Shading of solar cells

The influence of shading on commercial solar cell performance

Susanne Gooijer & Lisanne van Dijk
Cygnus Gymnasium
PWS
October 24th 2016

1st supervisor - F. de Nijs
2nd supervisor - N. Ran
External supervisor - B. Daiber (FOM Institute AMOLF)

1 Preface

Facing the threat of climate change, humanity has been looking for alternative, CO_2 free ways to generate energy. One of the most used ways to produce clean energy is energy generated from the sun. Solar cells could lead to less global warming. The efficiency of solar cells has improved a lot over the past decades and is expected to improve in the future.

Unsurprisingly, the market for commercial panels increased a lot. More and more households gain their own, CO_2 free energy. Of course, generating energy from the sun comes with certain challenges. To collect the most energy, solar cells are positioned outside. Because of this, the solar cells are exposed to changing weather. Besides the weather conditions, also shadow has influence on a solar panel. It could occur that parts of the solar panel are covered, for instance when the shadow of a chimney falls on the panel or because of birds, leaves and bird poo on the solar panel. It's important that shading has as little influence on the solar panel performance as possible, otherwise the solar panel will gain less energy. That's why we chose to do research on shading of solar cells. This study is intended for everyone interested in solar panels. This could be people with solar panels on their roof, people who want to buy solar panels or people who are just interested in the performance of solar cells.

Making this study possible, we got help from a few people. In first place, we would like to thank Benjamin Daiber from FOM Institute Amolf. Thank you for helping with our research and letting us use the facilities of FOM Institute Amolf. You really help us shape our study. Also thanks to Sander Mann and Hans Doeleman to start the study. And of course we would like to thank our teachers, mr De Nijs and mr Ran.

2 Summary

Starting this study, we wanted to examine how different solar cells react to shading. Our main research question was: what is the influence of horizontal and vertical shading on CdTe, Mono-Si and Poly-Si solar panels? We thought the effects of horizontal and vertical shading would differ between the three kinds of solar panels. We expected horizontal shading to have a less negative impact on the panels than vertical shading. This is because solar cells, mostly have bypass diodes. When a part of the solar panel creates a negative current, the bypass diode starts working and skips that column.

We also expected that mono-Si would react better on shading than poly-Si. Overall, we thought that CdTe would react the best to shading because it is one big solar cell, instead of several connected cells. We did our measurements by covering parts of the solar panels located at AMOLF institute. First, we shaded each panel horizontally, then vertically and lastly we decided to shade one cell at the time. We got all the result in excel-files. We calculated the efficiency and plotted it against the percentage of shading.

We also calculated the loss of efficiency, to see which solar panel would react the best to shading, and plotted it against the percentage of shading as well. We found that our hypothesis was correct. Without shading Mono-Si was found to have a higher efficiency. So naturally, mono-Si also had the highest efficiency when we shaded the panels horizontally and vertically. In terms of the loss of efficiency, showing which panel react better to shading, CdTe reacted the best when shaded vertically. The loss of efficiency was the lowest. But the absolute numbers of efficiency were still very low.

Horizontally, however, we didn't see much difference when we shaded the panels. This is most likely because there were bypass-diodes in the mono-Si and poly-Si panels. A few factors could have affected our study. Firstly, when we did our measurements the weather wasn't completely stable. To avoid this having an effect on our study we took a lot of zero-measurement. During this measurements we didn't cover the panels at all. Secondly, the solar panels we used weren't clean. On all the panels, a layer of dust was visible. On top of that, water had come into the CdTe panel, partly destroying the panel. Overall we think that these factors didn't affect our results too much, because the results support the information we got from literature.

3 Introduction

Our goal is to find out how different commercial solar panels react on shading. To reach this goal we want to answer the next question:

What is the influence of both horizontal and vertical shading on CdTe, Mono-Si and Poly-Si solar panels?

To answer this question, we decided to split the main research question in smaller research questions.

1. What is a semiconductor and how does it work?
2. How does the photovoltaic effect work?
3. What is recombination?
4. What is a PN junction and what influence does it have on the performance of solar cells?
5. How do bypass diodes benefit the solar panel performance when shaded?
6. How to measure the efficiency of solar panels?
7. Is there a theoretical limit of the efficiency?
8. What are the differences in the functioning of commercial solar panels?

These research questions will be answered during our literature study.

We expect that shading has an overall negative influence on the solar panel performance. Most strings of solar cells are located vertically, which means that horizontal shading will have less influence on the performance of the solar cell than vertical shading. If you shade horizontally, one whole string will probably be shaded, which results in only one activated bypass besides that one string. This is in contrast to vertical shading, when you will shade a few solar cells from each string. That results in all bypass diodes activated, which will lead to (almost) zero current and thus zero gained power.

We also expect that Mono-Si will react better on all forms of shading then Poly-Si, because of the structure of the two solar cells.

Poly-Si. We also think that CdTe will react better to shading because it's one big cell instead of several smaller cells connected.

