Nanostructured materials for solar energy

Water Splitting & Dye Solar Cells

Journée Scientifique des Comices « Energie Solaire » du WARE
23 avril 2012 à Jambes

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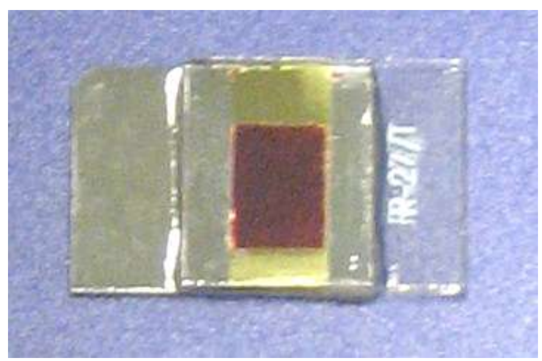
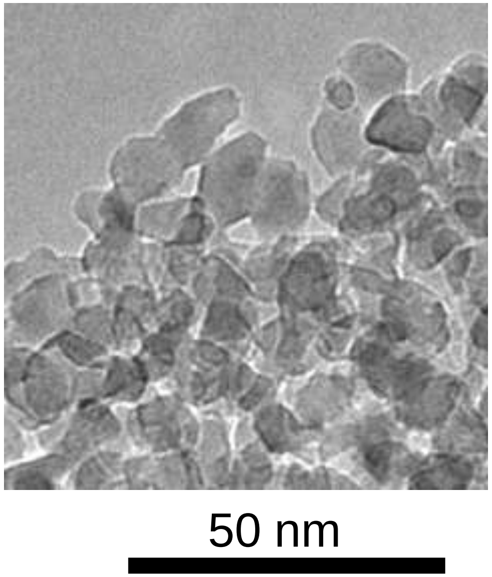
Group of Research in Energy & Environment from MATerials

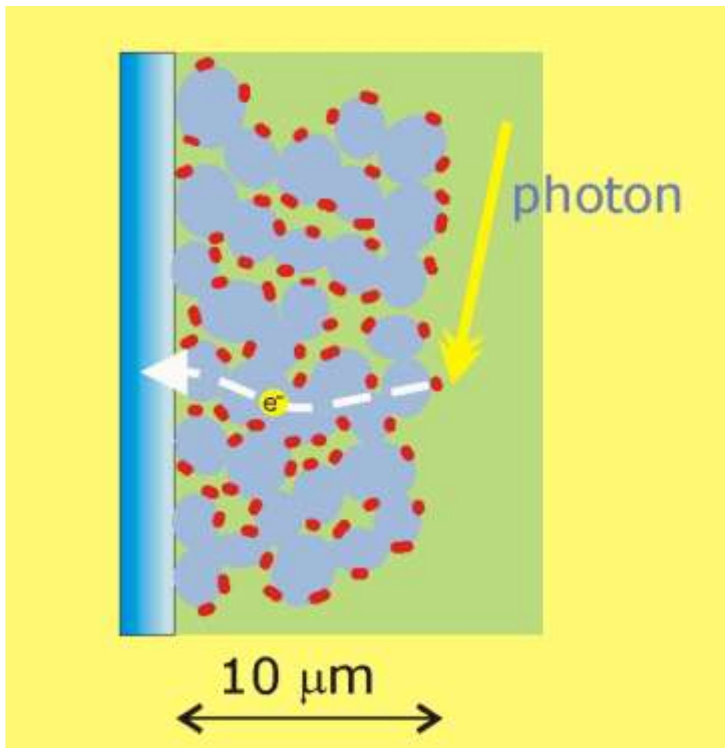
Université de Liège

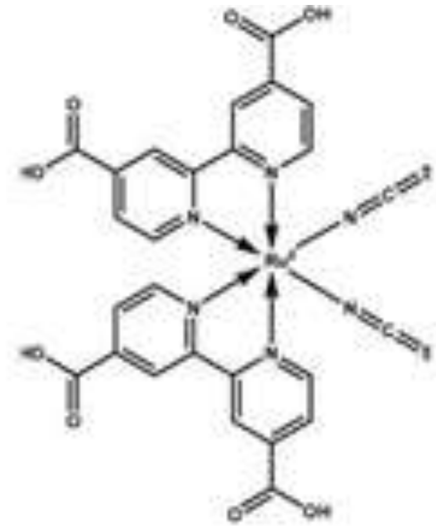
DYE-SENSITIZED SOLAR CELLS



How it works



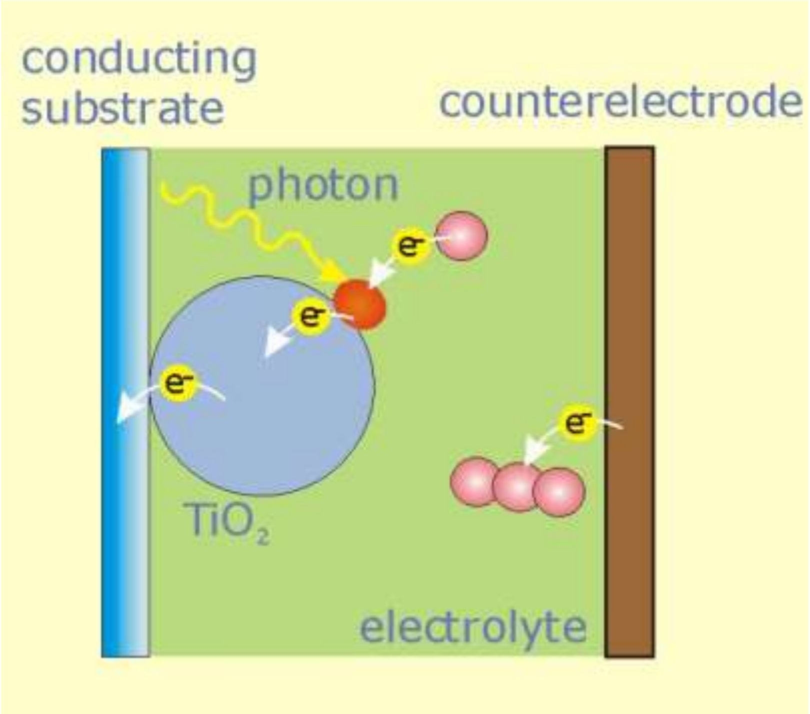


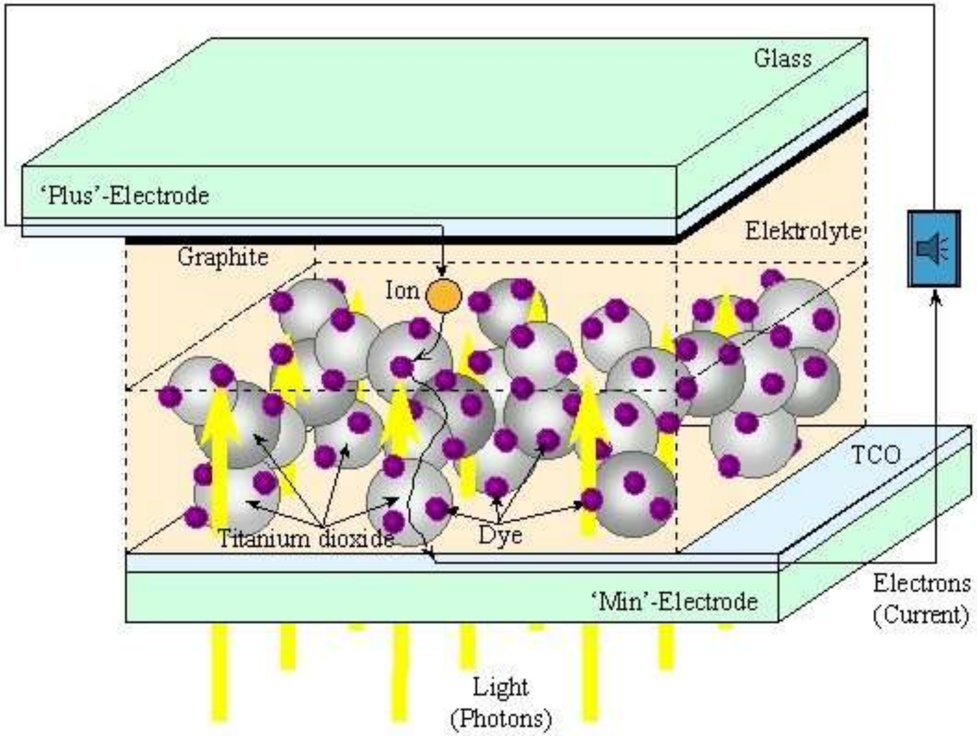


•When a dye molecule injects an electron, it becomes oxidized.

•It is very rapidly regenerated by liquid electrolyte.

•Solid electrolyte do exist but reduce overall efficiency (< 5%).



