Nanomaterials for High Efficiency Energy Conversion, Energy Storage and Sustainable Energy Processes

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IREC: Catalonia Institute for Energy Research

INTRODUCTION

IREC: new research Institute founded under trust of different governmental and private organisations:

- *Ministry of Industry*
- *Ministry of Science & Innovation*
- *Departments of Economy & Innovation of Catalan Regional Government*
- *Universities (Univ. Barcelona, UPC, URV)*
- *Companies: ENDESA (leading Spanish electrical utility company), Gas Natural (main Spanish gas energy company), AGBAR (leading water management & distribution company)*

This Institute will become the **Catalan Government's main reference body for channelling the promotion of technology research and development in the energy field.**

Objectives: Development of energy efficient technologies, with special attention to 4 research lines:

- *Smart Electricity Grids*
- *Off-shore Wind Energy*
- *Biofuels*
- *CO_2 capture & Storage*

and 2 transverse knowledge areas:

- *Power Electronics*
- ***Advanced Materials for Energy***

- *Mater. & Systems for Solar Energy*
- *Solar Hydrogen & CO_2 reduction*
- *Nanoionics & Fuel cells*
- *Thermoelectrics*
- *Systems for Energy storage*
- *Rational & sustainable use of Energy for safety & security appl.*

Advanced Materials for Energy: Main research lines

Synthesis of nanostructured materials & devices for:

- New solar cells for 3rd generation PV technologies (with emphasis on technologies based on chalcopyrite compounds and nanostructured materials)
- Nanoionic based devices with electrolyte and electrodes defining feasible low temperatures direct and reverse fuel cell for chemical energy storage, CHESS
- High zT thermoelectrics based on nanowires and stacked nanolayers
- Solar H_2 and CO_2 reduction

Future lines:

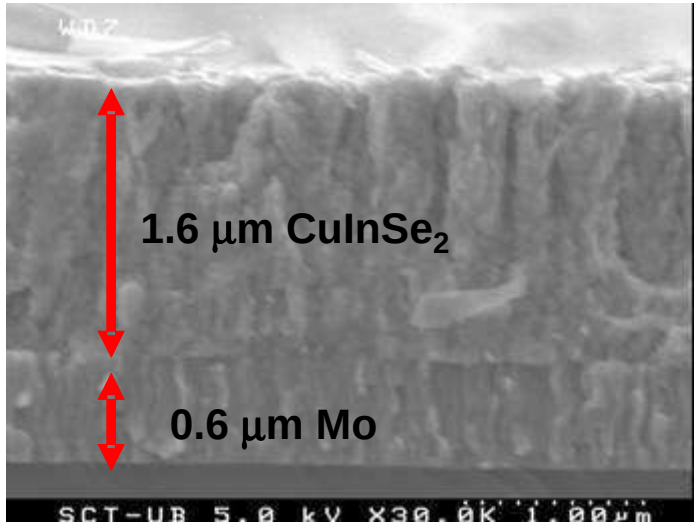
- Nano-materials for electrical, BEES, and thermal, TESS energy storage
- New systems for high efficient water/energy management.

New Solar cells for 3rd generation PV

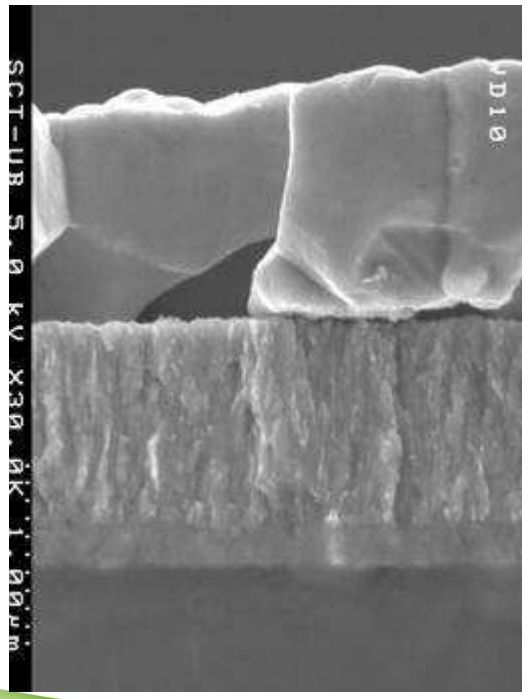
Previous activities (2nd generation CIS technology): Development & charact. of electrodeposition based processes for low cost high efficiency $CuIn(S,Se)_2$ solar cells (*colab. with IRDEP (Chatou, France)*)

