1. Laboratory Project: Making a Dye-Sensitized ("Grätzel") Solar Cell from Household Products

Overview

This project deals with the following concepts in nanotechnology:

1. thin film fabrication, and
2. electron transport in nanocrystals.

It demonstrates the importance of nanotechnology to innovative means of generating electricity, and opens the door to further discussion of what electricity is and where it comes from.

The lab takes 3 hours to complete.

It is appropriate for most ages.

Supplies

Kits are available from various sources, including the following:

- Sol Ideas, http://www.solideas.com/solrcell/cellkit.html:
- Institute for Chemical Education, http://ice.chem.wisc.edu/Catalog/SciKits.htm#Anchor-Exploring-57181 : $45.00. Kit contains supplies to build 5 cells.

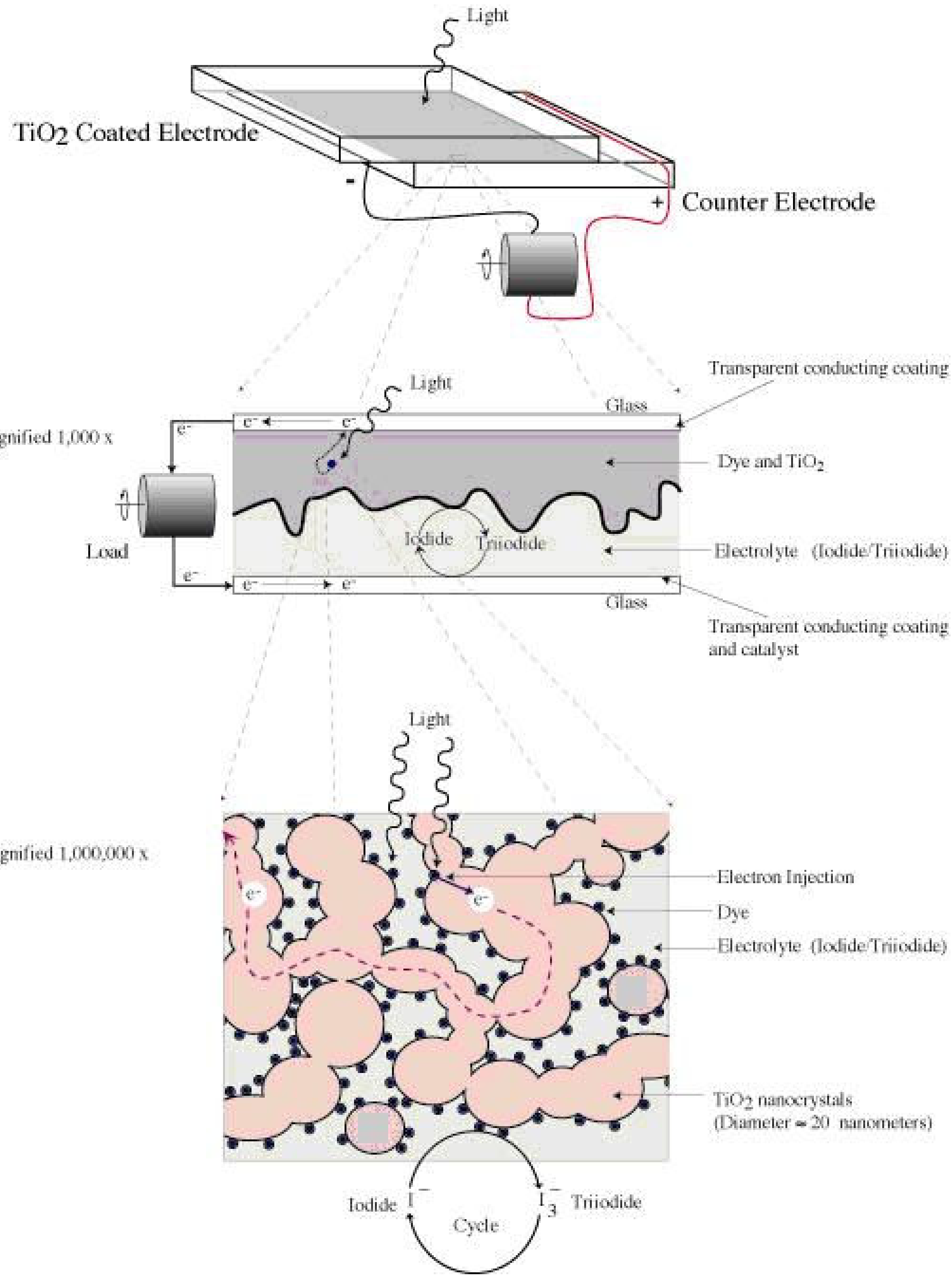
Many of the supplies (pencils, pipettes, tweezers, binder clips, multimeters, etc.) might be on hand in the school laboratory already. In that case the teacher might choose to order only the less common supplies:

