|  |  |  |
| --- | --- | --- |
| Name: Bram Vanderwegen | Schakel | Subgroup: Hibiscus: Laurence, Johannes, Bram  Tea: Brent, Bram |

Introduction:

This report will describe grätzel solar cells. Grätzel solar cells or dye solar cells are devices which are made with a natural dye. This allows them to be made from readily available low-cost sources. Using organic materials means the solar cells are also a lot more environmentally friendly.  
 The process begins with the absorption of photons by the natural dye molecules. These dye molecules, sensitizing the semiconductor surface, become excited and subsequently release electrons. These excited electrons are then accepted by iodine atoms present in the electrolyte of the cell.

Experimental procedure

In order to make the solar cells, we used the following materials:

* Two coated glass pieces
* Pencil (graphite)
* Tape
* TiO2 paste
* Pipette
* Aluminium foil
* Hotplate stirrer
* Dye
  + Hibiscus
  + Fruit tea
* Electrolyte solution
* Paperclip
* Tweezers

First, we laid down a sheet of aluminium foil on the table, this acts as a protective cover as well as having the property of being heat resistant. Then we taped down a piece of glass, conductive side up, to the aluminium foil. On this glass we applied titanium dioxide paste and spread it out as thinly as possible to our ability. Afterwards we let this dry until the was no more visible wetness. Furthermore, we designated this piece as the cathode. Simultaneously a layer of graphite was applied to the other piece of coated glass using a pencil. This one is designated as the anode. We also put the tea/hibiscus in water to make a dye solution in water. Once dried, we heated the titanium coated glass on a hot plate for 10 minutes at 300°C to sinter the titanium dioxide. Once the heating was finished, we let it cool down for another 10 mins. Then we applied multiple drops of dye to the titanium until it was completely covered, to let the dye soak in. We did this for 10 minutes as well. Then we washed away the access dye with tap water. Then we added the electrolyte with two drops on the titanium side and one drop on the graphite side and put the two electrodes together, with the coated side facing each other. Finally, we left a small gap for connectors to be attached. This concludes the construction of the device.

We measured the IV curves using local software. We connected the solar cell to a device which applies a voltage to the solar cell then a multimeter was attached in series to the solar panel to measure the current. Using these parameters an IV curve was measured by inputting the current to the software at certain applied voltage levels. These curves were made at different light levels, one in a completely dark environment, the other in a lit environment.

Results part 1: hibiscus dye

Hibiscus tea:

Laurence, Johannes, Bram Bjorn, Dries, Max

|  |  |  |  |
| --- | --- | --- | --- |
| **Dark** | | **Light** | |
| V fotocel (V) | I fotocel (A) | V fotocel (V) | I fotocel (A) |
| -1,00E+00 | -3,59E-03 | -9,95E-01 | -4,25E-03 |
| -9,03E-01 | -2,49E-03 | -9,00E-01 | -3,16E-03 |
| -8,02E-01 | -1,56E-03 | -7,96E-01 | -2,11E-03 |
| -6,99E-01 | -8,89E-04 | -6,93E-01 | -1,30E-03 |
| -5,95E-01 | -4,86E-04 | -5,89E-01 | -7,52E-04 |
| -4,88E-01 | -2,76E-04 | -4,85E-01 | -4,38E-04 |
| -3,84E-01 | -1,68E-04 | -3,81E-01 | -2,73E-04 |
| -2,77E-01 | -9,90E-05 | -2,77E-01 | -1,74E-04 |
| -1,74E-01 | -5,50E-05 | -1,71E-01 | -9,90E-05 |
| -6,36E-02 | -1,50E-05 | -6,67E-02 | -3,60E-05 |
| 4,01E-02 | 1,40E-05 | 4,32E-02 | 2,20E-05 |
| 1,47E-01 | 4,80E-05 | 1,50E-01 | 8,00E-05 |
| 2,54E-01 | 9,00E-05 | 2,57E-01 | 1,50E-04 |
| 3,64E-01 | 1,43E-04 | 3,61E-01 | 2,43E-04 |
| 4,64E-01 | 2,10E-04 | 4,64E-01 | 3,80E-04 |
| 5,71E-01 | 3,33E-04 | 5,68E-01 | 6,30E-04 |
| 6,75E-01 | 5,20E-04 | 6,75E-01 | 1,03E-03 |
| 7,82E-01 | 8,30E-04 | 7,79E-01 | 1,60E-03 |
| 8,89E-01 | 1,24E-03 | 8,83E-01 | 2,36E-03 |
| 9,90E-01 | 1,82E-03 | 9,83E-01 | 3,35E-03 |