Single step ED: nanocrystalline $CuInSe_2$ precursor

RTP Sulfurisation: High cryst. quality absorbers



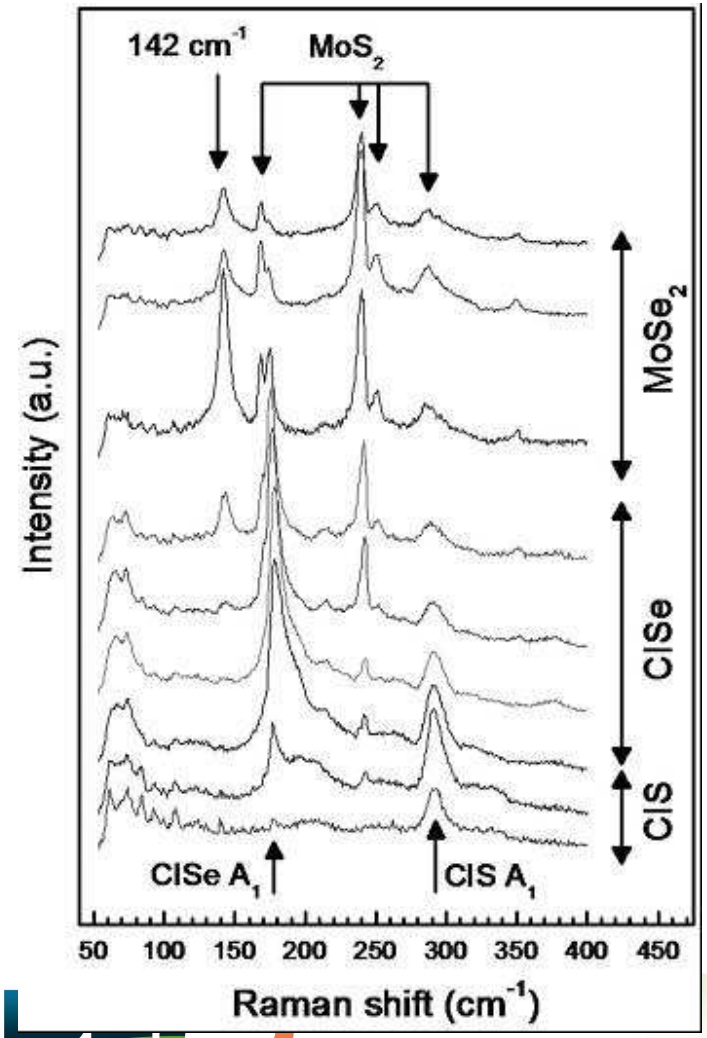
as-grown

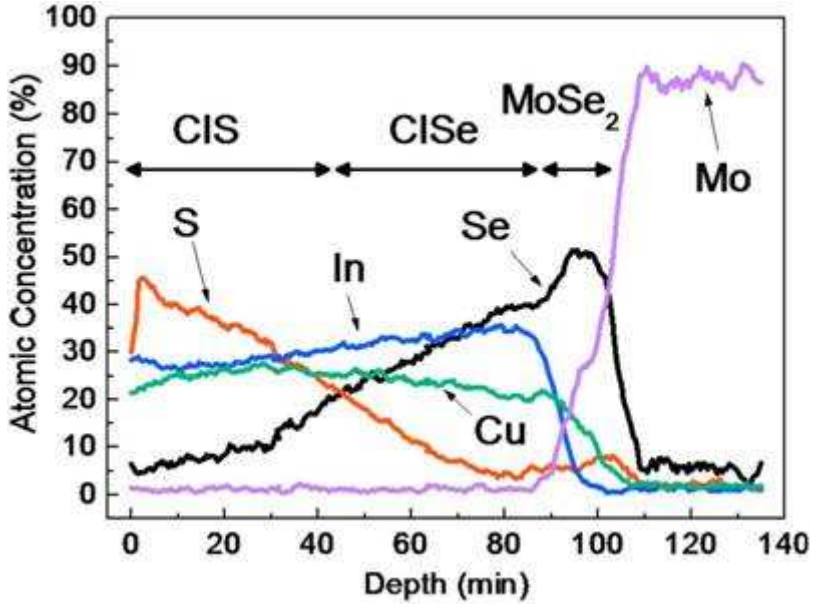


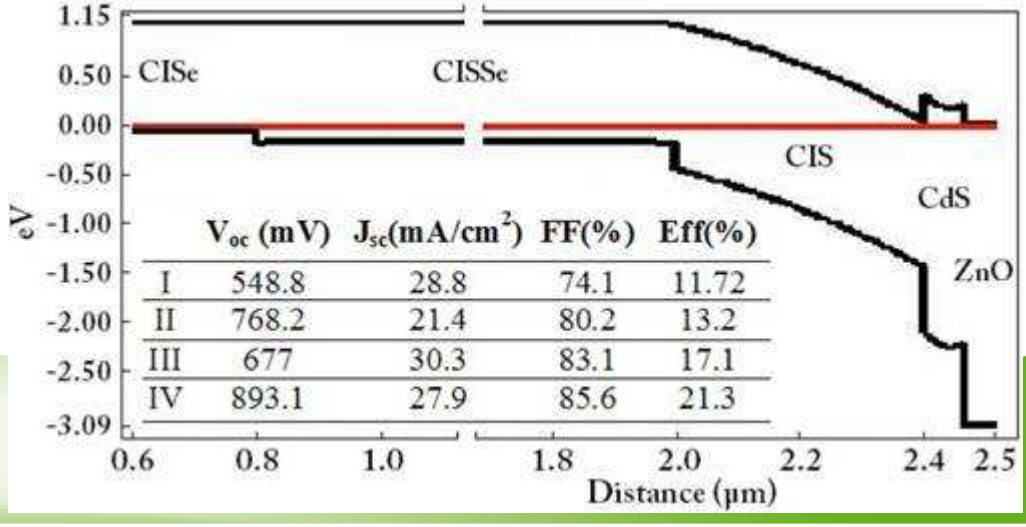
RTP annealed + etched

Control of RTP processes: absorbers with gradual composition (graded E_g layers for efficiency improvement)

V. Izquierdo-Roca et a1, APL (2009)

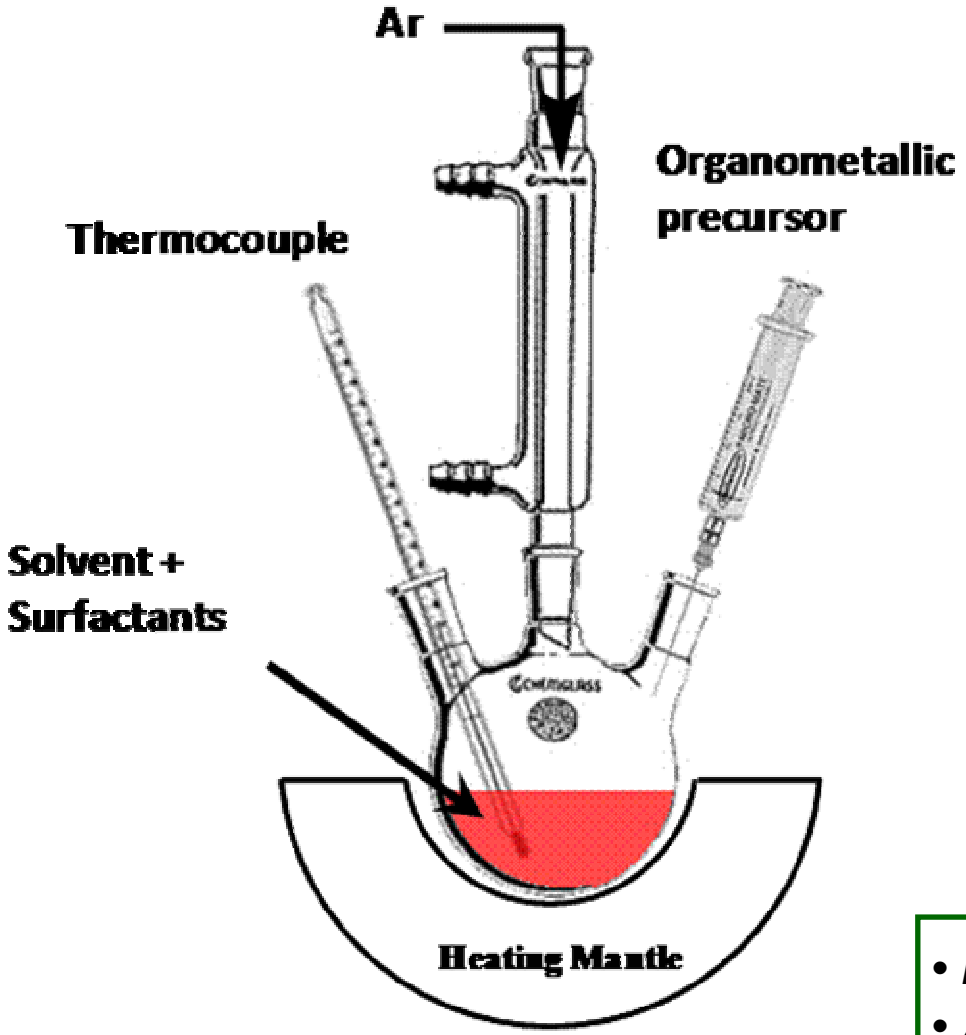


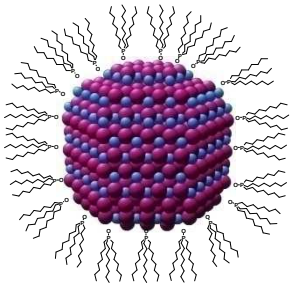


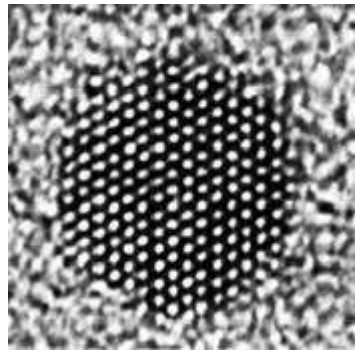


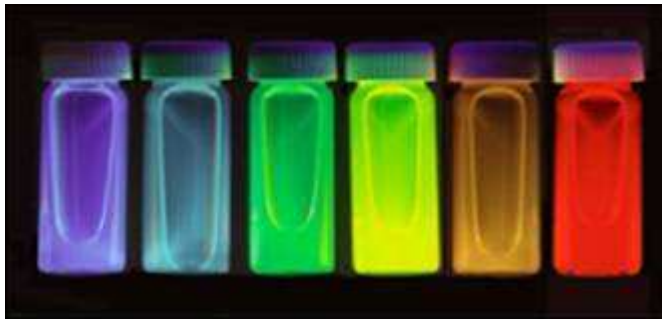
	V_{oc} (mV)	J_{sc}(mA/cm^2)	FF(%)	Eff(%)
I	548.8	28.8	74.1	11.72
II	768.2	21.4	80.2	13.2
III	677	30.3	83.1	17.1
IV	893.1	27.9	85.6	21.3