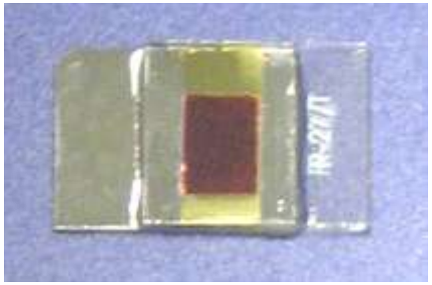


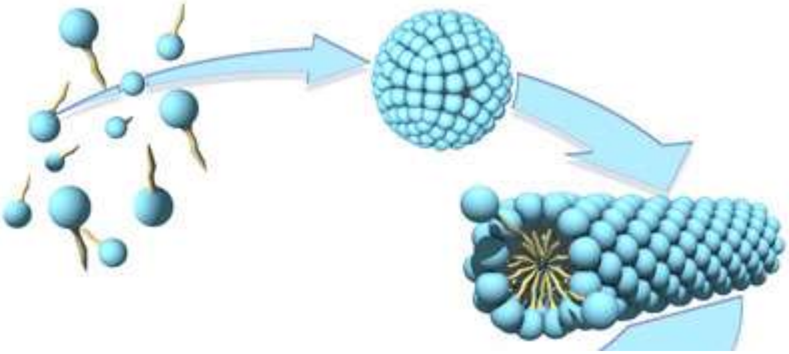
Scheme courtesy Imperial College of London

Maximum conversion efficiencies are currently about 11%, and long term stability has been improved using viscous solvents

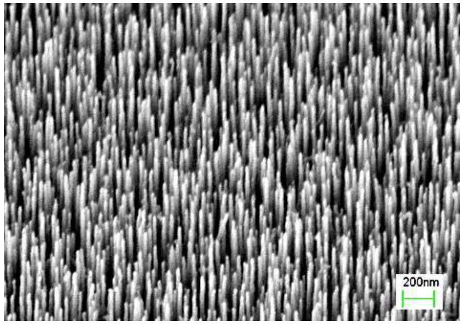
Advantages of DSC

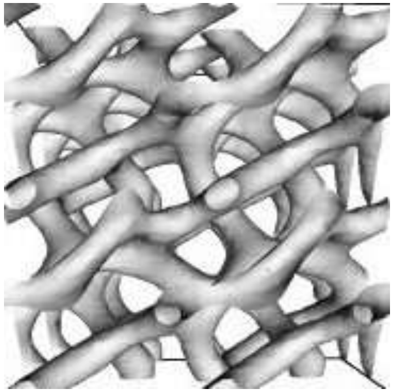
- Compared to conventional silicon based photovoltaic technology:
- DSC technology has **lower cost and embodied energy** in manufacture,
- it produces electricity more efficiently in **low light conditions**
- can be directly incorporated into **buildings** by replacing conventional glass panels or metal sheets rather than taking up roof or extra land area.





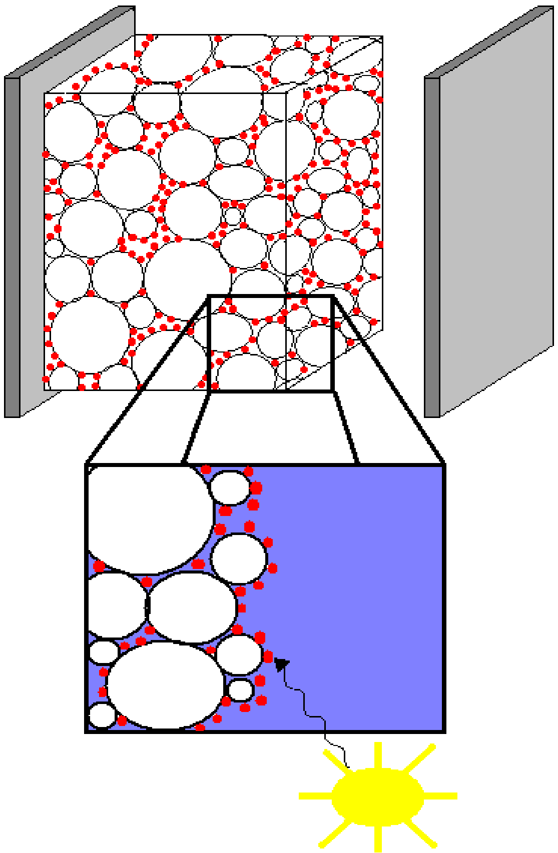
DSC in the GreenMAT group:
OUR WORK



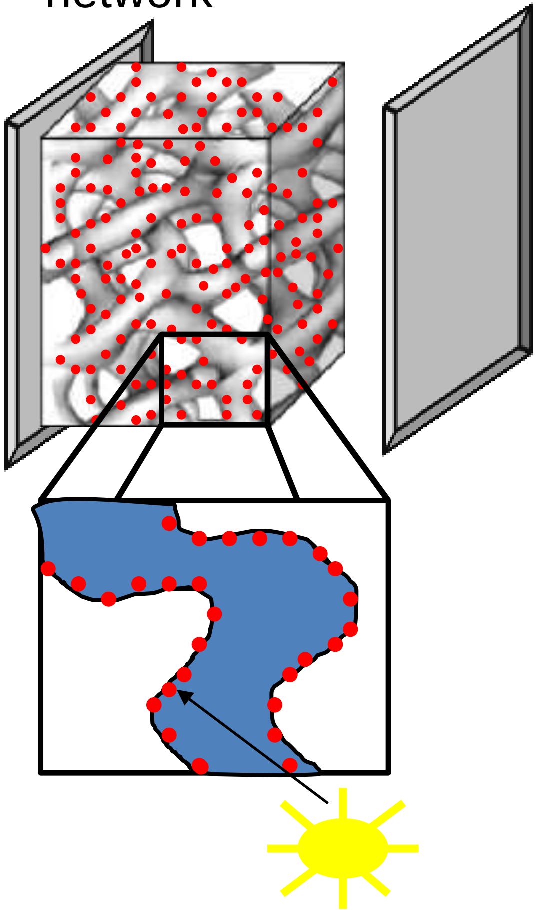


1. Ordered mesoporous films for solid-state DSC

Classical nanocrystalline film



Controlled porous network

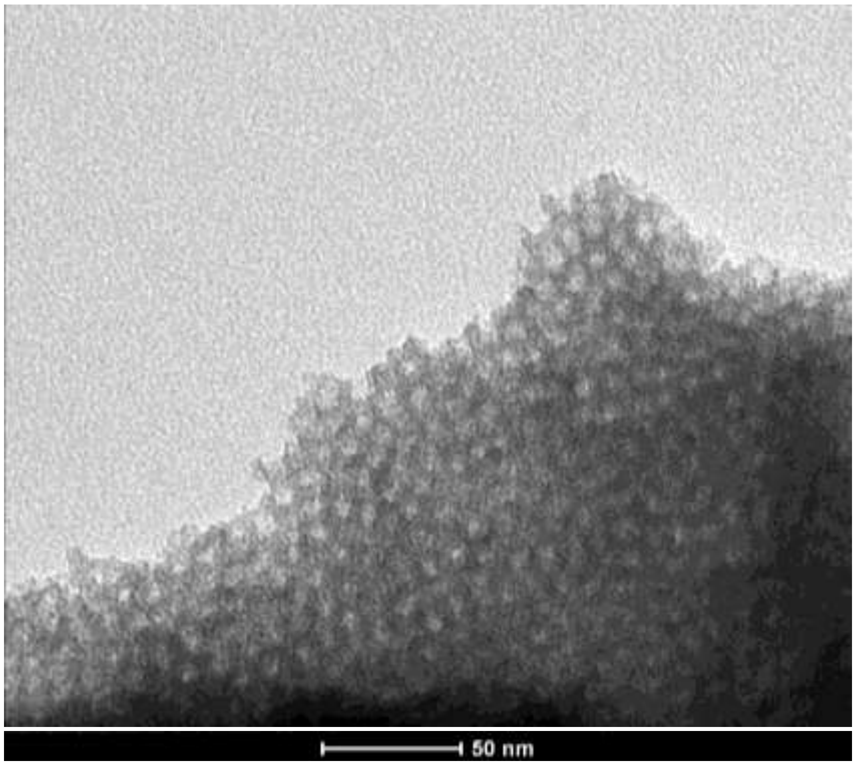


-Controlled & Homegeneous porosity

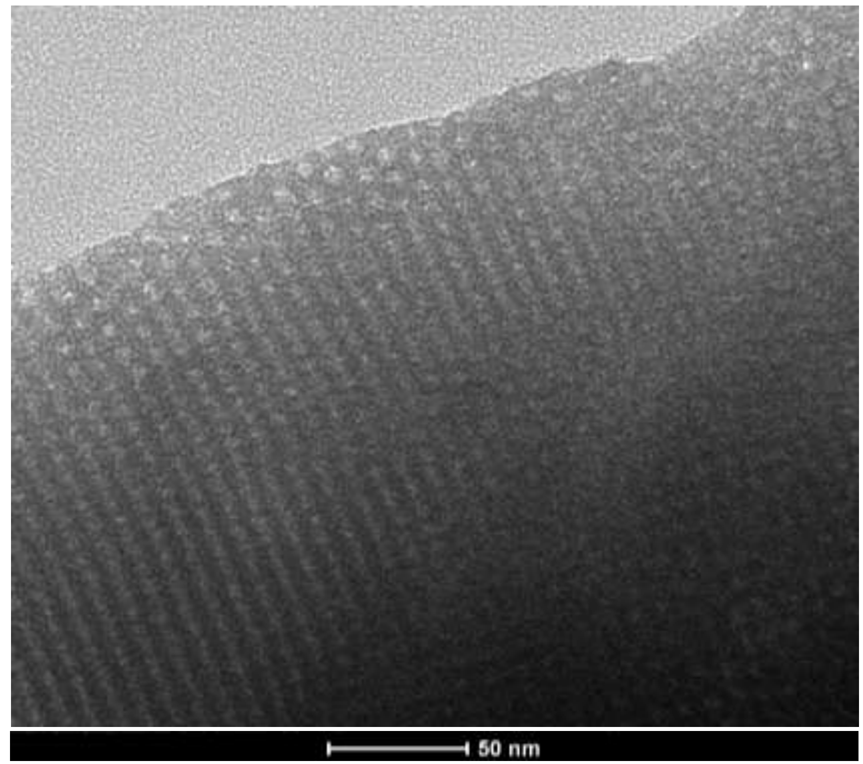
-Monodisperse crystal size
-Ordered TiO_2 network

