DYE SENSITIZED SOLAR CELLS

BACKGROUND INFORMATION VERSION 090718

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PROPERTIES OF SOLAR CELLS

- Silicon based Solar cells were developed by Bell labs approximately 50 years ago and the utilize a p-n junction.
- Absorbed light creates free electrons and holes, which act as charge carriers and are connected to electrodes (top and bottom) as shown in Fig. 1

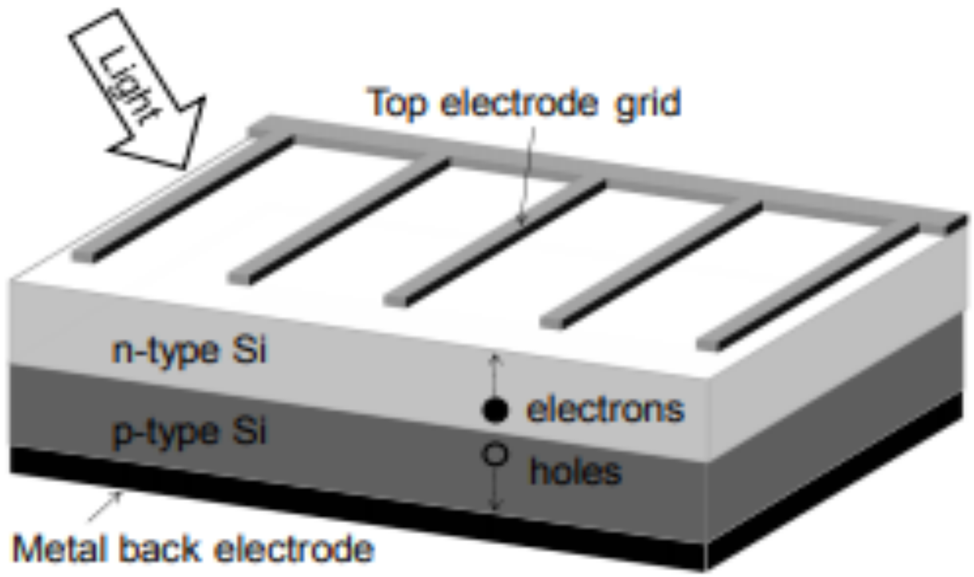


Fig. 1

PROPERTIES OF SOLAR CELLS

- The resultant current created can drive an external load (Fig. 2) or stored in a battery for later use.
- Conventional solar cells have a variety of uses from toys, electrical power generation to powering satellites or remote places where power cannot be reached by the distribution grid.
- Since these solar cells must be constructed from extremely pure silicon, these devices are often too expensive to be competitive with fossil fuels generation of electricity.