1. TiO_2
2. ITO (Indium Tin Oxide)

Introduction

The next page illustrates how the dye-sensitized solar cell functions. The student creates a thin film between two slides of conductive glass. The conductive glass aids in collecting electrons from the materials that will be placed in between the two glass slides. slides (shown as the top plate in the second illustration on the next page) will be coated with titanium dioxide (TiO_2) by the teacher or student beforehand. The student will stain (dye) this plate by soaking it in raspberry, blackberry, pomegranate juice, or red hibiscus tea. The dye and the TiO_2 together will constitute a thin film about 10 μm thick.

(Continued on p. 3.)



Source: http://www.solideas.com/solrcell/howworks.html

The other conductive plate (shown as the bottom plate in the illustration) should be coated on the conductive side with graphite: this can be accomplished simply by shading it completely with a pencil.

Finally, the stained plate (thin film) is coated with an iodide solution that will act as an electrolyte. This means that the iodide solution will conduct electrons from the film to the bottom plate.

Clip the glass plates tightly together with alligator clips. Leave the plates slightly offset, so that the conductive part of each is somewhat exposed.

Use a multimeter to measure the potential difference between exposed conductive parts of the top plate and the bottom plate when the film is exposed to light. Sol Ideas predicts an output of about 0.43V and 1 mA/cm^2 when the device is exposed to full sunlight.

Detailed Procedure

Preparation of Titanium Dioxide (sunblock)

1. Measure out 2 g of titanium dioxide on the scale using weigh paper or a weighing dish, and put into a mortar and pestle. (This is enough to make 2-3 devices)

2. Measure out 3 mL of vinegar in the 20 mL graduated cylinder.

3. Add about 1 mL of vinegar to the titanium dioxide in the mortar and pestle.
Note: Acetic acid (vinegar) diluted to a pH of ~3-4 works as well.

4. Mix thoroughly until the mixture is uniform and free of lumps.

5. Repeat steps 5 and 6 until all 3 mL of the vinegar is used.

6. Add 2-3 drops of colorless soapy water to the solution. (This will help the TiO_2 stick to the glass slide).

7. Let the suspension sit for 15 minutes.

Making the Solar Cell

1. Clean both 1” square glass slides gently with ethanol and Kim Wipes.

2. Identify which side is conductive by using a multimeter (ask an instructor for help here); the resistance of the conductive side will be 10-30 ohms, while the non-conductive side will be too high to measure.

3. Clean off an area of the lab bench, and place the square glass slides on the lab bench, orienting one glass slide with its conductive side up, and another immediately below it, with its conductive side down. Carefully keeping the slides touching, tape them to the lab bench using Scotch tape, as shown, leaving most of the surface of the slides exposed and only covering a thin strip (as shown here, about 2 mm wide) on either side. Place a third piece of tape over the top of the conductive slide, as shown, covering a larger area (about 5-6 mm wide):

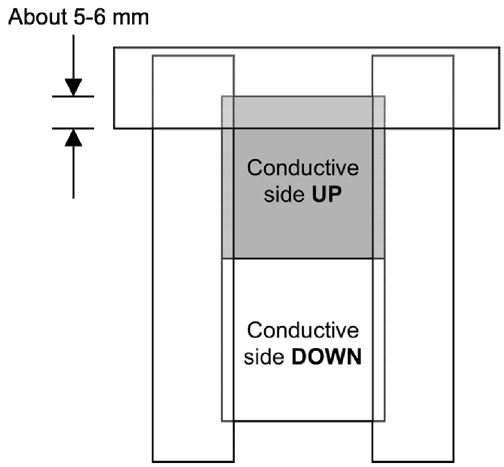


Figure 1: Diagram of ITO glass slides

4. IMPORTANT – THIS IS THE HARDEST STEP, SO PLEASE READ EVERYTHING HERE BEFORE STARTING.

Keep in mind that our goal in this step is to get a nice, smooth titanium dioxide film on the conducting slide; any film on the non-conducting slide does not matter. Using a metal spatula take a small amount of the titanium dioxide suspension you made earlier and spread it in a thin line just below the last piece of tape, on the conductive slide. **Immediately** take a glass stir rod, held horizontal as shown, and in contact with the tape, and slide it (*don't* roll it) in order to spread the suspension smoothly, first moving downwards, then reversing direction. Do this 2-3 times or until the film on the conducting slide is smooth. Add more of the suspension if necessary, but do it quickly, as it will dry rapidly. If something goes wrong, you can carefully wipe the slides off and try again.

