd



www.samlexsolar.com



Advantages and disadvantages of Si solar cell

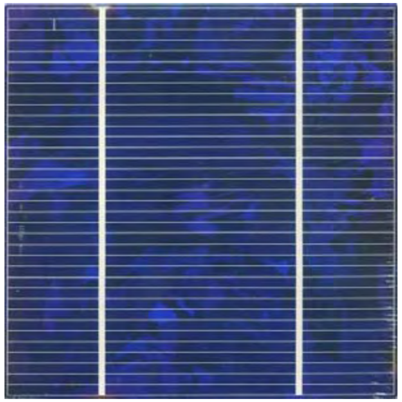
Advantages:

- High power conversion efficiency (single crystalline Si~ 25%、poly crystalline Si~20.4%，amorphous Si~10.1%)
- Long term stability

single crystalline

www.gintechenergy.com

poly crystalline



www.toufen.haibao.com.tw

amorphous

www.hkscipo.com

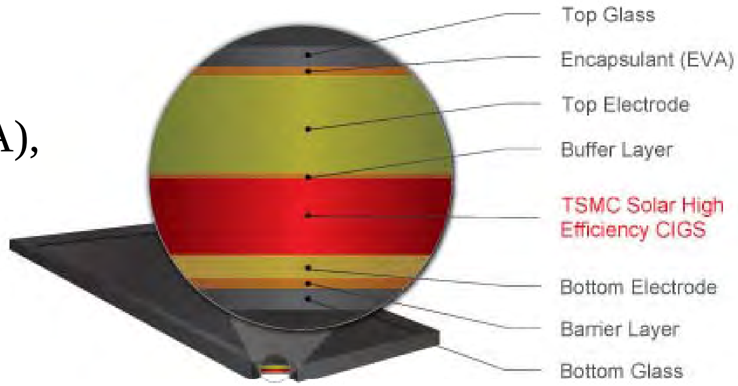
Disadvantages:

- High cost in material and fabrication process

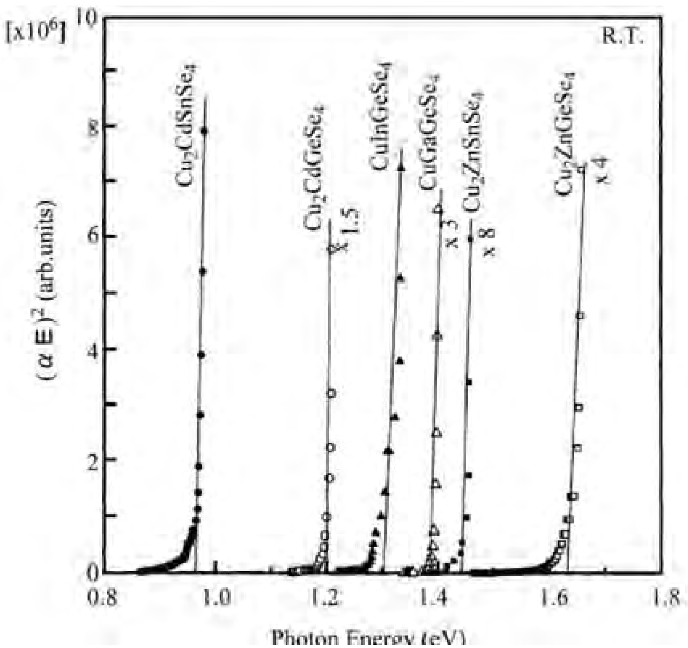
2nd generation : **Thin film solar cells**

- CuInGaSe$_2$, CuInS$_2$…
  - High absorption coefficient
  - Vacuum or non-vacuum process
  - Lower cost compared to Si based PV
  - Flexcell (Swiss), Nanosolar (U.S.A), Daystar (U.S.A), Sulfurcell (Germany), TSMC (Taiwan)

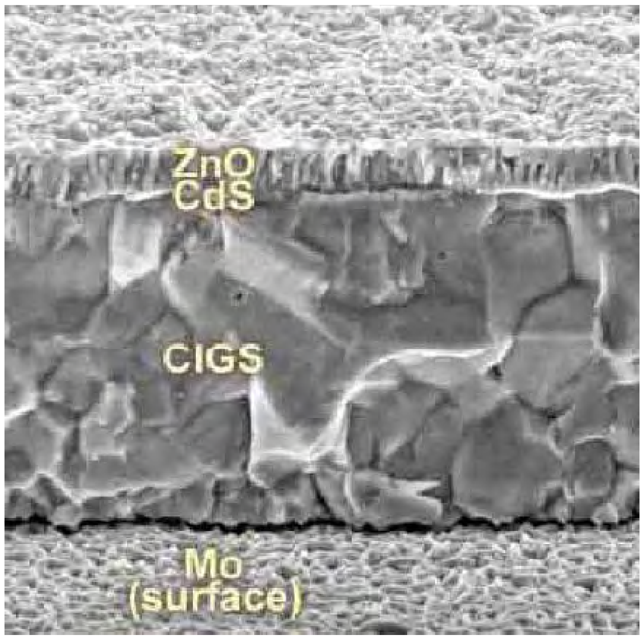
TSMC CIGS



Absorption coefficient and material band gap



www.solarnenergy.com



China International Container Leasing Co., Limited

Advantages and disadvantages of thin film solar cells

Advantages:

- High absorption coefficient
- Ink-jet printing
- roll-to-roll fabrication
- Low cost substrate (Cu tape)

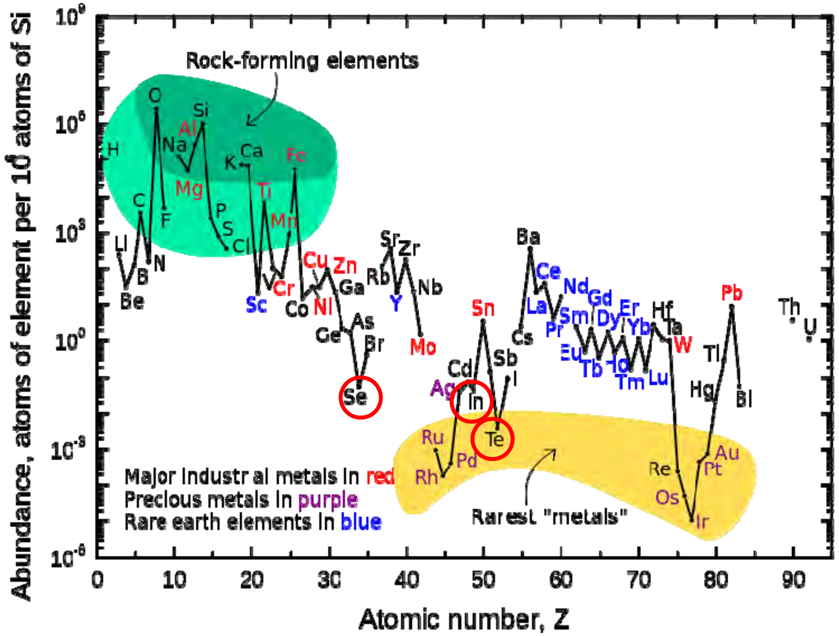
Disadvantages:

- Contamination from fabrication process
- Rare metals (Se, In, Te)

Flexible CIGS PV

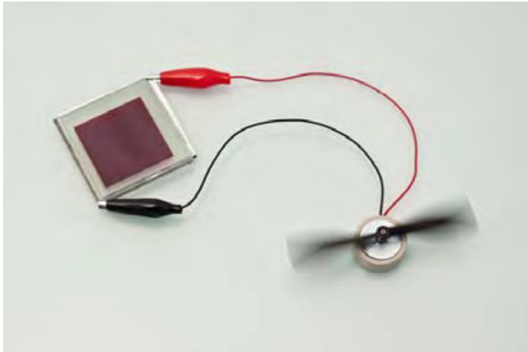
Roll to roll process

www.nanotechweb.org
www.greentechmedia.com



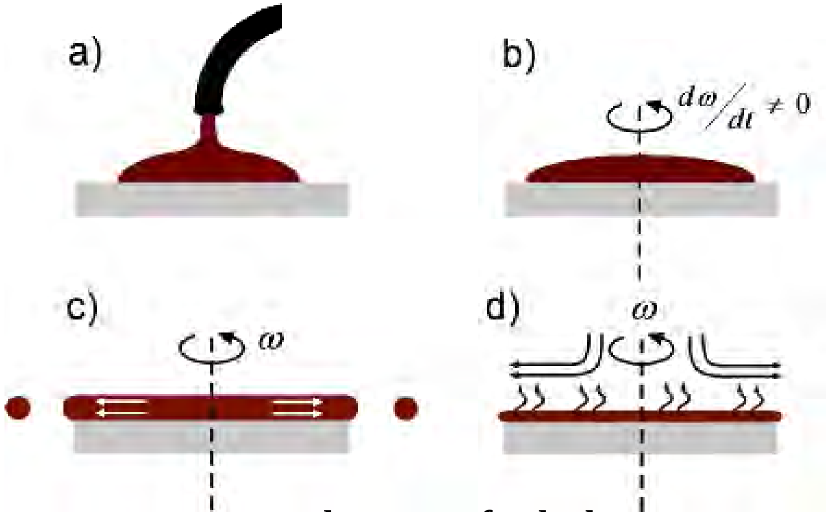
3rd generation : **Organic solar cells**

1. **Dye-sensizited solar cell (DSSC)**
2. **Polymer solar cell**
   - Organic materials
   - Solution-process
   - Simpler fabrication process
   - Lowest cost