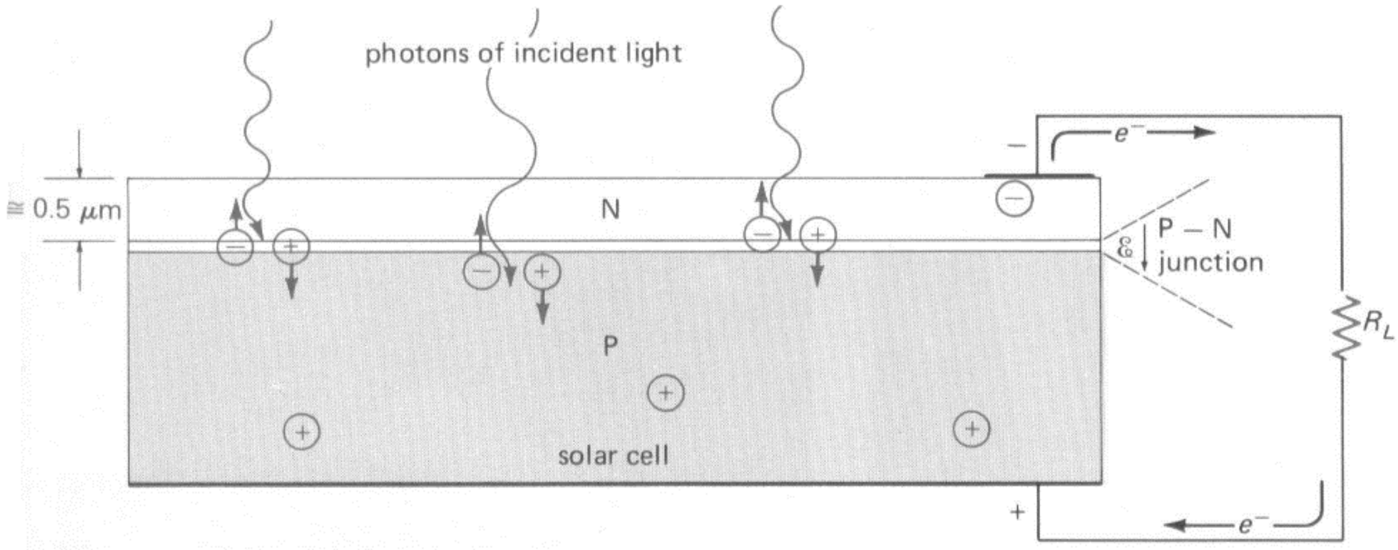
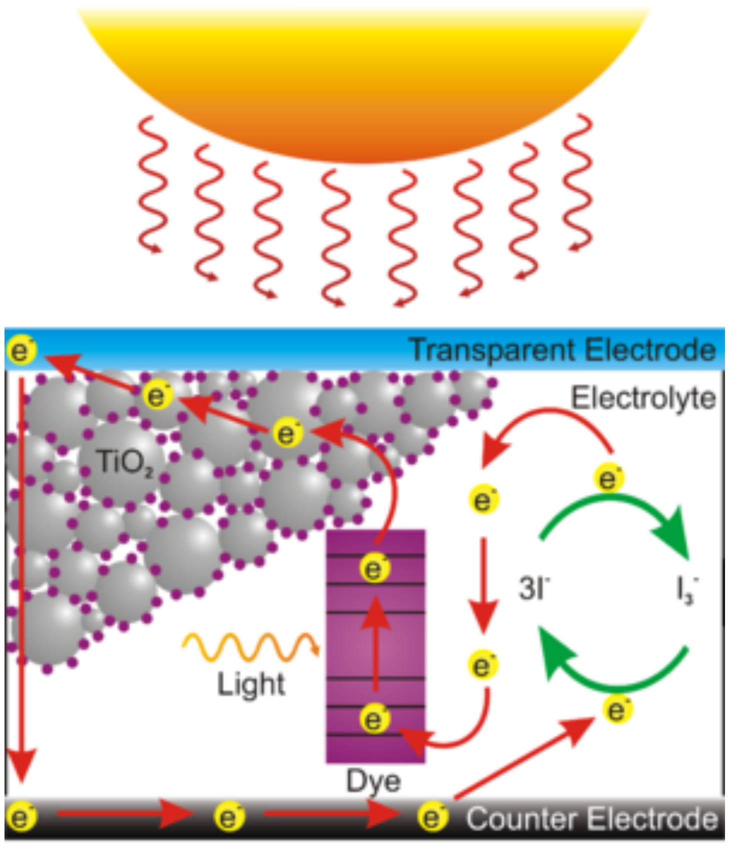


Fig. 2

DSC's VS CONVENTIONAL SOLAR CELL'S

- In this lab, we will construct a Dye sensitized solar cell (DSC) based on a paper published in *Nature* by O'Reagan & Gratzel in 1991[1]
- It consists of a photoelectrochemical cell, which means that a photo-induced chemical reaction causes electrons to travel from one substance to another.
- DSC's have challenged conventional solid-state photovoltaic technologies by functioning at the molecular and nano level



DSC's vs Conventional Solar Cell's

- DSC's have shown to possess efficiencies of 12% for small cells as well as exhibit promising stability data, 1000 h stability test at $80^{o}C$ [2]
- DSC's perform better than other solar technologies under diffuse light and at higher temperatures
- DSC's offer the potential to design solar cells with a large flexibility in shape, color, and transparency thus opening the possibility for a lot of commercial applications