-Facilitates pore filling and electron conduction in TiO_2

MESOPOROUS TiO_2 THIN FILM VIEWED BY TEM



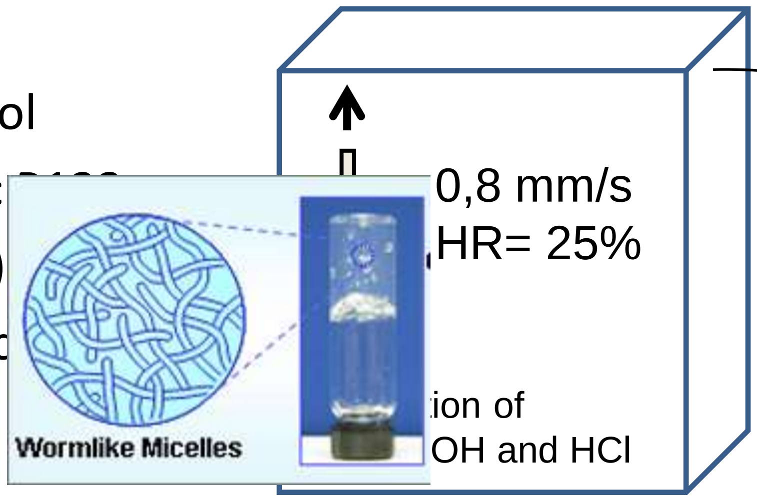
Wormlike porosity

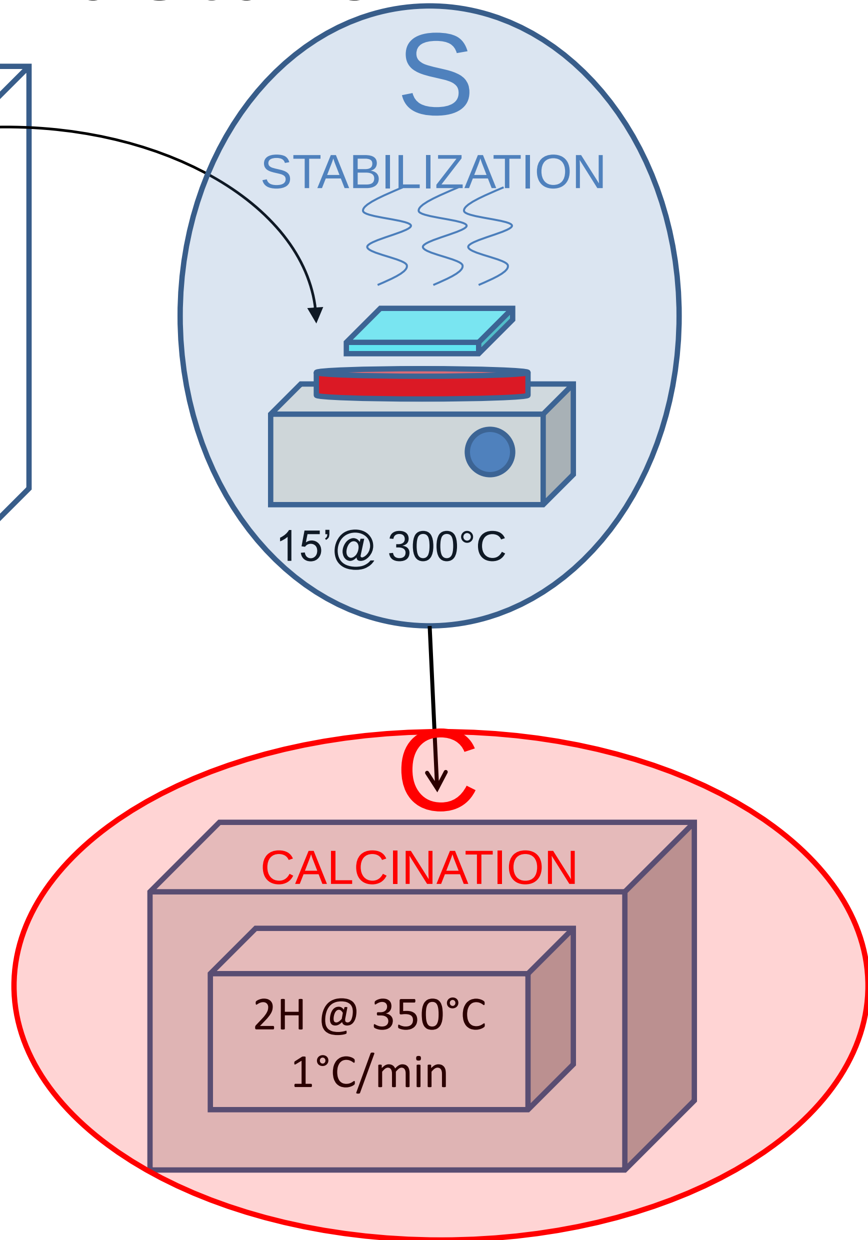


Gridlike porosity

Experimental details

- 1-butanol
- Pluronic
- Ti-(iPrO)
- HCl conc

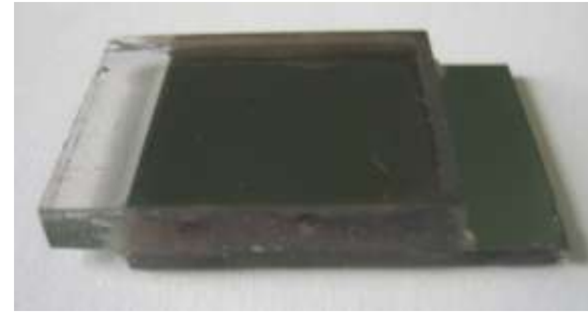




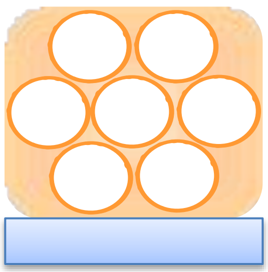
Stabilization
-Evaporation of solvent and by-product
-Condensation of inorganic network

Calcination
-Full removal of micelles
-Further condensation of TiO_2
-Crystallization & Crystal growth