www.worldimprovement.net

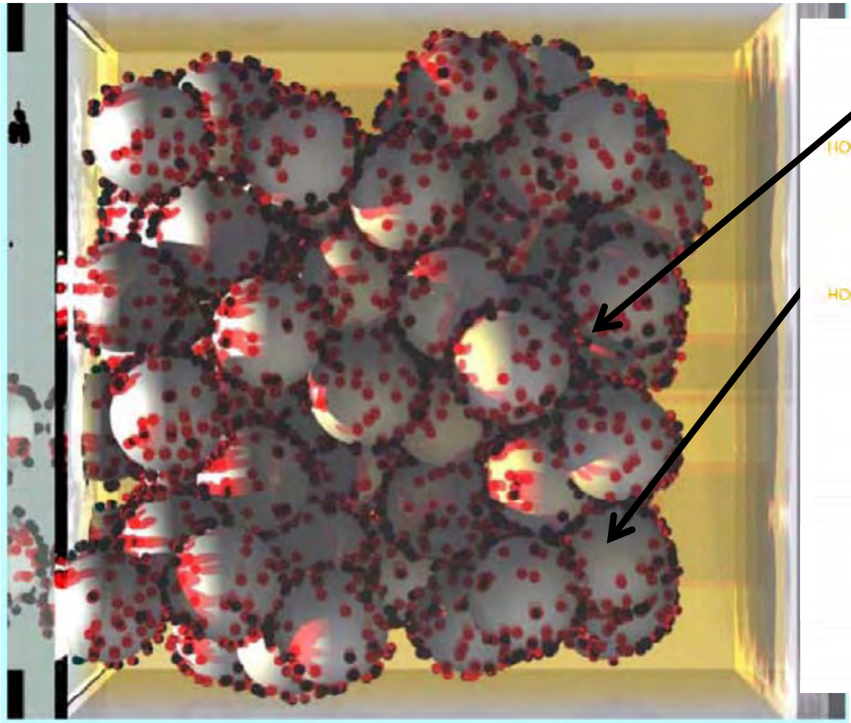
spin-coating



www.large.stanford.edu

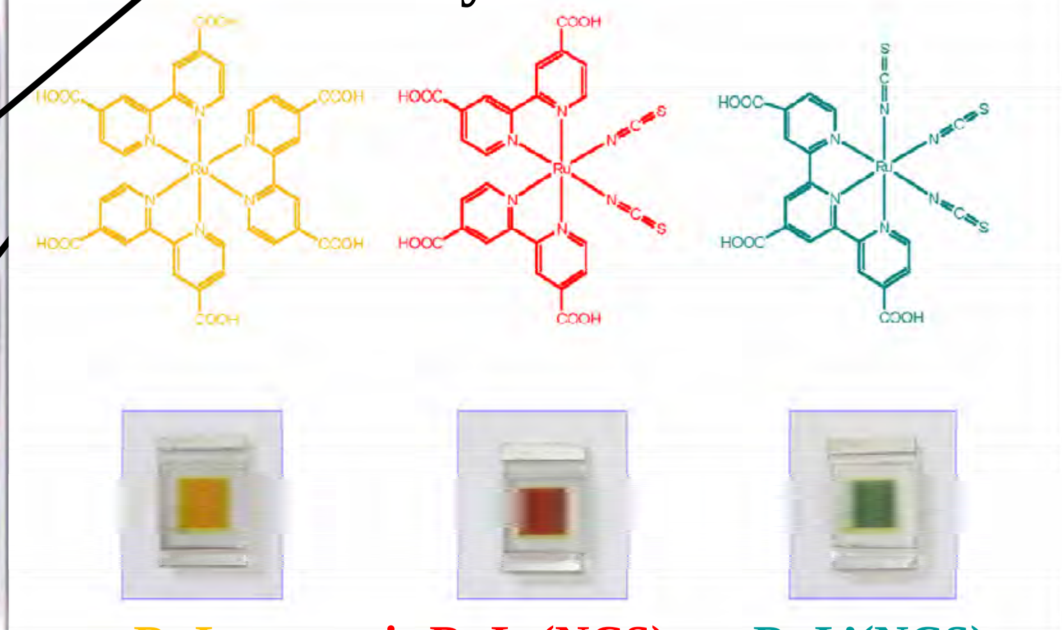
www.pennenergy.com

Device structure of DSSC



Courtesy of Dr. Arthur J. Frank, NREL, USA

Dye

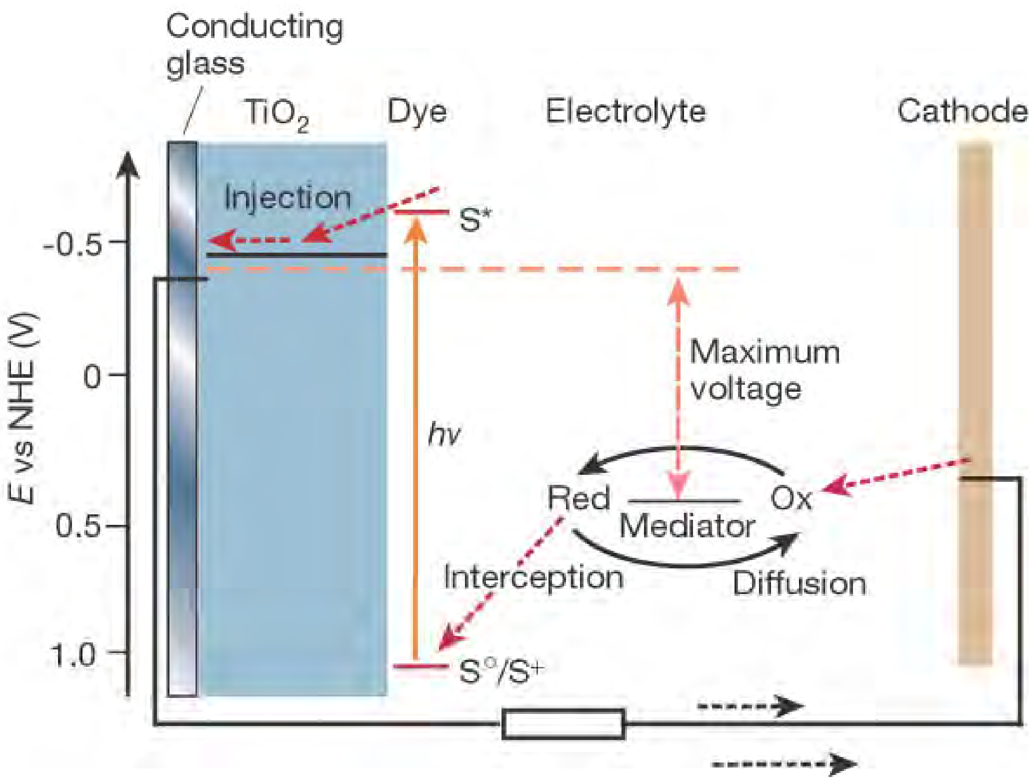


RuL$_3$ *cis*-RuL$_2$(NCS)$_2$ RuL'(NCS)$_3$

www.ipc.uni-stuttgart.de

Inorg. Chem. **2005, 44, 6841-6851**

Working principles of DSSC



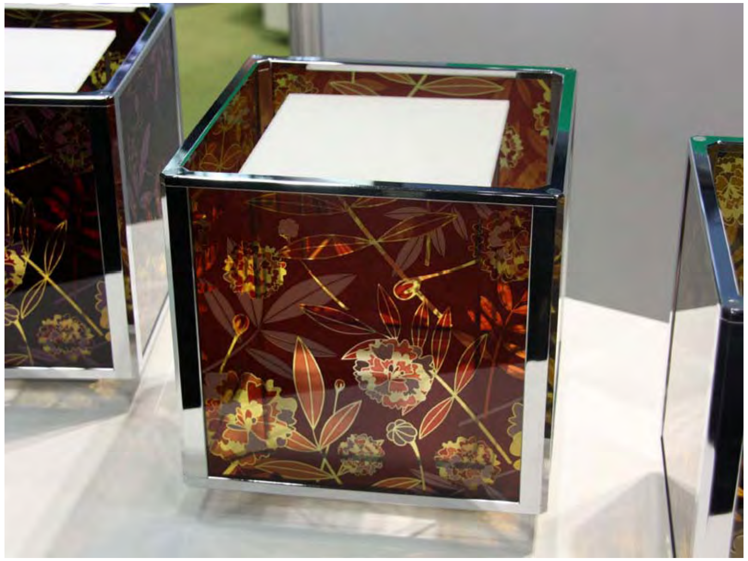
Grätzel cell

Products of DSSC

Decorations

Solar window

www.devindra.org

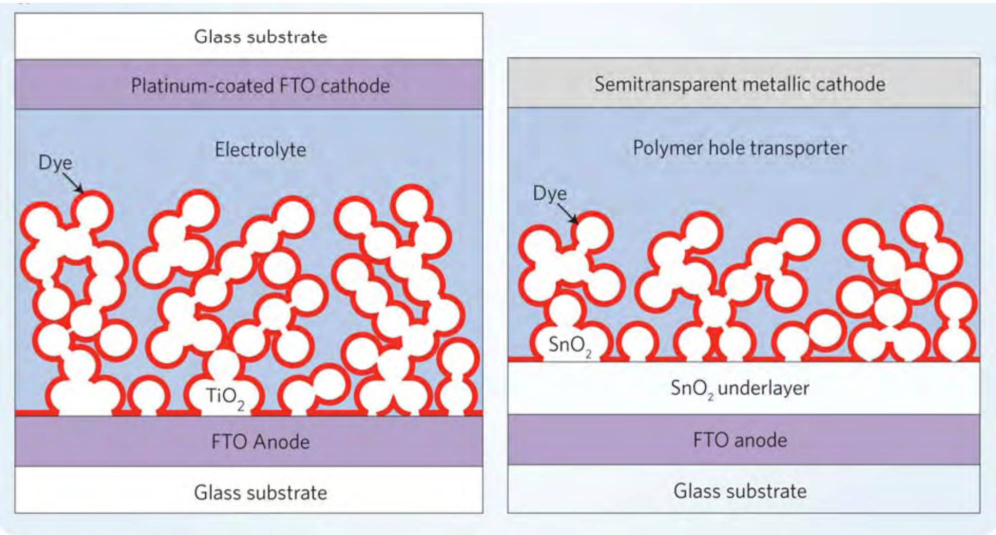


www.hitechreview.com

Disadvantages of DSSC

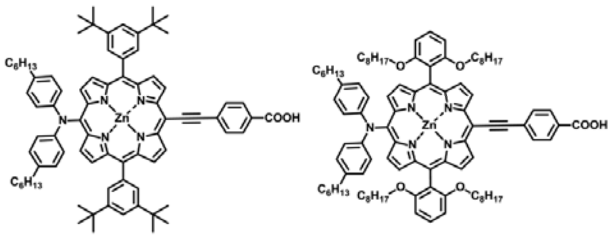
- Liquid electrolyte (low temperature and long term stability)
- High cost, Ru (dye) and Pt (electrode)

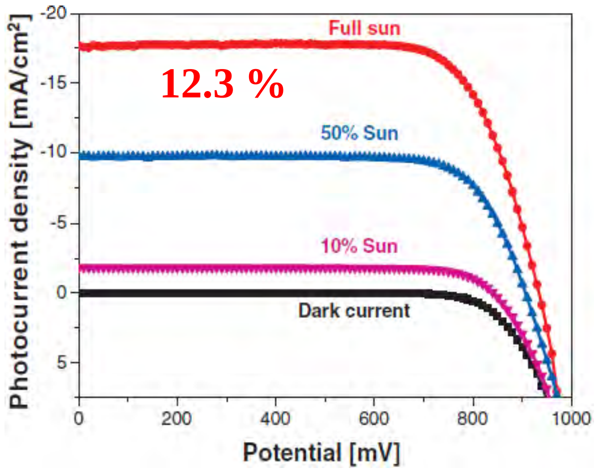
Solid-state DSSC



Nadya Anscombe, *Nature Photonics* **5**, 266–267 (2011)

Porphyrin



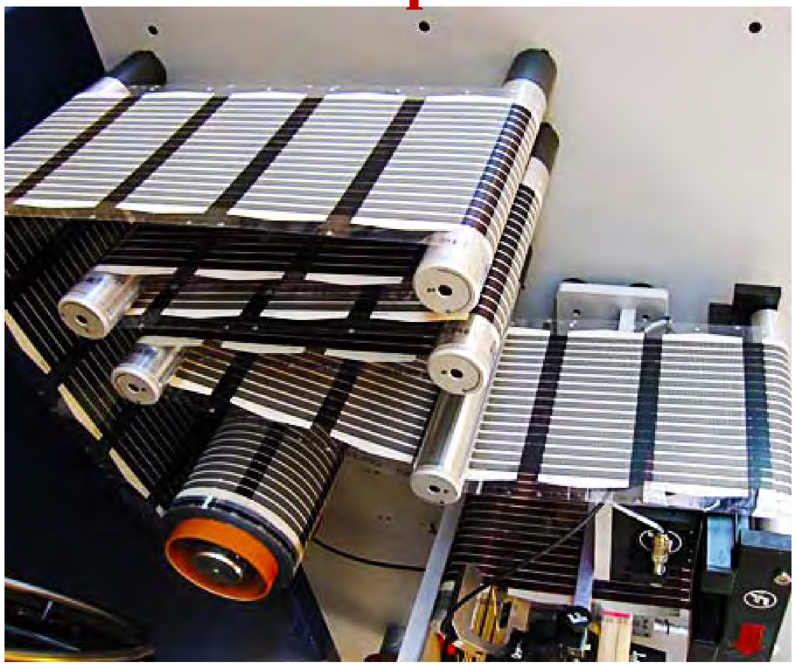


Yella, A. et. Al., *Science* **334**, 629 (2011)

Polymer solar cells

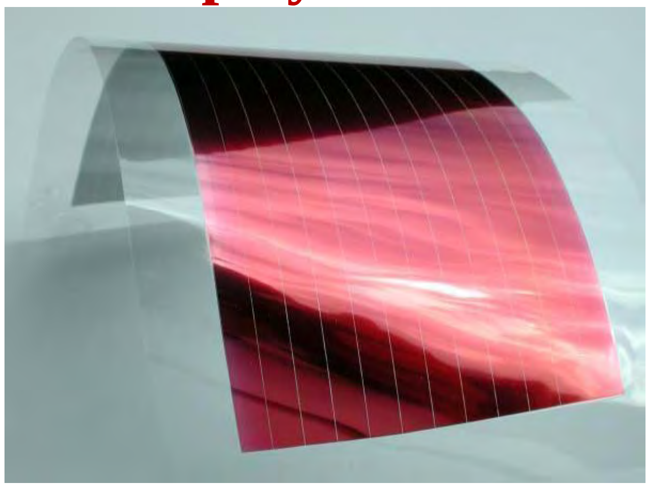
- Solid active layer
- Light weight and high flexibility
- High transparence (active layer~100 nm)
- Ink-printing
- Large area and low cost fabrication