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OPERATION OF DYE SENSITIZED SOLAR CELLS

- Dye-sensitized solar cells (DSCs) consist of a nanostructured semiconductor film coated with organic dye molecules. The nanostructure intimately contacts an electrolyte solution that contains an iodide-triiodide mediator (Fig. 3).
- The film and solution are sandwiched between two electrodes, which allow for electrical connections. Importantly, one electrode (the one coated with nanocrystals) must be transparent, while the other should be coated with a carbon catalyst to facilitate reduction of the iodide-triiodide mediator
- The anatase form of TiO_2 (a white pigment found in paints) is a semiconductor with a band gap of 3.2 eV, it primarily absorbs ultraviolet light rather than visible light.

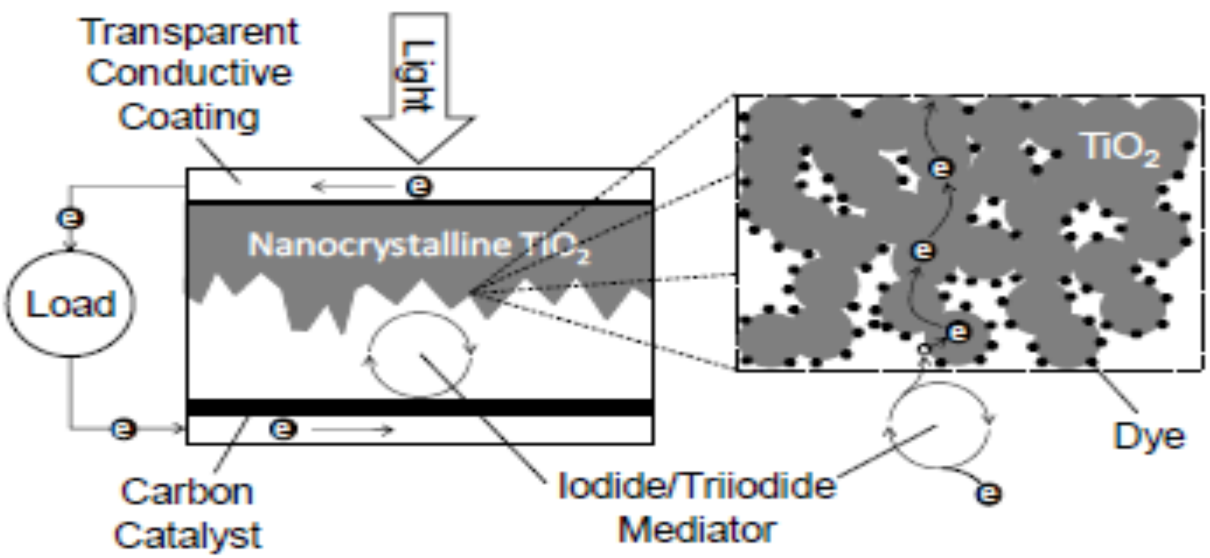

Fig. 3. The structure of a dye-sensitized solar cell. *Reproduced with the permission of NACK RAIN network*

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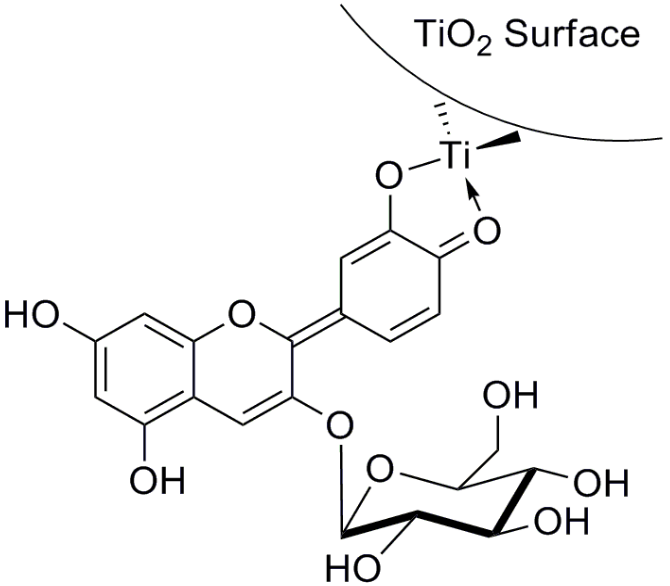
OPERATION OF DYE SENSITIZED SOLAR CELLS

