FLEXIBLE DYE-SENSITIZED SOLAR CELLS (F-DSSCs) FOR INDOOR APPLICATIONS

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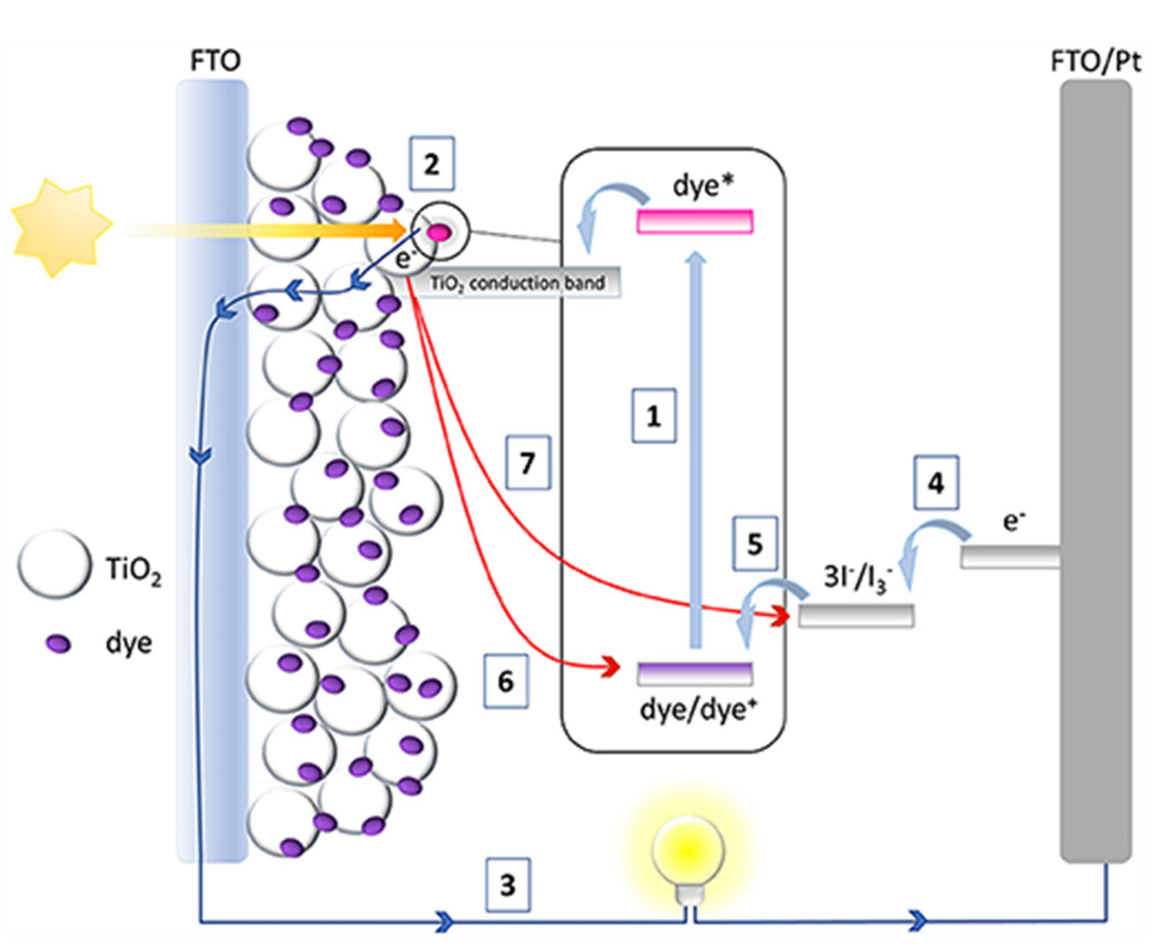
Introduction