Roll-to-roll process



www.nanotechwire.com

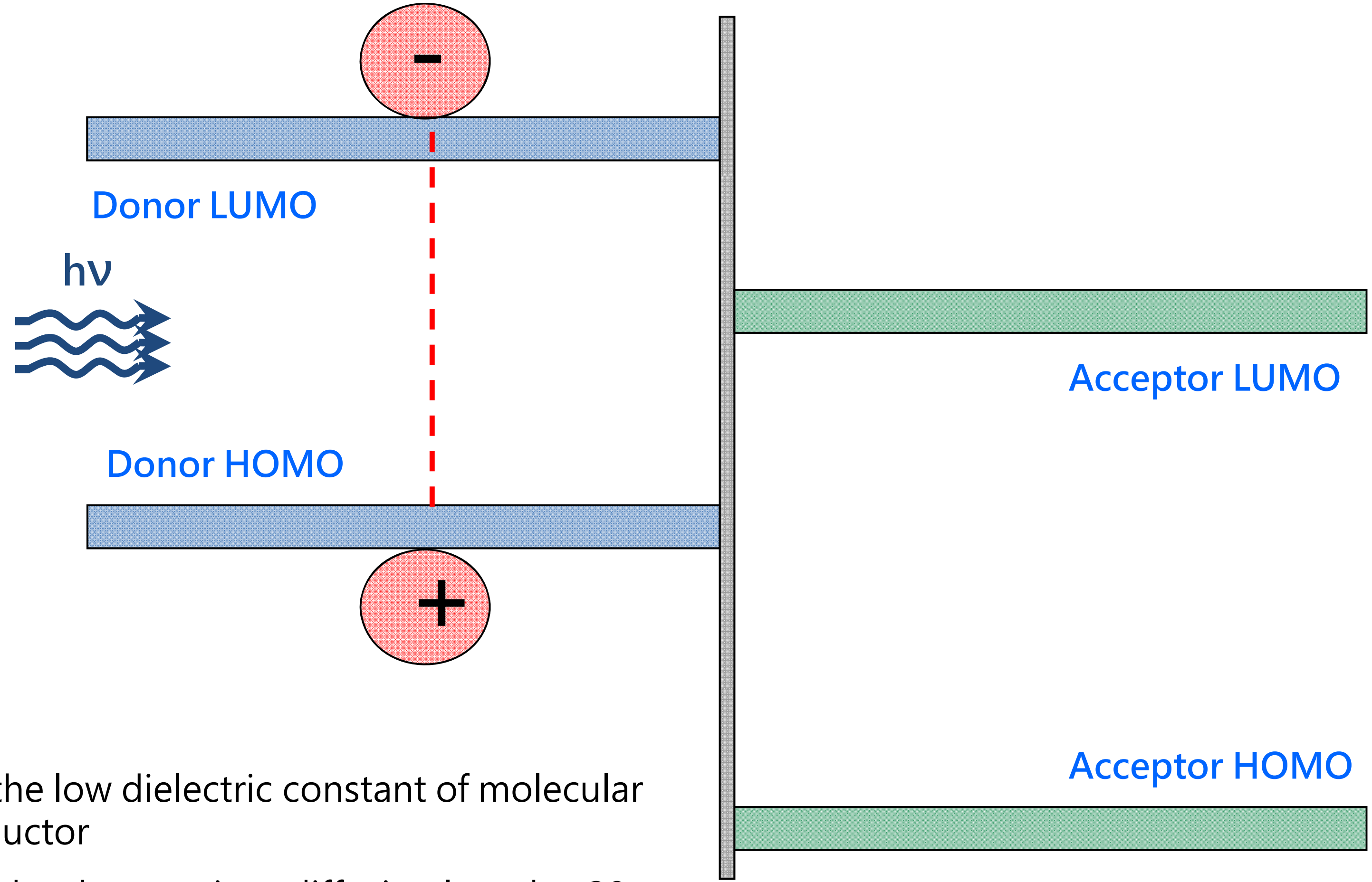
Flexible polymer solar cell



www.nanotechwire.com

Working principle of polymer solar cell

Exiciton diffusion | Charge separation | Charge transport | Charge collection

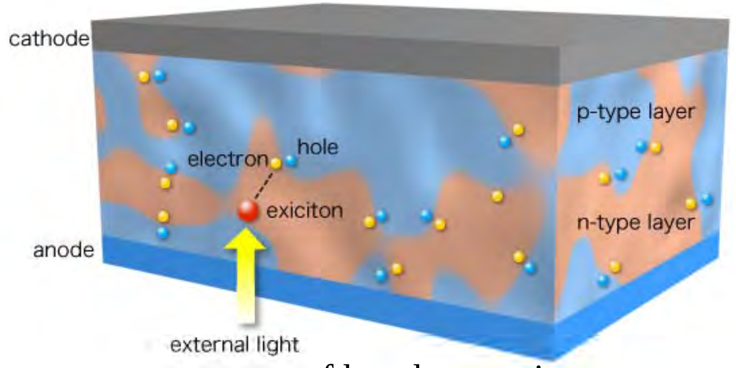


1.Due to the low dielectric constant of molecular semiconductor

2. Due to the short exciton diffusion length <20 nm

Bulk heterojunction structure

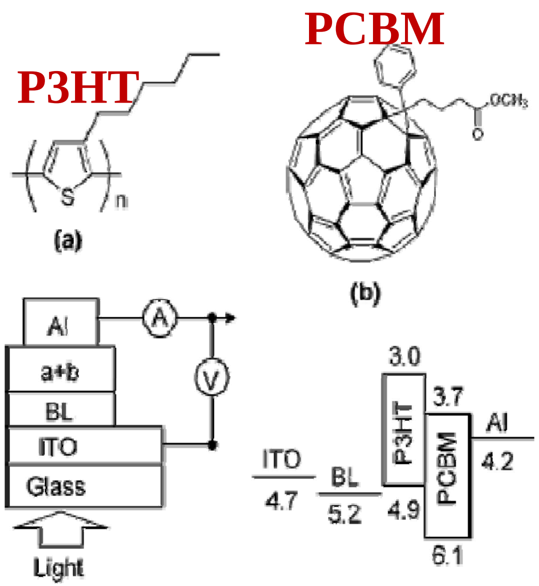
Bulk heterojunction (BHJ)



www.cstf.kyushu-u.ac.jp

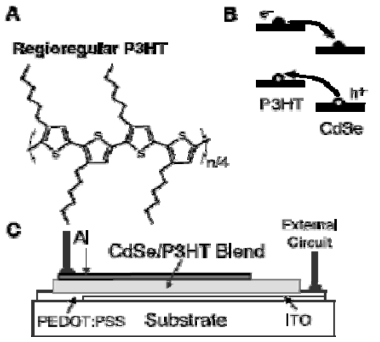
Electron donor material and
electron acceptor material are mixed

Polymer-fullerene

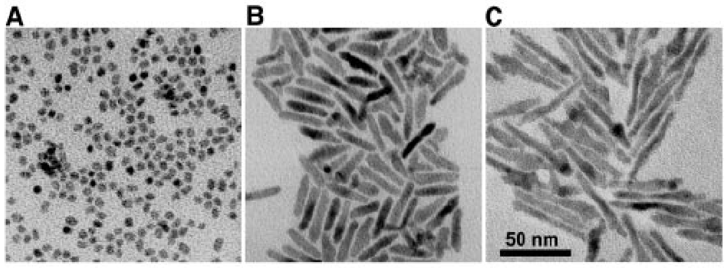


A. J. Heeger et al.

Polymer-inorganic

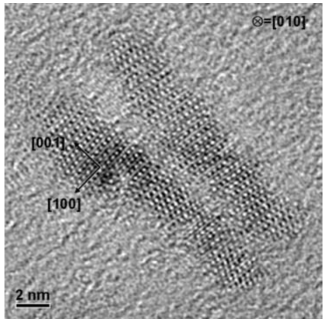


CdSe nanocrystal



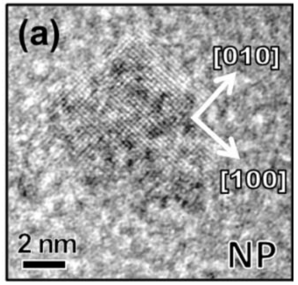
A.P. Alivisatos et al., 2002, SCIENCE, 295, 29

3D scanning transmission electron microscopy (STEM))
Electron tomography of P3HT/TiO_2 hybrids

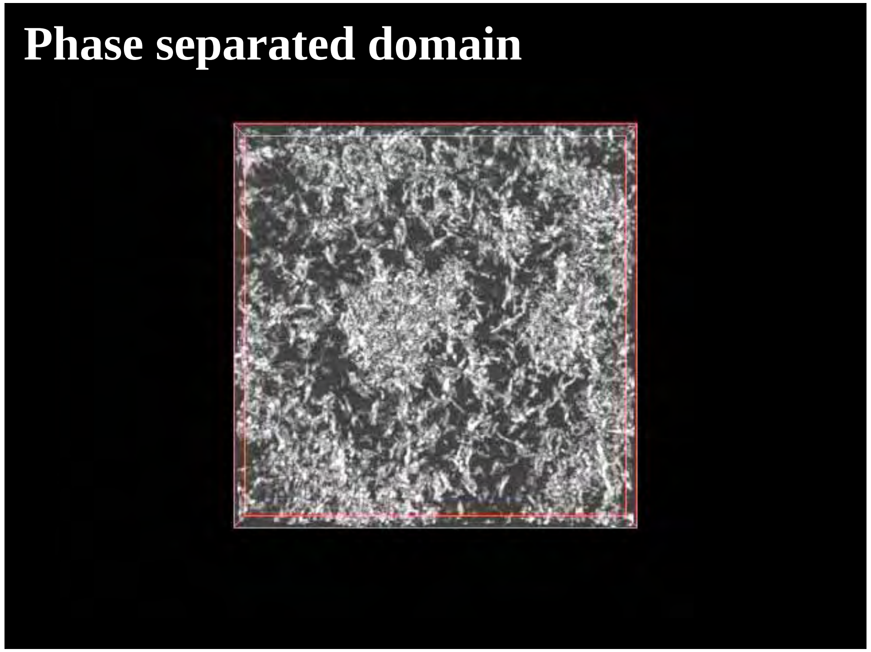


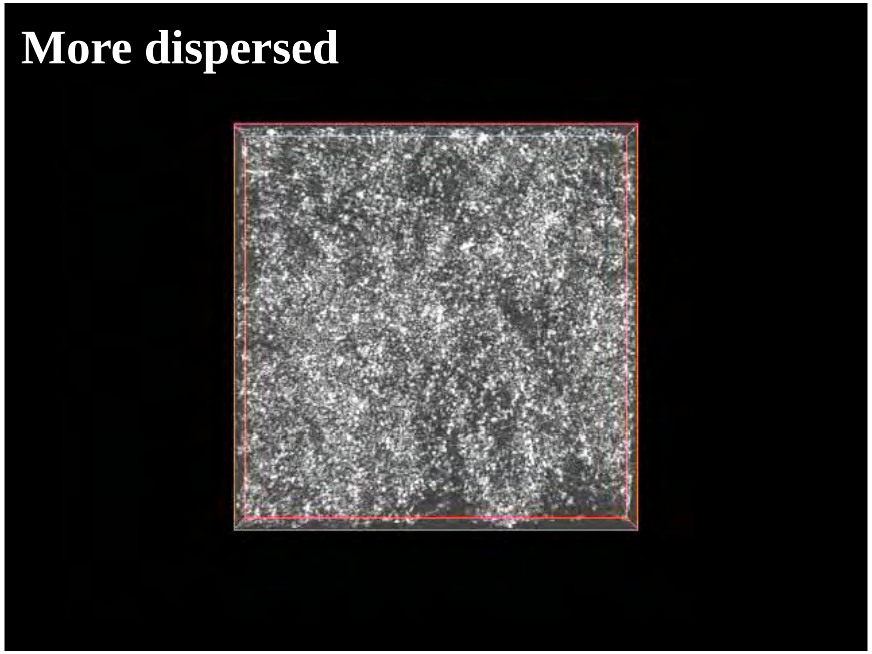
TiO_2 nanorod
(NR)
4nm x 20nm

TiO_2 nanoparticle
(NP)
5nm x 5nm

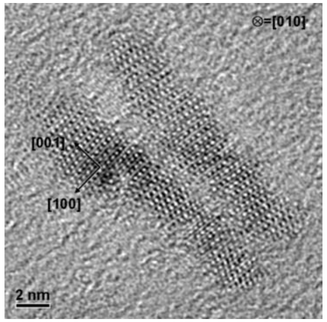


STEM-HAADF electron tomography



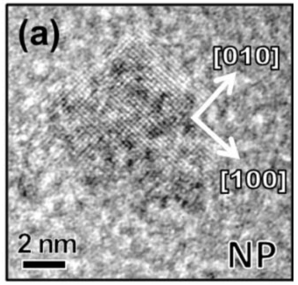


3D scanning transmission electron microscopy (STEM))
Electron tomography of P3HT/TiO_2 hybrids

