Solar Energy-Nanostyle

Subject Area(s)	**Physics, electrochemistry, chemical bonding, semiconductors, nanomaterials, Renewable Energy**
Associated Unit	**Renewable Energy Resources**
Lesson Title	**Solar Energy-Nanostyle**
Grade Level	11-12 (8-12)
Lesson #	1 of 1
Lesson Dependency	None
Time Required	180 minutes
Time Required Note	Lesson can be completed in 135 minutes provided nanotitanium dioxide suspension is prepared ahead of time by instructor.

Summary
Students learn about solar energy from a viewpoint of a materials engineer. Students will learn some of the solid state physics basics behind semiconductor technology, nanomaterial application benefits and synthesis and solar cell technologies. Additionally, students will have a chance to fabricate and test their own dye sensitized solar cell. This lesson provides a unique opportunity to the student to learn about a young and growing technology while relating to basic chemistry and material science principles.

Engineering Connection
Solar cells involve an incredible amount of materials engineering whether the cell is a traditional photovoltaic , dye sensitized, thin film or organic. Material scientists design semiconductors to improve photovoltaic properties to boost open circuit voltage and current. This is achieved by fluctuating band gaps through defect control/chemistry, alloying, and composite layer properties. A relatively new wave of solar cells incorporate nanomaterials as semiconductor films. Students will be introduced to nanomaterials and a few of their advantages over traditional “micro-scaled” materials.

Engineering Category = #1, 2
Choose the category that best describes this lesson’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

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 (5^{th} 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

fter this lesson, 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.**

Introduction / Motivation

(Instructor may open this lesson with an introduction to nanotechnology. This introduction may be in the form of a presentation, video, or other visual aid. NOTE this presentation should last no longer than 10 minutes.)

What is Nanotechnology? (encourage students to participate). *"'Nanotechnology' is the engineering of functional systems at the molecular scale. Nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, highly advanced products."*

What is the molecular scale? Atom arrangement 1×10^{-10}m; nanomachine/particle/material 1×10^{-9}m or 1 nm.

Did you know nanotechnology goods and services is predicted to be the first trillion dollar market. This futuristic-like technology is all around us and is growing at a fast rate. **What types of technologies and goods do you think nanotechnology is a part of?** (Make list of answers and add additional ones). Sample list:

- Car Bumpers (nanocomposites)
- Sporting goods (e.g. golf clubs, tennis rackets)
- Quantum dots – Optical Beackons
- Cancer Treatment
- Antibacterial dressings.
- Photovoltaic devices (solar cells)
- Sun Screens (similar to solar cells, want to absorb UV light)
- Protein Tracking
- Stain repellant clothes
- Rocket propellants
- Synthetic Bone
- Organic Light Emitting Diodes (Phone/radio screens)
- Nanostructured Materials for engineering applications
- Nanocatalysts
- Filters

What is so special about 100 nanometers (nm)? (Take answers from students). At this size scale new phenomena occur which is not possible with traditional "micro-sized" materials. Mechanical, optical, electrical, chemical and thermal properties begin to change and drastically improve when compared to bulk properties. This size range has required scientists to formulate new physics for these materials.

In the spirit of renewable resources, integrating nanomaterials and technology only seems fitting. So, over the next few days we are going to explore solar cells which utilize nanoparticles for functionality. You will be challenged with fabricating, testing and analyzing your own dye sensitized solar cell. Good luck and may the light be with you!!!

Lesson Background & Concepts for Teachers

Solar energy is abundant energy resource and has received much attention in the last two decades. Solar cells utilize the photovoltaic effect which converts light energy into electrical energy. Light is composed of photons. The photons are described as being small packets of energy in the form of both waves and particles. The characteristic energy is described by the formula below.

$$E = hf = \frac{hc}{\lambda}$$

Where h = Plank's constant, f= wave frequency, c= speed of light and λ = wave length. This wave length is associated with the energy spectrum; more specifically for solar energy, ultra-violet to infrared spectrum. Figure 1 below is an example of the energy (light) spectrum with corresponding wave lengths. Interesting enough, solar energy thrives on photons associated with the Visible light spectrum. At these wavelengths, the energies associated closely match the energy required to excite an electron in the semiconducting material. Thus the incoming light energy does not overpower the semiconductor with excess energy. Typical solar cells have maximum efficiencies that lie within 350-700nm wave lengths. This energy contribution coupled with large intensities of light (sunny days,) increases the amount of current produced which maximizes overall cell efficiency. However, in practice, there are typically material limitations that have adverse effects on solar cell performance.