New activities: low cost approaches based on synthesis of Colloidal Nanocrystals





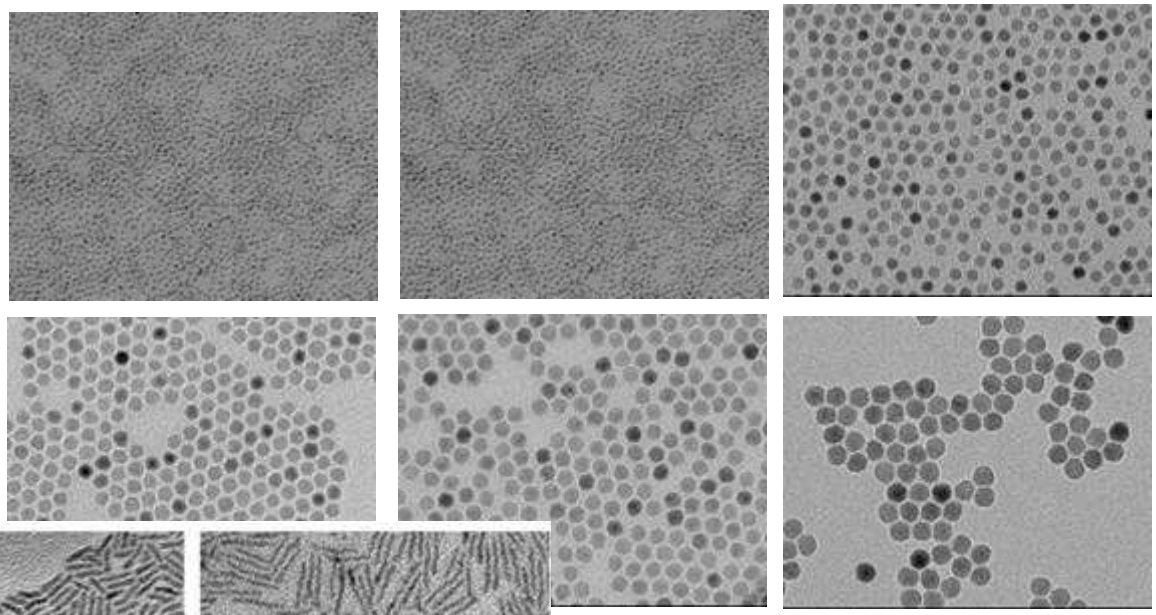


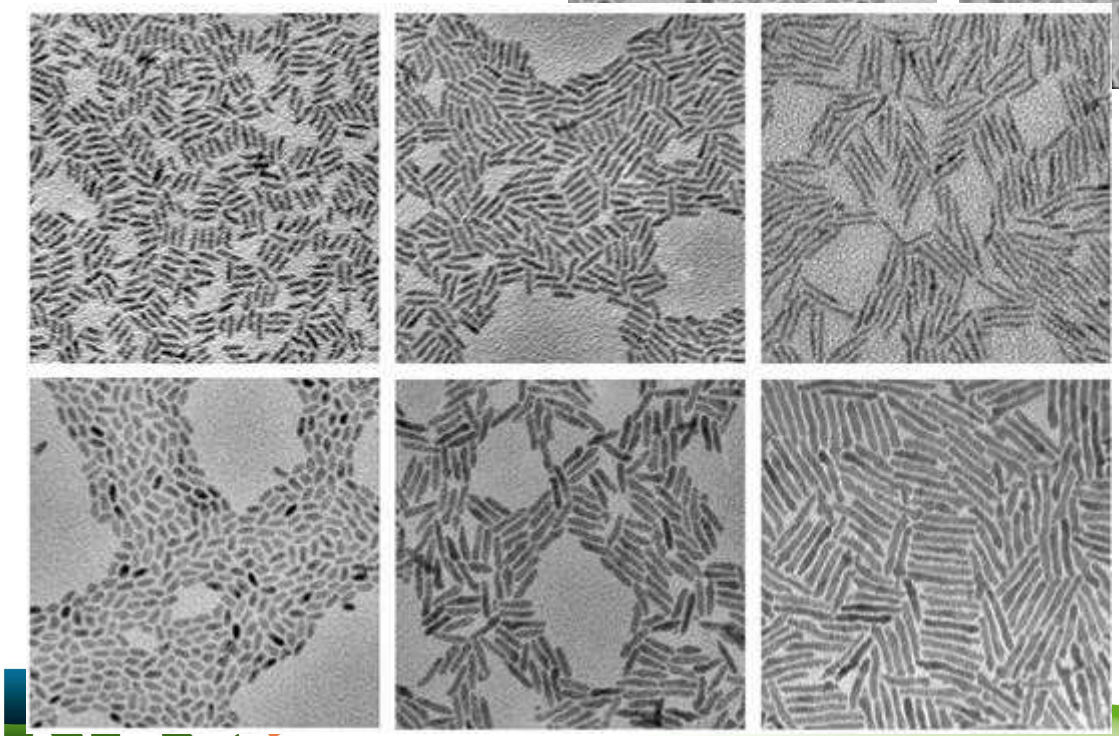


- *Easy control of bandgap (IR-UV)*
- *Allow multiple layers*
- *New architectures: Graded/Tandem solar cells*

100 nm

control of size ➔





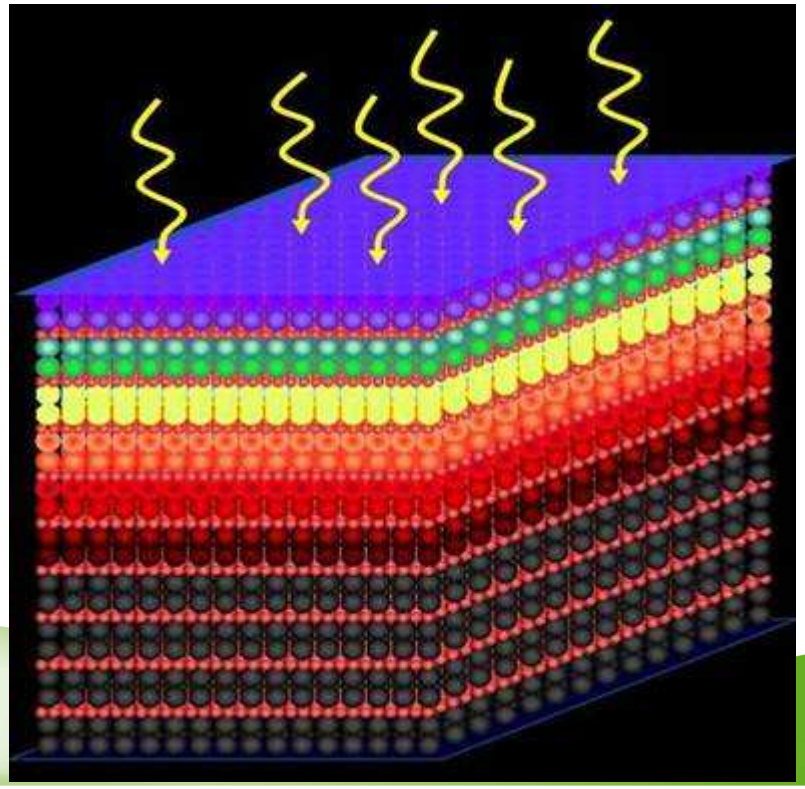
➔ and shape

CP alloying: control of E_g between 1 eV ($CuInSe_2$) & 2.6 eV ($CuAlSe_2$).
(Use of tellurides: Eg down to 0.5 eV (IR region))

Quantum confinement: further increase of E_g

➔ ***Synthesis of absorbers with complex in-depth band-gap grading (sequential deposition of layers with different composition)***

➔ ***Integration of nc's in new tandem structures (higher risk)***



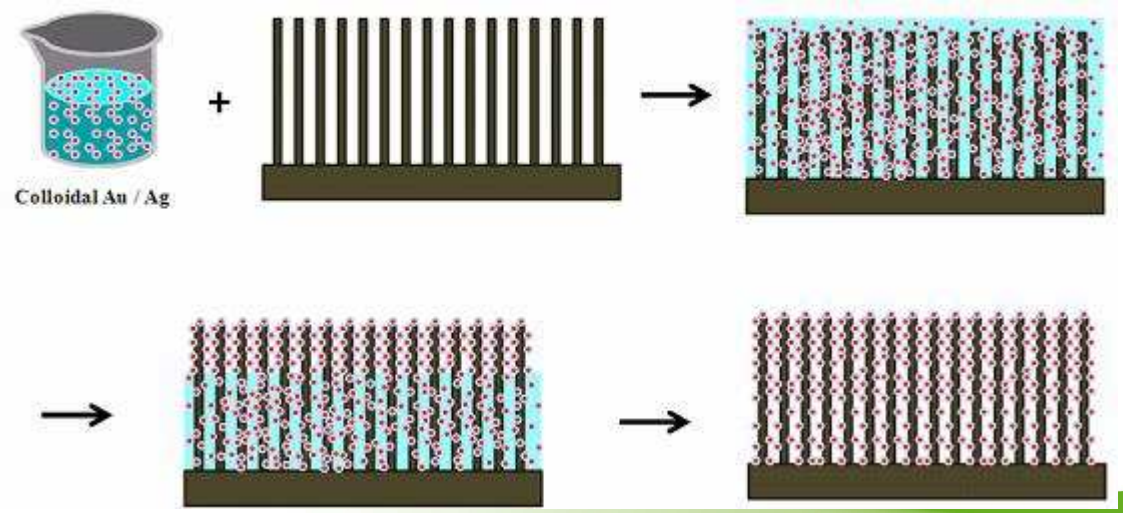
New activities: Si NW's solar cells

Metal-assisted electro-less etching through nanostructured Ag catalyst films: low T synthesis of high density of Si NW's with controlled dimensions and orientation

Application: New Si technology based PV devices:

