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EFFECT OF SYNTHESIZED 3-HYDROXYFLAVONE SOLUTIONS ON THE PERFORMANCE OF DYE-SENSITIZED SOLAR CELLS

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ABSTRACT

We investigated the influence of synthesized dye combination 3-hydroxyflavone with potassium hydroxide and sodium hydroxide as photosynthesizers for dye-sensitized solar cells (DSSCs). DSSCs are classified as hybrid inorganic/organic photovoltaic cells that have been reported to have lower production costs and efficiency as high as 12%. Annealed titanium dioxide pastes on fluorine-doped tin oxide was used as the front layer of the completed devices and the performance of 3-hydroxyflavone with potassium hydroxide and sodium hydroxide was compared with the performance of dyes extracted from berries. UV-vis spectroscopy was used to characterize the absorbance of the respective absorber dyes. 3-Hydroxyflavone in potassium hydroxide demonstrated the best photoactive performance with the highest open circuit voltage of 468 mV. However, it is vital to know that further research needs to be done on 3-hydroxyflavone to evaluate and enhance the performance of dye-sensitized solar cells.

Keywords: dye-sensitized solar cells, 3-hydroxyflavone, anthocyanin, Graetzel

INTRODUCTION

Dye-sensitized solar cells (DSSCs), hybrid inorganic/organic structures, have garnered more research attention over the past 20 years (Ye et al. 2015). Dye sensitizers are classified as chemicals that are able to absorb energy from the sun and then excite electrons in a semiconductor, consequently producing electricity (Jayaweera et al. 2008). DSSCs' main advantages are their low-cost production and low energy payback time through the use of natural dyes (Hug et al. 2013). One of the first successful tests of DSSCs was done at the Swiss Federal Institute of Technology in Lausanne in 1991 by Michael Graetzel. He and his team observed that molecules found with chlorophyll could absorb sunlight better than the manufactured solar cells during that time, which used rare, expensive metals. It was concluded that the anthocyanin has a maximum efficiency of 12% (Yella et al. 2011). Researchers from Madonna University in Nigeria used a wide variety of different plant leaves, flowers, and fruits in the area that contained natural anthocyanin. Further analysis indicated that the absorption process mimicked the natural light harvesting procedures in photosynthesis when combined with a semiconductor (Ozuomba et al. 2013). To understand whether synthetic compounds could be incorporated with a natural dye, a group of researchers from the University of Sebelas Maret, Indonesia, studied the impacts of incorporating red cabbage anthocyanin with the synthetic dye N719. The efficiency of the red cabbage dye alone was found to be 0.024%, while the addition of the N719 increased the conversion efficiency to 0.054% (Pratiwi et al. 2016). The study confirmed that using synthetic compounds could have the potential to substantially increase the conversion efficiency of a natural DSSC. A recent study of 3-hydroxyflavone provides evidence that a synthetic inorganic dye can be beneficial to enhancing the performance of DSSCs. A group of researchers from the Department of Chemistry at Istanbul Technical University in Turkey found that modification of 3-hydroxyflavone provided longer reaction times and 3-hydroxyflavone could act as a prospective fluorescent dye (Gunduz et al. 2012). A recent study of 3-hydroxyflavone provides evidence that a synthetic, inorganic dye can be beneficial in enhancing the performance of DSSCs. Researchers from Maharshi Dayand University, India, found that hydroxide ions were lacking in the 3-hydroxyflavone chemical composition in comparison with the closely related anthocyanin structure and suggested that the combination of 3-hydroxyflavone with a basic solution could lead to the synthesis a new compound with the potential to absorb light (Kumar 2012).

Although the studies mentioned above and others proposed the significance of 3-hydroxyflavone, there remains a significant gap in the literature as far as decisive evidence of hydroxide's role in the performance of the dye combination in DSSCs. We investigated the influence of synthesized dye combination 3-hydroxyflavone with potassium hydroxide and sodium hydroxide as photosynthesizers for DSSCs. According to the Open Chemistry Database, potassium hydroxide and sodium hydroxide are widely used chemicals that are highly abundant. We examined the role of the combination of 3-hydroxyflavone with potassium hydroxide or sodium hydroxide in increasing the performance of DSSCs.

Figure 1 shows the cross-sectional schematic of the device structure. The device consists of a transparent conducting oxide layer, nanopores, titanium dioxide adsorbed with a dye sensitizer, electrolyte, and a counter electrode. The semiconductor layer is placed in contact with the electrolyte consisting of I^- and I_3^- redox species. Dye sensitizers are adsorbed to the titanium dioxide layer. Photoexcitation of the latter results in the injection of an electron into the conduction band of the oxide. The dye is regenerated by electron donation from the electrolyte, usually an organic solvent containing a redox system, such as the iodide/triiodide couple. The regeneration of the sensitizer by iodide intercepts the recapture of the reduction of the conduction band electron by the oxidized dye. The iodide is regenerated in turn by triiodide at the counter electrode when the circuit is completed via electron migration through the external load (Kim et al. 2011).

