Optimization of Tin(IV) Nanoparticles for Improved Performance in Dye-Sensitized Solar Cells

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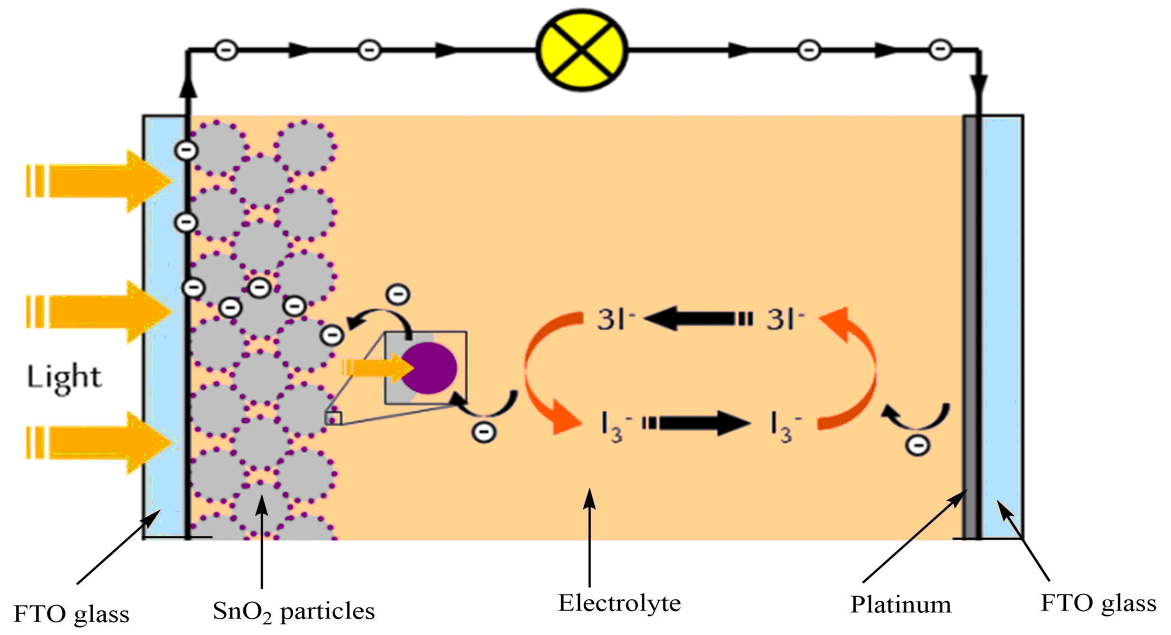
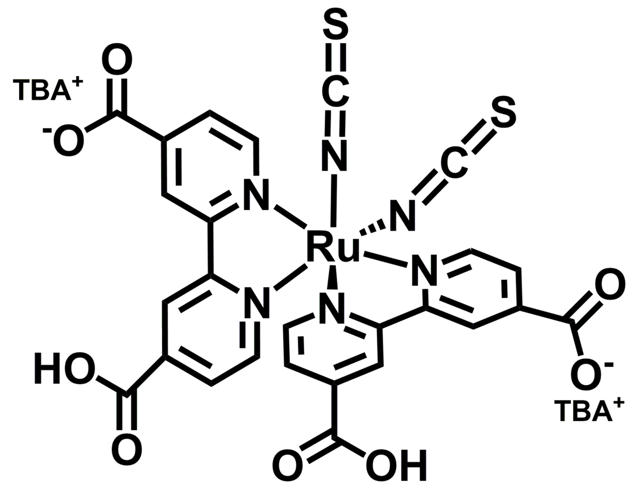
Introduction

Dye-sensitized solar cells (DSSCs) are a possible alternative tool to harvest solar energy instead of the traditional silicon-based solar cells. DSSCs offer various advantages, such as good energy conversion efficiencies in low-light conditions, simple fabrication, low cost, and the ability to modify key properties of the solar cell such as the absorbance wavelengths.[1] In this study, we examine the performance of DSSCs constructed using tin(IV) oxide semiconductors. Tin(IV) oxide offers a wide band gap and higher electron mobility as compared with the more widely used titanium dioxide.[2] Two nanoparticle (NP) morphologies of tin(IV) oxide, spherical and flower-like NPs, are synthesized, and these two types of tin(IV) oxide NPs and mixtures of both at various ratios are used to fabricate DSSCs



A general scheme of a DSSC.[3] Incident light contacts the photoanode and excites the photosensitive dye, which then sends an electron into the conduction band of the semiconductor, in this case SnO_2, if it possesses enough energy. The electrons then go to the cathode and a series of redox reactions ensures a close circuit.