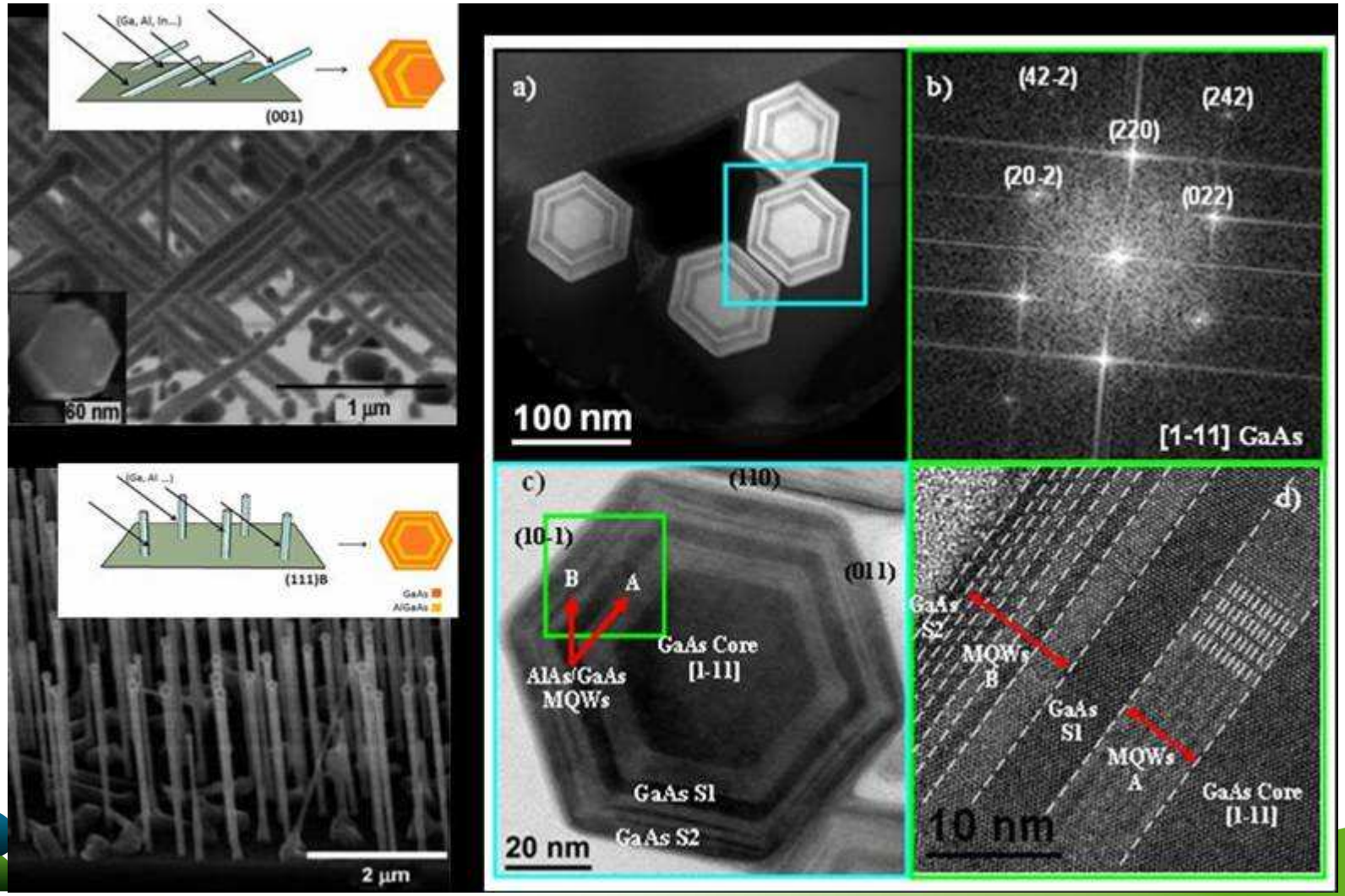
⇨ *Improvement of absorption of solar light in NW array*

⇨ *Implementation of Au nps': efficiency enhancement through plasmonic resonators*



Semiconducting NW's for PV devices:

Si & GaAs NW's grown by MBE (colab. with EPFL):



NANOIONICS

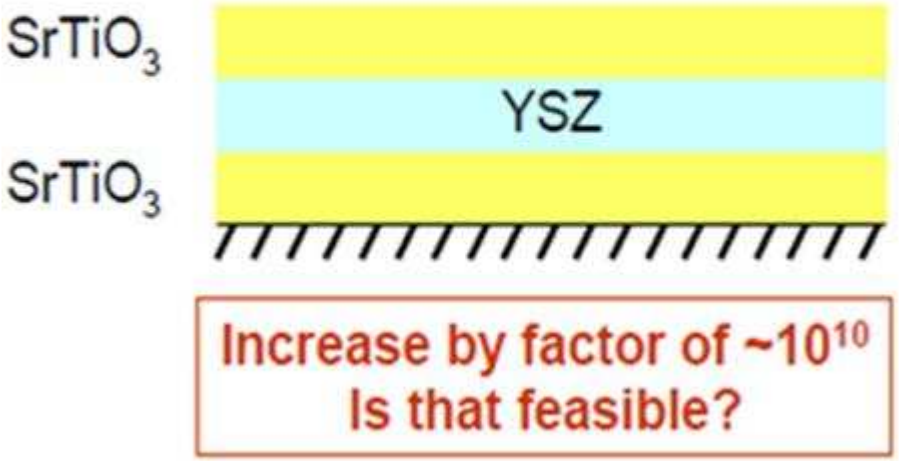
SOFC: Efficient, Fuel versatile & clean but costly and requires high temperature operation!!

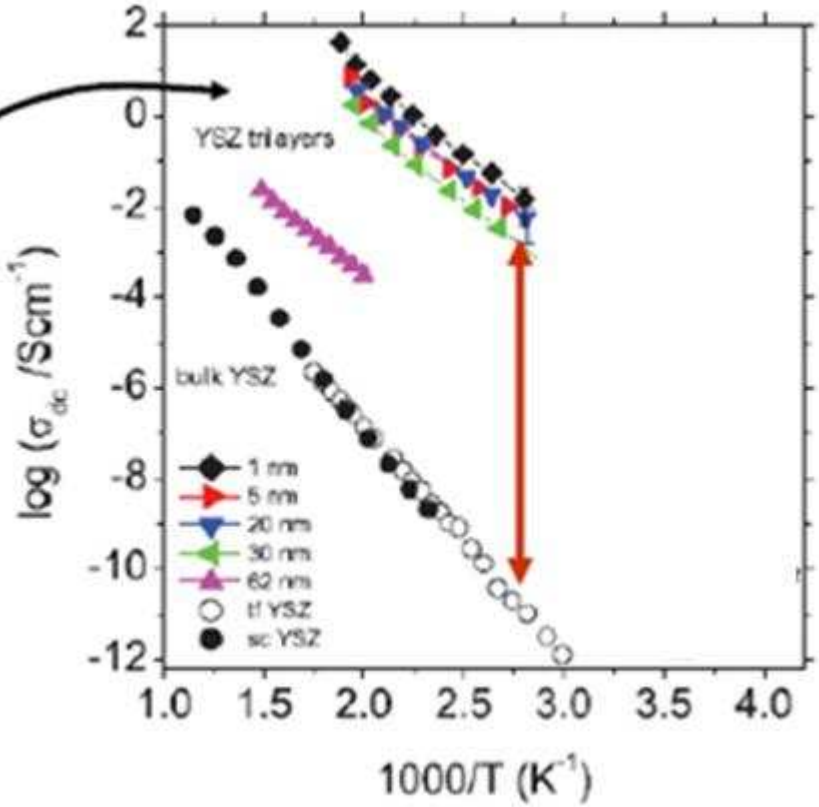
Goal: find ways to lower operating temp. & cost without sacrificing power output

Role for Micro and Nano-ionics?

Modularity: mW to MW (stacking & scaling up)

Garcia-Barriocanal et al., *Science* 321 (2008) 676.