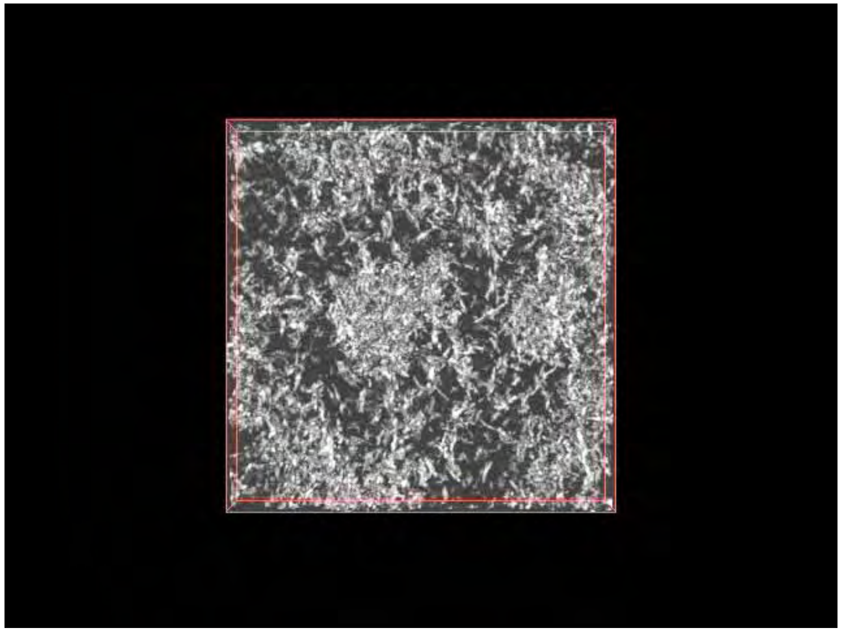


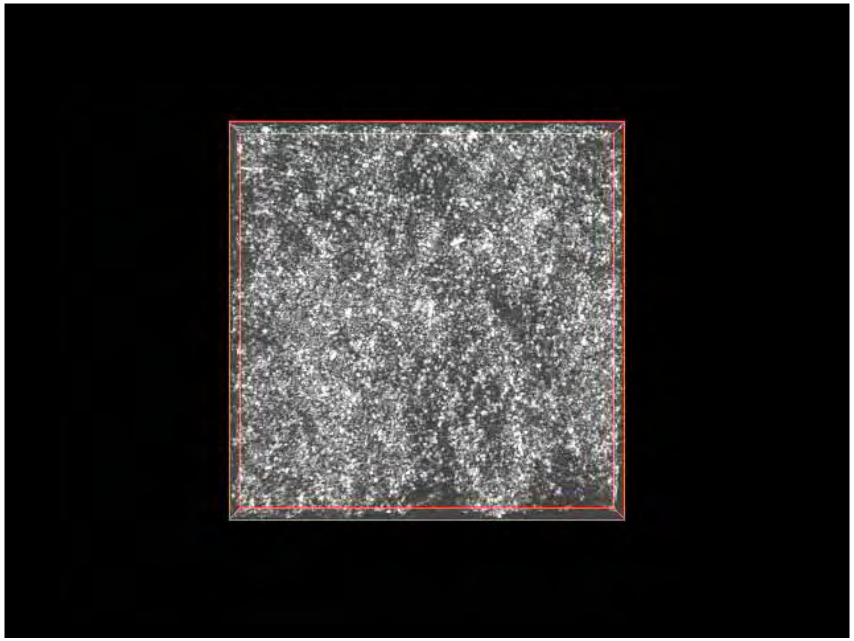
TiO_2 nano rod
(NR)
4nm x 20nm

TiO_2 nano particle
(NP)
5nm x 5nm



STEM-HAADF electron tomography (2 Å resolution)



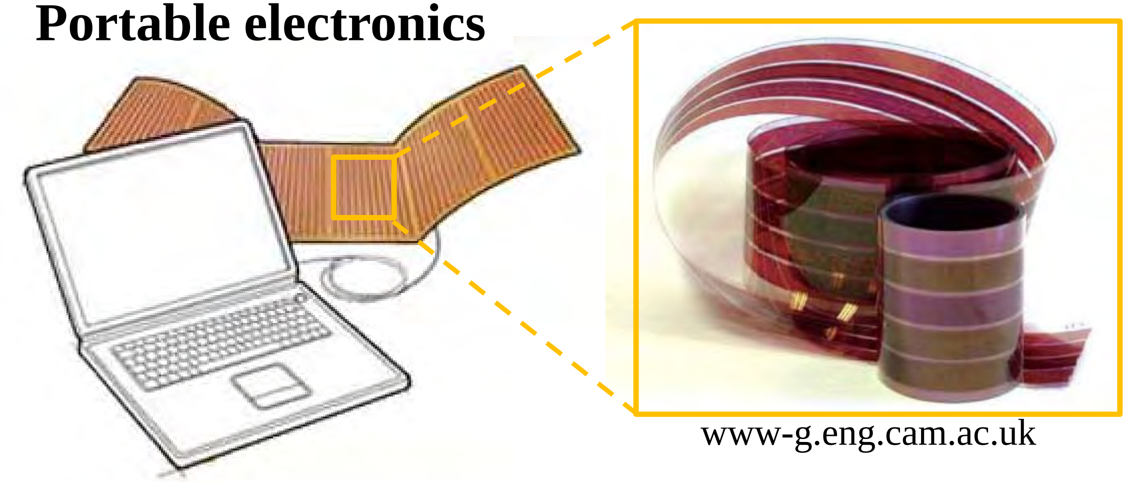


Phase separated domain

Journal of American Chemical Society, 133,11614, (2011)

Applications of polymer solar cells

Portable electronics



www-g.eng.cam.ac.uk

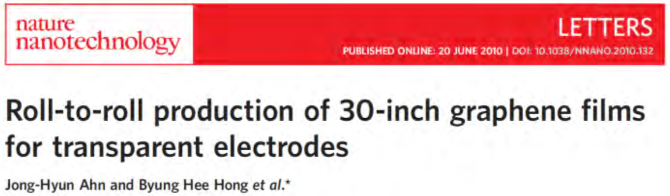
backpacks

www.thebluemarble.org

Military tent

From Konarka Inc.

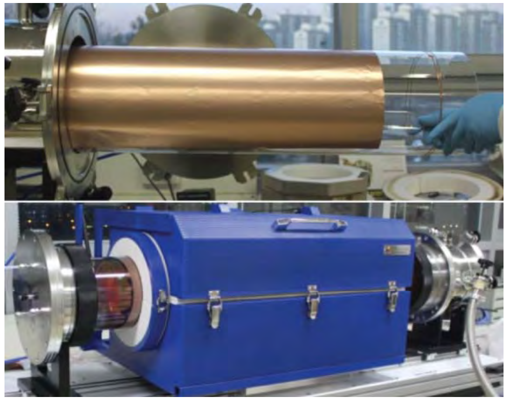
Large area fabrication of graphene
(Chemical Vapor Deposition)

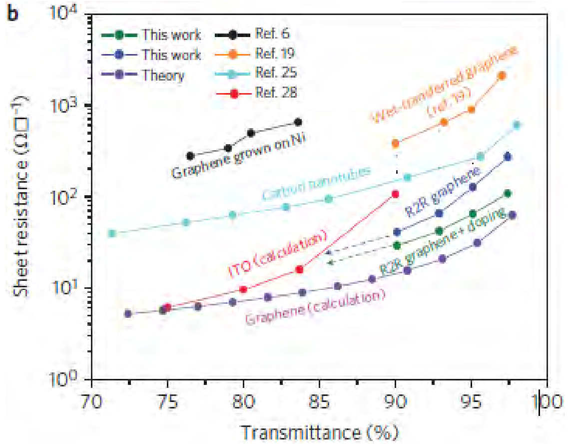

nature nanotechnology — LETTERS

PUBLISHED ONLINE: 20 JUNE 2010 | DOI: 10.1038/NNANO.2010.132

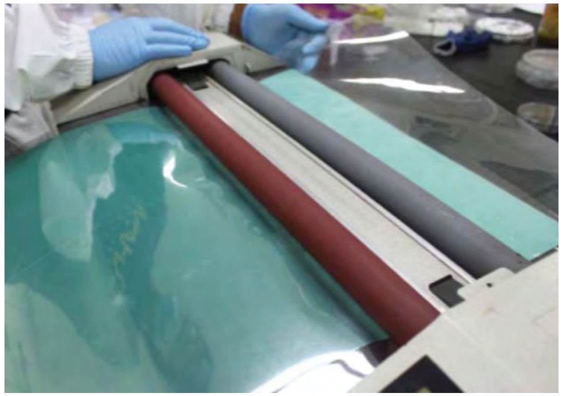
Roll-to-roll production of 30-inch graphene films for transparent electrodes

Jong-Hyun Ahn and Byung Hee Hong et al.*



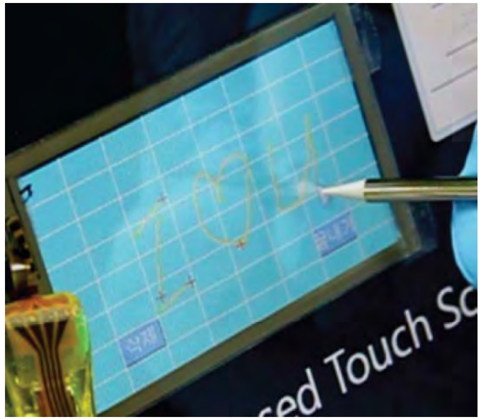


~30W /sq at ~90% transmittance



Roller printing

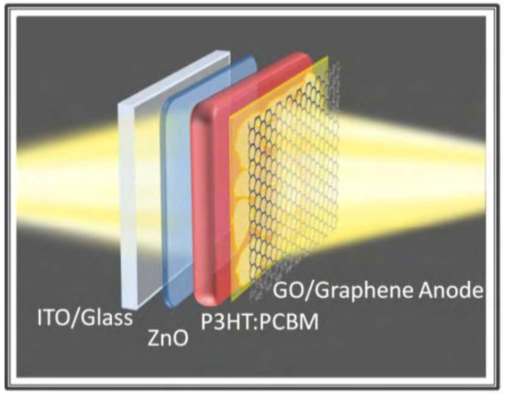
Scale up

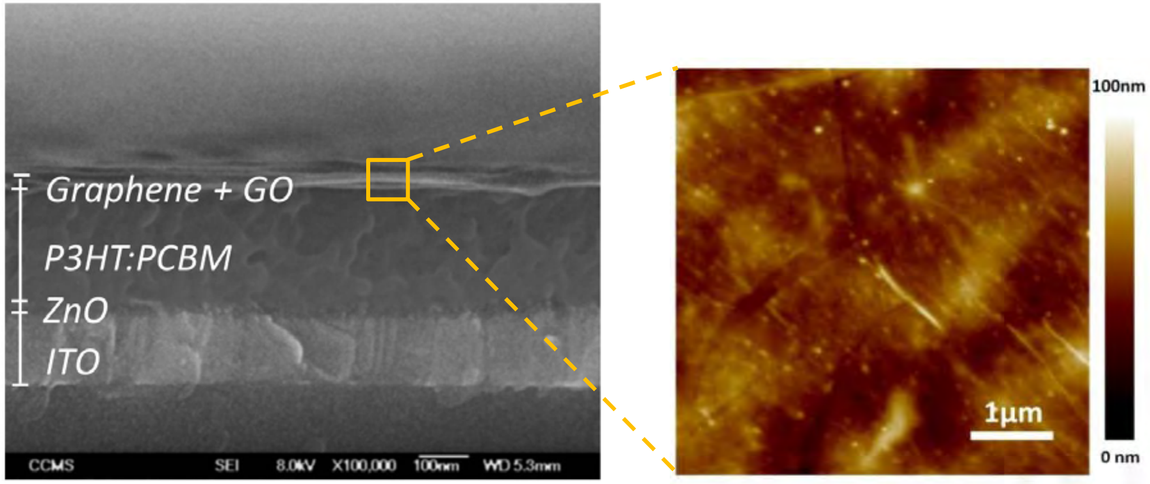


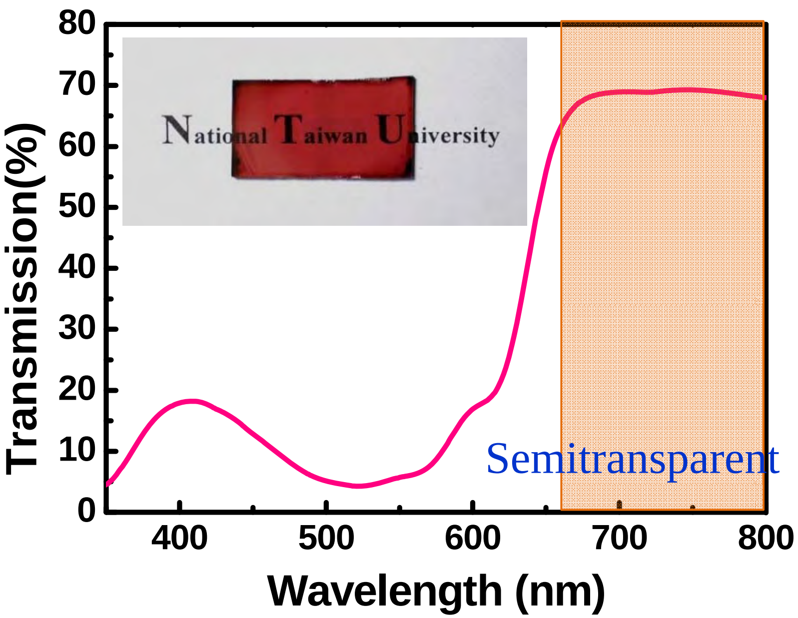
Touch panel

Bae et al. Nature Nanotechnology 5, 574–578 (2010)