- Anthocyanin dyes (raspberry, blackberry, bing cherry) on the other hand, are organic molecules that absorb visible light extremely well. This gives them a deep red-purple color. When certain anthocyanin dyes come in contact with TiO_2, they can chemically react with and attach to the surface of the nanocrystals (Fig. 4).
- The dye molecule acts as a ligand and forms bonds with titanium atoms on the TiO_2 surface.
- The dye molecules absorb visible light and transfer the photo-excited electrons to the TiO_2.



Surface of TiO2 particle with organic dye molecule.
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Fig. 4

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OPERATION OF DYE SENSITIZED SOLAR CELLS

- The iodide/tri-iodide mediator transfers electrons to the oxidized dye molecules, which results in the dye molecule reduced back to their original state, while the mediator gets oxidized
- Electrons that were injected into the TiO2 percolate are collected by the top electrode
- Having passed through the external circuit an possibly used to drive a load, the electrons reach the carbon coated counter electrode
- The carbon acts as a catalyst to transfer the electrons back into the oxidized mediator, reducing it to its original state and thus completing the electrical circuit.

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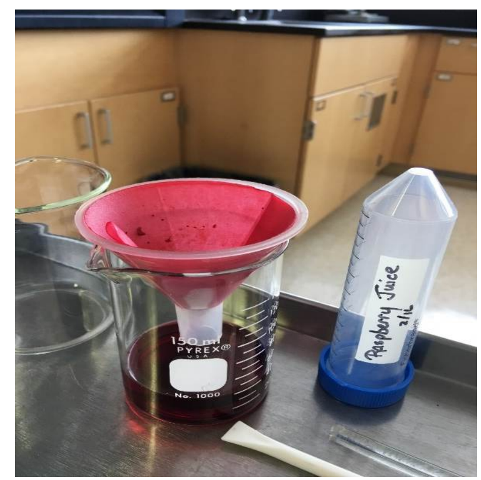
HELPFUL HINTS FOR PERFORMING THE LAB

- Purchase kits from the Institute of Chemical Education (ICE) which contain the supplies to create five titanium dioxide raspberry solar cells: Kits may be ordered at *ice.chem.wisc.edu/Catalog/SciKits.html#Anchor-Nanocrystalline-41703)*
- Assemble all the materials needed on a laboratory cart, and perform the experiment under a fume hood.
- Wear eye protection and gloves when performing the lab
- We used thawed out frozen raspberries pulverized in a blender; the mixture can be refrozen and thawed many times.
- For step by step instructions on performing this lab, please watch the video link below (courtesy of MRSEC[3] at UW Madison) http://www.youtube.com/watch?v=Jw3qCLOXmi0



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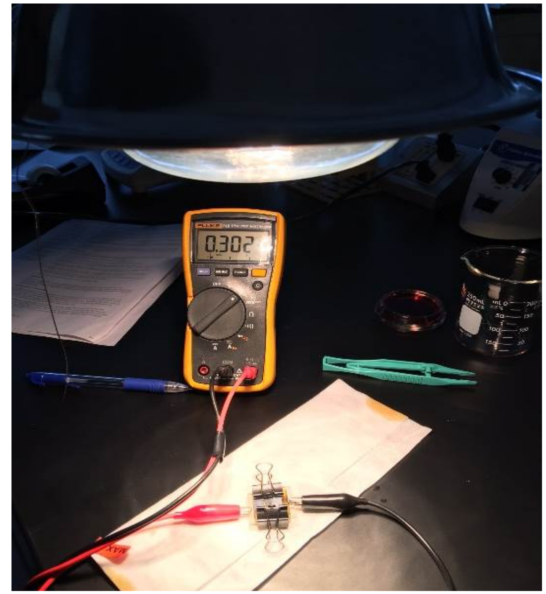
TESTING & SAMPLE RESULTS

