Hybrid Dye – Sensitized Solar Cells based on Titanium Dioxide and Metal - Phthalocyanines

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Abstract

To improve the hybrid dye-sensitized solar cell (HDSSC)'s efficiency, new metal-phthalocyanine solutions were employed. In this research, copper, silver, and zinc phthalocyanine were synthesized and applied as molecular sensitizers into the cells. It was hypothesized that HDSSCs based on metal-phthalocyanines would generate better efficiency than those made of phthalocyanine dyes.

UV-Visible spectroscopy was the first test to verify if three metals were successfully chelated into the metal cores of phthalocyanines. Depend on particular lighting conditions; the optimal energy efficiency of these HDSSCs of 1.6% has been reached.

Background

Hybrid solar cells are solar cell devices that contain both organic and inorganic semiconductors, and combine the unique properties of inorganic semiconductors. This combination of materials in the photoactive layer can result on a greater efficiency when converting light into electricity [1].

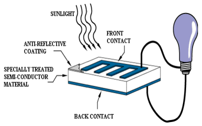


Figure 1: Hybrid solar cell structure [1]

For the inorganic semiconductor, titanium dioxide (TiO_2) is introduced because of its high efficiency and low cost compared to porous silicon or gallium arsenide. Gratzel cells contain particles of TiO_2, which are coated with a dye that absorbs a wide range of wavelengths given off by sunlight. These cells are placed between two electrodes in an electrolyte solution containing iodine ions and generate electricity when the energy captured by the dye.

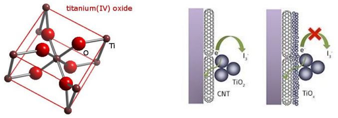


Figure 2: Titanium dioxide structure and cell [3]

Metal-phthalocyanine was used as organic dye synthesized material for photo-conducting in chemical sensors and electricity-generating in photovoltaic cell [2]. Copper, silver, and zinc are three good candidates for metal core in phthalocyanine structure because of their high thermal conductivity and electrical conductivity.

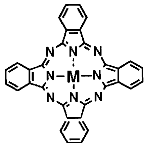


Figure 3: Metal-Phthalocyanine Structure [2], M = Cu^{2+}, Ag^{+}, and Zn^{2+}

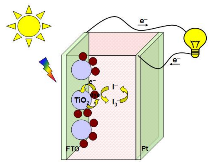


Figure 4: Mechanism of Dye-Sensitized Solar Cell [2]

Project Design

Syntheses of Metal-Phthalocyanine Solutions
- Copper phthalocyanine (CuPc)
- Silver phthalocyanine (AgPc)
- Zinc phthalocyanine (ZnPc)

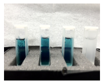
Constructions of Hybrid Dye-Sensitized Solar Cells
- Semiconductor: Titanium dioxide
- Dye-sensitized materials: Metal-phthalocyanine solutions
- Electrolyte: I_3^- solution

Comparisons of Energy Conversion Efficiency
- Normal room illumination
- Compact UV-Light (UVGL-25)
- Sunny daylight
- Cloudy daylight

Methodology

Syntheses of Metal-Phthalocyanine Solutions

- Synthesize CuPc by mixing Pc powder and copper acetate monohydrate in the presence of pyridine solvent.
- Synthesize AgPc by mixing Pc powder and silver nitrate in the presence of ethanol solvent.
- Synthesize ZnPc by mixing Pc powder and zinc acetate dihydrate in the presence of acetonitrile solvent.
- Run the UV-Visible tests for all solutions.

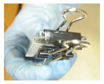


Preparations of Semiconductor Titanium Dioxide

- Prepare TiO_2 paste by adding nano-crystalline titanium dioxide with very diluted acetic acid and Triton X100.
- Paste titanium dioxide on conductive side of tin-oxide coated glass.

Constructions of Hybrid Dye-Sensitized Solar Cells

- Add the dye-sensitized solutions drop-wise on tin-oxide coated glass.
- Heat another tin-oxide coated glass under Bunsen burner to coat the conducting side with carbon.
- Assemble two glass plates with coated sides in.
- Add I_3^- solution drop-wise to the edge of the plate.
- Measure the currents and voltages by using the multimeter.



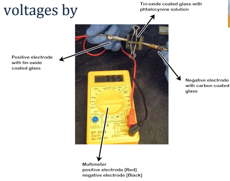


Figure 5: Current and Voltage Measurements under Normal Room Illumination

Results

The UV-Visible test was run to characterize the metal-complexes. The UV-Visible spectra confirmed the attachment of these conducting metals on porphyrin ring by comparing the experimental maximum wavelengths with the literature values.

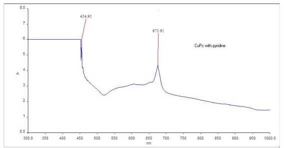


Figure 6: UV-Visible Spectrum of Copper Phthalocyanine

Table 1: Experimental and Literature Wavelengths of Metal-Phthalocyanines

Compounds	Literature wavelength (nm)	Experimental wavelength (nm)
Phthalocyanine (Pc)	640	688
Copper phthalocyanine (CuPc)	431-624	675
Silver phthalocyanine (AgPc)	300-900	685
Zinc phthalocyanine (ZnPc)	500-900	683

The energy efficiency of three metal-phthalocyanine solutions under normal room illumination, compact UV-lamp, sunny day and cloudy light were computed by using the Equation 1 and presented in Figure 7.

Equation 1: Energy Conversion Efficiency Formula

$$\eta = \frac{P_m}{E \times A}$$

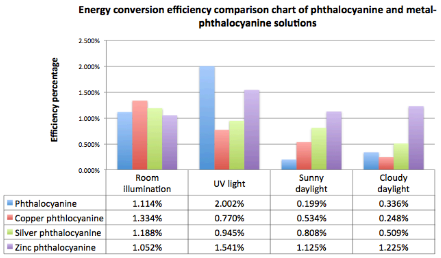
$$P = IV = V^2/R$$

$$\eta = \frac{V^2}{E \times A \times R}$$

E is the magnitude of the light illumination (in W/m^2)

A is the area of the solar cell surface (m^2)

R is the internal resistance of the multi-meter (Ω)



	Room illumination	UV light	Sunny daylight	Cloudy daylight
🟦 Phthalocyanine	1.114%	2.002%	0.199%	0.336%
🟥 Copper phthlocyanine	1.334%	0.770%	0.534%	0.248%
🟩 Silver phthalocyanine	1.188%	0.945%	0.808%	0.509%
🟪 Zinc phthalocyanine	1.052%	1.541%	1.125%	1.225%

Figure 7: Column Chart for Comparisons between the Efficiency of Phthalocyanine and Metal-Phthalocyanine Solutions

Conclusions

- This hybrid dye-sensitized solar cell model is produced at lower cost and more friendly to the environment than other commercial models.
- The overall energy conversion efficiency of metal-phthalocyanine solutions was higher than those of phthalocyanine dyes .
- This result fully supported the hypothesis that metal-phthalocyanine solutions would generate better efficiency than phthalocyanine dyes.

References

1. Günes, S. & Serdar Saiciftci, N. (2008). Hybrid Solar Cells, Inorganica Chimica Acta, Vol. 361, pp. 581-588.
2. Kadish K., Kevin M. Smith, Guilard R.,The Porphyrin Handbook, Vols. 15-20; (eds); Academic Press 2003.
3. O'regan B. and Gratzel M. "A low-cost, high efficiency solar cell based on dye-sensitized colloidal TiO2". Nature 353, 737 - 740 (24 October 1991).