Semi-transparent polymer solar cell with graphene electrode (solar window)



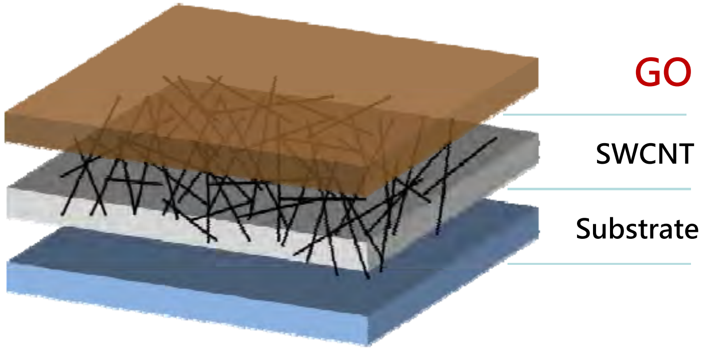




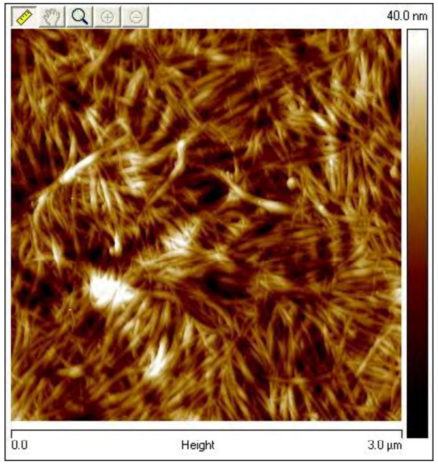
ACS Nano ,5,6564, (2011)

CNT transparent electrode (by solution process)

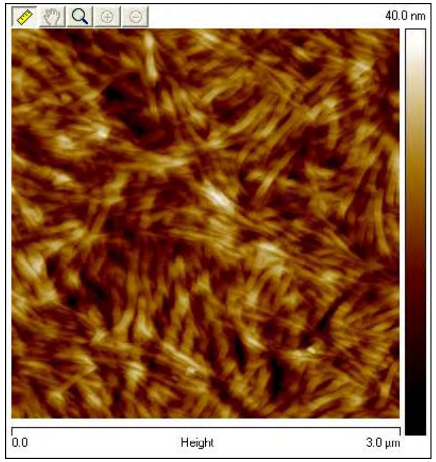
Carbon nano tube

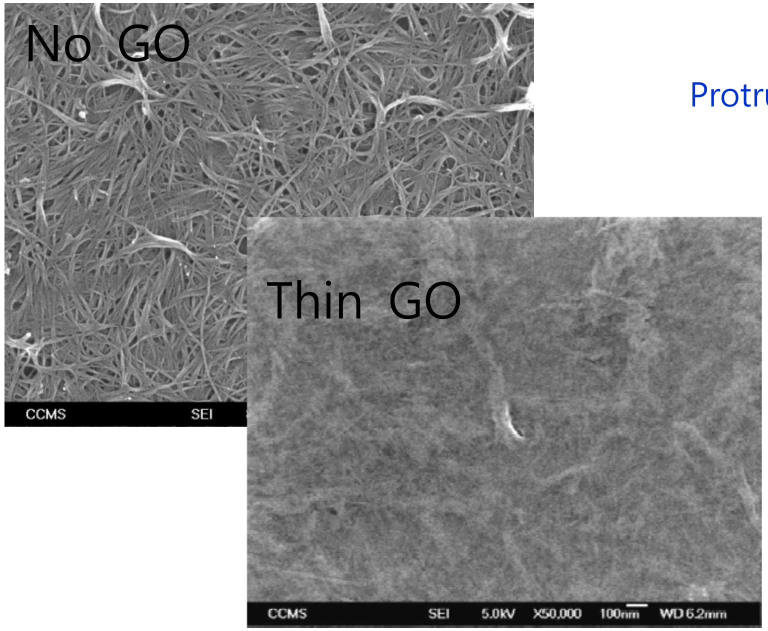


SWNT



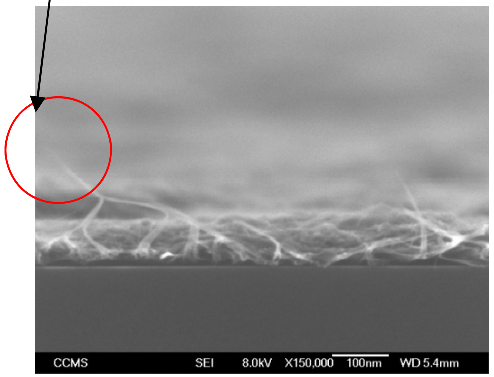
SWNT/GO





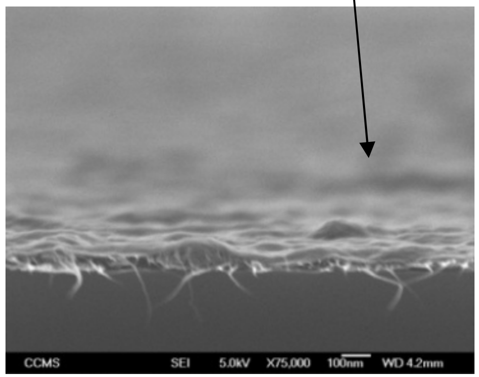
GO can planarize the SWNT surface

Protrusion into active layer



Without GO
Ra = 8.01 nm
Φ = 4.92 eV

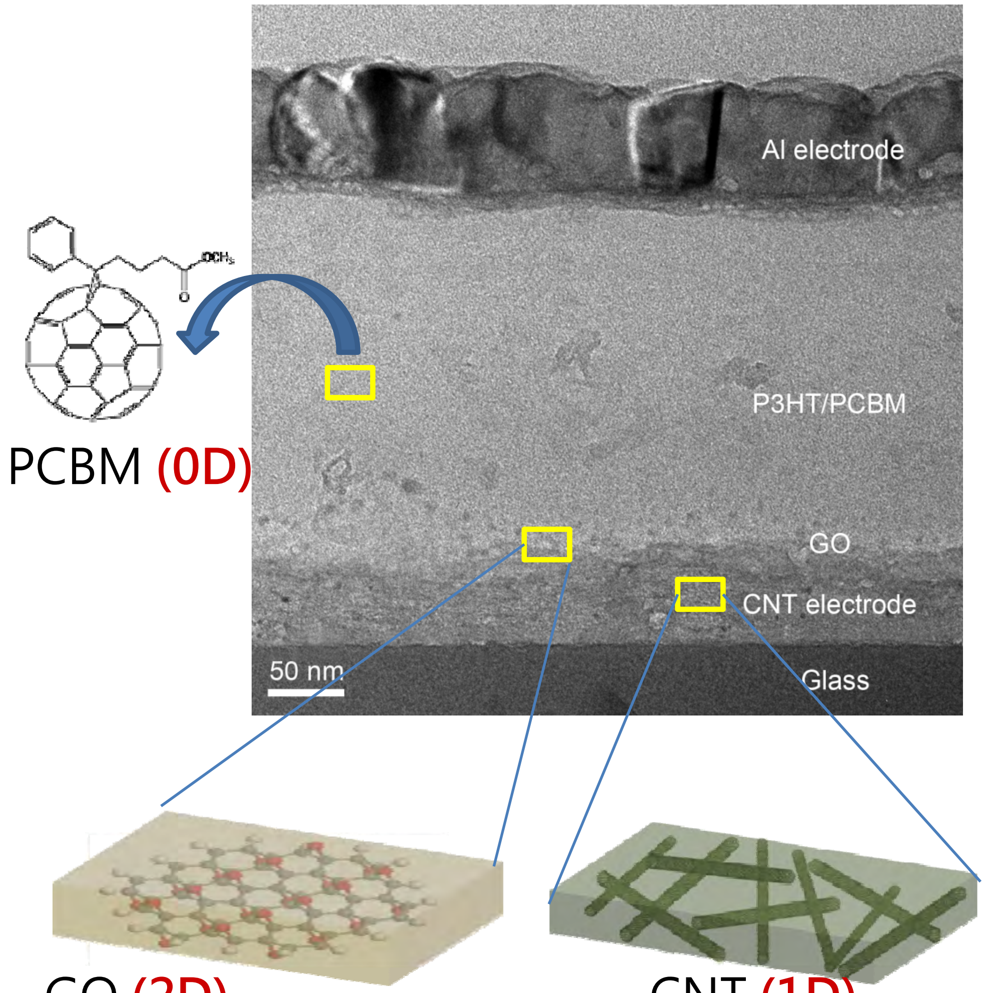
Planarize the surface

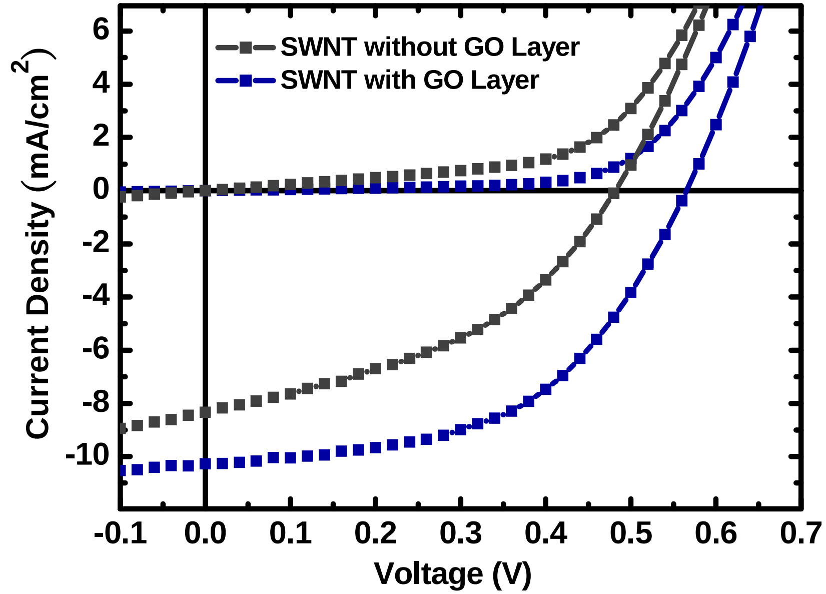


With GO
Ra = 4.20 nm
Φ = 4.88 eV

Nanocarbon platform for polymer solar cell

"Cocktail" nanocarbon polymer solar cell !



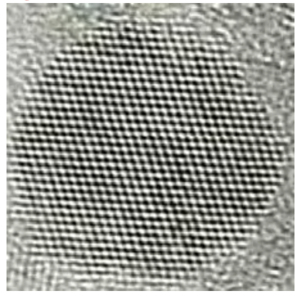


Energy and Environmental Science, 4,3521 , (2011)

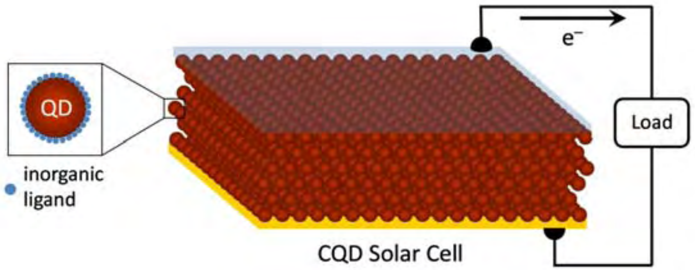
Quantum dot solar cells

- Size and band gap tunable
- Light weight and flexible
- NIR absorption
- Large area and low cost