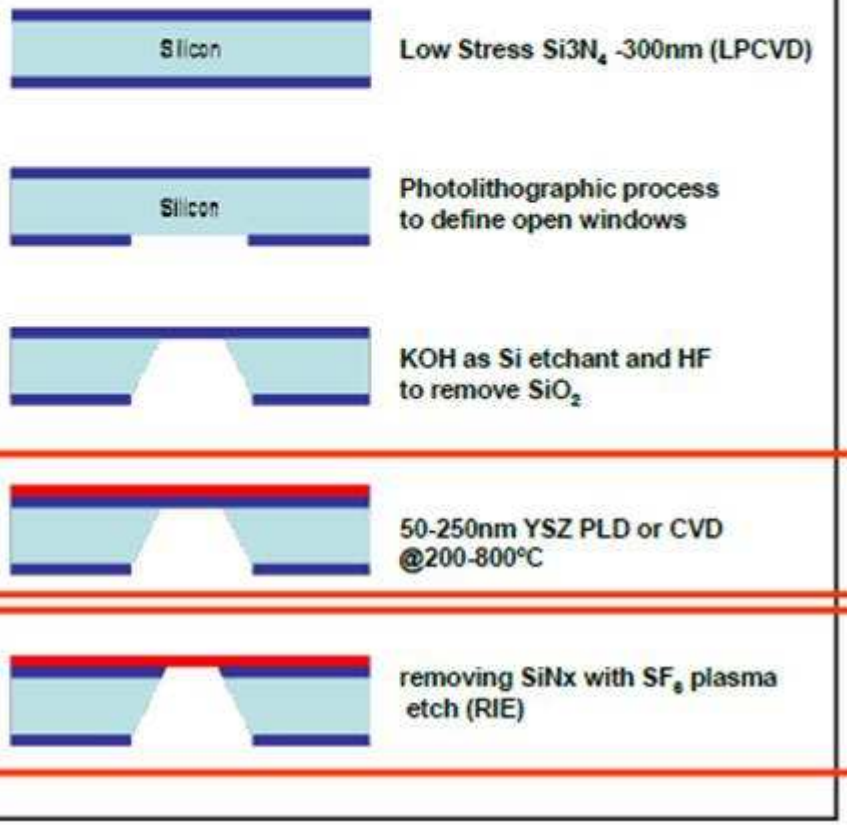


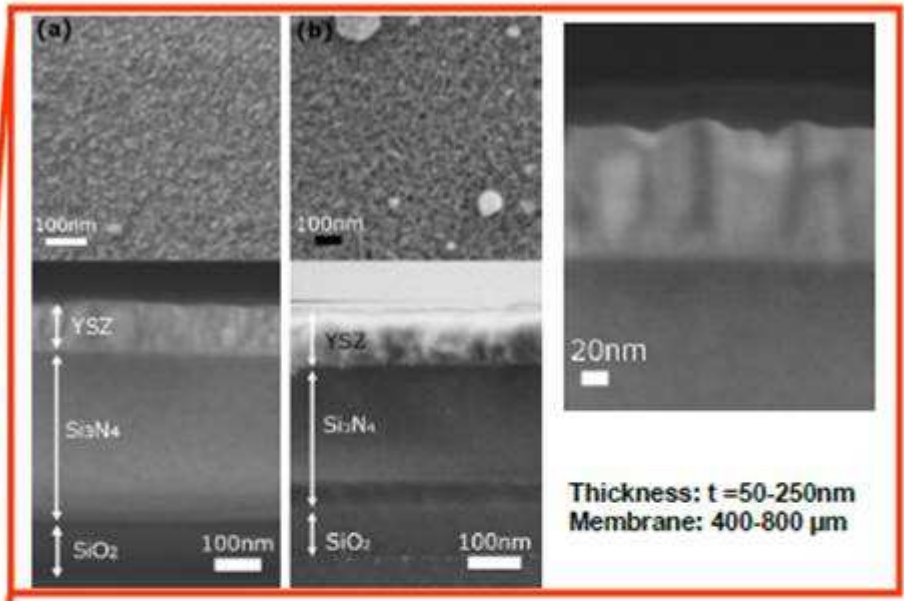
Alternative electrolites with controlled thicknesses from few nm: YSZ, Ceria ...

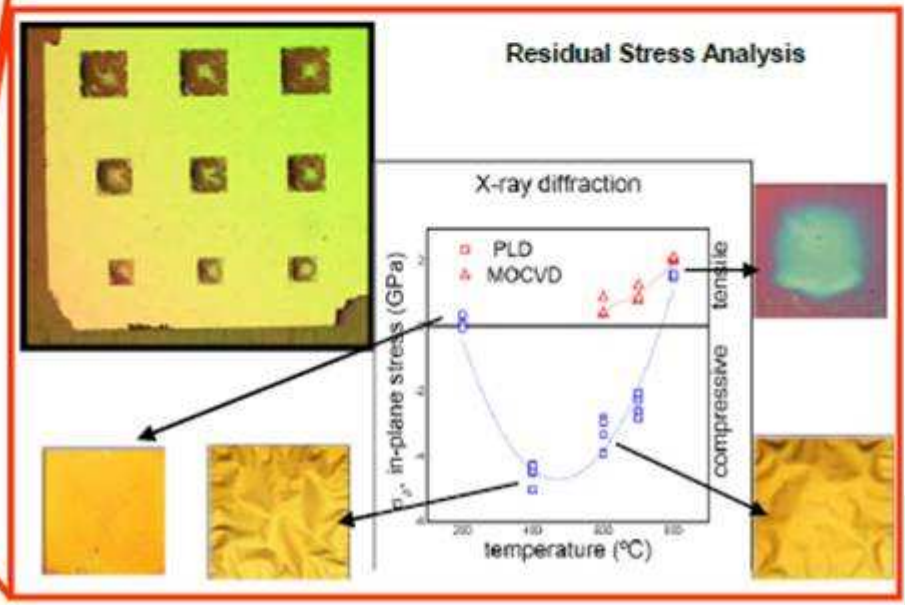
Alternative cathode & anode materials

Micro Solid Oxide Fuel Cells

Free-Standing YSZ membranes PLD or MOCVD

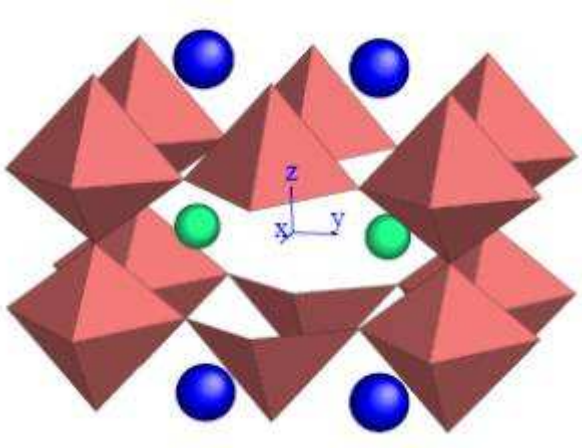






A.Tarancon et al

Using this Si micromachined platform, we are also investigating on new cathode and anode materials to be applied in this nanoionic stack elements. In this, sense, special interest on double perovskites



Polyhedral view of orthorhombic perovskite structure of $GdBaCo_2O_{5+x}$:

Co ions are coordinated in pyramids (CoO_5) and octahedra (CoO_6) with oxygen vacancies along (100), i.e. in the Gd plane

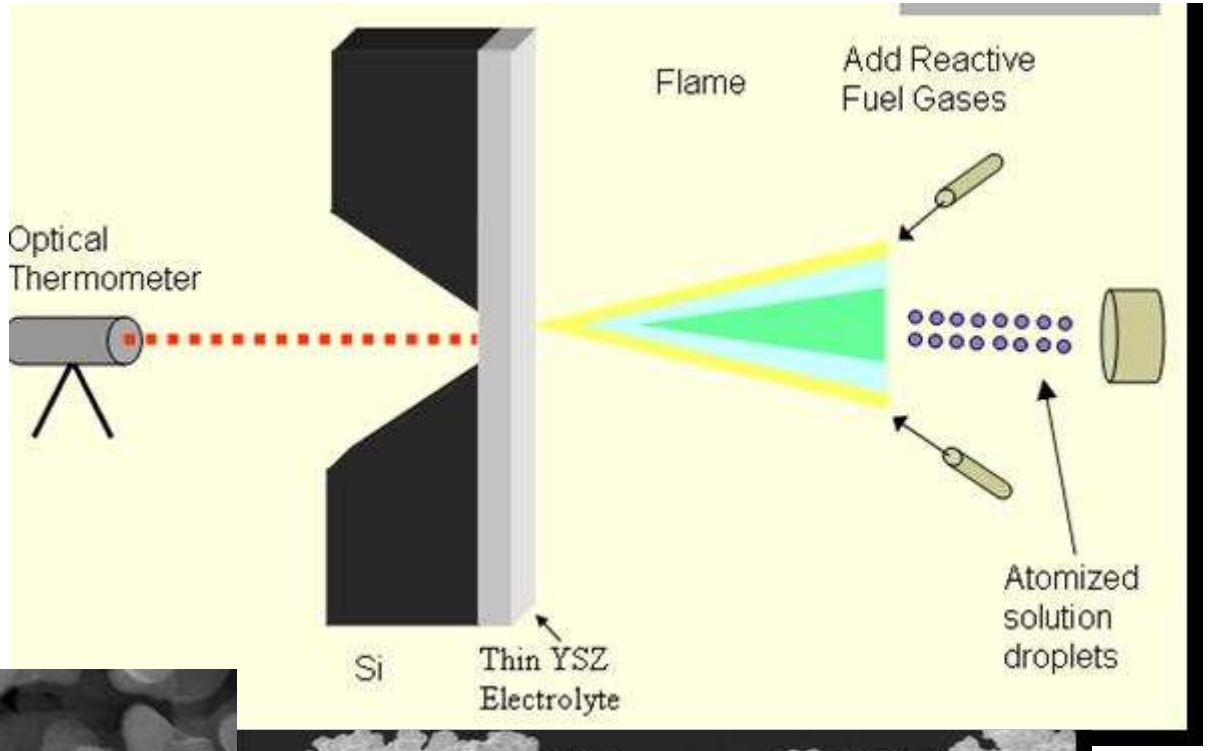
➔ *Improvement of oxygen transport properties in relation to non-ordered perovskites*