|  |  |  |  |
| --- | --- | --- | --- |
| Dark | | Light | |
| Voltage (V) | Current(A) | Voltage (V) | Current(A) |
| -9,84E-01 | -6,00E-03 | -9,90E-01 | -5,10E-03 |
| -8,83E-01 | -4,90E-03 | -8,89E-01 | -4,00E-03 |
| -7,83E-01 | -3,80E-03 | -7,86E-01 | -3,10E-03 |
| -6,79E-01 | -2,80E-03 | -6,85E-01 | -2,30E-03 |
| -5,75E-01 | -2,10E-03 | -5,75E-01 | -1,70E-03 |
| -4,77E-01 | -1,50E-03 | -4,74E-01 | -1,30E-03 |
| -3,74E-01 | -1,10E-03 | -3,74E-01 | -9,40E-04 |
| -2,64E-01 | -7,25E-04 | -2,67E-01 | -6,30E-04 |
| -1,57E-01 | -4,26E-04 | -1,63E-01 | -3,60E-04 |
| -5,30E-02 | -1,48E-04 | -5,60E-02 | -1,15E-04 |
| 4,78E-02 | 1,22E-04 | 4,78E-02 | 1,13E-04 |
| 1,55E-01 | 4,00E-04 | 1,55E-01 | 3,46E-04 |
| 2,58E-01 | 6,63E-04 | 2,58E-01 | 6,03E-04 |
| 3,65E-01 | 1,00E-03 | 3,68E-01 | 8,90E-04 |
| 4,66E-01 | 1,40E-03 | 4,63E-01 | 1,20E-03 |
| 5,73E-01 | 1,90E-03 | 5,73E-01 | 1,60E-03 |
| 6,74E-01 | 2,50E-03 | 6,74E-01 | 2,00E-03 |
| 7,80E-01 | 3,20E-03 | 7,80E-01 | 2,60E-03 |
| 8,78E-01 | 4,10E-03 | 8,84E-01 | 3,20E-03 |
| 9,82E-01 | 5,10E-03 | 9,88E-01 | 4,00E-03 |

Jayson, Sam

|  |  |  |  |
| --- | --- | --- | --- |
| light | | dark | |
| V fotocel (V) | I fotocel (A) | V fotocel (V) | I fotocel (A) |
| -9,87E-01 | -4,20E-03 | -9,88E-01 | -5,00E-03 |
| -8,90E-01 | -2,93E-03 | -8,87E-01 | -3,92E-03 |
| -7,86E-01 | -1,87E-03 | -7,83E-01 | -2,92E-03 |
| -6,85E-01 | -1,08E-03 | -6,82E-01 | -2,07E-03 |
| -5,78E-01 | -5,72E-04 | -5,79E-01 | -1,38E-03 |
| -4,74E-01 | -2,75E-04 | -4,78E-01 | -8,50E-04 |
| -3,71E-01 | -1,21E-04 | -3,71E-01 | -4,80E-04 |
| -2,64E-01 | -5,00E-05 | -2,67E-01 | -2,44E-04 |
| -1,60E-01 | -1,80E-05 | -1,64E-01 | -1,05E-04 |
| -5,01E-02 | -7,00E-06 | -5,66E-02 | -1,00E-05 |
| 5,07E-02 | 1,00E-06 | 4,72E-02 | 7,90E-05 |
| 1,58E-01 | 6,00E-06 | 1,57E-01 | 1,70E-04 |
| 2,64E-01 | 2,60E-05 | 2,61E-01 | 2,85E-04 |
| 3,74E-01 | 8,10E-05 | 3,65E-01 | 5,15E-04 |
| 4,75E-01 | 2,25E-04 | 4,68E-01 | 9,60E-04 |
| 5,79E-01 | 5,63E-04 | 5,75E-01 | 1,69E-03 |
| 6,80E-01 | 1,17E-03 | 6,76E-01 | 2,50E-03 |
| 7,86E-01 | 2,07E-03 | 7,77E-01 | 3,65E-03 |
| 8,84E-01 | 3,19E-03 | 8,74E-01 | 4,80E-03 |
| 9,88E-01 | 4,47E-03 | 9,78E-01 | 6,02E-03 |