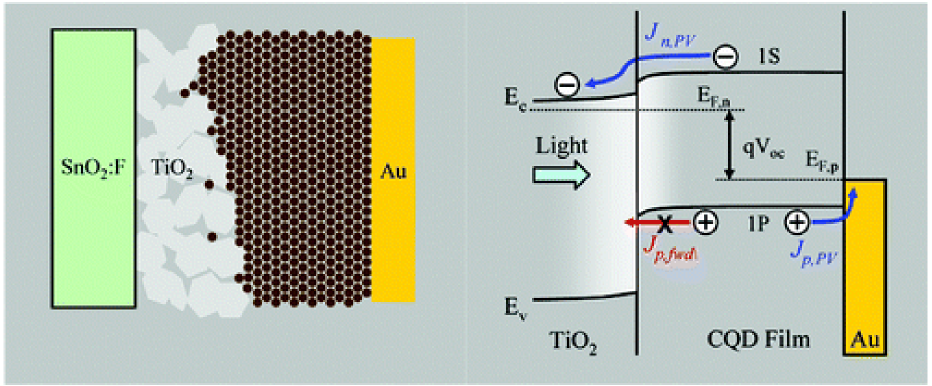
Quantum dot

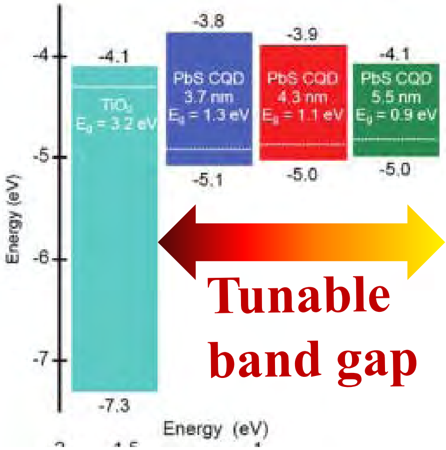


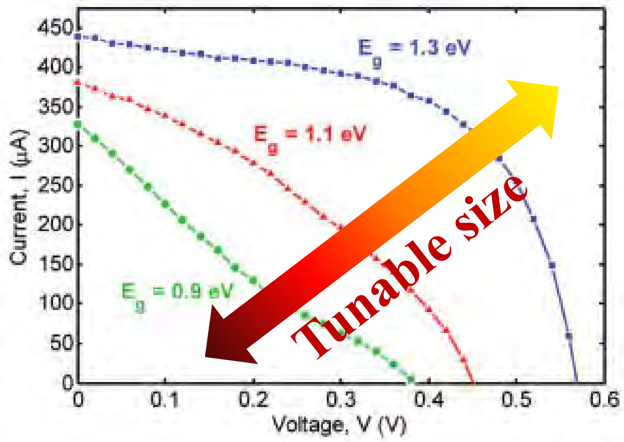
www.solarfeeds.com



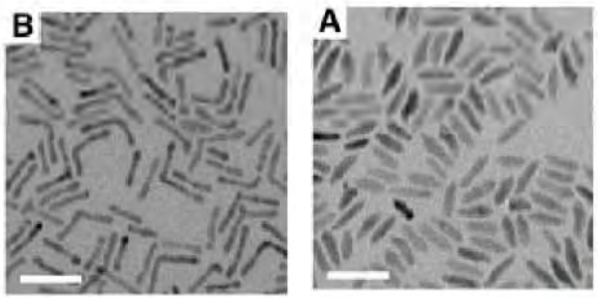
www.science.psu.edu





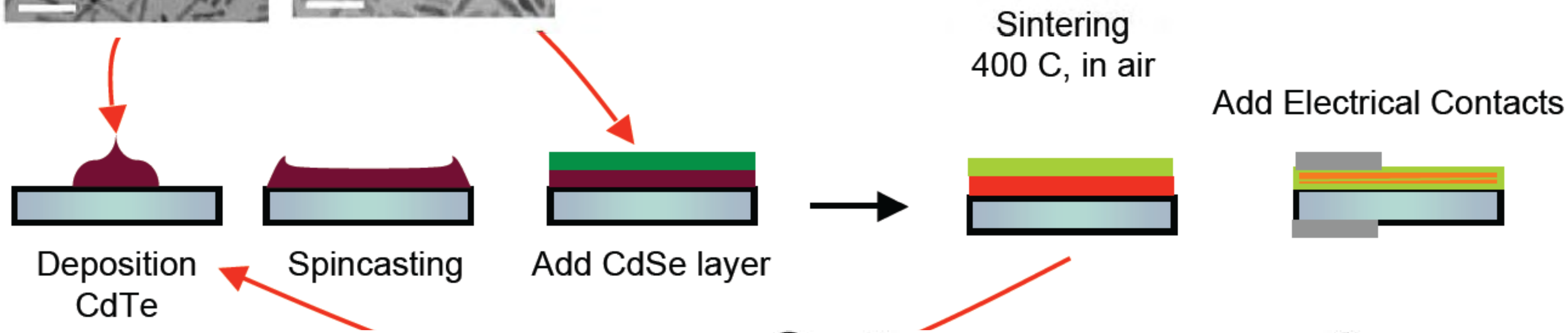


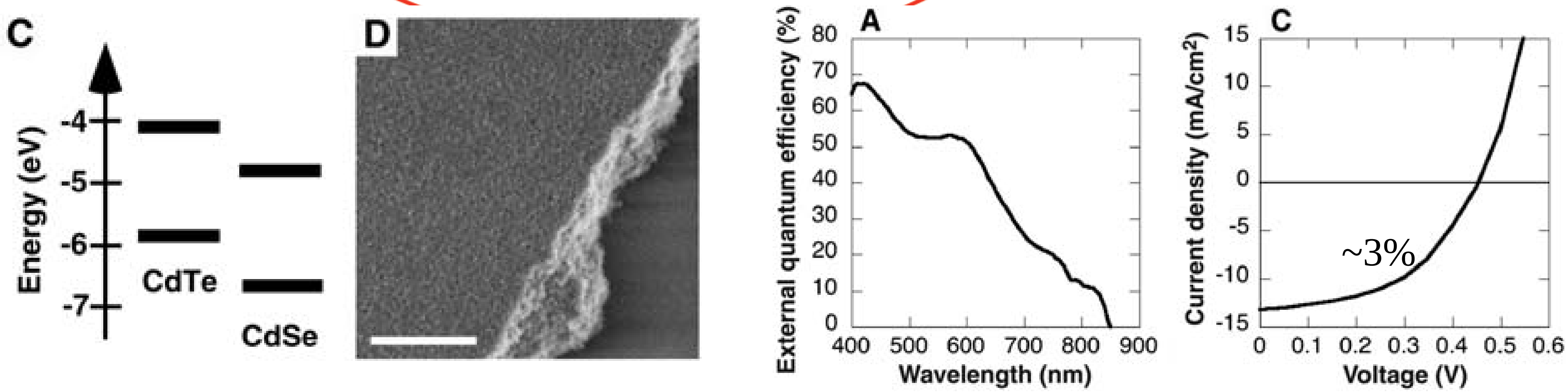
QD solar cell with double layer structure (CdTe-CdSe)



***Fabrication of all-inorganic nanocrystal solar cells by spincasting**. CdSe is spincast above a layer of CdTe.*

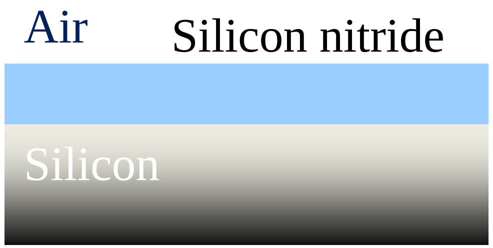
Low fabrication cost,
large number of p-n junctions





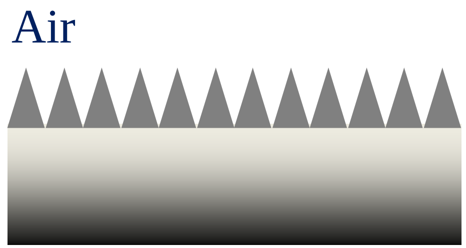
Alivisatos, P. et. al., Science, 310, 462.

