Dye Sensitized Solar Cell Fabrication

Subject Area(s)	**Physics, electrochemistry, chemical bonding, semiconductors, nanomaterials, renewable energy**
Associated Unit	**Renewable Energy Resources**
Associated Lesson	**Solar Energy-Nanostyle**
Activity Title	**Dye Sensitized Solar Cell Fabrication**
Grade Level	11-12 (8-12)
Activity Dependency	None
Time Required	135 minutes
Time Required Note	Lesson can be completed in 100 minutes provided nanotitanium dioxide suspension is prepared ahead of time by instructor.
Group Size	3-4 students

Expendable Cost per Group US$ Variable

Summary

Students learn about solar energy from a viewpoint of a materials engineer and what is required to fabricate a solar cell. Students will find that testing and analysis are extremely important when developing or fabricating new and mature technology. This activity provides a hands on experience to engage and inspire students to look into technical career paths.

Engineering Connection

Materials engineers not only develop and design materials but must also test those materials. This activity focuses on the fabrication, testing, analysis, and forming conclusions. Engineers accomplish all of these tasks every day in a variety of ways. Each student will experience this process first hand during an unconventional activity.

Engineering Category = #1, 2

Choose the category that best describes this activity's amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Photovoltaic effect, solar, cell, dye sensitized, chemical bonding, electrochemistry, REDOX, semiconductor, nanotechnology, nanomaterials, nanotitanium dioxide, excitation, photon, materials, fabricate, test, analysis

Educational Standards

Texas Chemistry 2009, grades 10-12, 112.3.E, 112.8.D:

Standard 3: Scientific processes. The student uses critical thinking, scientific reasoning and problem solving to make informed decisions within and outside the classroom.

E. Describe the connection between chemistry and future careers.

Standard 8: Science concepts. The student can quantify the changes that occur during chemical reactions.

D. Use the law of conservation of mass to write and balance chemical equations

ITEEA 2000, Grades 9-12, 16.J-K, 16.M-N.

Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

J. Energy cannot be created nor destroyed; however, in can be converted fro one form to another.

K. Energy can be grouped into ajor forms: thermal, radiant, electrical, mechanical, chemical, nuclear and others.

M. Energy resources can be renewable or nonrenewable.

N. Power systems must have a source of energy, a process, and loads.

AP Requirements (North Shore Senior High School 2010-2011)

Zumdahl, S. S. and Zumdahl, S. A. (2000). Chemistry (5th ed.). Boston: Houghton Mifflin

1) Unit 1 Chemistry Fundamentals:
   - Manipulate Chemical Quantities
   - Demonstrate safe laboratory practices
2) Unit 14 Reactions in Aqueous Solutions:
   - Write molecular (empirical), ionic and net ionic equations for reactions.
   - Identify redox, precipitation (metathesis), and acid-base (metathesis) reactions.
3) Unit 9 Electrochemistry:
   - Identify oxidizing and reducing agents in a reaction
   - Write net ionic equations for redox reactions.
   - Label parts of the cell, including electron flow; write half reactions for processes at the electrodes; write the balanced equation for the cell.
4) Unit 10 Atomic Structure and Periodicity:
   - Quantitatively relate frequency, wavelength and speed of a wave.
   - Describe Planck's concept of quantized energy. Calculate the energy of a photon using the relationship $\Delta E=nhv$.
5) Unit 11 Bonding:
   - Compare the general nature of ionic and covalent bonds.
   - Write Lewis dot structure for molecules or polyatomic ions, including species that are exceptions to the octet rule.

Pre-Requisite Knowledge

Students must be introduced to concepts in electrochemistry, REDOX reactions, chemical bonding and must be able to conduct laboratories in a safe manner.

Learning Objectives

After this activity, students should be able to:

- Describe the Photovoltaic effect and how light energy is converted to electrical energy.
- Understand the importance of semiconductor technology to solar cells.
- Describe benefits for using nanomaterials, both economical and technical.
- Understand light intensity, light angle and distance effects on photovoltaic properties.
- Understand role of material defects size, shape and distribution on photovoltaic properties.

Materials List

Each group needs the following:

- 2 -Fluorine doped tin oxide glass slides (F-SnO_2)
- 0.127g Iodine (I_2)
- 0.83g Potassium Iodine (KI)
- 10 ml ethylene glycol
- Dish Washing detergent (surfactant)
- Colloidal Titanium Dioxide Powder (TiO_2)
    - 2ml 2,4-Pentanedione ($C_5H_8O_2$)
    - 100ml Anhydrous Isopropanol
    - 6.04ml Titanium Isopropoxide ($Ti[(CH_3)_2CHO]_4$)
    - 2.88ml Distilled Water
- Nitric or Acetic acid
- Blackberries, raspberries
- 2ml de-ionized water
- Ethanol
- Filter paper
- Masking Tape
- Tweezers
- Binder Clips
- Multimeter
- Glassware (beakers, stirring rods etc.)
- Mortar/Pestle
- Hot Air Gun
- Bunsen Burner
- Tissue Paper
- Alligator clips with connecting wires
- 1 LED if applicable
- Desk lamp with incandescent light bulb
- Fluorescent lighting (indoor)
- One sunny day

Introduction / Motivation

Reference “Solar Energy-Nanostyle” Lesson Plan for Introduction/Motivation.