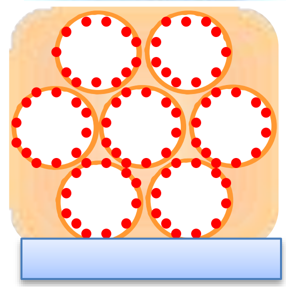
4. ASSEMBLY & PV TESTING

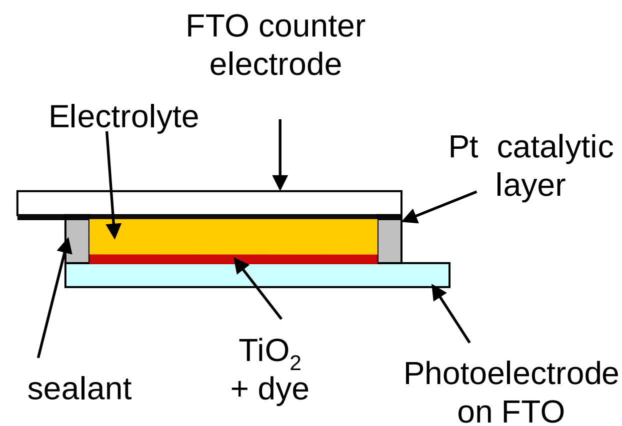


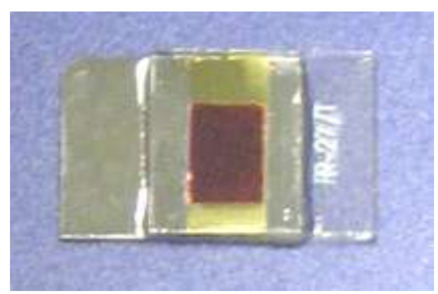
THERMAL TREATMENT



DYEING

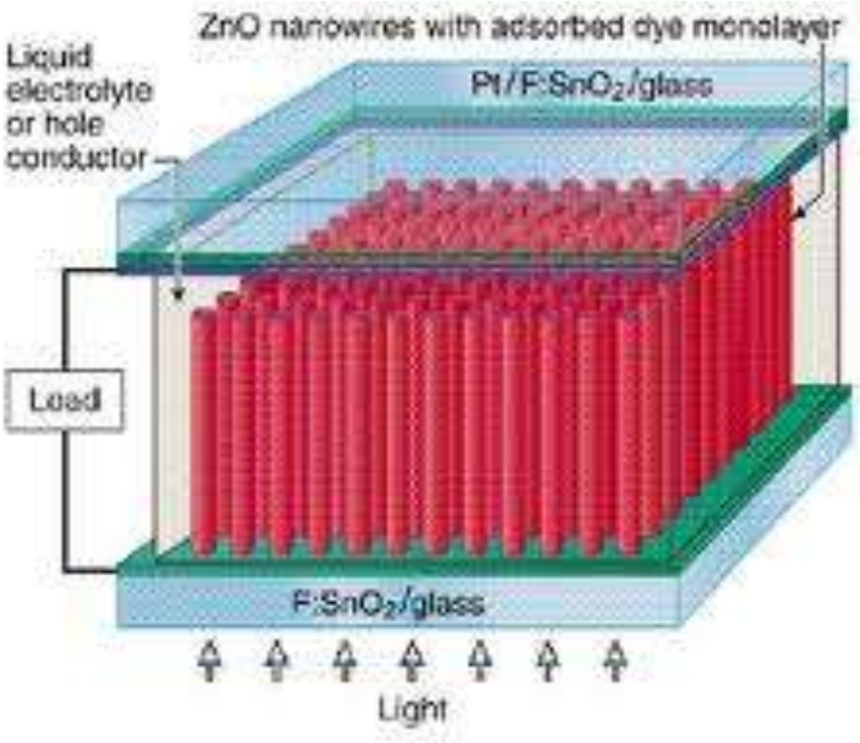


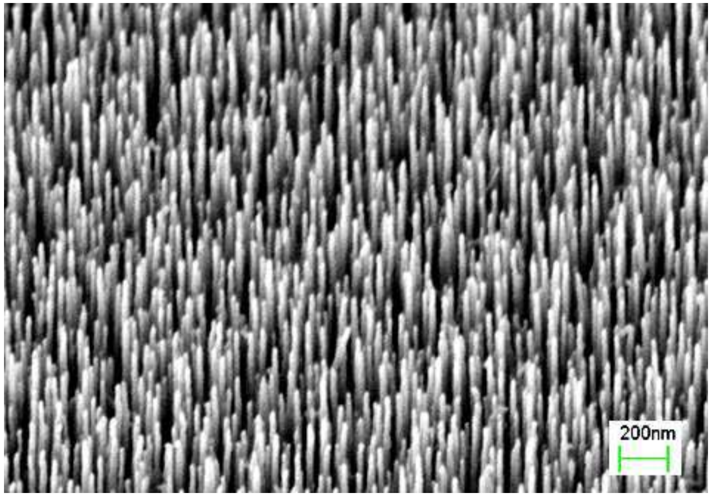




ASSEMBLING & SEALING

2. ZnO nanorods arrays





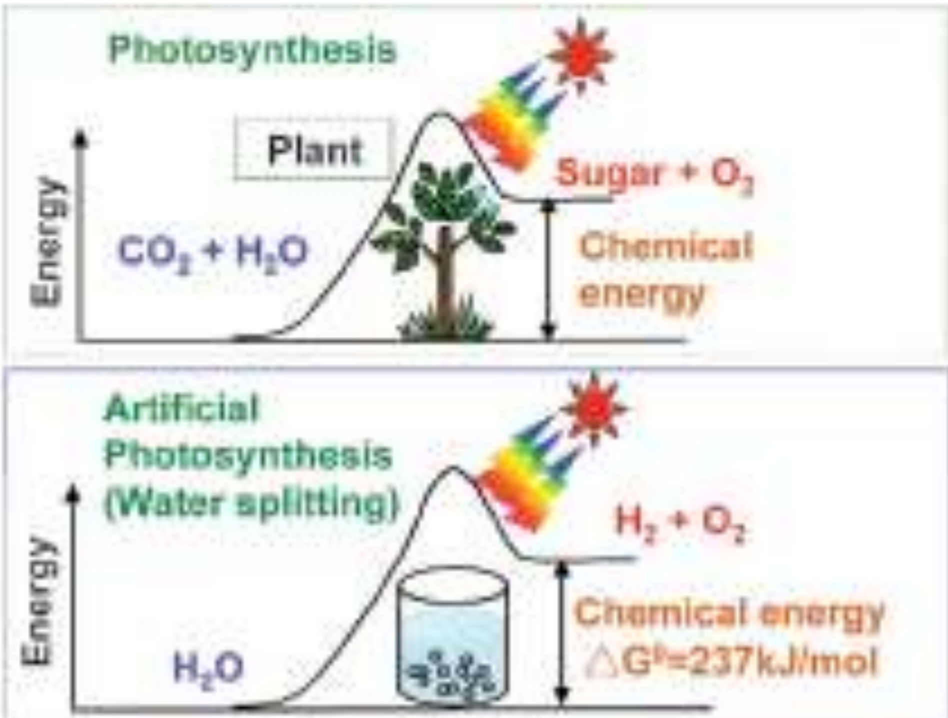
3. Integration of stainless steel in DSC

Industrial Partner:
ArcelorMITTAL

Water splitting

H_2O+☼ → H_2 + ½ O_2

Also known as « artificial photosynthesis »

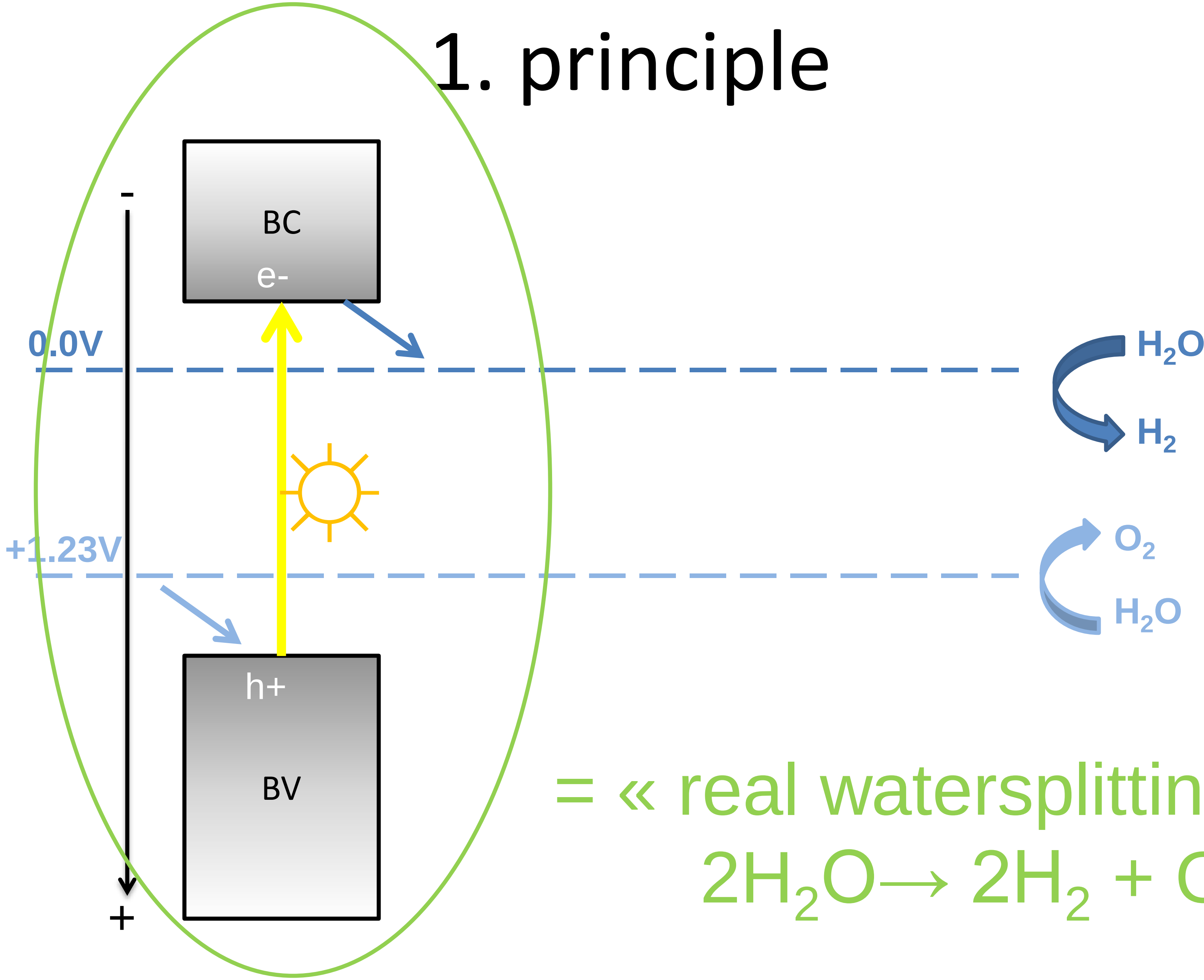


- Energy is stored in the form of hydrogen instead of sugar (NADPH)