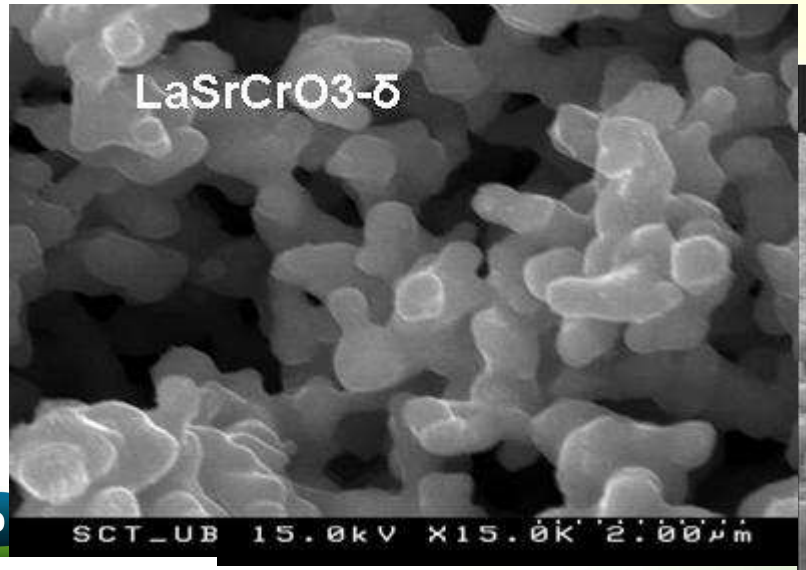
Tarancon et al Proc SOFC 7 Lucern2006
Tarancon, A., S.J. Skinner, R.J. Chater, F. Hernandez-Ramirez, and J.A. Kilner, Journal of Materials Chemistry, 2007. 17(30): p. 3175-3181.

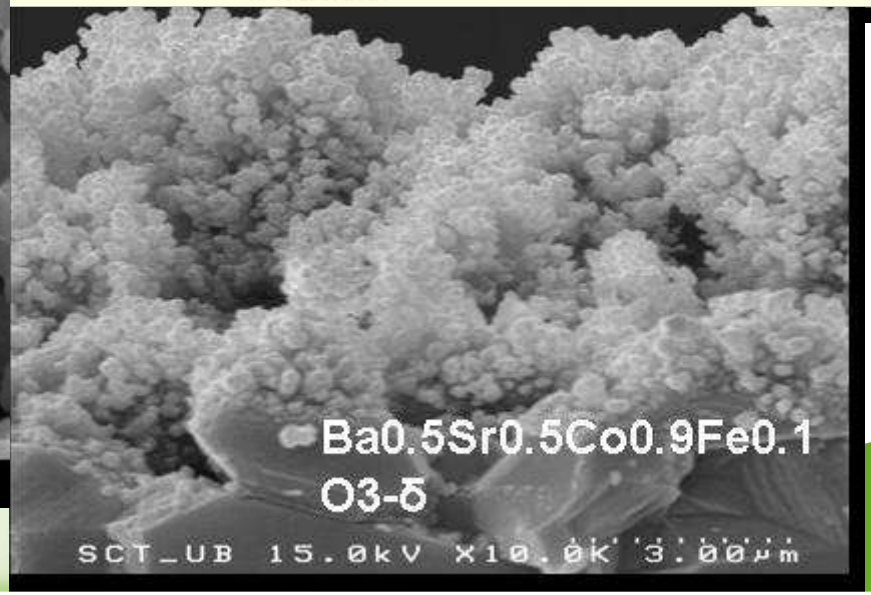
➔ *New materials are possible with high new performances*

Combustion CVD: Synthesis of high surface electrode materials

- ✓ *Reduced Temp. Deposition*
- ✓ *No annealing required*
- ✓ *Extremely high surface area*
- ✓ *From thin to thick films*