Vocabulary / Definitions

Word	Definition
n/a	n/a

Procedure

Background

In the past decade research has been conducted on a different solar cell that divides the photon absorption and charge separation processes into two steps. These cells are based on a combination of photovoltaic effect physics and electrochemistry; more commonly known as photoelectrochemical solar cells. These cells incorporate nanostructured semiconductor layer with a light absorbing dye sensitizer and a regenerating iodide/triiodide electrolyte. Currently, dye sensitized solar cells approach efficiencies of 11% and produce equivalent open circuit voltage and current to traditional silicon solar cells, at a fraction of the cost. So why all of a sudden does one want to use nanostructured materials?

Nanomaterials offer a unique combination of properties that traditional "micro" materials do not. Because the bulk scale is closer to the atomic size scale, new physics apply to all optical, mechanical, electrical, chemical and thermal properties. In the case of photoelectrochemical cells, the volume to surface area ratio is far smaller than conventional materials yielding enhanced light absorption and electron transfer than similar micromaterials. These changes are directly associated with the increase in surface area per volume, but also due to more particles present in a given volume. Another advantage is more economical method for synthesizing nanoparticles and suspensions. A series of solvents and evaporation steps are typically used to synthesize nanoparticles and ultimately create a suspension. Eventually these suspensions can be sintered by methods consistent with tape casting. In the end, process time and equipment needs are reduced.

Photoelectrochemical solar cell efficiency relies on three main components: light absorbing die sensitizer, electron transfer and electron regeneration. As the name suggests, light absorbing dye sensitizer absorbs photons to excite electrons and create holes. The electrons are excited and transferred into the conduction band of the nanoparticle semiconductor. Electron transfer to and through the nanoparticle semiconductor is near 100% efficient thus boosting the overall cell efficiency. Electrons are transferred through a conductive path to a counter electrode. Oxidation of iodide to triiodide takes place at the photosensitized nanoparticle film/dye sensitizer interface supplying the necessary electrons to newly created (positive charge) holes. Electron flow to a counter electrode (metal or carbon) supplies the necessary electrons to reduce the triiodide to iodide. This cycle is regenerative and important to the cell efficiency.
To achieve a high efficiency the following must be met. First: light absorbing dye must produce excited electrons and holes over a wide light spectrum. Meaning, the cell is using the majority of light energy supplied by source thus boosting current. Secondly, the nanoparticle layer needs to maximize the dye/semiconductor surface area to achieve near 100% electron transfer. Third, the oxidation and reduction electrolyte reaction rates proceed at a rate equal to or greater than

electron excitation. A rate less than electron excitation rate will result in an oversupply of electrons and holes to the cell causing recombination to occur decreasing current.
Within each of these topics there are numerous ideas and innovations to improving these types of cells. In order to run we must walk and by that I am challenging you to build your own photoelectrochemical solar cell. While building your cell, make sure to follow all instructions and complete the attached handouts. Good luck and may the light be with you!!!

Pre-Activity Procedure: Make enough for all groups.

- *Nano TiO_2 Colloidal Synthesis*
    1) Add 2ml of 2, 4-Pentanedione ($C_5H_8O_2$) to 100 ml of anhydrous isopropanol and stir covered for 20 minutes.
    2) Add 6.04ml of titanium isopropoxide ($Ti[(CH_3)_2CHO]_4$) to the solution and stir for a minimum of 2 hours.
    3) Add 2.88ml of distilled water and stir for another 2 hours.
    4) Age solution at room temperature for 12 hours.
    5) Evaporate solvent at 100°C in an oven to collect powder.

- *Electrolyte Solution*
    1) Measure out 10ml of ethylene glycol
    2) Weigh out 0.127g of Iodine and mix with the ethylene glycol.
    3) Weigh out 0.83g of potassium iodide and mix with the same ethylene glycol mixture.
    4) Continue stirring.
    5) Store solution in dark container with a screw top lid.
- Necessary Laboratory Equipment is to be placed out in advance.
- Instruct students to get into groups of 3-4 students.
- Instruct students to get their appropriate PPE for the activity (e.g. aprons and goggles).
- Students are to begin making nanotitanium oxide suspension. Alternatively, if suspension is pre-made, students then proceed to dye sensitizer instructions.
- Once solar cells are created students need to answer all questions on lab handout.