The Half Reactions of Water Splitting

Water Oxidation:	$2\ H_2O \rightleftharpoons O_2 + 4\ H^+ + 4\ e^-$	$E^0 = -1.23\ V$
Water Reduction:	$4\ H^+ + 4\ e^- \rightleftharpoons 2\ H_2$	$E^0 = 0.0\ V$
Overall Water Splitting:	$2\ H_2O \longrightarrow 2\ H_2 + O_2$	$E_{rxn} = -1.23\ V$

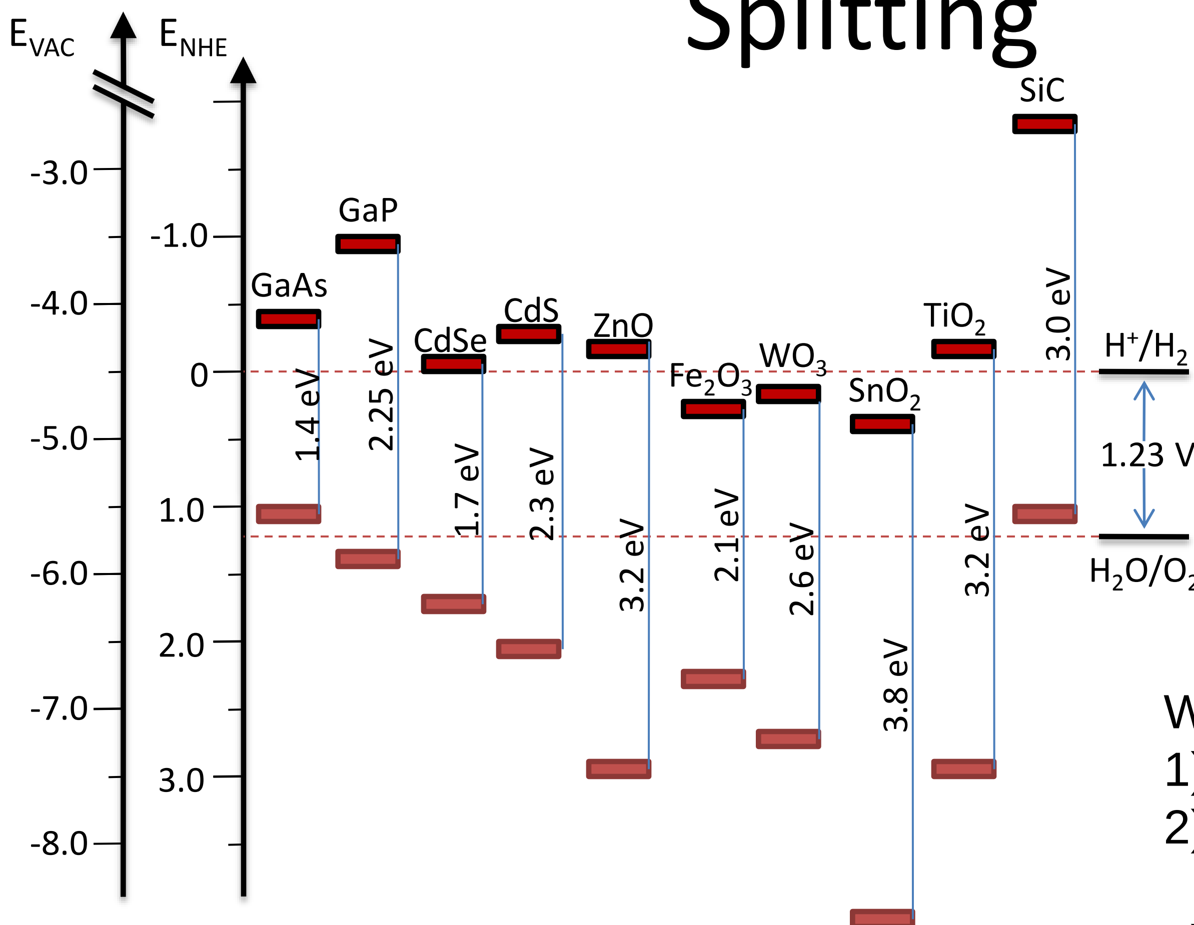
1. principle



= « real watersplitting »

$$2H_2O \rightarrow 2H_2 + O_2$$

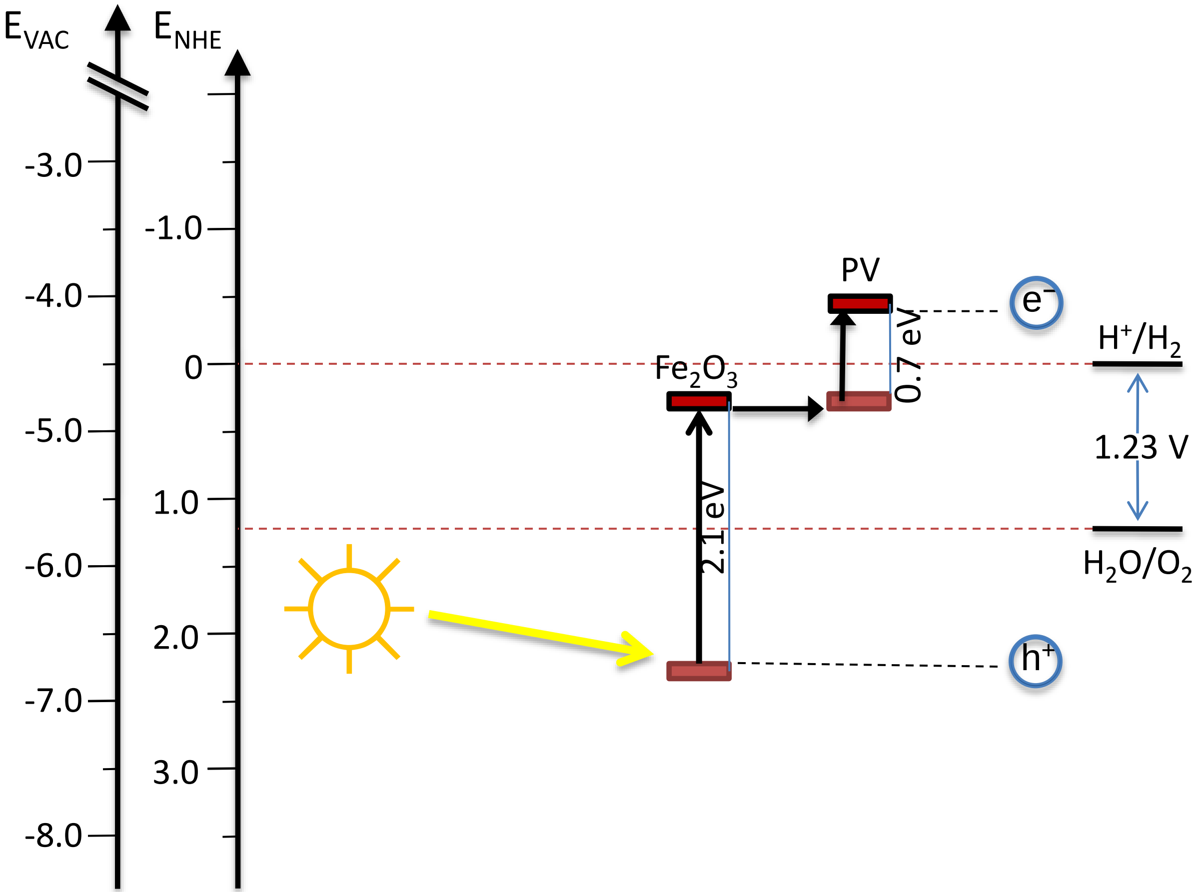
Some Candidates for Solar Water Splitting



Water Splitting Criteria:
1) Band gap
2) Overlap of redox potentials
3) Stability
4) Toxicity
5) Cost