Dye-sensitized solar cell (DSSC), first reported in 1991 by O'Regan and Grätzel, is third-generation electrochemical photovoltaic technology capable of producing electrical energy from solar energy. To allow industrial-scale manufacturing, low-cost materials and processes must be used. Indoor applications are a primary market entry point since parameters like efficiency and durability may not be as rigorous as for outdoor applications. These aspects can be addressed by using a flexible substrate as indium-tin oxide (ITO)-coated polyethylene terephthalate (PET) (ITO/PET) and the use of low temperatures in the manufacturing process. However, due to its chemical nature, this type of plastic substrate has weak thermal stability, which does not allow it to withstand temperatures higher than 150 ° C. This would cause a reduction in the electron transport rate, electronic lifetime, high recombination rates and hence low cell efficiencies. In this work, different approaches are investigated to allow the manufacture of an efficient F-DSSC such as TiO_2 powder cleaning (UV/Heat), a novel aqueous bi-modal paste with enhanced interparticle connection and adherence to the substrate, ITO activation treatments to increase the surface energy. Finally, preliminary results and future work are discussed.

DSSC working function and components



DSSC regenerative cycle

1.-Excited state of a dye molecule by the absorption of a photon with energy hv
2.-Injection of electrons into the TiO_2 conduction band
3.-Electric energy is produced by the electron flux through an external circuit
4.-Reduction of I_3^- to form I^- by an electrocatalyst material at the counter electrode
5.-Regeneration of the oxidized dye by an I^- ion

Recombination processes (loss process):

6.-Electron from the TiO_2 reduces the dye back to its ground state
7.-Electron from the TiO_2 reduces the I_3^- ion back to form I^-

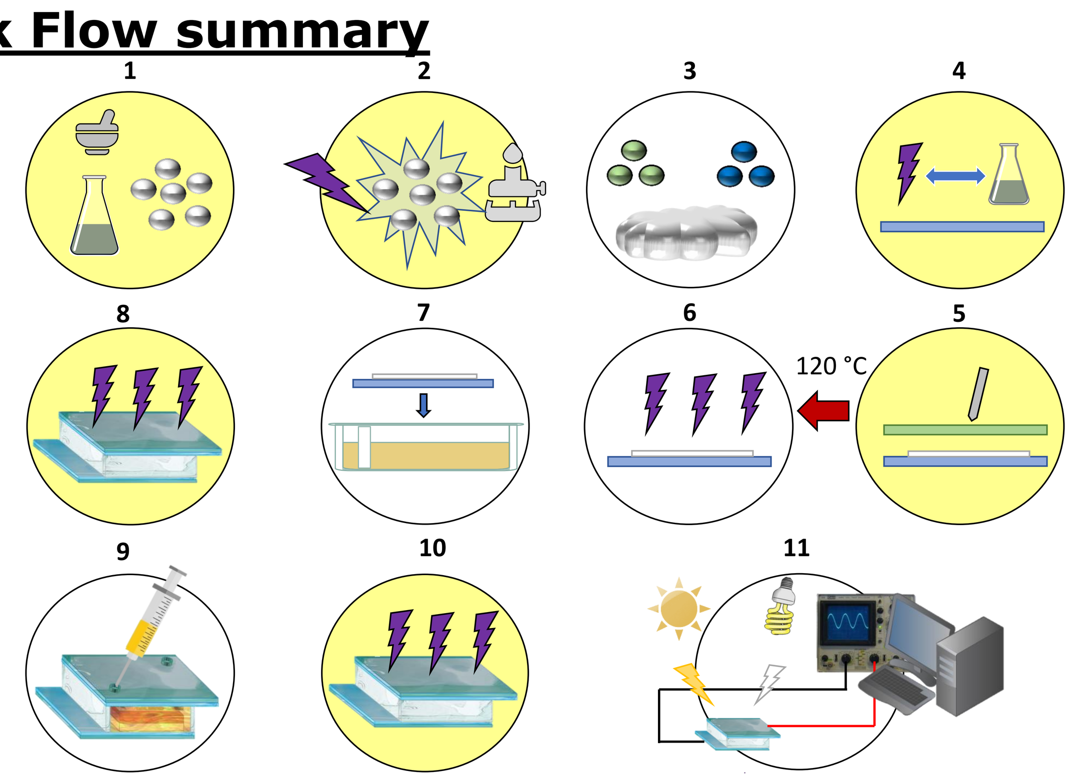
Main components of a DSSC

a) Substrates
b) Dye
c) Metal oxide semiconductor material photoelectrode
d) Redox couple mediator
e) Electrocatalyst material counter electrode
f) Termo-plastic sealing material