Anti-reflection nano-structures in solar cells

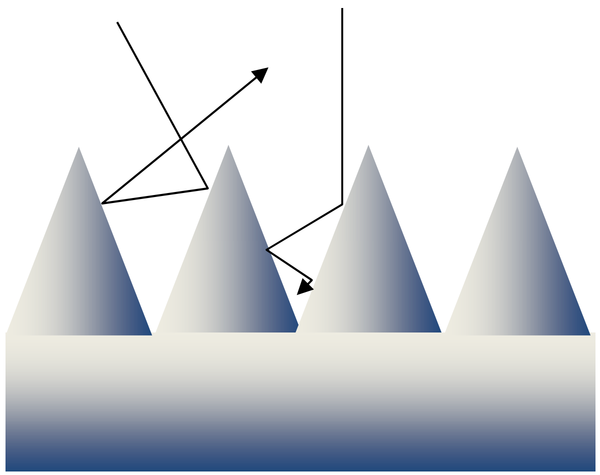


Single-layer
anti-reflective film

Multi-layer
antireflective films

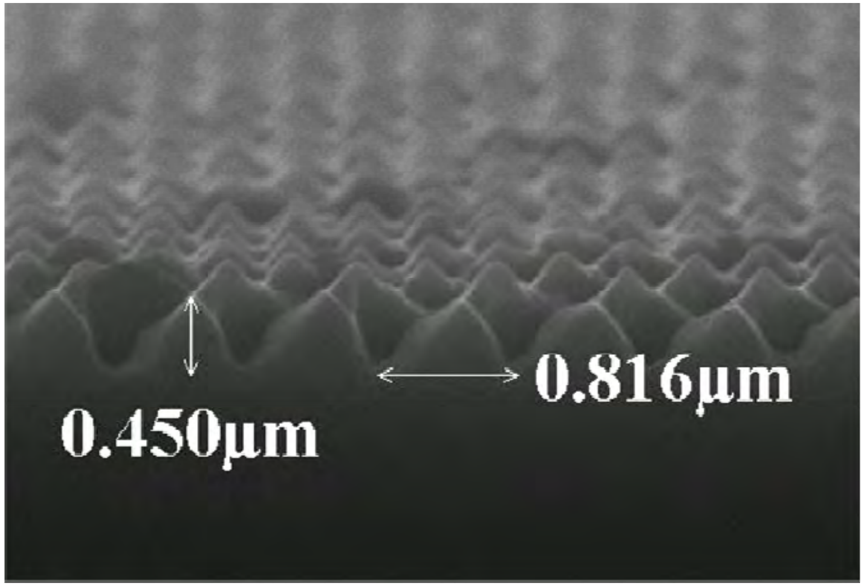


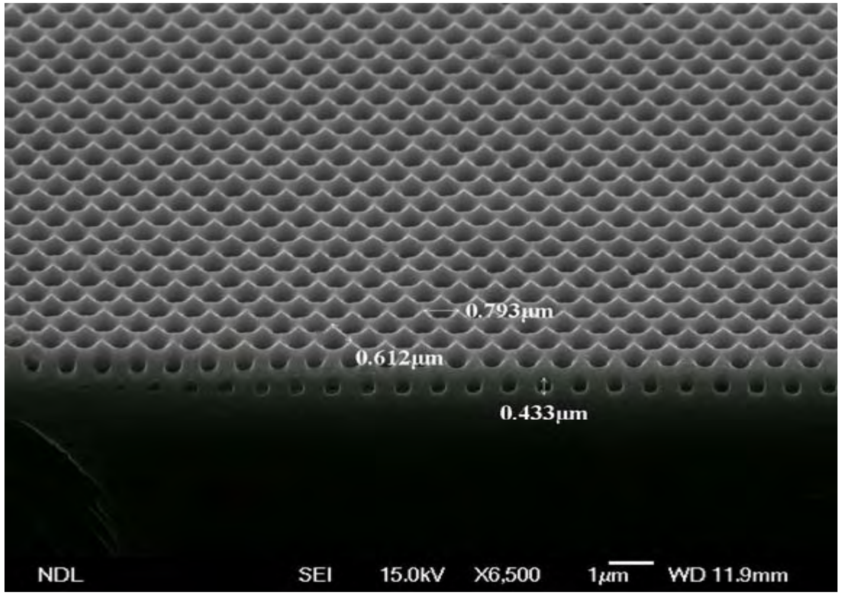
Antireflective Substrate



Fabrication of anti-reflection nanostructures

After RIE process

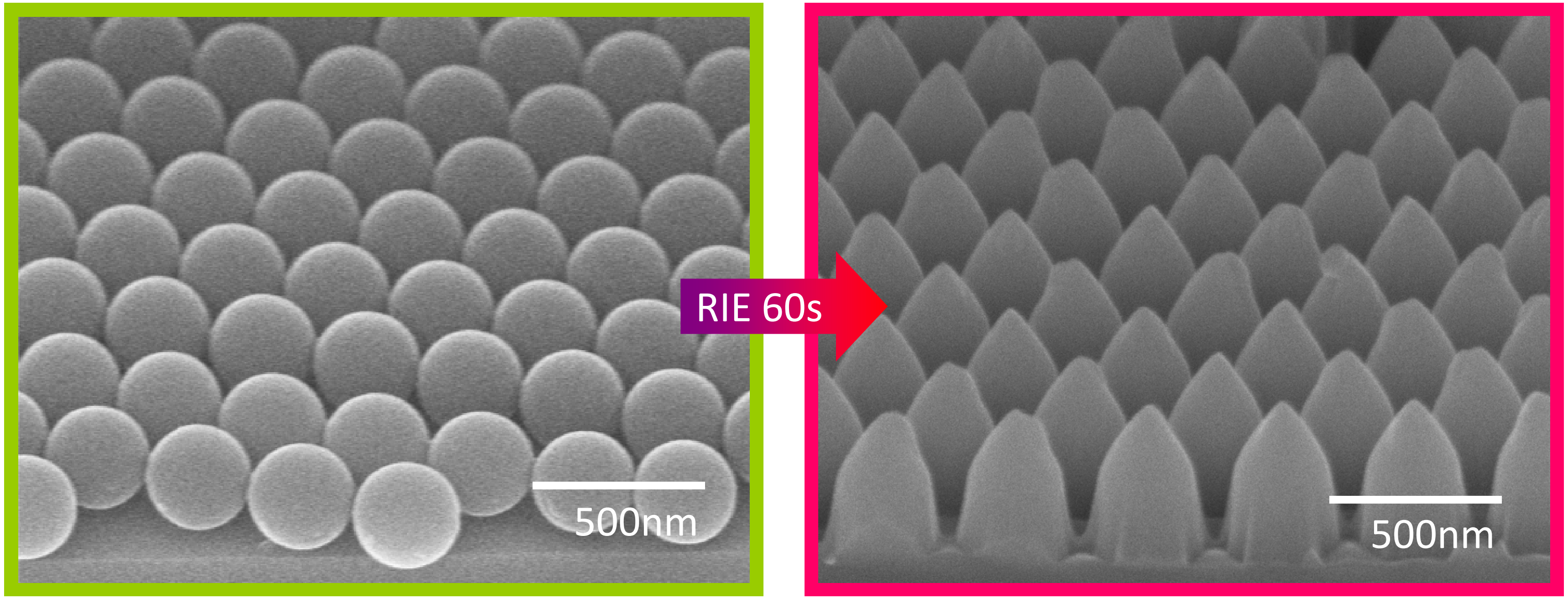




Courtesy of Prof. H. L. Chen,
Dept. of MSE, NTU

Fabrication of anti-reflection nanostructures

SEM images of colloidal lithography



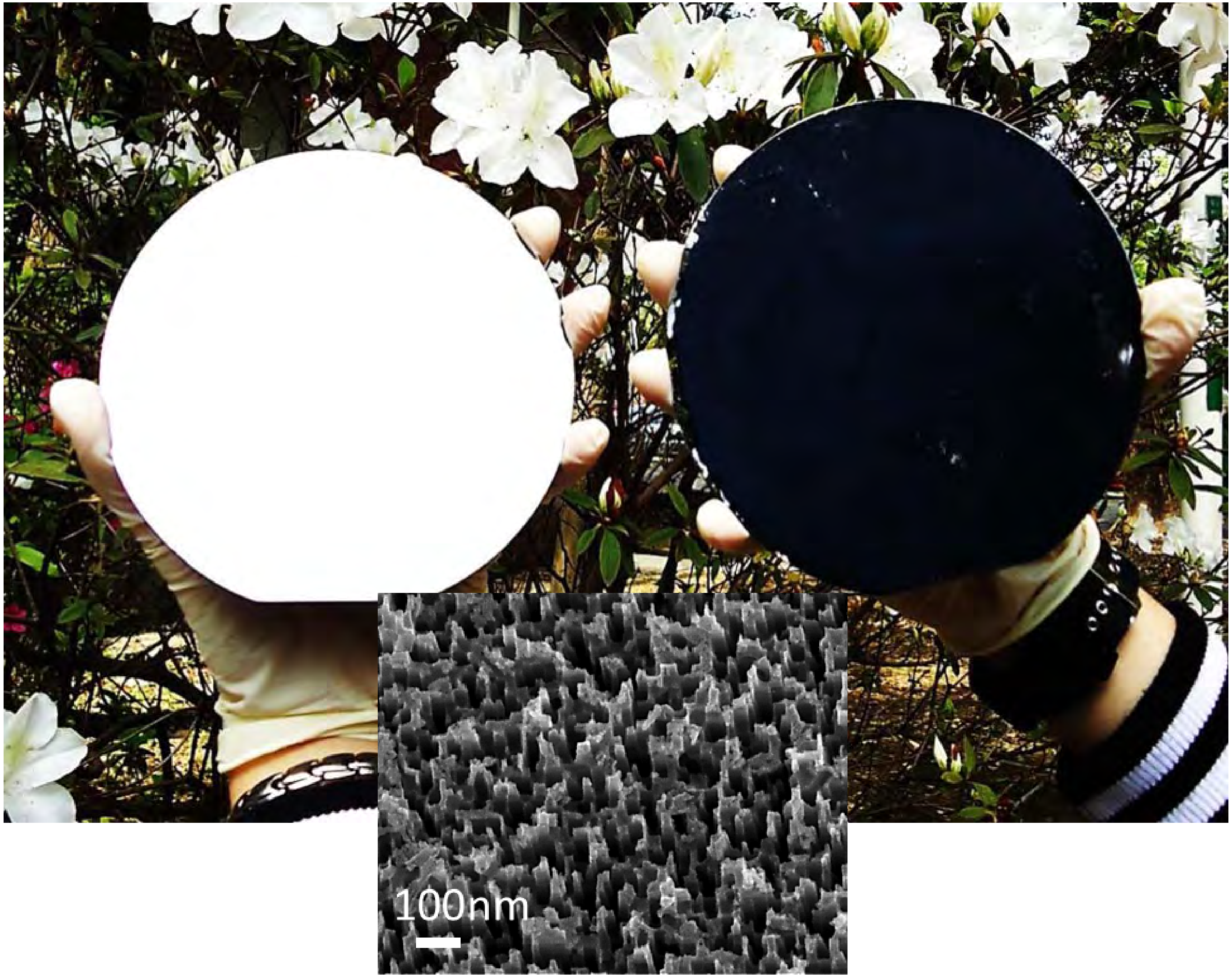
(a) (b)

PS sphere size = 350nm

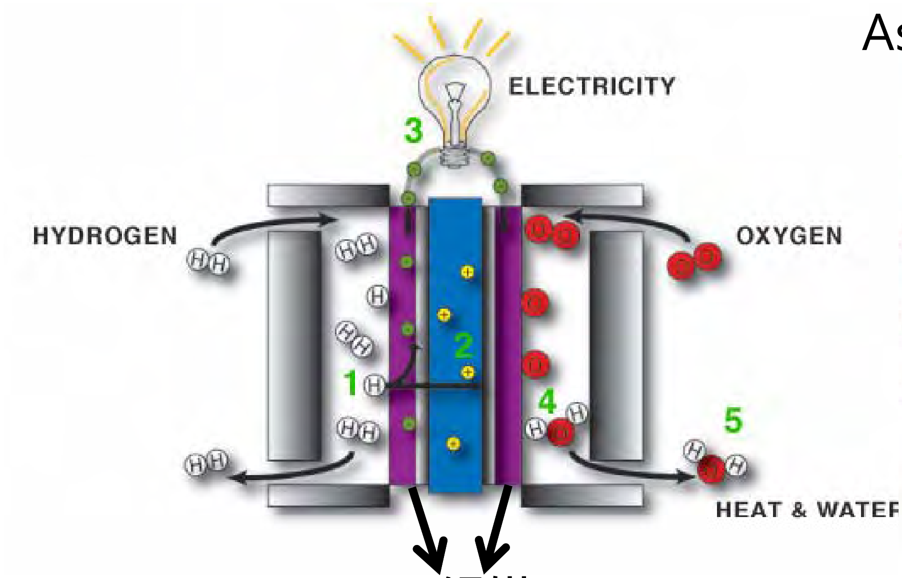
RIE: $Cl_2/O_2/SF_6$ = 90/5/5
Etching time: 60s

台大材料 陳學禮教授提供

Fabrication of anti-eflection nanostructure: Silicon solar cell



Hydrogen Fuel cell



Pt觸媒

Assembly fuel cell

http://www.greenspec.co.uk/fuel-cells.php

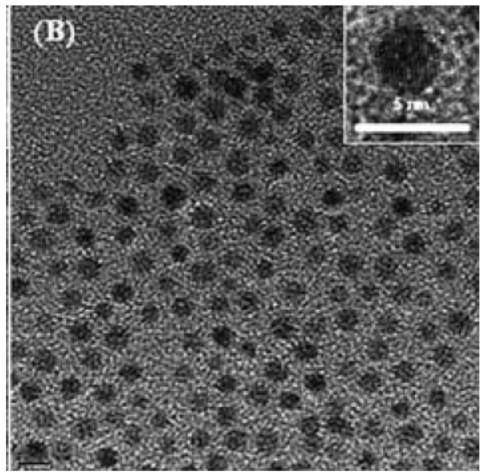
Advantages:

- **non-polluting**
- **High conversion efficiency of electric energy**
- **renewable**

However, **noble metal is nessesary. (Pt metal)**

- Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
- Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
- Total reaction：$2H_2 + O_2 \rightarrow 2H_2O$

Total reaction potential $E_{total} = 1.2V$

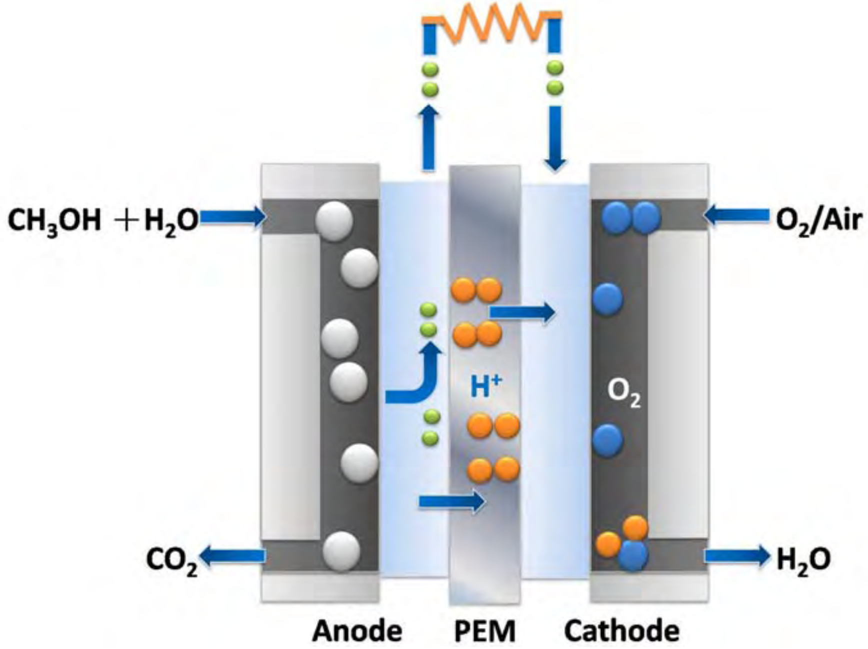


Catalysts: Pt nanoparticles

Nanoscale, 2010, 2, 573–581

Hydrogen Fuel cell Car

Direct Methanol Fuel cell



PtRu catalyst　　　　Pt catalyst

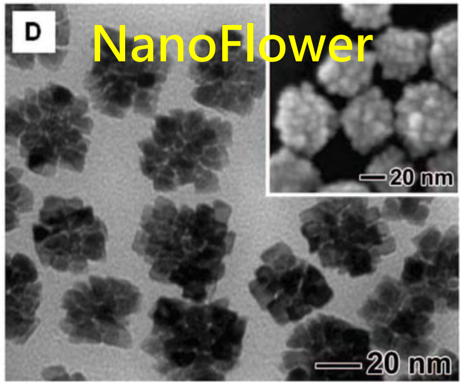
Anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode: $3/2O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

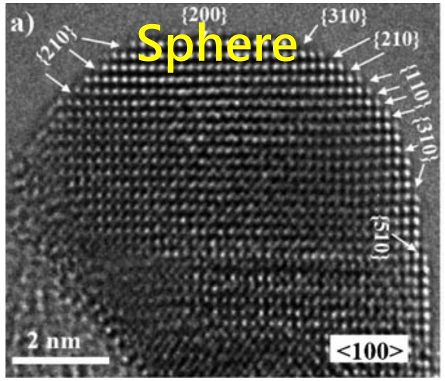
Total reaction：$CH_3OH + H_2O + 3/2O_2 \rightarrow CO_2 + 3H_2O$

Total reaction potential $E_{total} = 1.19V$

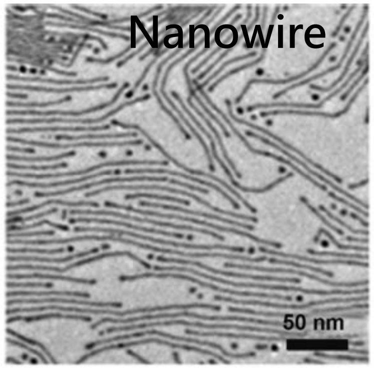
Different shape of nanocrystal catalysts

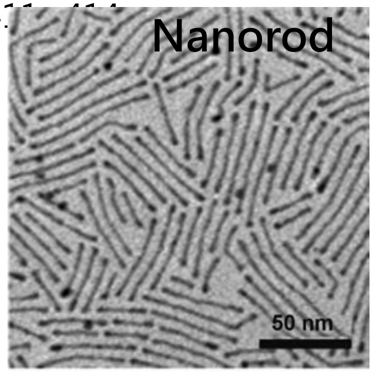


Lim, B. et. al., Nano Lett., 2008, 8, 4043.