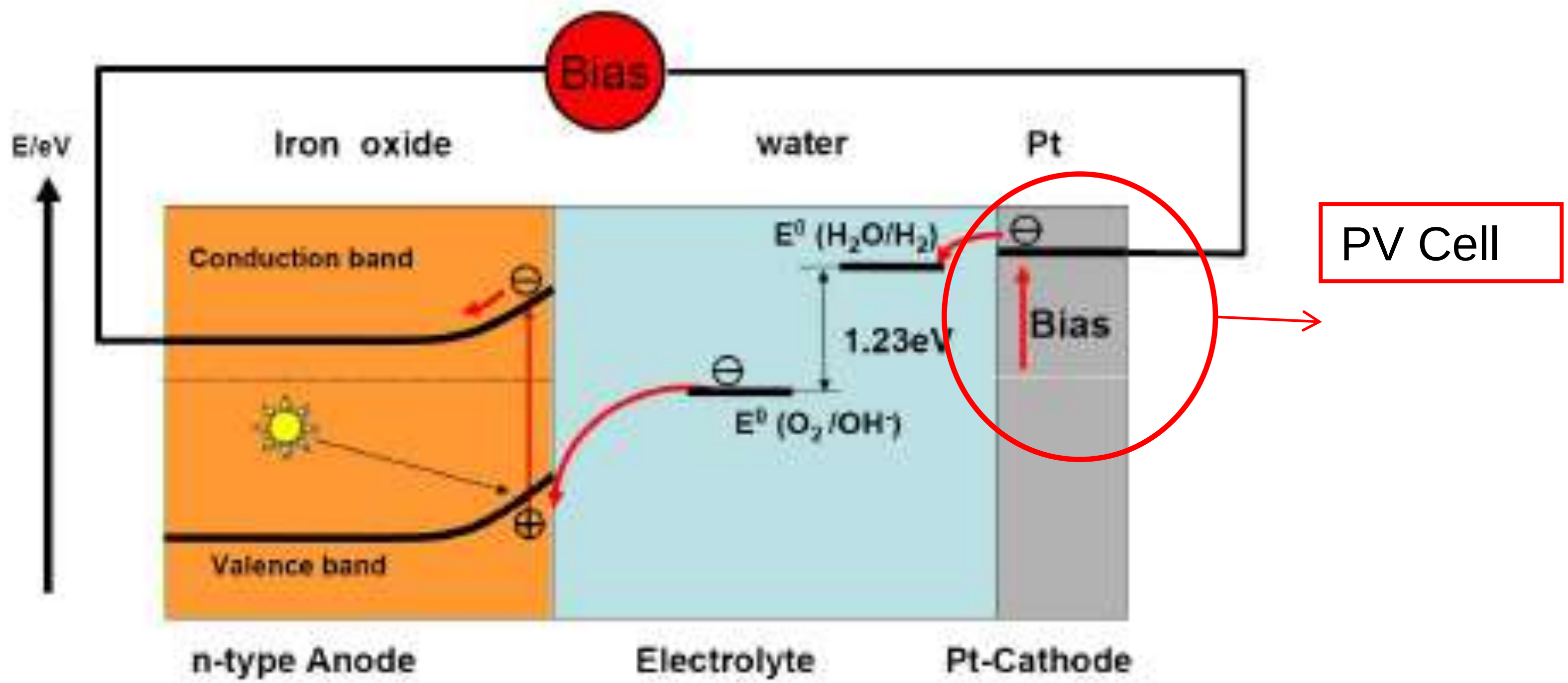
Seminal demonstration:
Fujishima, A.; Honda, K. *Nature* **1972**, *238*, 37.

A Review:
Grätzel, M. *Nature* **2001**, *414*, 338.



E_VAC
E_NHE
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-1.0
0
1.0
2.0
3.0
PV
Fe2O3
2.1 eV
0.7 eV
e−
h+
H+/H2
1.23 V
H2O/O2

Envisaged solution

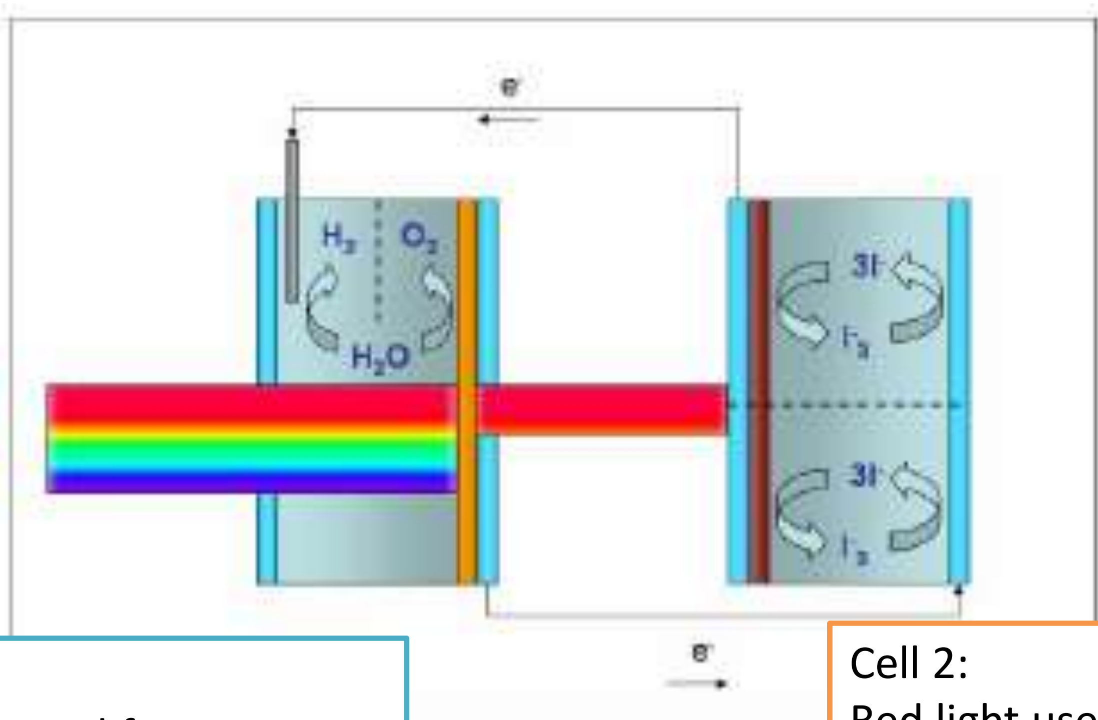


Part 1: partial water splitting= photooxidation of water on a photoanode
(**production of oxygen**)

Part 2: required bias for hydrogen production at the counterelectrode
(**production of hydrogen**)

Tandem cell: bias provided by a DSC

Collaboration EPFL Lausanne (prof. Graetzel)



Cell 1:
Blue light used for water oxidation
(**production of oxygen**)

Cell 2:
Red light used by a DSC to produce the bias voltage
(production of hydrogen)