Activity With the Students:

- *Nanotitanium suspension*
    1) Measure out 6 grams of titanium dioxide.
    2) Add 9ml of nitric or acetic acid to titanium dioxide in a mortar and pestle.
    3) Grind for 30 minutes to create a lump free paste.
    4) Add 1 drop of dish washing detergent (surfactant).
    5) Set suspension aside for 15 minutes to equilibrate.

- *Dye sensitizer preparation*
    1) Crush 5-6 fresh berries in a mortar and pestle with 2ml of de-ionized water.
    2) Filter dye, collect and set aside.

- *Photoelectrochemical solar cell preparation*
    1) Using the multimeter, determine the conductive side of each glass slide.
    2) Mask off one of the glass slides, conductive side up, with masking tape 1-2 mm on three sides.
    3) After the nanotitanium suspension has equilibrated, place a 2-3 drops of nanotitanium paste and distribute across the unmasked area with a glass rod.
    4) Let slide dry for one minute.
    5) After slide has dried for one minute, remove the tape and place under a hot air gun.
    6) Heat the slide, using the hot air gun, for 30 minutes to sinter the paste.

7) Allow the heat sintered slide to cool to room temperature.
8) Once the slide has cooled, place slide face down in the filtered dye sensitizer for 5 minutes. This will allow the dye to be absorbed into the nanopores.
9) While the first slide is soaking, take the second glass slide and heat the conductive side over an open flame.
10) Move the slide back and forth for a few seconds to create a carbon catalyst layer.
11) Remove from flame and allow cooling.
12) Remove the first slide from the dye and quickly rinse with ethanol to remove water. Dry the rinsed slide with tissue paper or paper towel.
13) In a quick manner, place the two slides together (paste and carbon layer facing each other) in an offset manner.
14) Attach two binder clips to the two ends (not the offset sides) to hold the slides together.
15) Add one drop of the electrolyte solution between the slides. The electrolyte will stain the entire inside of the slides by capillary action.
16) You have now completed your photoelectrochemical solar cell. ENJOY!!!

Activity Data Collection and Analysis

- Fluorescent Light (standard school lighting)
  1) Connect one alligator clip and wire assembly to each glass slide. Make sure the negative (black) wire is connected to the Nano layer glass slide and positive (red) wire to the opposite glass slide.
  2) Measure the open circuit cell voltage by applying the corresponding colored probes to the correct wires. Make sure the multimeter is on the voltage setting. Record your results in the summary table.
  3) Connect each wire to the correct terminal on the LED bulb. Record your observations when the wires are connected.
  4) Set multimeter to measure current and connect probes to the corresponding wire colors (one probe on each side of the LED. Measure the current produced from your solar cell and record value in the summary table.
- Incandescent Lighting (Desk lamp)
  1) Turn off classroom lighting and turn on incandescent lighting.
  2) Position lighting directly over head of your solar cell approximately 8-12 inches away. Record this distance in the summary table.
  3) Complete Fluorescent Light steps 1-4 recording the necessary data and observations on the summary page.
  4) Now move the incandescent light angle approximately 30° from vertical to the right or left. Maintain the same distance.
  5) Complete Fluorescent Light steps 1-4 recording the necessary data and observations on the summary page.
  6) Move the incandescent light an additional 30° from the previous position. Maintain the same distance.
  7) Complete Fluorescent Light steps 1-4 recording the necessary data and observations on the summary page.
- Sun Light (Outdoors):
  1) Complete Fluorescent Lighting steps 1-4 and record all necessary data and observations on the summary table.
  2) Record the relative position of the sun when testing outside (i.e. degree offset from vertical).

- Data Analysis: Using a graphing calculator plot the following
    1) Open cell voltage as a function of lighting type. For incandescent lighting comparisons plot only the vertical data point.
    2) Current as a function of lighting type. For incandescent lighting comparison plot only the vertical data point.
    3) Incandescent lighting open cell potential and current as a function of lighting position.
    4) Use each graph to answer the questions below. (Refering to questions in student handout)

Attachments

SEN_Student Handout (doc)

SEN_Student Handout with Answers (doc)

Safety Issues

- Goggles and aprons are to be used throughout the duration of the activity.
- All light sensitive materials must remain in a dark sealed container.

Troubleshooting Tips

None

Investigating Questions

None

Assessment

Pre-Activity Assessment

Opening Discussion: Reference "Solar Energy-Nanostyle" Lesson Plan

Activity Embedded Assessment

Activity Problem Set Handout: This handout is a two part handout. First, a data collection and summary sheet for students to complete while they are making their measurements must be completed. This sheet enourages observation recording and data trend analysis Second, an applications and subject understanding problem set. This second problem set is to test the students' understanding of the subject areas listed in this document.

Post-Activity Assessment

Post-Activity Discussion: Reference "Solar Energy-Nanostyle" Lesson Plan

Activity Extensions

None

Activity Scaling

None

Additional Multimedia Support

None

References

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Other
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Supporting Program

NSF GK12 program, Grant #0840889, University of Houston

Version: September 2010