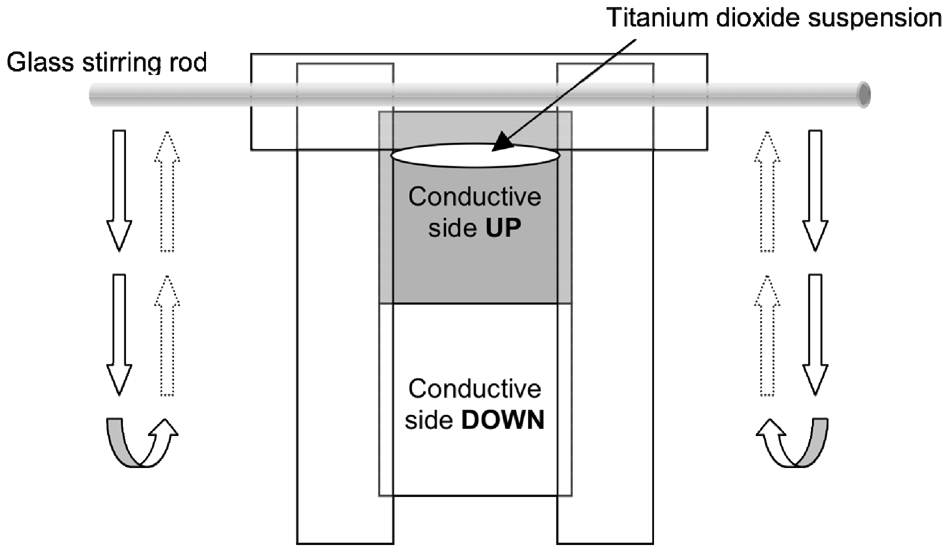


Figure 2 Diagram of how to make a thin layer of TiO_2 on the glass slide.

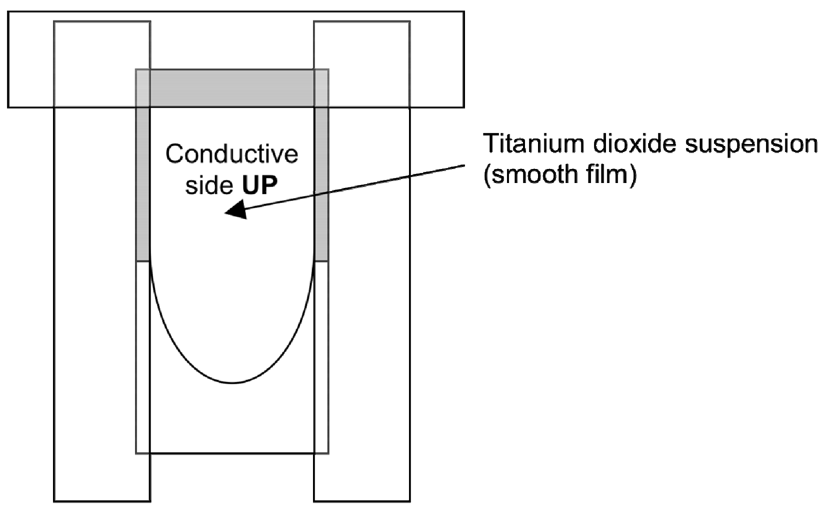


Figure 3 The TiO_2 will cover all of the slide with the conductive side up.

5. Carefully remove the top piece of tape first, and then place your finger (you should be wearing gloves, make sure they're clean ones) on the uncoated area where the tape just was (see below), **being sure not to touch the film**. If you are worried that you may accidentally touch the film, ask an instructor for help. While the conductive slide is held down in this way, have someone else very carefully pull the other two pieces of tape off, peeling from the top down. The non-conducting slide will come loose at some point. Take the slide whose conductive side has been coated with the titanium dioxide film and cover it with a glass petri dish. You may leave it on the lab bench for this. Finish removing the tape from the other slide, and gently wash the titanium dioxide suspension off of it and into the sink. Use ethanol and Kim-Wipes to finish cleaning it.
Clean the glass rod in the same way.