Work Flow summary

1. Small and large TiO_2 nanoparticles synthesis, 5 and 20 nm, respectively. (Forced hydrolysis/Sol-gel)
2. Powder cleaning treatment (thermal/UV)
3. Novel bi-modal aqueous TiO_2 paste preparation, with enhanced properties (H_2TiF_6/TTIP)
4. ITO layer activation (UV/RCA)
5. Deposition by screen printing technique and dry at 120 °C
6. UV post-treatment
7. Co-sensitization (YKP-88, YKP-137, MG-207)
8. FDSSC assembly and UV sealing
9. Electrolyte injection through pre-drilled holes ($[Co(bpy)_3]^{2+/3+}$)
10. UV sealing of pre-drilled holes
11. Photovoltaic Characterizations (JV, EIS)

- **In yellow circles**: *Processes that have been already carried out. Some of them need further optimization*
- **In White circles**: *Processes that have not yet been carried out.*



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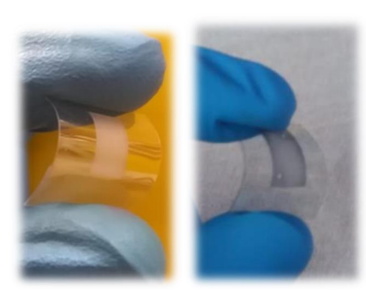
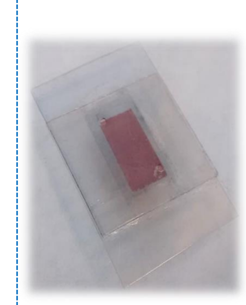
Previous work



A flexible photoelectrode (left) was prepared by screen printing deposition of a bi-modal aqueous TiO_2 paste by mixing small (5 nm) and large (20 nm) particles synthesised by forced hydrolysis and sol-gel, respectively.

A flexible PEDOT counter electrode (right) was prepared by electropolymerization in a 0.1 M SDS (Sodium dodecyl sulfate) and 0.01M EDOT (Ethylene dioxythiophene) aqueous solution in a two electrode configuration (WE: ITO/PET, CE: platinum disk) using a GAMRY potentiostat in galvanostatic mode (13 mA for 60 seconds)



An FDSSC was fabricated using low temperature processes (< 150 °C).

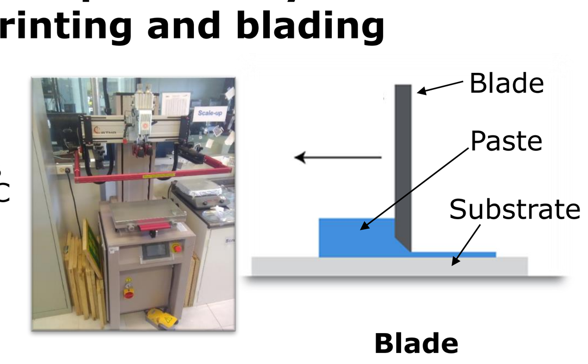
A good interparticle connection and adherence to the substrate could not be achieved. Hence, a poor performance was obtained.

This opened the possibility to investigate different approaches in order to optimize this device.

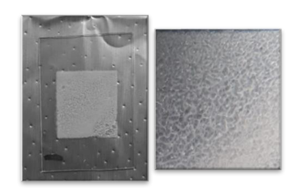
Experimental and preliminary results

Paste deposition by screen printing and blading

- 1 g of P25
- 4 mL of DIW
- 35 μL of H_2TiF_6
- Dried at 100 °C
- *TIIP addition (future work)*