α-Fe_2O_3 (Hematite) as a Promising Material

Kidney ore hematite from Michigan

Advantages

Cheap and abundant

Stable

Environmentally benign

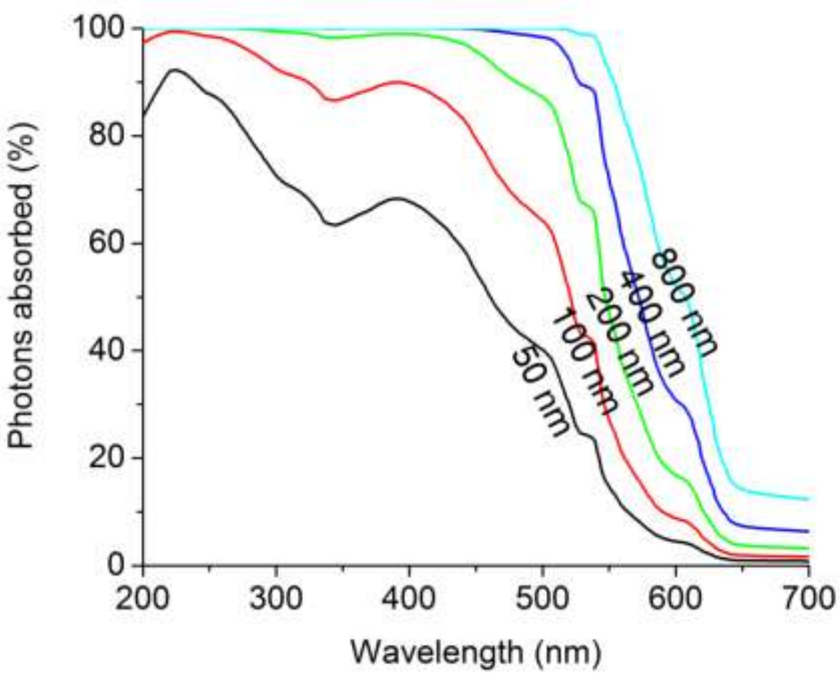
Great light absorber

Challenges

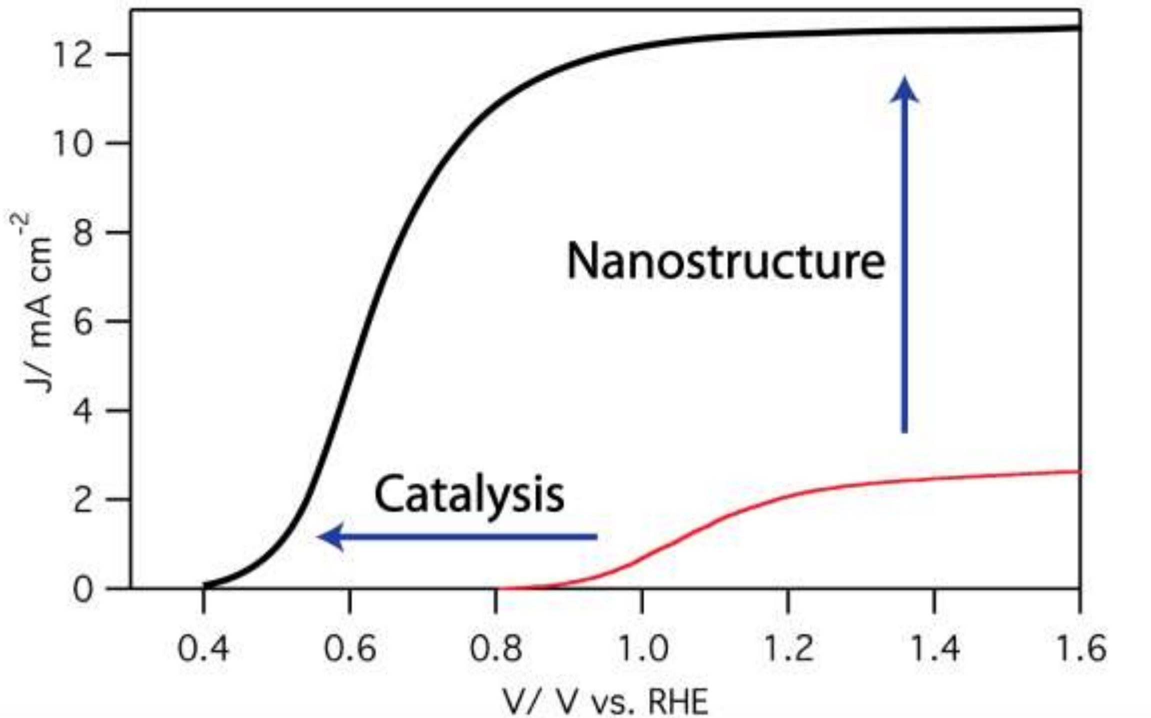
Short hole diffusion distance

Poor electronic conductivity

High overpotential for water oxidation



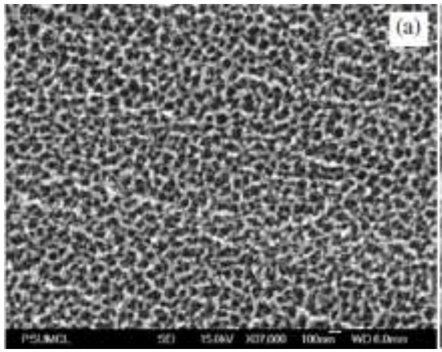
The Parameters for Improvement of a Hematite Photoanode

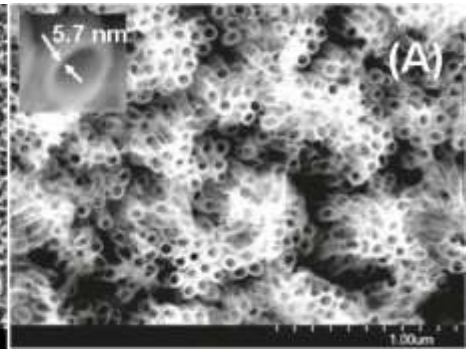


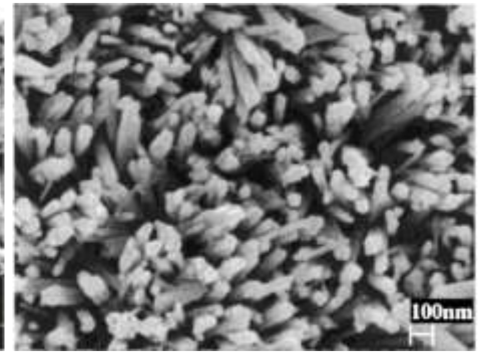
RHE = Reversible Hydrogen Electrode

Tilley, S. D.; Cornuz, M.; Sivula, K.; Grätzel, M. *Angew. Chem. Int. Ed.* **2010**, *49*, 6405.

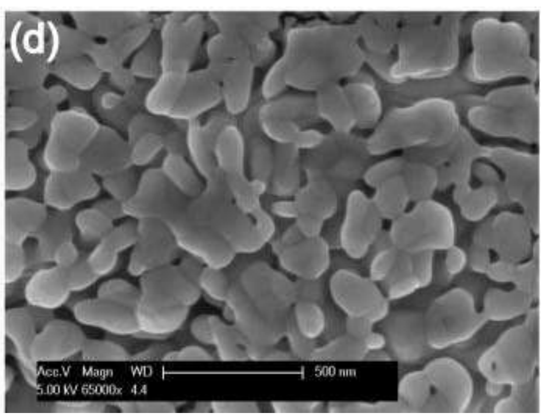
Nanostructuring Iron Oxide

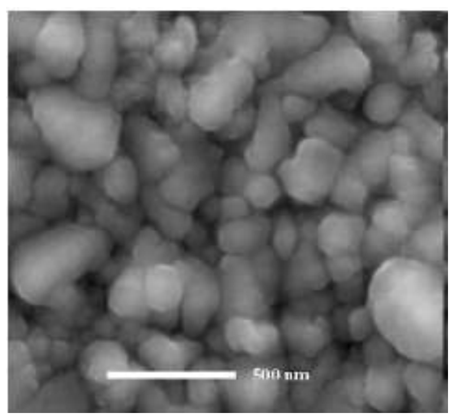




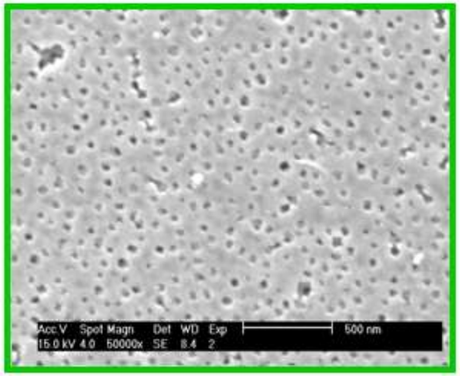


Vayssieres, L. et al. *Chem. Mater.* ***2001,*** 13, 233-235.
Prakasam, H. E .et al. *Nanotechnology* ***2006***, 17, 4285-4291.
Mohapatra, S. K. et al. *Chem. Mater.* ***2009,*** 21, 3048-3055.



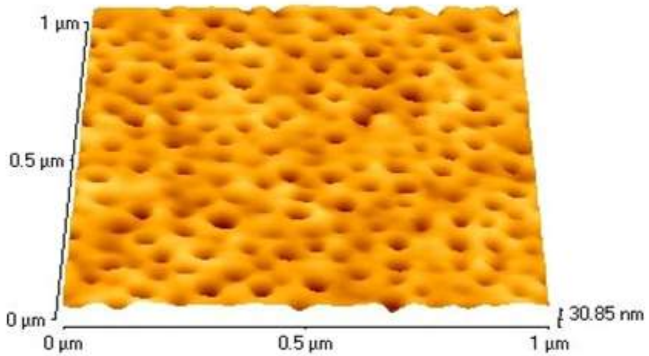


Sartoretti, C. J. et al*. Phys. Chem. B* ***2005***, 109, 13685-13692.
Hu, Y. S. et al. *Chem. Mater.* ***2008***, 20, 3803-3805.