The procedure was largely identical to other groups and was done in accordance with the instruction paper. The main differences are in the variables ill described by the paper. These are mainly the TiO2 paste thickness, the times for drying, sintering, and cooling as well as the amount of electrolyte drops.

Results part 2: chosen dye

Brent, Bram: group 1 Bjorn, Dries, Max: group 2

|  |  |  |  |
| --- | --- | --- | --- |
| Dark | | Light | |
| Voltage (V) | Current(A) | Voltage (V) | Current(A) |
| -9,93E-01 | -4,70E-03 | -9,65E-01 | -1,18E-02 |
| -8,89E-01 | -3,90E-03 | -8,68E-01 | -1,00E-02 |
| -7,85E-01 | -3,10E-03 | -7,67E-01 | -8,40E-03 |
| -6,82E-01 | -2,40E-03 | -6,69E-01 | -6,90E-03 |
| -5,81E-01 | -1,90E-03 | -5,66E-01 | -5,40E-03 |
| -4,74E-01 | -1,40E-03 | -4,65E-01 | -4,00E-03 |
| -3,70E-01 | -9,30E-04 | -3,64E-01 | -2,70E-03 |
| -2,66E-01 | -6,00E-04 | -2,63E-01 | -1,70E-03 |
| -1,63E-01 | -3,44E-04 | -1,60E-01 | -8,50E-04 |
| -5,88E-02 | -1,25E-04 | -5,57E-02 | -2,95E-04 |
| 4,50E-02 | 1,00E-04 | 4,50E-02 | 2,50E-04 |
| 1,49E-01 | 3,60E-04 | 1,49E-01 | 8,88E-04 |
| 2,56E-01 | 6,68E-04 | 2,53E-01 | 1,70E-03 |
| 3,59E-01 | 1,00E-03 | 3,53E-01 | 2,70E-03 |
| 4,60E-01 | 1,50E-03 | 4,54E-01 | 4,00E-03 |
| 5,64E-01 | 2,00E-03 | 5,55E-01 | 5,40E-03 |
| 6,74E-01 | 2,70E-03 | 6,53E-01 | 6,90E-03 |
| 7,78E-01 | 2,10E-03 | 7,53E-01 | 8,50E-03 |
| 8,81E-01 | 2,30E-03 | 8,57E-01 | 1,02E-02 |
| 9,85E-01 | 2,60E-03 | 9,55E-01 | 1,19E-02 |

|  |  |  |  |
| --- | --- | --- | --- |
| Dark | | Light | |
| Voltage (V) | Current(A) | Voltage (V) | Current(A) |
| -9,76E-01 | -9,30E-03 | -9,79E-01 | -8,13E-03 |
| -8,79E-01 | -8,14E-03 | -8,79E-01 | -7,30E-03 |
| -7,78E-01 | -6,24E-03 | -7,78E-01 | -6,44E-03 |
| -6,74E-01 | -5,24E-03 | -6,77E-01 | -5,56E-03 |
| -5,73E-01 | -4,46E-03 | -5,73E-01 | -4,68E-03 |
| -4,73E-01 | -3,80E-03 | -4,73E-01 | -3,81E-03 |
| -3,69E-01 | -2,99E-03 | -3,69E-01 | -2,98E-03 |
| -2,68E-01 | -2,18E-03 | -2,65E-01 | -2,16E-03 |
| -1,64E-01 | -1,39E-03 | -1,64E-01 | -1,35E-03 |
| -6,36E-02 | -5,50E-05 | -6,36E-02 | -5,36E-04 |
| 4,01E-02 | 2,96E-04 | 4,01E-02 | 2,93E-04 |
| 1,44E-01 | 1,17E-03 | 1,44E-01 | 1,12E-03 |
| 2,48E-01 | 1,99E-03 | 2,45E-01 | 1,93E-03 |
| 3,48E-01 | 2,85E-03 | 3,48E-01 | 2,75E-03 |
| 4,49E-01 | 3,60E-03 | 4,49E-01 | 3,55E-03 |
| 5,53E-01 | 4,43E-03 | 5,53E-01 | 4,38E-03 |
| 6,54E-01 | 5,25E-03 | 6,57E-01 | 5,20E-03 |
| 7,54E-01 | 6,04E-03 | 7,58E-01 | 6,02E-03 |
| 8,83E-01 | 7,13E-03 | 8,61E-01 | 6,84E-03 |
| 9,83E-01 | 8,25E-03 | 9,65E-01 | 7,68E-03 |