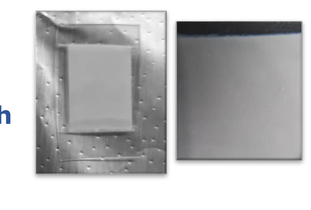


Screen printing

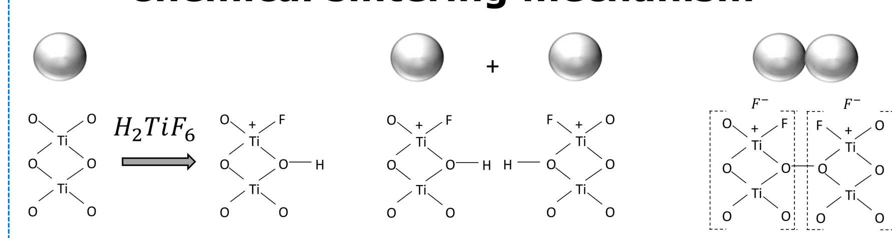


The paste showed good adherence with the substrate

Blade



Chemical sintering mechanism

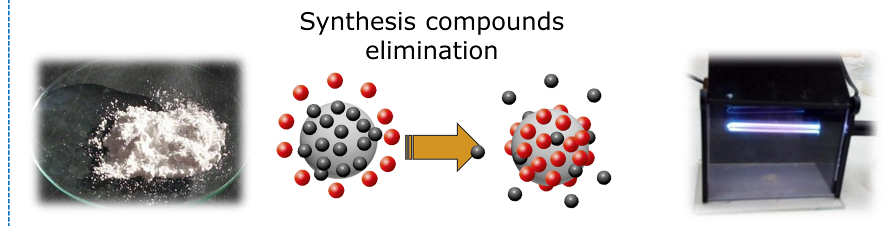


TiO_2 powder clean treatments

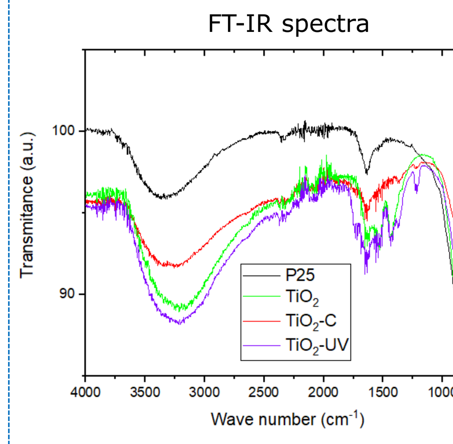
Heat treatment:
- 450 °C for 2 hours
- Heat magnetic stirring

UV treatment:
- UV source – Oriel lamp model 6035
- 5 mm from the sample
- 30 minutes

Synthesis compounds elimination



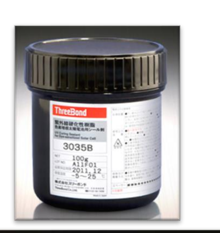
FT-IR spectra



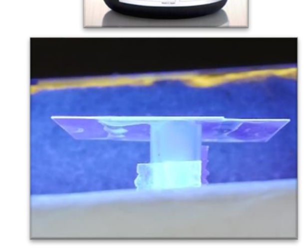
- **TiO_2 powder visually changed (from yellowish to white)**
- **So far, powder pre-heating (TiO_2-C, red) seems to eliminate more organic compouunds.**
- **Optimization of treatments is needed**

UV sealing

Advantages:
- Long term stability
- Prevent leackage
- Good mechanical support
- Ease, faster and economic



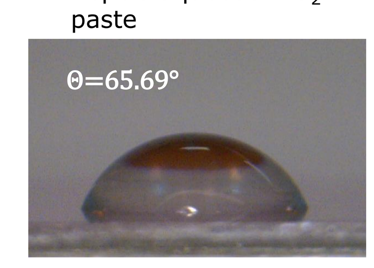
Experimental set:
- UV curable resin (TB-3035)
- UV lamp (UVP, 365 nm, 4 W)
- 2 cm of distance from the sample
- 1 minute exposure

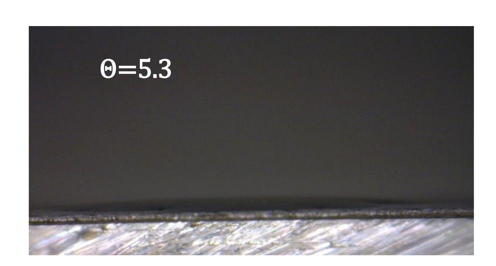


Plastic substrates were firmly attached each other

ITO layer activation

- **ITO (In_2O_3:Sn)**
  - Optical transparency
  - Good conductivity
  - Hydrophobic surface
  - Repels aqueous TiO_2 paste
- **Surface activation**
  - Increases surface energy
  - Improves electrical contact
  - Increases charge injection



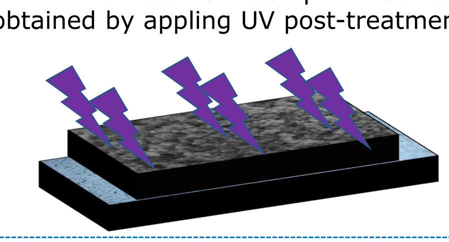


Among several surface treatments (UV light exposure, RCA protocol, acetone wash) a water/soap/etanol/isopropanol wash showed the best results by significantly decreasing contact angle θ from 65.69° to 5.3°.