6. Once you are done cleaning things, the coated glass slide (above, at right) you placed under the petri dish on the lab bench should be dry (make sure it has had at least one minute to dry; longer is fine). Take the dried glass slide and find an instructor to help you put it into an oven at 450 °C or use a blow dryer. The slides will be taken out of the oven by the instructors after 30 minutes of heating, and allowed to cool.

7. Take a small petri dish (ensure that it is clean) and, using an eyedropper, put a very small amount of blackberry juice into it – Just enough to cover the entire bottom of the dish and form a pool a millimeter or two thick. Smashing up fresh or frozen blackberries works just fine. If you make blackberry juice from blackberries, be sure to filter the solution before using it. A coffee filter would work just fine.

8. Take your completely cooled titanium dioxide coated glass slide and place it into the juice in the dish, with the titanium dioxide coated side face down. Make a note of the time (you will do something further with this in 10 minutes or so).
Note: Another way to do this is to use the eye dropper or pipette and drop the juice directly on the TiO_2 until the entire slide is covered (this prevents the TiO_2 from getting scratched).

9. While you are letting your titanium dioxide film soak in blackberry juice, take your other clean glass slide and identify the conductive side with a multimeter (ask an instructor for help); the resistance of the conductive side will be 10-30 ohms, while the non-conductive side will be too high to measure.

10. Having identified the conductive side, take the pencil that has been provided and coat the conductive side with graphite. The most effective technique is to use not just the point but the entire side of the pencil tip (as shown below), and to look at the reflection of the light off of the surface of the slide while doing this, as this will allow you to tell the difference between graphite-coated and uncoated areas. Make sure that the slide is *completely* coated in graphite, including the corners. Once the slide is coated, **be sure not to touch the coating with anything**. Hold it up by its edges only.

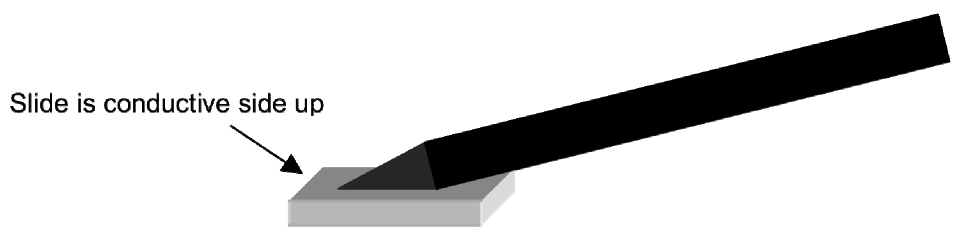
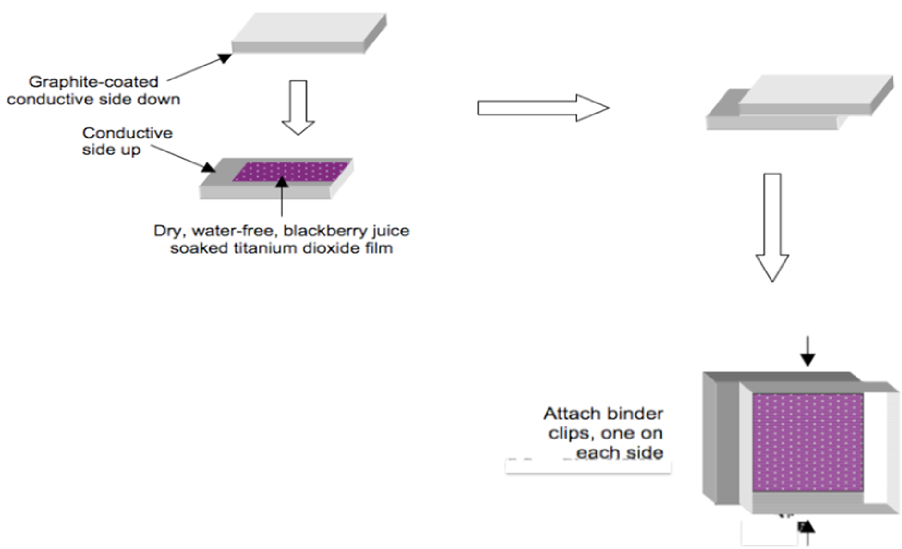


Figure 4 The graphite from the pencil will help collect electrons.