Jayson, Sam: group 3

|  |  |  |  |
| --- | --- | --- | --- |
| Dark | | Light | |
| Voltage (V) | Current(A) | Voltage (V) | Current(A) |
| -1,00E+00 | -5,60E-04 | -9,99E-01 | -6,02E-04 |
| -8,96E-01 | -3,90E-04 | -8,99E-01 | -4,40E-04 |
| -7,92E-01 | -2,58E-04 | -7,89E-01 | -3,20E-04 |
| -6,88E-01 | -1,56E-04 | -6,88E-01 | -2,06E-04 |
| -5,81E-01 | -8,40E-05 | -5,78E-01 | -1,24E-04 |
| -4,77E-01 | -3,90E-05 | -4,77E-01 | -6,90E-05 |
| -3,68E-01 | -1,60E-05 | -3,71E-01 | -3,70E-05 |
| -2,64E-01 | -5,00E-06 | -2,67E-01 | -2,00E-05 |
| -1,57E-01 | -2,00E-06 | -1,60E-01 | -1,00E-05 |
| -5,01E-02 | -1,00E-06 | -5,31E-02 | -1,00E-06 |
| 4,76E-02 | 3,00E-06 | 5,07E-02 | 6,00E-06 |
| 1,58E-01 | 7,00E-06 | 1,61E-01 | 1,40E-05 |
| 2,64E-01 | 1,50E-05 | 2,64E-01 | 2,60E-05 |
| 3,71E-01 | 2,80E-05 | 3,71E-01 | 4,20E-05 |
| 4,72E-01 | 4,50E-05 | 4,72E-01 | 6,40E-05 |
| 5,82E-01 | 6,60E-05 | 5,79E-01 | 9,70E-05 |
| 6,86E-01 | 9,40E-05 | 6,83E-01 | 1,25E-04 |
| 7,92E-01 | 1,28E-04 | 7,92E-01 | 1,95E-04 |
| 8,93E-01 | 1,84E-04 | 8,93E-01 | 2,80E-04 |
| 1,00E+00 | 2,25E-04 | 1,00E+00 | 3,60E-04 |

When trying to measure the short-circuit current and the open-circuit voltage we were unable to confirm a stable value, the multimeter would read a value and quickly go back to zero without a change in measurement setup, changing the light-level had no impact on this behaviour.

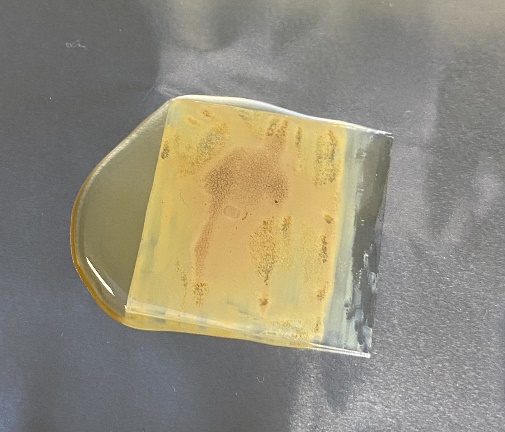
The IV curves between the hibiscus dye and the chosen dye differ quite a bit with the chosen dye having higher current rating for the respective voltages. The hibiscus dye responds interestingly, as the light current curve is smaller than the dark current curve. This would imply the cell works better at darker light levels, which would be counterproductive for a solar cell. Therefore, it is assumed this is an error during the data acquisition phase. The dark current for both devices lay close to each other. This is when the solar cell is inactive, and the parasitic effects of the design influence the readings. While for the light currents the tea exhibits the clearest change in response. The hibiscus response can be identified as within margin of error compared to tea.