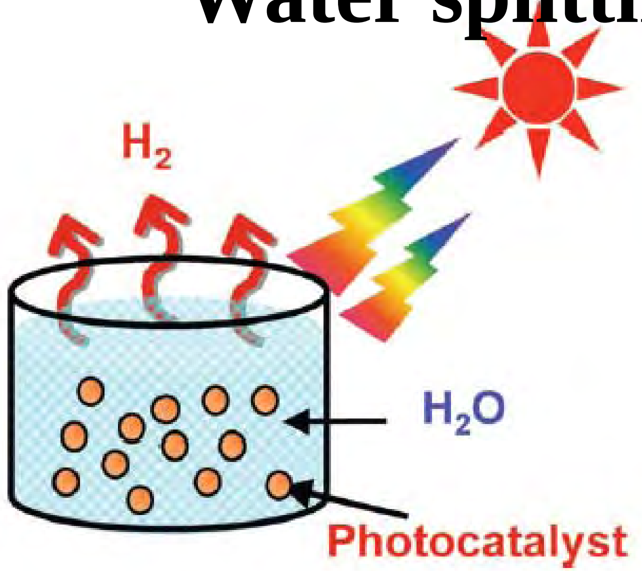
Zhou, Z. Y., el. al., Angew. Chem. Int. Ed. **2010**, 49, 4



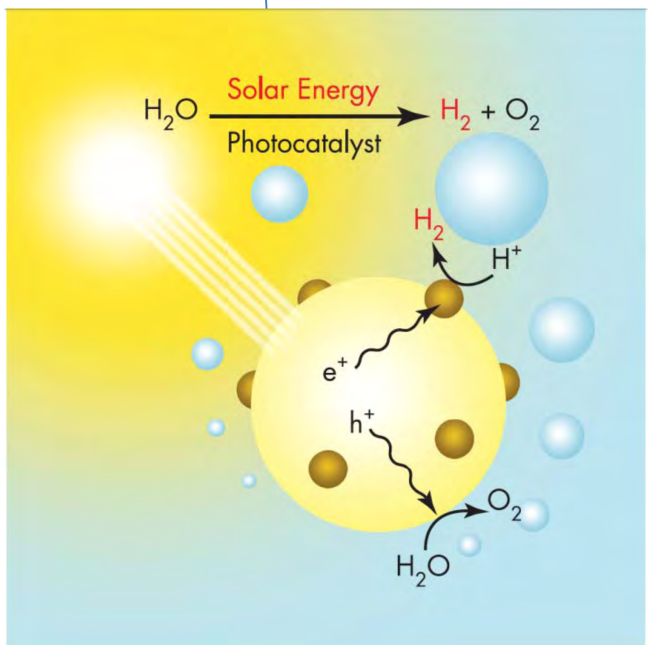


Wang, C., et. al., Angew. Chem. Int. Ed. 2007, 46, 1 – 4

Water splitting ➡ H_2 production



Chem. Soc. Rev., 2009, 38, 253–278 | 255

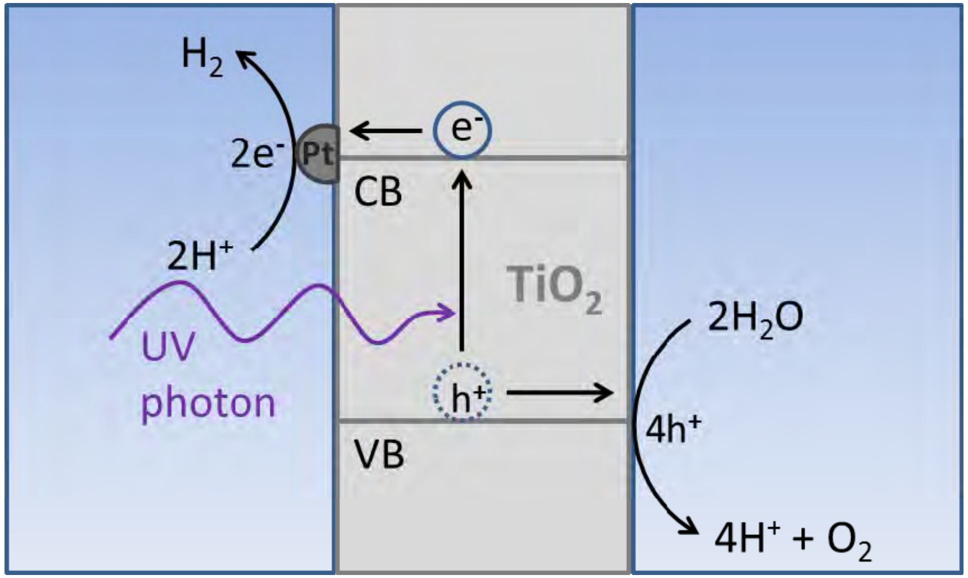


Nano-photocatalyst

Light→ Water splitting

→H_2 production (Fuel cell)

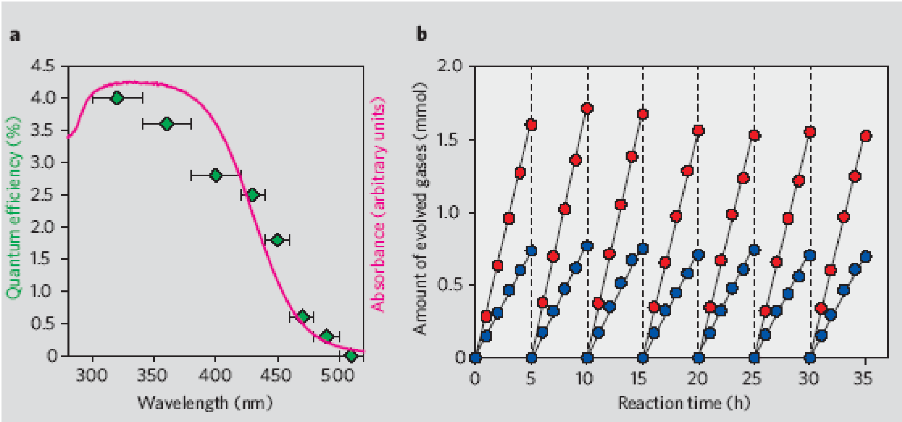
$4H^+ + 4e- \rightarrow 2H_2$

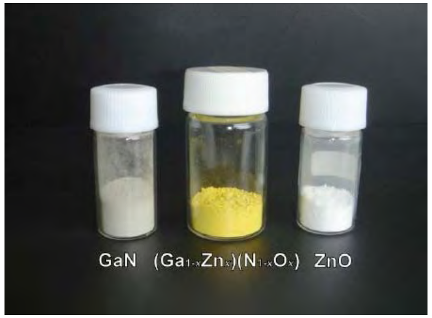


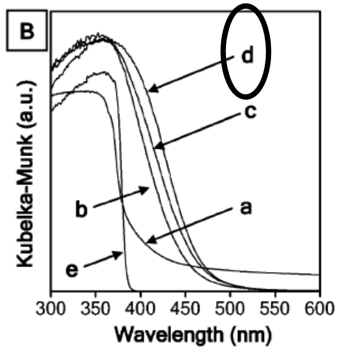
$4H_2O + 4h^+ \rightarrow 2O_2 + 4H^+$

Photocatalytic reaction under visible light $(Ga_{1-x}Zn_x)(N_{1-x}O_x)$-$RuO_2$

$(Ga_{1-x}Zn_x)(N_{1-x}O_x)$-$RuO_2$ Photocatalyst

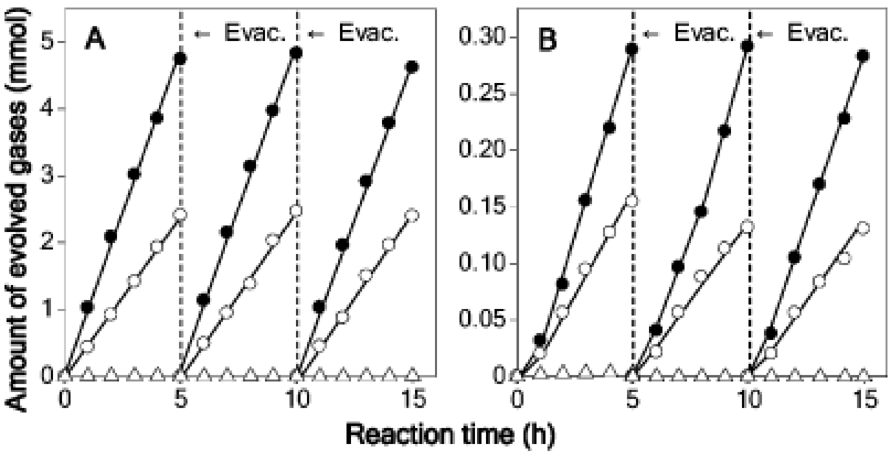






Under UV light

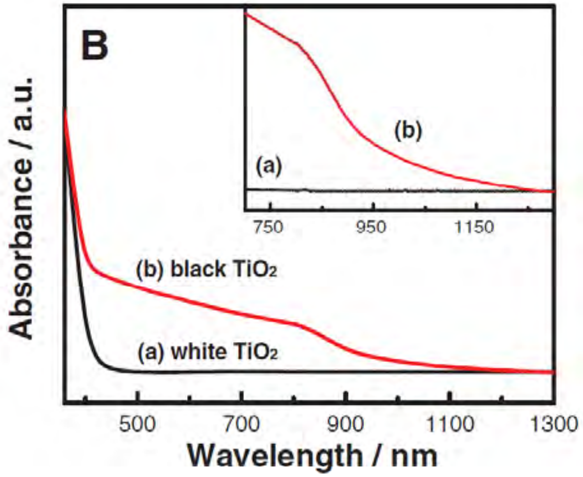
Under Visible light

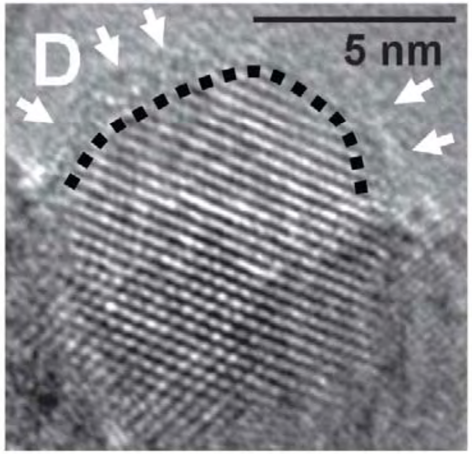


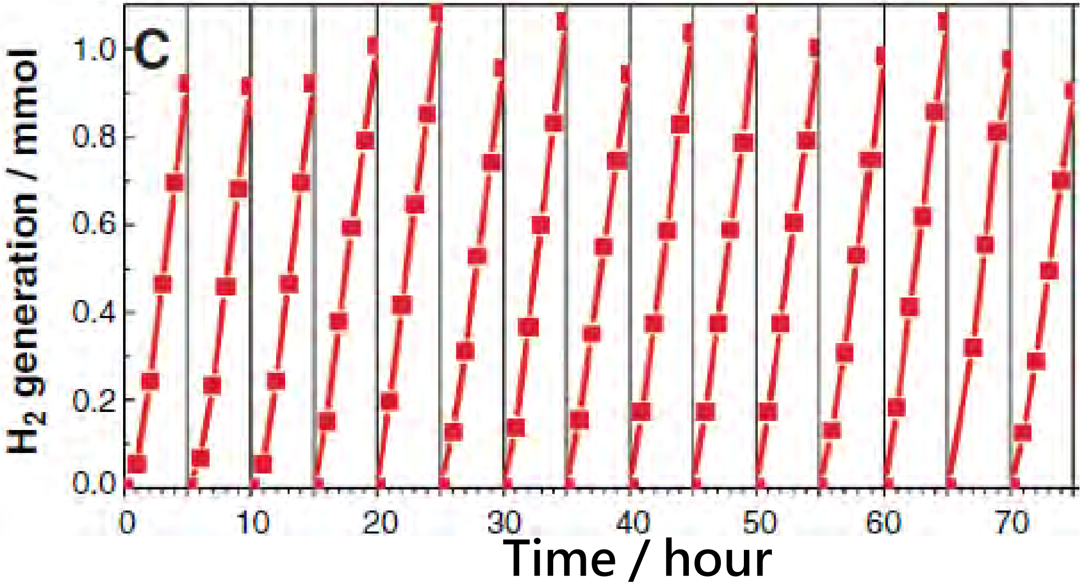
Maeda, K. et. al., Nature, 2006, 440,295.

Photocatalytic reaction under visible light (black TiOx)

black TiO_x nanocrystals







Xiaobo Chen*, et al., Science* ***331*, 746 (2011)**

Conclusion

- Nano materials and technology play a very important role in the development of new energy in future.
- Nano materials and technology is a relevant interdisciplinary science including materials, physics, chemistry, electric engineering, biology.

Save our planet by Nanos

From WWF

Thank you for your attention !!