11. By this time, your titanium dioxide coated slide should have soaked in the blackberry juice for at least 10 minutes. If not, wait until it has. Examine the slide from the back as it sits in the petri dish, and ensure that the titanium dioxide film now has a deep purple color throughout. If it does not, wait until it does. Once it does, carefully pick it up, handling it by the edges if you can and ensuring that you **do not touch the titanium dioxide film**. Examine the film from the other side (the side on which it is coated) in order to verify that it is deep purple throughout on that side as well. If not, put it back in the petri dish as before and let is soak longer, first adding more blackberry juice to the petri dish with an eyedropper if necessary.

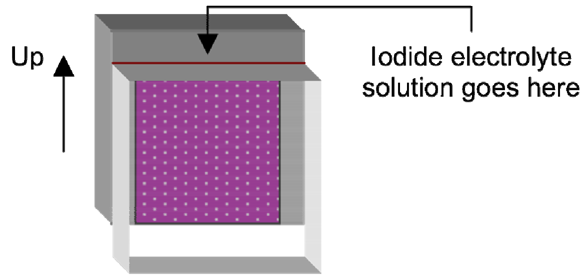
12. The blackberry juiced soaked titanium dioxide film should now appear deep purple throughout when viewed from both sides, with no bright white spots remaining (ask an instructor if you are not sure whether your slide is OK). Holding the slide very carefully so as not to touch the titanium dioxide coating, gently but thoroughly wash the film with deionized water from a wash bottle – Do this over the sink. Once you are done, repeat this process with ethanol from a wash bottle, ensuring that all of the water is rinsed away. It is very important at this point that no water remains in your film. Once you are done washing the film, put the slide with the film side face up on a clean paper towel, and use a Kim-Wipe to very gently blot it dry. This slide is now ready for use, and must be used very rapidly so as to avoid significant exposure to the air (which results in oxidation of the dye in the blackberry juice and loss of photosensitivity).

13. You must now construct the cell itself. Take the graphite-coated slide and identify the graphite-coated side. Place this side facedown on top of the dry, blackberry juice soaked, titanium dioxide coated side of the other slide, in such a way that the two slides are offset (see the diagram below; the titanium dioxide film should just be covered). Once you have done this, carefully pick up both slides, keeping them in contact and ensuring that they do not slide past each other, and use binder clips to attach the two.

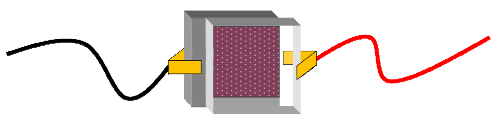


Optional: Step 14
14. Once your cell is clipped together, you will need to add the electrolyte solution. Holding the cell such that the one of the steps is facing upwards towards you, put one to two drops of the iodide electrolyte solution at the point where the two slides meet (see below). You will see that the solution is slowly drawn into the cell by capillary action. In order to ensure that the solution completely saturates the cell, loosen one of the binder clips, then clip it on again, then loosen the other binder clip and clip it on again. Repeat

this process until the iodine solution has clearly saturated the entire cell, and then ensure that both clips are once more firmly attached. Use a cotton swab to remove any iodide solution that is present where you put the drops in the first place, or anywhere else along the edge of the cell. It is very important that all of the excess solution is removed.



15. Your solar cell is complete! Now, get a multimeter and use the alligator clip leads to attach your cell to the multimeter, in the positions shown below (make sure neither alligator clip touches both slides). Measure both the voltage and the current output of your cell in light and in darkness, and examine its behavior (ask an instructor to assist in this step).



Physical Principles

Nanocrystals or nanoparticles are substances that are between 1-100 nanometers. The TiO_2 forms such nanocrystals; when the student soaks the TiO_2 in the berry juice or tea the dye molecules coat the outside of these crystals. The importance of the word "nano" in this case is the amount of dye that can soak the outside of the crystals. If the crystals were on the order of micrometers, for example, much less dye could soak the crystals, and the solar cell would not work as well, if it worked at all. The dye can soak more titanium dioxide when it forms nanocrystals, because nanocrystals have a greater surface area to volume ration. This means there is much more titanium dioxide for the dye to soak.

The dye absorbs light, and the light's energy excites electrons in the dye molecules. The excited electrons travel out of the dye molecules and into the TiO_2 nanocrystals, and from there through the iodide solution to the bottom plate. The electrons build up at the bottom plate, which therefore becomes negatively charged relative to the top plate. The negative charge on the bottom plate constitutes a potential difference between the two plates, and a potential difference is the source of electrical current.

References

Smestad, Greg P. and Grätzel, Michael, *Journal of Chemical Education.* **1998,** *75,* 752.
http://www.solideas.com/solrcell/cellkit.html
http://cnsi.ctrl.ucla.edu/nanoscience/pages/solarCells