Chemical structure of N719 dye used in this experiment to fabricate DSSCs

Method

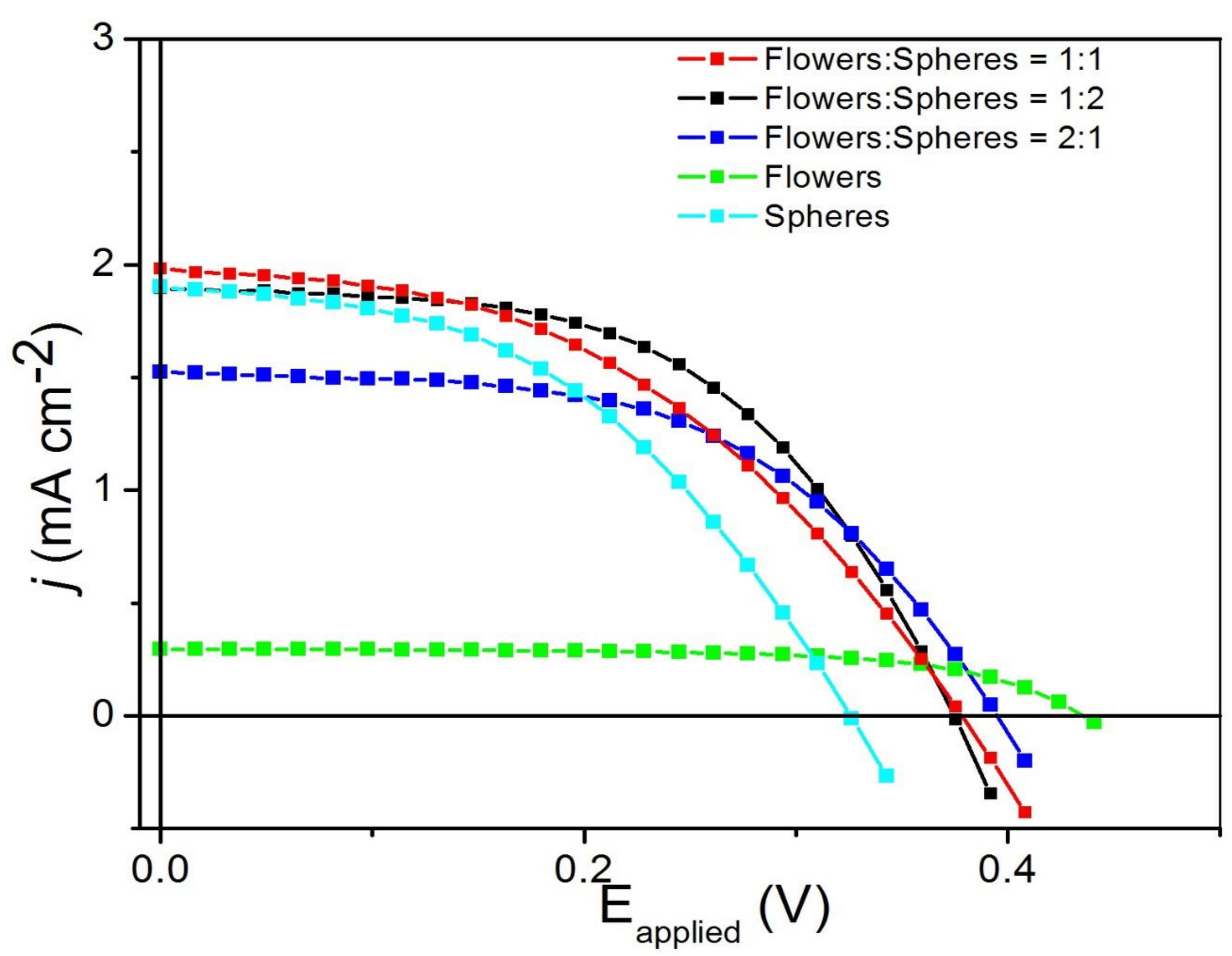
SnO_2 nanospheres are synthesized from SnO_2 colloids in water using a hydrothermal method (240 ºC, 60 hours). PEG and PEO polymers are added (2.5% wt) to the resulting solution to make the SnO_2 nanospheres paste.

SnO_2 nanoflowers are synthesized from $SnCl_4 \bullet 5H_2O$ using hydrothermal method (180 ºC, 48 hours). PEG and PEO are added (2.5% wt) to the resulting solution to make the SnO_2 nanoflowers paste.