MATERIALS & METHODS

Titanium dioxide was coated on commercially available tin(IV) oxide-coated glass substrates. About 1.03 g of titanium dioxide was placed into a mortar and dissolved slowly with 2.5 mL of diluted hydrochloric acid. During the stirring, dish detergent was mixed with distilled water and added in incremental drops until the solution had a smooth and paint-like texture. Dish detergent was used to act as a surfactant, which tended to reduce the surface tension and help keep the paste's shape, resulting in better conversion efficiency (Thuy et al. 2016). The resulting paste was applied using a razor blade on the conductive side of the transparent conducting oxide substrate and annealed at 450 °C for 15 min. During the annealing process, slides were observed to change to a brown-like

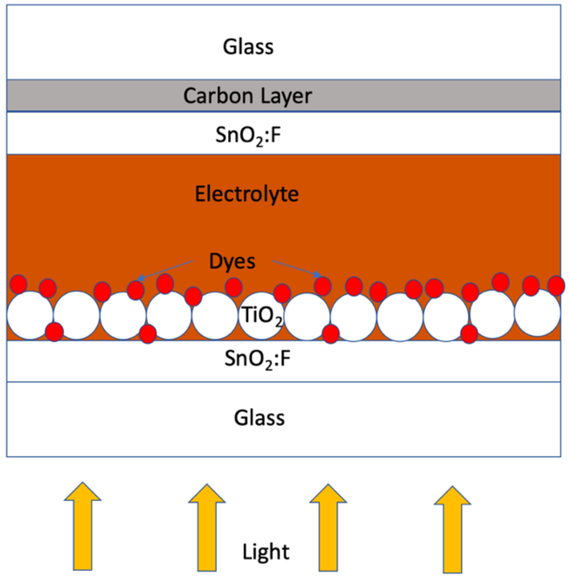

Figure 1. A cross sectional schematic of the DSSC.

Figure 2. Titanium dioxide semiconductor paste applied to the tin(IV) oxide transparent conducting oxide-coated substrates.

color and revert back to light cream color indicating the nanoporous structure was completed.

The dye-sensitized electrodes were prepared by the following process: about 0.03 g of 3-hydroxyflavone and 0.41 g of potassium hydroxide or sodium hydroxide were placed in a Petri dish using 2 mL of ethanol as the solvent. The reference was made by crushing raspberries and filtering the resulting liquid through a coffee filter. Raspberry was chosen as the reference, given that it had extensive results with its anthocyanin illustrated in the paper *Fruit based Dye Sensitized Solar Cells*, by a group of researchers from the University of Malaysia. The berries tested in the paper indicated an efficiency of 0.04% (Ung et al. 2007). The reactants were thoroughly mixed. The films were then immersed in 3-hydroxyflavone with potassium hydroxide, 3-hydroxyflavone with sodium hydroxide, or the reference sample, raspberry anthocyanin for 15 min. The dye-sensitized electrode was assembled in a typical sandwich-type cell as shown in Figure 3 (b). The identical tin(VI) oxide counter electrode was placed over the dye-sensitized electrode. Then the electrolyte solution, iodine, was sandwiched between the photoanode and the counter electrode by firm pressure and with the use of two binder clips (Ozuomba et al. 2013). After the devices were completed, the performance of the devices was measured using a lamp calibrated with a standard silicone solar cell.

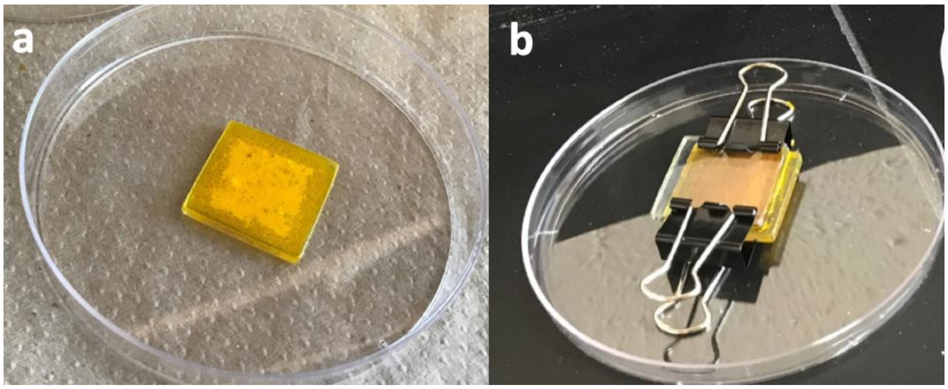

Figure 3. (a) Synthetic dye applied to tin(IV) oxide substrates and (b) an assembled DSSC with a synthetic dye solution.

RESULTS & DISCUSSION

Prior to completing the devices, the absorbance of 3-hydroxyflavone dissolved in different chemicals was measured. Figure 4 shows the normalized absorption curves for 3-hydroxyflavone dissolved in potassium hydroxide, sodium hydroxide, and potassium oxalate. Absorption of blackberry and raspberry extracts are shown for comparison. From all five absorbers, 3-hydroxyflavone dissolved in potassium hydroxide showed the highest absorbance followed by 3-hydroxyflavone dissolved in sodium hydroxide. These results also indicate that the performance of 3-hydroxyflavone dissolved in potassium hydroxide should show superior performance compared to others considering its higher absorptivity.

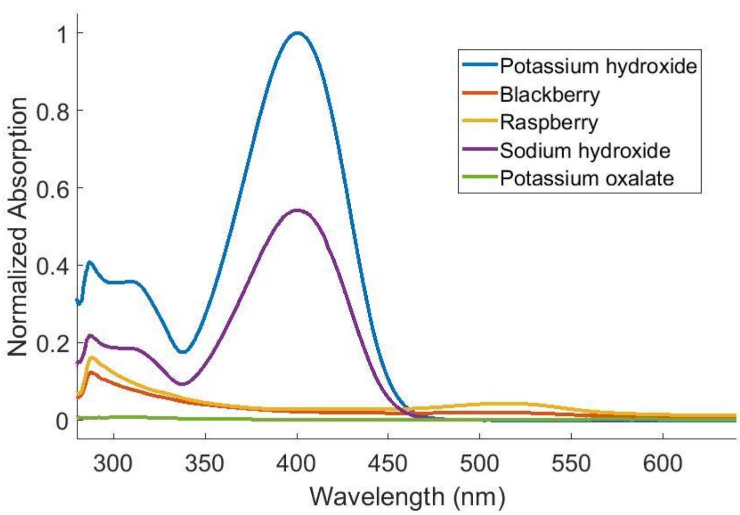

Figure 4. Normalized absorption of 3-hydroxyflavone dissolved in potassium hydroxide, sodium hydroxide, and potassium oxalate compared with blackberry and raspberry extracts.

Completed devices all showed rectification. However, due to short circuit currents in the range of microamperes, the efficiencies of all the completed devices were well below 1%. The current-voltage graphs for the best devices completed with 3-hydroxyflavone dissolved in potassium hydroxide and sodium hydroxide are shown in Figure 5.

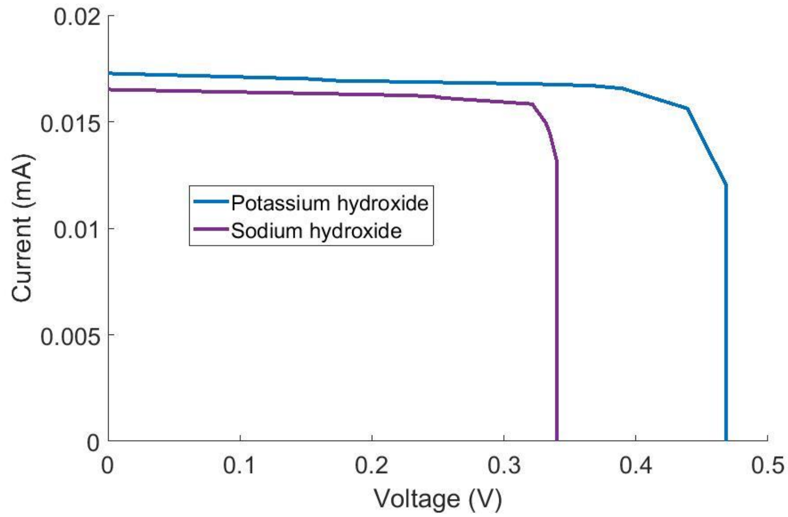

Figure 5. Current-voltage curves for a DSSC completed with 3-hydroxyflavone dissolved in potassium hydroxide and sodium hydroxide.

3-Hydroxyflavone in potassium hydroxide demonstrated the best photoactive performance with the highest open circuit voltage of 468 mV. However, the completed devices were not stable and their performance, primarily their open circuit voltages, decreased significantly overtime. According to a group of researchers from the University of Naples Federico II, this behavior may be due to low stability in the electrolyte solution (iodine) used in the DSSC. Although the iodine functions to reduce the solvent evaporation, the dye solution may not have been excited by the electrolytes and, consequently, reversed the reactions (Carella et al. 2018). It is also possible that the combination of the titanium dioxide semiconductor paste and the dye concentration caused the behavior of these cells to not be photoactive. Performance of devices with 3-hydroxyflavone dissolved in potassium hydroxide and sodium hydroxide provides insight into the applications of synthetic, inorganic dye compounds that are not constrained by organic properties. Knowing this, further study into the possible effects of 3-hydroxyflavone dye should include a variety of different bases as potential candidates. In addition, researchers in the field can also focus on the length of time the DSSC maintains its performance and conduct a stability test.

CONCLUSIONS

3-Hydroxyflavone dye was successfully used as a photoabsorber in DSSCs and the completed devices showed rectification. Open circuit voltage as high as 468 mV was measured, but the performance of the overall devices was limited by the short circuit current. These results indicate a proof of concept for using 3-hydroxyflavone with hydroxide ions as a photoabsorbent dye in DSSCs.

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