Image Insert Figure 1 here, centered

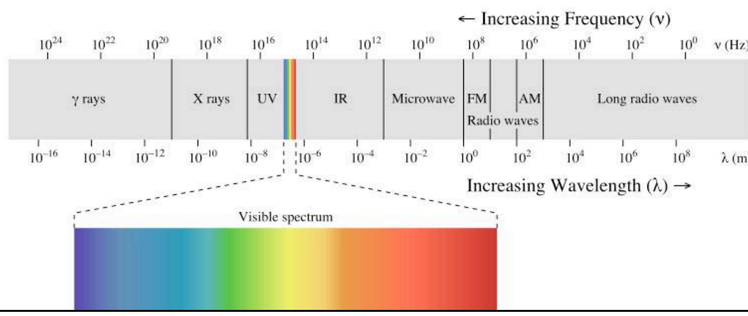

Figure #1

ADA Description: Light spectrum detainling both corresponding wave frenquencies and lengths. Special emphasis is given in the visible light spectrum.

Image file: Light Spectrum.jpg

http://www.sciencestew.com/display2.php?articleID=0005

Traditional solar cells are manufactured using polycrystalline silicon semiconductors. Pure Silicon material, by itself, is not very useful, but becomes a very powerful semiconductor when alloyed with small amounts of impurity elements. The specific doping impurity defines the semiconductor type: n-type (electron source) or p-type (hole source). The junction of these semiconductor types is what creates a separation between the negative and positive charges resulting in a net potential difference and electron flux. However, tradition semiconductors are costly to manufacture due to the stringent chemistry specifications required to maximize semiconductor efficiency and methods for meeting those requirements. One example is application of zone refining to control impurity level. This method consists of large furnace equipment and a tremendous amount of time to produce useful chemistries. Additionally, chemical vapor deposition is used to add additional dopants which also require large equipment and time.

For a solar cell to work as an anti-reflecting coating and a series of layers composing of n/p – type semiconductors must be used to transmit photons, excite electrons and flow electrons to create a current. For a traditional solar cell, each layer facilitates this process in one step. Overall efficiencies for these types of materials may range from 5% to 33% efficient. Silicon based solar panels perform in the 10% to 25% range and exhibit relatively large open-circuit voltage and current. This efficiency range is a drastic improvement from earlier solar cells (order of 1%), but still is relatively low when compared to other energy conversion methods. These lower efficiencies have been, among others, attributed to reflective losses and narrow wave length operation range. Certainly improvements in material properties could improve these losses and boost efficiency.

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.

Vocabulary / Definitions

Word	Definition
Photovoltaic Effect	Conversion of light energy (Photo) to electrical (voltaic) energy by direct means or through secondary energy conversion process.
Dye Sensitizer	Organic or inorganic dye that absorbs light to excite and inject electrons into a semiconductor.
Conductive Band	Semiconductor energy band where electrons are transferred to when excited from the valence band
Valence Band	Semiconductor energy band where holes are transferred when electrons are excited and transferred to the conductive band
Band Gap	Energy gap between conductive and valence bands. The size is characteristic of the material. For conductive materials the band gap is non existant and both conductive and valence bands overlap. In semiconductor matierals both valence and conductive bands are separated. The band gap is the energy required to excite and electron into the conductive band.
Photoelectrochemical	A combination of light energy converted to electrical energy with an electrochemical reaction to recombine electrons with holes
Holes	Positive charged space that is created when an electron is excited and moving. Holes can move free about the crystal. Typically they are separated and form in p-type semiconductors
n-type	Semiconductor type which is alloyed to yield one additional electron per four bonds. For silicon semiconductors [hosphourous is used for this purpose
p-type	Semiconductor type which is alloyed to yield one less electron per four bonds. For silicon semiconductors boron is used for this purpose
Zone Refining	A refining process that incorporates melting a portion (zone) of a bar of material very slowly across its length to push impurities to one end. This is a slow, but effective process for producing very small impurity levels.
Tape Casting	Casting method for ceramic materials. Ceramic slurry is sintered onto a polymer tape or backing. Very effective and cheap method of manufacturing nanoparticles.