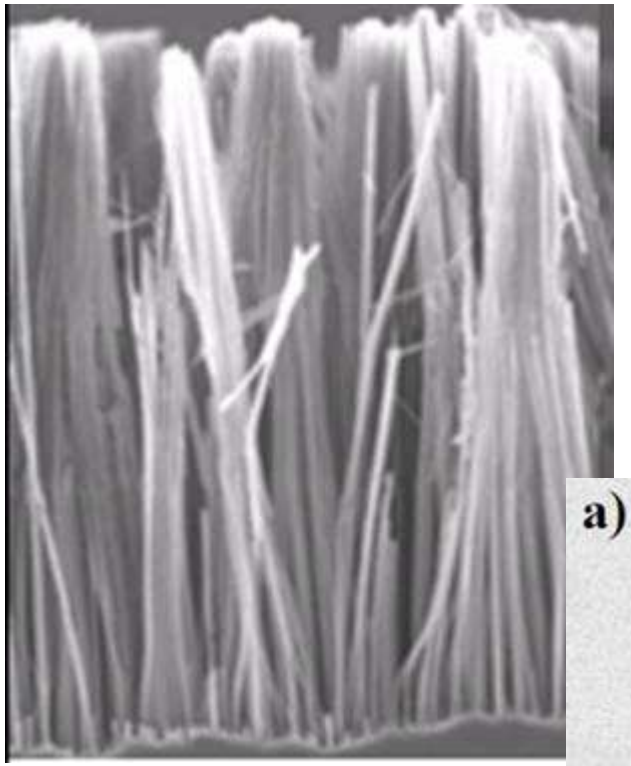




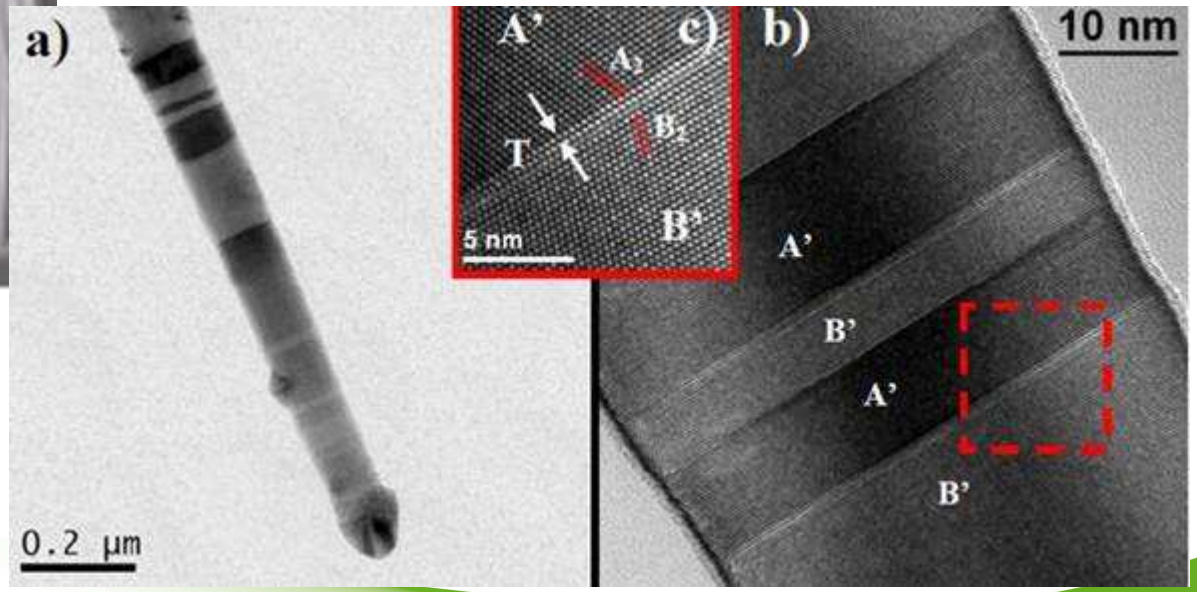


E. Koep et al

High zT thermoelectrics based on NW's & stacked nanolayers

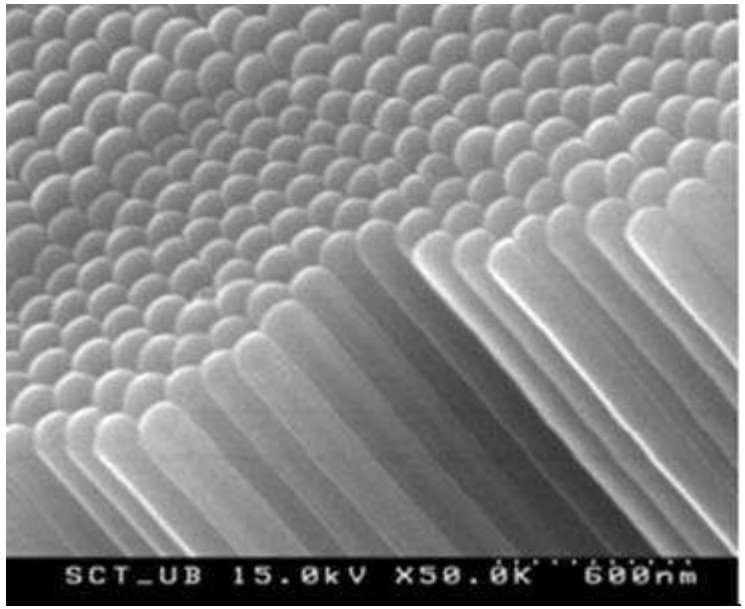


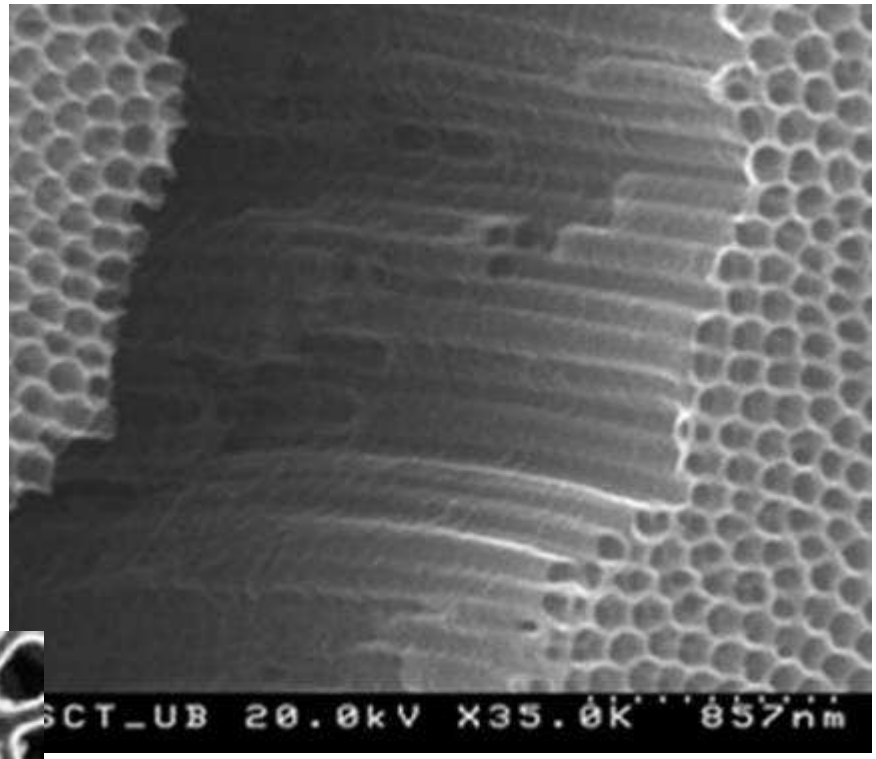
Combining doping with surface roughness (metal assisted electroless etching)& twins (MBE) for control of electrical and thermal conductivity