However, when the hibiscus tea is compared to other groups, the curves are in the expected ranges. Making us assume they are correct.

The IV curves for the chosen dyes between groups are quite interesting as the differences are quite pronounced. Group 1 had the greatest curve, followed by group 2, and finally group 3. Group 2 however has an interesting curve, as it is almost linear, and the light and dark current are really close together in comparison to their offset from the x-axis. Group 3’s curve’s shape is as expected but it is noticeably smaller, even in comparison to the hibiscus dyes. This makes it clear the chosen dye has a great impact on the curves.

Informal discussion:

The main thing I learned from this lab is how relatively easy it is to make solar cells. Most items can be sourced from household materials. The only materials that would be difficult to find would be the coated glasses, the titanium dioxide, and the electrolyte. However, titanium dioxide is a commonly used white pigment, and the electrolyte’s active component is iodine which could be theoretically sourced from iodine-based disinfectant. The other materials and processes are easily done dyes and graphite are easily sourced, and heating can be done on a stove, rather crudely, however.

The comparison between different dyes also showed that the dye choice has a tremendous impact on the cell’s performance and therefore should be picked carefully.  
Spreading the titanium dioxide paste is also an interesting subject as it involves multiple parameters: how thin must it be spread, how rough does the surface need to be, how long does it need to dry, how long does it need to be sintered...

Here I have a couple theories:

A thin layer is desirable as titanium dioxide has a relatively high typical resistance, so the distance between the conductive glass and the operating surface should be as small as possible. A good way to approach this is by making a square by taping down the glass plate, putting the titanium dioxide paste on the glass and wiping it away at the height of the tape. This ensures a thin and uniform coating of titanium dioxide.

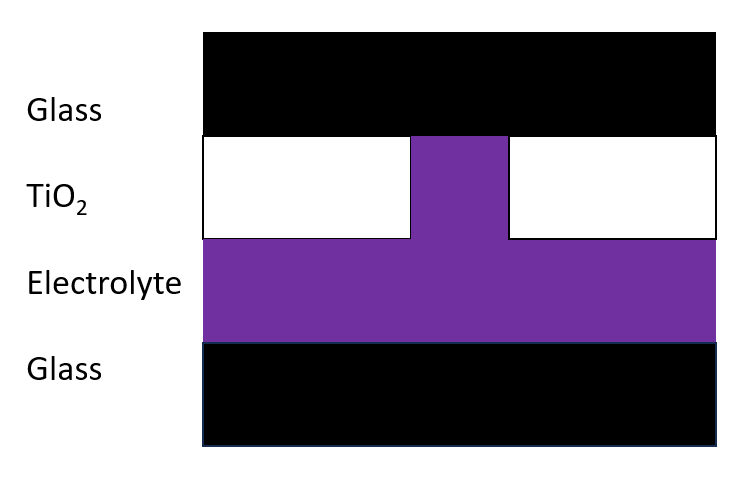
Another factor which might influence the working principle is the surface area of the titanium dioxide coating. A higher surface area might increase the workable area. Or it might increase the amount of dye that can be absorbed. Our chosen dye cell was not yet completely dried and cracked during the sintering process, and this might have unexpectedly given us more surface area to work with. However, this will be hard to say for sure, more research should be done.

Figure 1: Cathode covered in dye, notice the cracks on the surface

A potential problem that could occur with these cells is a short-circuit with the coated glass. Although due to the relatively high resistance of the electrolyte this shouldn’t be too much of a problem however it is still an additional introduced parallel resistance.

Figure 2: electrolyte occupying space unoccupied by TiO2

Appendix:

Charts:

Group 1: Laurence, Johannes, Bram/Brent, Bram

Group 2: Bjorn, Dries, Max

Group 3: Jayson, Sam

Hibiscus solar cells:

Chosen Dye solar cells: