Anthocyanin Dye-Sensitized Nanocrystalline Energy Lab

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ABSTRACT

Solar technology has gained an increased level of attention worldwide as affordable and clean energy sources garner more demand. While public awareness of solar technology continues to grow, it is often not well understood how the technology works. Also, lesser known is the fact that there exists a large variety of solar materials and device configurations. Of these technologies, Dye-sensitized solar cells (DSSC) can be constructed with relatively simple fabrication methods, from readily available materials. These attributes make it a great technology to demonstrate how solar technology works in the classroom setting. The inquiry-based DSSC classroom activities are a high-gain hands on learning experience.

Keywords: Inquiry-based learning/problem-based technology, interdisciplinary- academia and industry.

1. INTRODUCTION

DSSC's were first introduced as a low cost, high efficiency solar cell by Michael Grätzel in 1991. The inventor also published a paper detailing how DSSC's could be used by educators as an interdisciplinary classroom project. The DSSC type of solar cell has seen a steady rate of improvement since its invention and is now commercially available. This technology shows promise in applications such as Building-Integrated Photovoltaics (BIPV) and Internet of Things (IoT) due to its low cost and flexibility of substrate.

A broad range of electronic devices can be powered by conversion of both natural and artificial light into energy. A dye such as anthocyanin is the photoactive material of the DSSC can generate electricity once it is induced by light. The anthocyanin dye catches the photons of the incoming light and thus utilizes the energy to excite the electrons. The anthocyanin dye infuses these excited electrons into the white pigmented titanium dioxide and a nano-scale crystallized form of titanium dioxide created. The electrons return back to the dye by the chemical electrolyte in the cell that closes the circuit for this to occur. Thus the motion of these electrons that create energy that may be garnered into a rechargeable battery.

2. EXPERIMENTAL

1. Identify conductive side of two Indium-doped Tin Oxide (ITO) coated glass, 25 mm X 25 mm
2. Add a spatula of titanium dioxide nanopowder (18 nm) powder and mix with distilled vinegar in an evaporating dish, to a paint-like consistency.
3. Take the one conductive side and place face up on a flat surface then scotch tape off all three edges of the ITO glass. Utilize the rubber spatula to apply the paste of titanium dioxide paint like solution onto the ITO surface using a glass draw down rod.
4. Place the slide, coated side up onto the middle of a hot plate for approximately 5 minutes, or until a color changes through light-brown color back to white. Carefully remove the slide from the hot plate to cool.
5. Crush the raspberries in a zip lock bag to obtain a uniform juice of anthocyanin dye. Place cooled slide into the bag and set aside to soak for 5 minutes.
6. Use a candle to heat the second piece of ITO glass to create carbon catalyst on the conductive side.
7. Use a q-tip to clean carbon catalyst off of three edges.
8. Remove the slide from the zip lock bag with the raspberry solution and clean off gently with alcohol.
9. Face the two slides sides together so the coated sides are touching (carbon touching the raspberry dye).
10. Place the coated edge onto of the uncoated edge to make an overlap to allow for electrical contacts. Insert binder clips to hold the slides together and add the electrolyte solution (0.5 M KI and 0.05 M iodine in vegetable glycol)
11. Take measurements with multimeter to analyze voltage and current changes.

3. RESULTS/DISCUSSION

The students were given a pre-quiz before beginning fabrication of their solar cells. The students were also given a laboratory workbook to work from. During the fabrication process, students were encouraged to ask questions about the devices they were making. Classroom discussions ranged from technical inquiry to social/economic impacts of energy generation.

After solar cells were finished, the students were able to test their devices and prove that the devices were generating electrical energy from light. An indoor lamp or cell phone light was used to show the increase in current produced. At this point in the lab, basic electric circuit principles were reviewed in context of how the students' solar cells can be used practically in the real-world.

Once the students have finished their discussions and compiled their data, the students took a duplicate test as the one taken at the beginning of the lab. During this period, the students were challenged to answer the questions with minimal input from the instructor.

Using the R.R. Hake' method, the results were analyzed in an effort to quantify the engagement of the laboratory activity. The method involves the calculation of normalized gain and is determined by the following equation.

Normalized Gain= (Post Test Score -Pre Test Score)/(100 - Pre Test Score)

Two small classes of undergraduate university students were given the laboratory experiment and were tested as described above. The results showed medium to high gain learning in this inquiry-based problem solving activity. The results of the two trial classrooms are shown in Table 1.

Class Number	Class Size	Normalized Gain	Gain Level
1	8	0.68	Medium
2	8	0.80	High

Table 1. Hake' method results from two pilot classroom studies of the DSSC laboratory experiment.

Example of Pre-test and Post-test questions to analyze the students learning

How much electrical energy could potentially be produced if all sunlight that hits the earth's surface is harvested at 100% efficiency?

a) 50 terawatts
b) 10 gigawatts
c) 120,000 terawatts
d) 16 terawatts

What are the projected energy needs of our world in 2050?

a) 10 gigawatts
b) 16 terawatts
c) 120,000 terawatts
d) 50 terawatts

Of the following materials, which are used by plants to absorb light for photosynthesis?

a) Graphite
b) Chlorophyll
c) Anthocyanin (plant pigments)
d) Both a) and c)
e) Both b) and c)

The electrodes of a Dye-Sensitized Solar Cell (DSSC) are made of which material?

a) Conductive metal
b) Insulating glass
c) Transparent polymer
d) Conductive glass

The energy of a specific wavelength of light is related by which equation?

(E: light energy (Joule), h: Plank's constant (6.626 x 10-34 Joule/s, c: speed of light (3 x 10^6 m/s), λ: wavelength of light (m), ν: frequency of light (Hz or s^{-1})

a) $E = hc/\lambda$
b) $E = \lambda c^2$
c) $E = \lambda\nu$

Which best describes the function of I^-/I_3^- electrolyte in a DSSC?

a) It is a wideband gap semiconductor that conducts electrons excited from the dye molecules
b) It serves as a catalyst at the counter electrode
c) It transports a positive charge from the dye molecule to the counter electrode and restores the dye to its original electrically neutral state
d) It absorbs light and excites an electron to initiate the production of a voltage potential across the device

Which best describes the function of the mesoporous TiO_2 in a DSSC?

a) It is a wideband gap semiconductor that conducts electrons excited from the dye molecules
b) It serves as a catalyst at the counter electrode
c) It transports a positive charge from the dye molecule to the counter electrode and restores the dye to its original electrically neutral state
d) It absorbs light and excites an electron to initiate the production of a voltage potential across the device

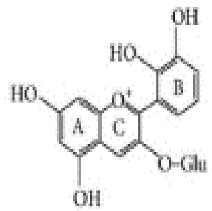
Which best describes the function of the carbon layer in a DSSC?

a) It is a wideband gap semiconductor that conducts electrons excited from the dye molecules
b) It serves as a catalyst at the counter electrode
c) It transports a positive charge from the dye molecule to the counter electrode and restores the dye to its original electrically neutral state
d) It absorbs light and excites an electron to initiate the production of a voltage potential across the device

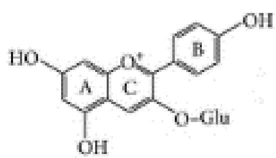
Which best describes the function of natural anthocyanin in a DSSC?

a) It is a wideband gap semiconductor that conducts electrons excited from the dye molecules
b) It serves as a catalyst at the counter electrode
c) It transports a positive charge from the dye molecule to the counter electrode and restores the dye to its original electrically neutral state
d) It absorbs light and excites an electron to initiate the production of a voltage potential across the device

Select which of the two natural fruit anthocyanins below would more readily attach to a mesoporous TiO_2 structure?



Cyanidin-3-glucoside



Pelargonidin-3-glucoside

4. LAB INTRODUCTION

In this lab you will fabricate a working solar cell that converts light to electricity. The type of cell is called a Dye-Sensitized Solar Cell (DSSC) and works differently than Silicon Solar Cells you might see on rooftops. The key ingredient in your DSSC will be natural fruit juice, acting as a dye, which will absorb photons of light and initiate the generation of electric current. The dye molecule is called anthocyanin and occurs in many plants. It also plays a role, along with chlorophyll, in photosynthesis for many plants.

5. LAB INSTRUCTIONS

Prepare the nanocrystalline TiO_2 paste by combining 4 spatula scoops of TiO_2 powder with approximately 20 drops of white vinegar in a mortar. Use the pestle to combine the powder and vinegar until it is smooth (5-10 minutes). It should have the consistency of cream (optional: add a few drops of clear laundry detergent and let stand for 10 additional minutes)
Test one conductive slide and place the conductive side face up on a flat clean surface. With Scotch tape, mask off three sides of the slide, approximately 2 mm. With rubber spatula, apply paste onto the glass slide on the top side opposite of the untapped side. Draw the paste down past the untapped edge.

Supplies and Materials
Multimeter with alligator clips
TiO_2 nanopowder (provided)
Iodide/Triiodide electrolyte (provided)
Raspberries/Blackberries
Plastic bag
Hot Plate
Mortar and Pestle, Spatula , Glass Rod, Graphite pencil or Candle, Binder Clips
Distilled White Vinegar
Ethanol

Step 1. Warm up Hot plate to 10 ^{0}C and place the slide with coated side facing up. Watch as the coating turned light brown and then back to white. This indicates the film porous structure of the TiO_2 film has formed.

Step 2. Crush berries in a flat glass container and place the cooled slide, film face down, into the dye. Let it soak in the berry juice while you create the counter electrode.

Step 3. Use a digital multimeter to determine the conductive side of the second conductive slide. If using a candle, light the candle and wave the glass side, conductive side to flame, across the candle flame to create a coating of carbon. CAUTION: Be very careful not to touch the glass slide, since it will be very hot. This will act as a catalyst of the counter electrode.

Step 4. Using a Q-tip or Kim-wipe, clean off three edges of the coated glass slide to match the size of the TiO_2 slide.

Step 5. Place the two slides together so the coated sides are touching. Use small binder clips to hold them together. Ensure there is an offset of uncoated conductive glass to be used at the electrical contacts.
Using the dropper inside the electrolyte bottle, place a few drops along the edge of the tow slide. Gently open and close the binder clips slightly to allow for capillary action to pull the liquid into the device. Make sure the entire coated surface is wetted by the electrolyte.

Step 6. Setup a light source or if it is sunny, take the cells outside. If you are using an artificial light source, make sure record the distance between the cell and the light, keep this distance consistent between measurements.

Step 7. Attach the alligator clips of the multi-meter to the uncoated conductive surface conductive slide created by the offset. Turn the multi-meter on to measure the voltage, then current while exposing the dyed side of the cell to the sun or light source.

Step 8. Compare results with other classmates or to cells created with variation in the procedure.
Create a table below to track your fabrication parameters and results for each group.

(Describe your results in a few sentences. From your knowledge of how the device works, describe why you obtained the results. Mention any error or uncertainty that may play a role in your results.)

6. CONCLUSION

The experiment has enlightened students about household chemicals such as raspberries (anthocyanin dye) and vinegar to create as DSSCs. These inexpensive lab materials allowed students to create a working solar cell that was verifiable. Classroom activities considered "interactive engagement" courses have normalized gains in the range of N=0.45 to 0.55. This DSSC solar laboratory was shown to have high gains in learning and interactive engagement as high as N=0.80, showing its merit as a meaningful energy lab.

7. REFERENCES

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