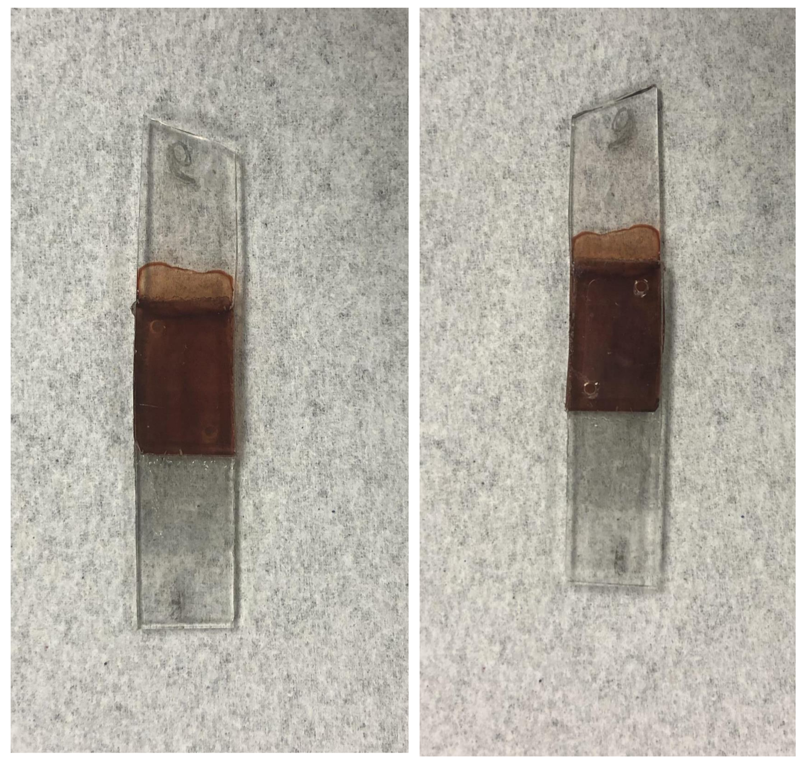
The photoanodes are prepared by spreading the paste on to a conducting side of the FTO glass to form a uniform layer. Each photoanode is subjected to UV-Vis spectroscopy. Then, a DSSC is constructed by putting the photoanode and a platinum-containing cathode together with their conducting sides facing each other. The photovoltaic performance of the DSSC is recorded by a multimeter.

Photovoltaic Performance

Overall, DSSCs made from SnO_2 nanospheres shows high photocurrent but the generated voltage is relatively low. On the other hand, DSSCs made from SnO_2 nanoflowers generate high voltage but the photocurrent is very low. However, DSSCs made from the mixture of these two morphologies generate both high photocurrent and voltage. Therefore, the mixed paste allows DSSC to produce more electric power



Current density vs. voltage plot of DSSCs using different types of semiconductor layers: mixture of nanoflowers and nanospheres at 1:1 ratio (red), mixture of nanoflowers and nanospheres at 1:2 ratio (black), mixture of nanoflowers and nanospheres at 2:1 ratio (blue), only nanoflowers (green), and only nanospheres (cyan).

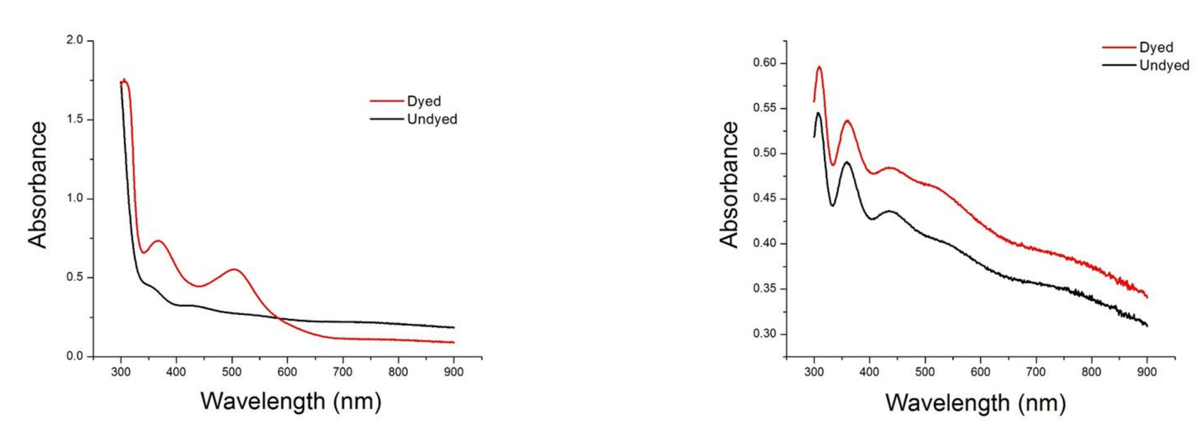


An assembled DSSC with the photoanode facing up (left) and with the platinum-coated cathode facing up (right). The cathode has 2 drilled holes for introduction of the electrolyte solution in between the electrodes.