Associated Activities

Fabricating Dye Sensitized Solar Cells	Students get to fabricate their own solar cell, test photovoltaic properties and analyze results. Students will then be expected to answer related questions in the activity handout.

Lesson Closure

New technologies are essential to improving efficiencies of renewable energy resources. As you have seen with solar cells, there are many options available to provide improved and efficient means for ustilizing these energy resources. However, we constantly push ourselves for improvement. This involves young engineers (you!!) to think outside of traditional materials and methods and incorporate new technologies.

Millions of dollars are spent each year on nanotechnology research for the reason that this size scale has much more to offer in certain applications. **Why nanomaterials are even considered for solar applications?** (Answer: these materials absorb more light and can transfer electrons more efficiently than their bulk counterparts). **Why else would nanoparticles be considered?** (Answer, economical advantage; cost of developing nanoparticles and thin films is lower than convential refining and deposition processes).

To improve solar energy conversion what things might a materials engineer want to accomplish? (Answer, build nanomaterial-thin film solar panels, improve regenerative electrolyte properties-speed up reaction kinetics, improve electron transfer through controlling nanostructure and maximizing operable wavelenghths).

Materials engineers, scientists and chemists play a large role in selecting and improving materials for photovoltaic applications. If you were one of these scientists which material would you be interested in researching? Conventional micro-structured semiconductors or nanomaterials?

Assessment

Pre-Lesson Assessment

Discussion Questions: Encourage student participation and discussion. Organize and integrate student responses to continue thought processes.

- What is Nanotechnology?
- What is the molecular scale? And Nano scale?
- What types of technologies and goods do you think Nanotechnology is apart of?
- What is so special about 100 nanometers?

Activity Assessment

Data analysis questions and problem set: Students are expected to complete all questions regarding data analysis and technical questions. Once students complete these questions they may use them for the Post-Activity Assessment. However, students will be expected to submit handouts to instructor.

Post-Activity Assessment

Discussion Questions: Students are to participate in a review of concepts discussion incorporating their answers to the activity handouts. Students are encourage to solicit ideas while the instructor organizes them and integrates them into the conversation.

- Why are nanomaterials considered for solar cell applications?
- How can a materials engineer improve the efficiency of solar cells?

Lesson Extension Activities

None

Additional Multimedia Support

1) Refer to "Nanotechnology takes off" for an excellent film that includes a variety of nanotechnology applications supported with entertaining 3D animations. See film at http://www.nanowerk.com/nanotechnology/videos/Nanotechnology_takes_off.php.
2) Refer to "Nano: The next dimension" for a film that includes a good introduction to the tools and practical applications of nanotechnology and some of the principles. This film utilizes very detailed 3D animations to reinforce concepts. See Nano: The next dimension at http://www.nanowerk.com/nanotechnology/videos/Nano_The_next_dimension.php.
3) Refer to "Nano Revolution" which is an excellent film that includes a compilation of illustrations and explanations into the world of nanotechnology. See Nano Revolution at http://www.paladinpictures.com/nano.html

4) Refer to "Kavli Foundation: Introduction to Nanoscience" which is an introductory film thatprovides basic nanoscience information and links to specific applications. Film incorporates excellent use of illustrations and 3D animations. See Nanoscience introduction at http://www.nanowerk.com/nanotechnology/videos/Kavli_Foundation_Introduction_to_Nanoscience.php

References

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Attachments

Fabricating Dye Senstized Solar Cells (Doc)

Other

None

Redirect URL

None

Contributors

Marc Bird

Copyright

None

Supporting Program

NSF GK12 program, Grant #0840889, University of Houston