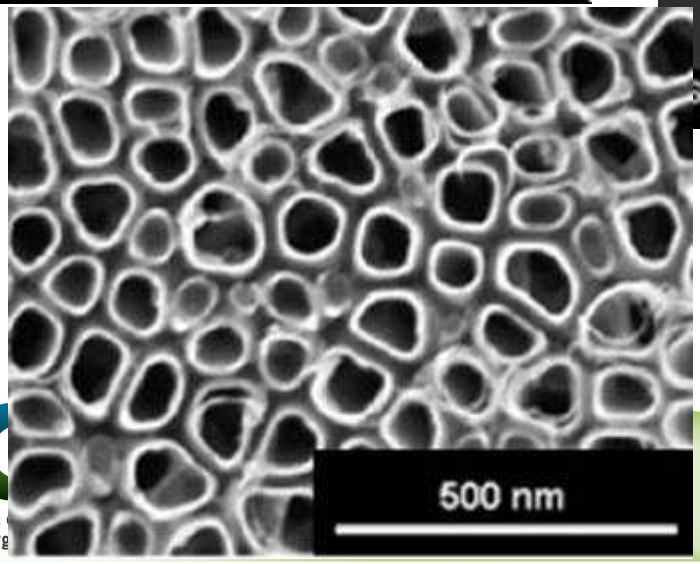


Solar H_2 and CO_2 reduction

New modified TiO_2 nanostructures

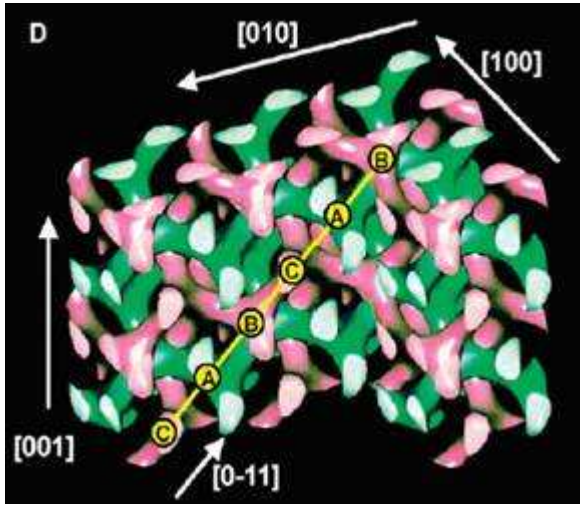


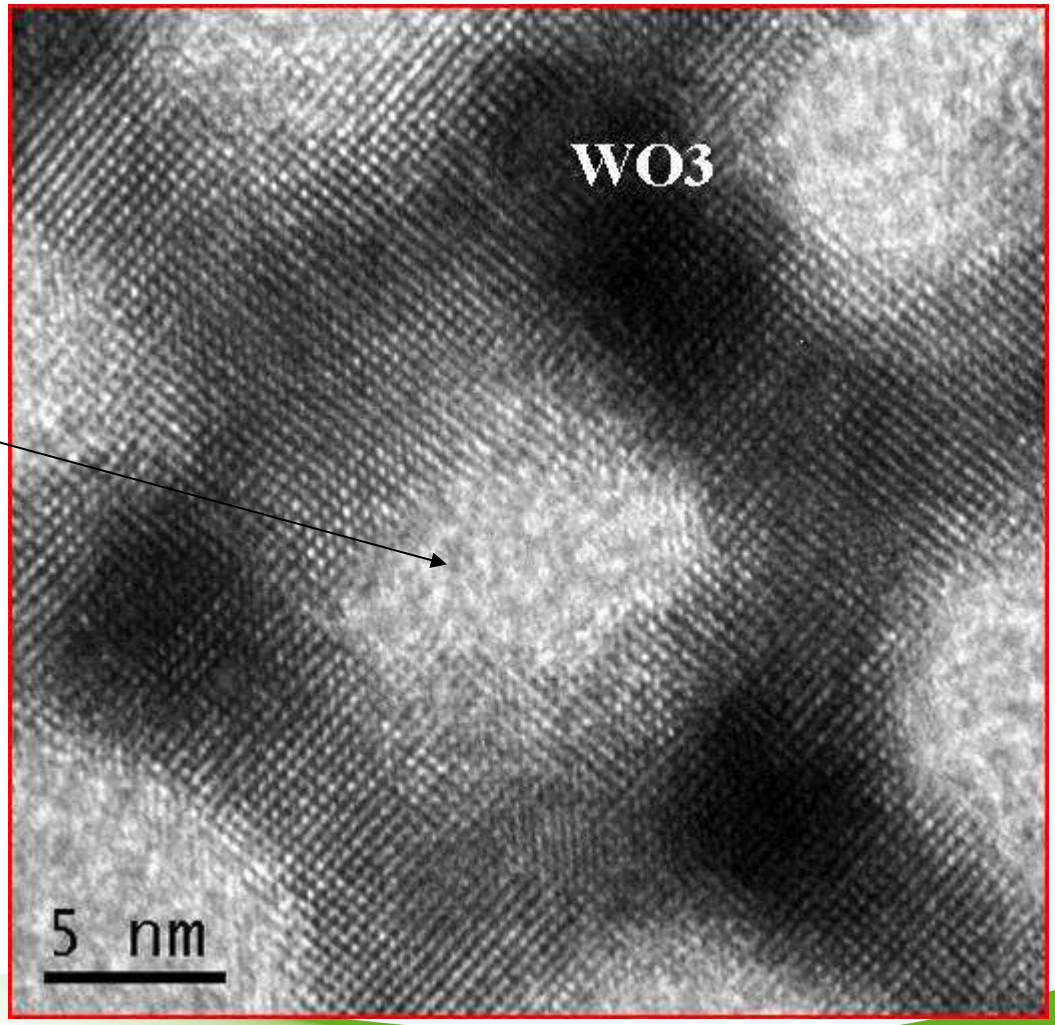




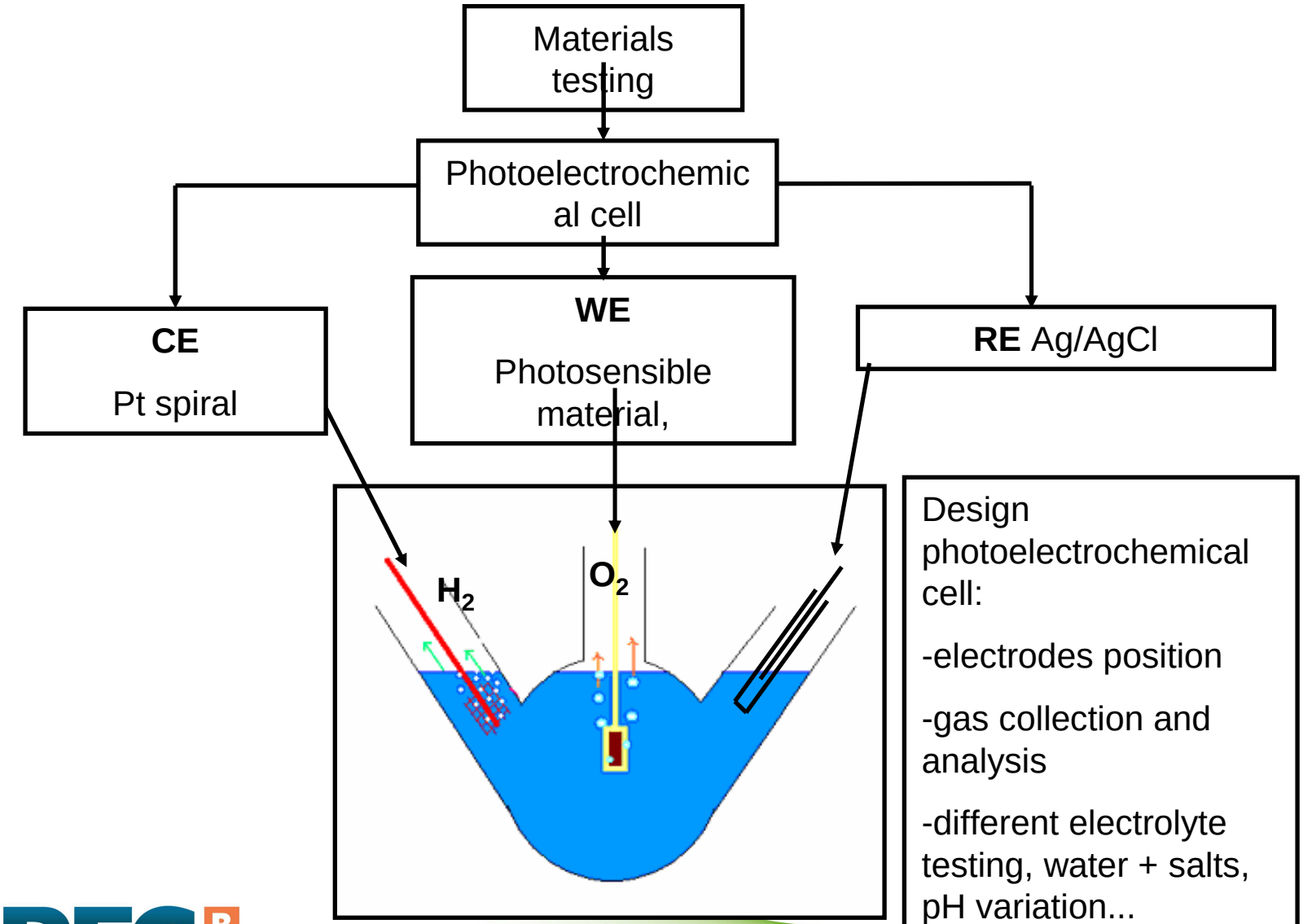
Synthesis of new materials for the development of innovative technologies

To be filled with TiO_2





Design of an electrochemical cell



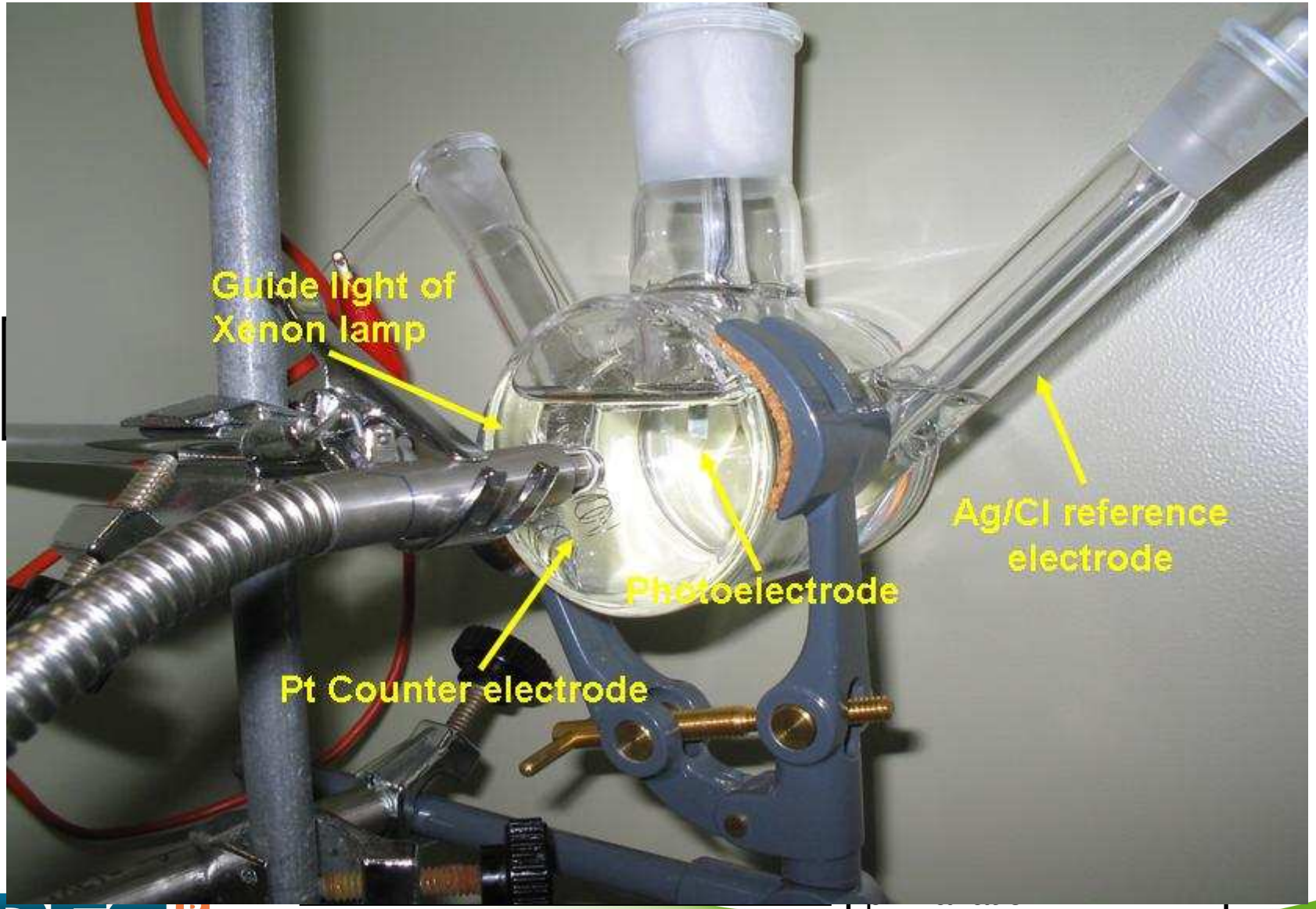
Design photoelectrochemical cell:

-electrodes position

-gas collection and analysis

-different electrolyte testing, water + salts, pH variation...

Design of an electrochemical cell



New activities for 2010:

➔ **Nano-materials for electrical, BEES, and thermal, TESS energy storage**

➔ **Energy and water (in collaboration with AGBAR)**

- ✓ Improvement on energy efficiency of water cycle
- ✓ Use of waste from sewage treatment water plants (bioenergy) and desalinization plants (thermal storage)
- ✓ Use of renewal energies for water process
- ✓ Water for production of H_2