- Fasten alligator clips and electrical test leads to the device. Attach the black (-) wire lead to the TiO_2 coated glass. Attach the red (+) wire lead to the counter electrode (carbon coated glass).
- Test the current and voltage produced by illumination from an overhead projector or heat lamp (as shown)
- To characterize the cell, use the potentiometer and the detailed instructions that are provided with the kit to obtain the current and voltage data for your students' solar cells as shown in Fig. 5, which is an example of a J-V curve for a solar cell. Note the current density J (blue, in units of mA/cm^2) is on the left axis and power density (red, in units of mW/cm^2) is on the right axis.

(*Data reproduced with permission from the NACK RAIN network*)



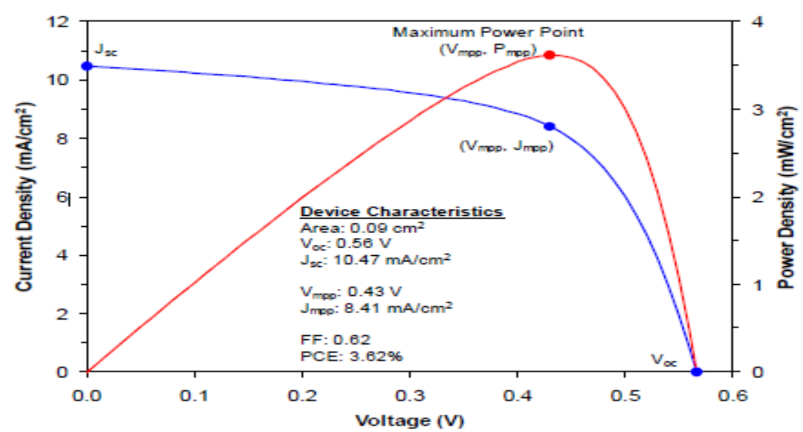


Fig. 5

Extensions – Future & Drawbacks

- One advantage of DSC's is that they be can be fabricated on a variety of substrates such as thin film, flexible or robust plastics, and applied to metal and glass substrates.
- DSC's could also power small electronic devices. One application gaining a lot of attention is the Internet of Things, which refers to a network of appliances, vehicles, and other objects that are fitted with sensors and other electronics to enable them to collect and transmit data
- In the future, some DSC companies intend to manufacture DSC powered beacons that broadcast Bluetooth signals. These devices can be used in many ways. One such example is to direct game-day attendees from the entrance of a sports stadium to ticketed seats via cell phone communication
- One drawback of DSC technology is in relation to the liquid electrolyte. The electrolyte is corrosive, volatile, and prone to leaking[4]; all of which limit the long term stability of the cell. However, Northwestern University researchers have replaced the liquid electrolyte with a novel semiconducting inorganic solid: fluorine doped cesium tin iodide ($CsSnI_{2.95}F_{0.05}$). Implementing lab findings and improvements into the manufacturing process usually takes several years.

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REFERENCES

1 O'Regan, B.; Gra¨tzel, M. Nature 1991, 353, 737.

2 **Dye-Sensitized Solar Cells:** Anders Hagfeldt, Gerrit Boschloo, Licheng Sun, Lars Kloo, and Henrik Pettersson *Chemical Reviews* **2010** *110* (11), 6595-6663
DOI: 10.1021/cr900356p

3 University of Wisconsin Madison MRSEC Education group
http://www.education.mrsec.wisc.edu/289.htm

4 **Characteristics of the Iodide/Triiodide Redox Mediator in Dye-Sensitized Solar Cells**
Gerrit Boschloo and Anders Hagfeldt, *Accounts of Chemical Research* **2009** *42* (11), 1819-1826
DOI: 10.1021/ar900138m