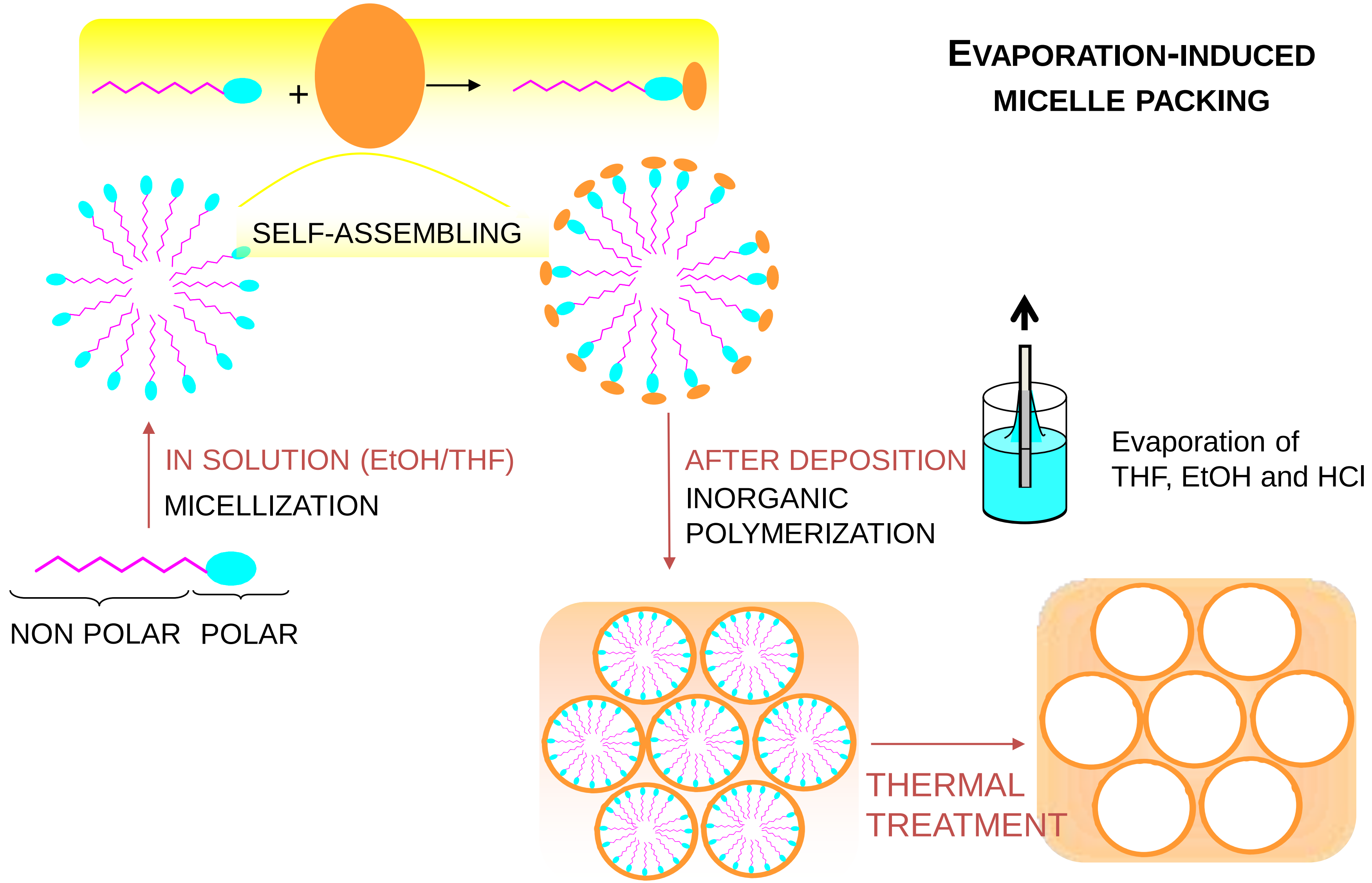


Mesoprous Fe_2O_3
Nanoparticles $YFeO_3$

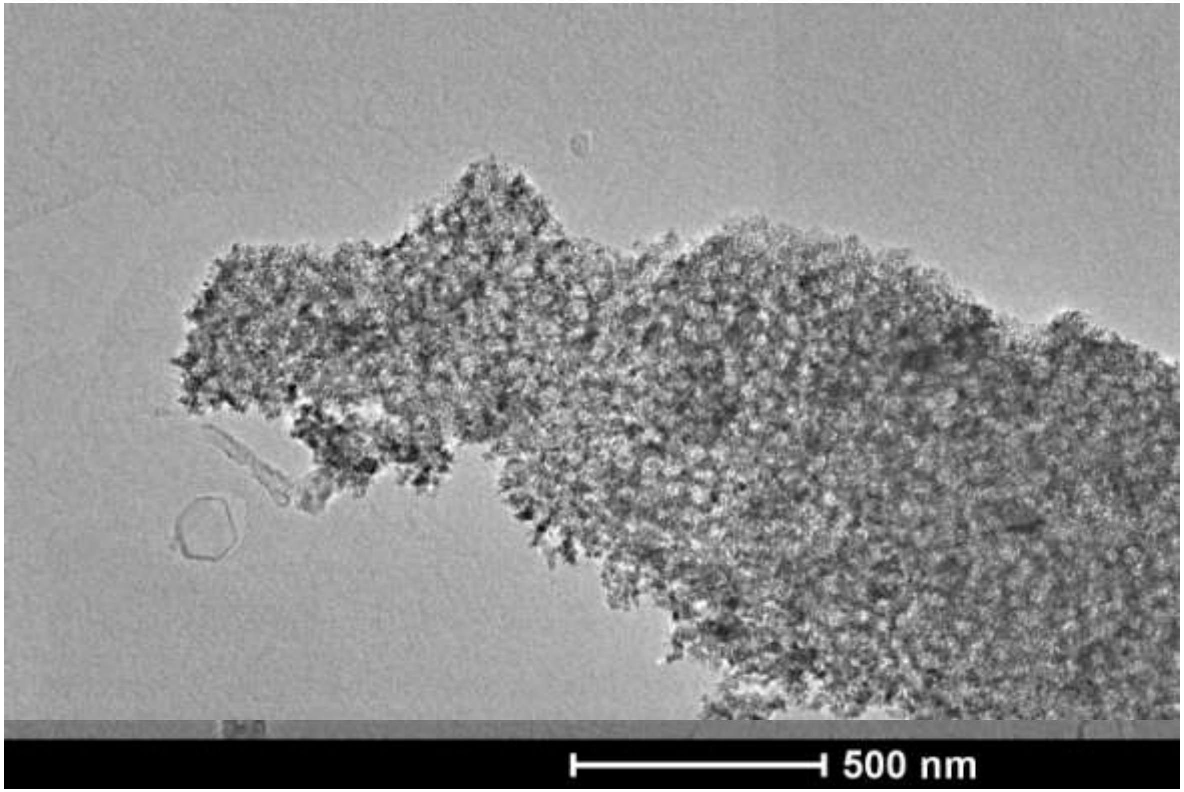
Water Splitting at GreenMAT : OUR WORK

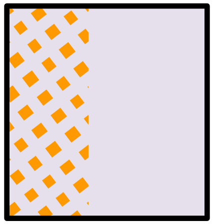


MESOPOROUS THIN FILMS



MESOPOROUS FE_2O_3 THIN FILM VIEWED BY TEM



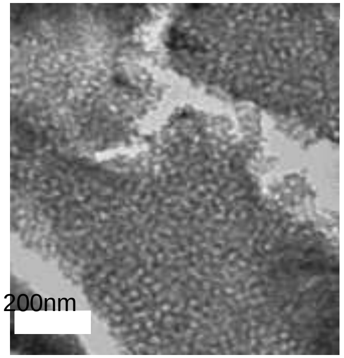


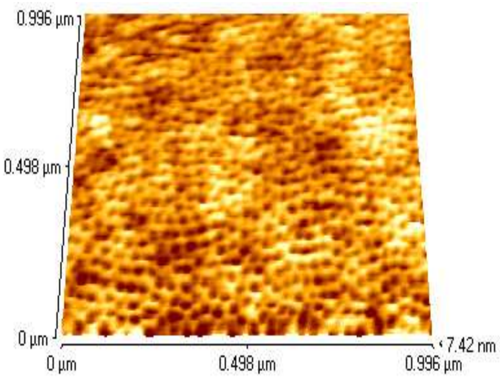
Fe-based oxides

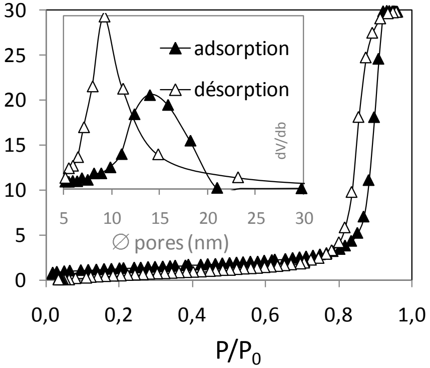
Fe2O3
YFeO3

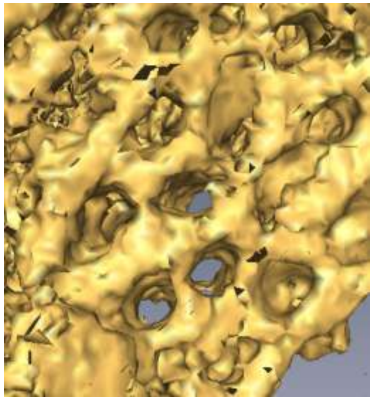
Morphology of nanostructure

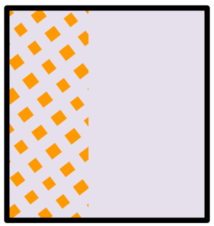
TEM	AFM	ELLIPSO-PORO	ELECTRON TOMOGRAPHY











Fe-based oxides

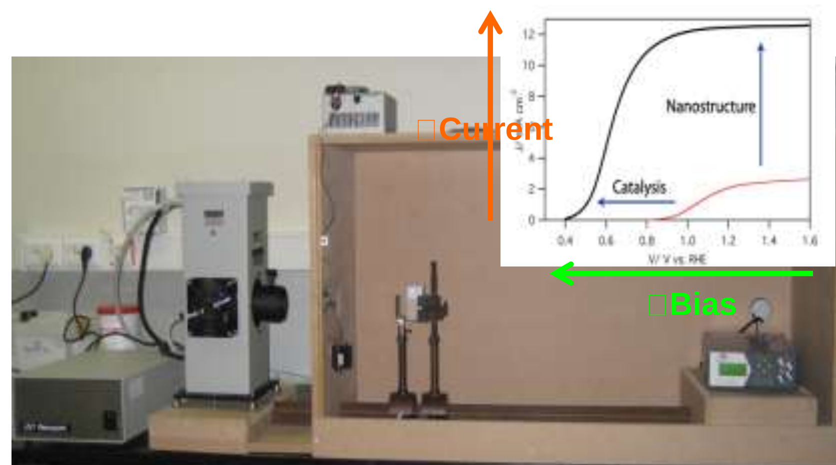
Fe2O3

YFeO3

Opto/Electronic properties

EIS

I/V under illumination



Researchers

- Water splitting: 2 PhD on nanostructured Fe_2O_3 and $YFeO_3$
- DSSC:
  - 2 PhD on TiO_2
  - 1 post-doc on concentrated sunlight
  - 1 postdoc on ZnO

Thank you for your attention