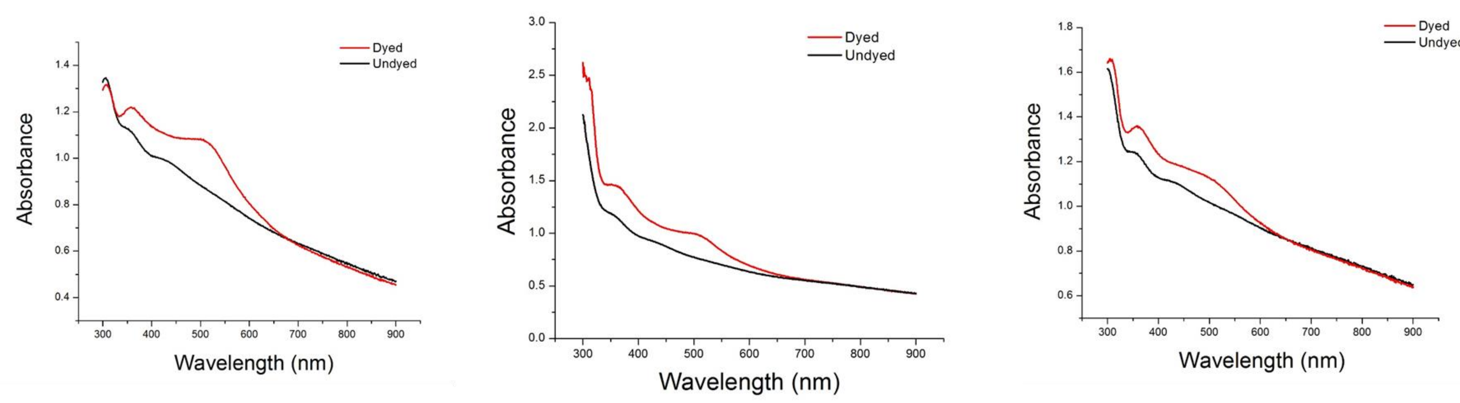
Cell types	Mean J_{SC} (mA.cm^{-2})	Mean V_{OC} (V)	Mean P_{max} (mW.cm^{-2})	Mean Fill Factor
Spheres	2.6 ± 0.6	0.30 ± 0.03	0.3 ± 0.1	(41 ± 9)%
Flowers	0.23 ± 0.07	0.41 ± 0.01	0.06 ± 0.02	(62 ± 2)%
Flowers:Spheres = 1:2	2.2 ± 0.2	0.38 ± 0.01	0.38 ± 0.07	(50 ± 4)%
Flowers:Spheres = 1:1	1.8 ± 0.5	0.36 ± 0.02	0.29 ± 0.07	(45 ± 4)%
Flowers:Spheres = 2:1	1.8 ± 0.1	0.399 ± 0.002	0.40 ± 0.04	(44 ± 5)%

Mean short circuit current density, open circuit voltage, maximum power, and fill factor, along with their uncertainties, of five DSSC types with different semiconductor layer.

Ultraviolet-visible profiles



UV-Vis profiles of electrodes using SnO_2 spherical particles (left) and SnO_2 nanoflowers (right) on FTO glass, before and after adsorption of the dye.



UV-Vis profiles of electrodes using nanoflower - spherical particle mixture of ratios F:S = 1:2 (left), F:S = 1:1(center), and F:S = 2:1 (right) on FTO glass, before and after adsorption of the dye.

Conclusion

- The mixture of tin(IV) oxide nanospheres and nanoflowers increase the performance of the solar cell overall.
- Future approach: study DSSCs made by the aforementioned mixture that are further modified by a titanium coating on the SnO_2 surface and evaluate how good these DSSCs are in performing water-splitting reactions.

References

1) Grätzel, M. Photoelectrochemical Cells. *Nature*, **2001**, *414*, 338-344.
2) Arote, S. A.; Tabhane, V. A.; Pathan, H. M. Enhanced Photovoltaics Performance of Dye Sensitized Solar Cell Using SnO_2 Nanoflowers. *Optical Materials* **2017**, *75*, 601–606.
3) Xu, P.; Mccool, N. S.; Mallouk, T. E. Water Splitting Dye-Sensitized Solar Cells. *Nano Today* **2017**, *14*, 42–58.