Future work

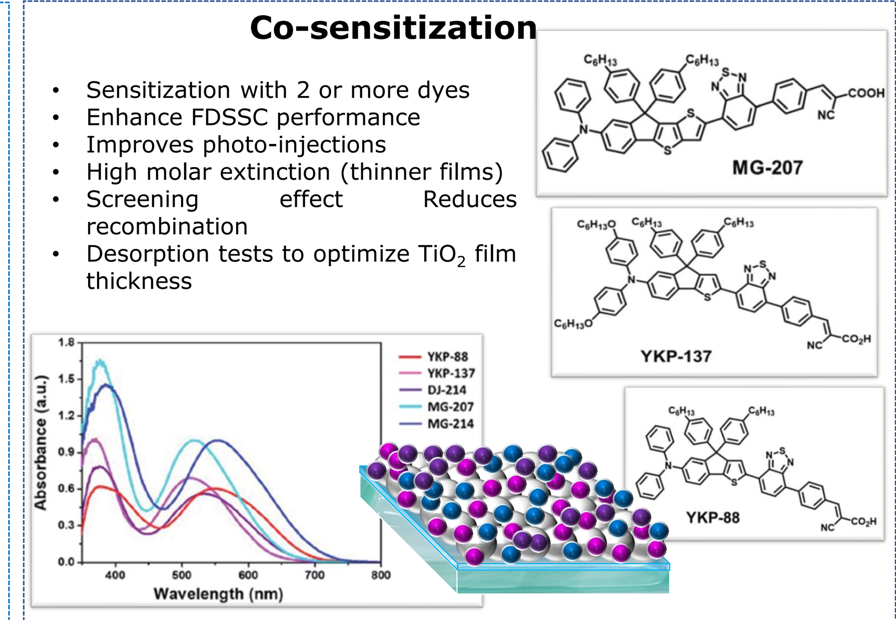
UV film post-treatment

- TiO_2 films deposited on ITO/PETO substrates needs an additional processing.
- UV post-treatment is considered a low temperature sintering because it has shown to enhance interparticle connection when TIIP precursor is present in the paste formulation.
- Film thickness of 10 μm has been obtained by appling UV post-treatment



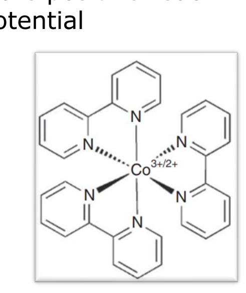
Co-sensitization

- Sensitization with 2 or more dyes
- Enhance FDSSC performance
- Improves photo-injections
- High molar extinction (thinner films)
- Screening effect Reduces recombination
- Desorption tests to optimize TiO_2 film thickness



Cobalt coordinated complex

- **$[Co(bpy)_3]^{2+/3+}$**
- Used with organic dyes, thinner TiO_2 films can be prepared which reduces recombination
- Slow penetration in PET
- More positive redox potential



Conclusions

The manufacture of efficient F-DSSCs on ITO/PET substrates face with a great challenge due to the restriction in the processing temperatures of the components. In this work, novel strategies have been presented for the manufacture of a FDSSC processed at low temperatures. Mainly, the development of a novel aqueous bi-modal TiO_2 paste with improved adhesion and interconnectivity properties, co-sensitization with new organic dyes to improve device photo-response and reduce recombination, and the use of redox mediator $[Co(bpy)_3]^{2+/3+}$, that has shown a positive interaction with the components proposed in this work. Moreover, the study of the interaction of these new materials used in a FDSSC will allow a clear vision of the final performance through EIS measurements. Promising preliminary results have been obtained, however, UV experimental should be optimized to achieve a positive cost-time-effective method in the fabrication process.

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