The measuring equipment at FOM Institute Amolf, Science Park Amsterdam, gave us a good opportunity to do experimental research on different commercial solar panels. With this equipment we were able to shade the solar panels and measure different parameters. The values of the parameters are observed objectively by a instrument, which means these parameters are really trustworthy. To make the data more accurate we did several zero measurements. This measurements consist of not covering the panels at all.

4 Content

5 Literature study

5.1 Overview

A solar cell or a photovoltaic cell is a device that turns the energy of light into electricity. This works because of the photovoltaic effect. The photovoltaic effect means that light is absorbed by a material, such as silicon. Light consists of photons, energy particals without mass. The photon will be absorbed when its energy is equal or higher than the band gap energy.The energy that is provided when the light is absorbed in the material is used to excite electrons from their ground state into an excited state (Encyclopaedia, 2016). When they are separated from their atom, we speak of an electron-hole pair. A solar cell consists of a n-part (negatively charged) and a p-part (positively charged). The concentration of electrons and holes is different: the n-part has relatively more electrons and the p-part more holes. To produce current, the electron and the hole need to be separated. The p-n junction has this job. This separations from electrons and holes create a voltage through the device. Connecting the two ends results in a current which can be used to generate energy (Alternative Energy, no date).

5.2 Semiconductor

All solar cells consist of a semiconductor. A semiconductor is a material that has properties of both an insulator and a conductor depending on various parameters. The atoms of a semi-conductor form a crystalline lattice. Many lattices are made of silicon atoms, which is because of the silicon structure. Silicon atoms have four electrons in their largest shell (valence electrons) but they want eight electrons to be as stable as possible. That's why they have four covalent bonds. But because these atoms are so close to each other, their electrons overlay and actually push the other electrons away (Honsberg & Bowden, n.d.). Through this process some electrons get free of their atom and can act like molecules in a gas. This only happens however, when the temperature is high enough. They have to gain enough energy to escape (Honsberg & Bowden, n.d.). When the temperature is low, the semiconductor behaves as an insulator and when the temperature is high, it behaves as a conductor.

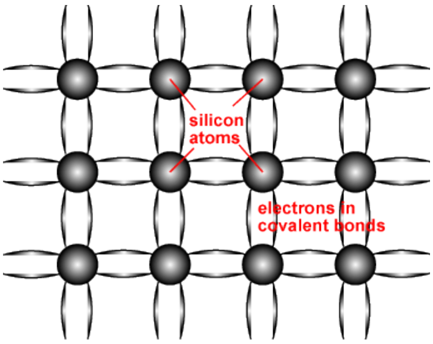

Figure 1. Crystalline lattice

The minimum amount of energy that an electron needs to escape, is called the band gap (Eg). Thus, when the band gap is small, it is quite easy for electrons to escape. So the band gap is the difference in energy between the valence band and the conduction band.(Honsberg & Bowden, n.d.) (Figure 2) To excite an electron from valence band to conduction band, a

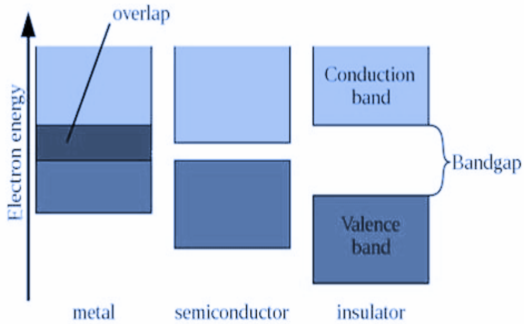

Figure 2. Difference between a metal and an insulator

certain amount of energy is needed from the sun. The bandgap determines that amount of energy and with that, it also determines the energy that can be converted (Honsberg & Bowden, n.d.).

When an electron becomes free, it leaves a space between two atoms. This space is called a 'hole'. Now an electron from another atom can move to this hole and then, that electron leaves a hole (Honsberg & Bowden, n.d.). So this positive hole is actually 'moving' through the lattice. They both participate in conduction which is why they are called charge carriers (Honsberg & Bowden, n.d.).

The charge carriers can move in any direction, called 'free' carriers. It will go in a random direction, until it collides with another atom (from the lattice). Then it will go in another random direction or recombine with a different charge carrier. The temperature of the lattices has influence on the velocity of the carrier. But not each carrier has the same speed, the velocity is on average, which means some are faster than others (Honsberg & Bowden, n.d.). When there's no concentration gradient or an electric field, the direction of the carriers is completely random. But if there's a concentration gradient, charge carriers will move from a place with a high concentration gradient to a place with a lower concentration gradient (Honsberg & Bowden, n.d.). To produce a current, the electrons have to move in the same direction. An electric field is a way to make that possible (IOP, n.d.). That's why solar cells are made out of a n-part and a p-part, which will be explained further in section 5.5.

5.2.1 Intrinsic Carrier Concentration

To measure the amount of electron-hole pairs if no light is hitting the solar cell, the intrinsic carrier concentration, denoted by n_j, is introduced. "The intrinsic carrier concentration is the number of electrons in the conduction band or the number of holes in the valence band in intrinsic material." (Honsberg & Bowden, n.d.) A large band gap will result in a small intrinsic carrier concentration, for example. A low temperature will also lead to a small intrinsic carrier concentration.

5.3 The absorption of light

When a photon hits the surface of a solar cell three things can happen (Figure 3):

1. The photon reflected
2. The photon absorbed
3. The photon transmitted

The only useful option to generate energy is when the photon is absorbed (Figure 3). If the energy of the photon (E_{ph}) is smaller than the energy of the band gap (E_g) the photons will be transmitted through the solar cell. However, if the photon has more energy than Eg, the photon will be absorbed. But, the energy of a photon higher than the band gap is wasted. That's because the electrons will thermalize back from the valence band to the conduction band as soon

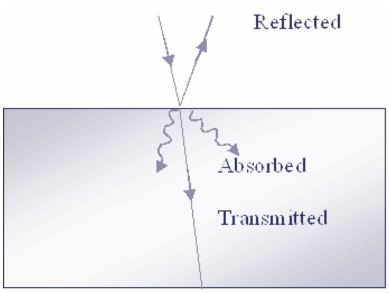

Figure 3. Difference between reflection, absorption and transmitting

as possible (Honsberg & Bowden, n.d.).

The absorption depth is a rate to describe how deep a photon can get on average, before it will be absorbed. The absorption depth is equal to the inverse of the absorption coefficient (a^{-1}) (Honsberg & Bowden, n.d.). The lower the photon energy, the longer the wavelength of the light, shorter the absorption depth. To provide a rough estimation the absorption depth of solar cells made out of silicon is a few hundred micrometers for a photon with a wavelength of red light, about 700 nm (Honsberg & Bowden, n.d.).

5.4 Recombination

Electron-hole pairs are used to generate energy with solar cells, as described in section 5.2. But what happens, if the electron moves back to the valence band and loses its extra energy? This is what we call recombination. Obviously, recombination should be prevented as much as possible. There are 3 types of recombination called Radiative (sending out photons), Shockley-Read-Hall (giving the energy away by heat) and Auger (a three electron loss mechanism).

Radiative recombination or band-to-band recombination is the mechanism where a photon is released when recombining a hole and an electron. This photon has energy similar to the band gap and will therefore exit the semiconductor.

Shockley-Read-Hall recombination is a two step process. First an electron moves to a defect level between the conduction and the valence band, there it gives its energy away with a photon. Then the hole and the electron recombine in the valence band and give their energy away through heat.

Auger recombination involves a third carrier. When an electron and a hole recombine, they give their energy away to an electron in the conduction band. This electron moves up in the conduction band but will eventually come back to the edge of the conduction band.

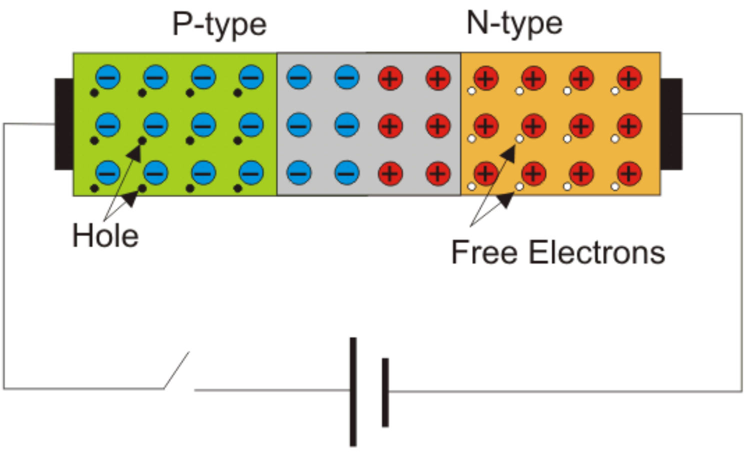

Figure 4. PN junction

To create a voltage, there has to be an electric field. To create an electric field, we need a PN junction, which separates the holes and the electrons. The PN junction consists of a n-type part (negative) and a p-type part (positive). The n-type part is a material increased electron density. The p-type is a material with less electron concentration which is equivalent to high hole concentration.

Doping is the way the n-part and the p-part are created. In the silicon lattice an atom with 5 valence electrons is placed. Because of the 4 valence electrons of silicon atoms, there's on electron extra which can move freely. Silicon lattice with atoms with 5 valence electrons is called n-type material. It's called negative-type (n-type) because the negative electrons can move.

To create a p-type material, an atom with 3 valence electrons is put in the silicon lattice. Because of the lack of a fourth electron, there is an extra hole in this part. This hole can 'move' through the lattice. Silicon lattice with atoms with 3 valence electrons is called p-type material. The p in p-type is because of the positive free holes.

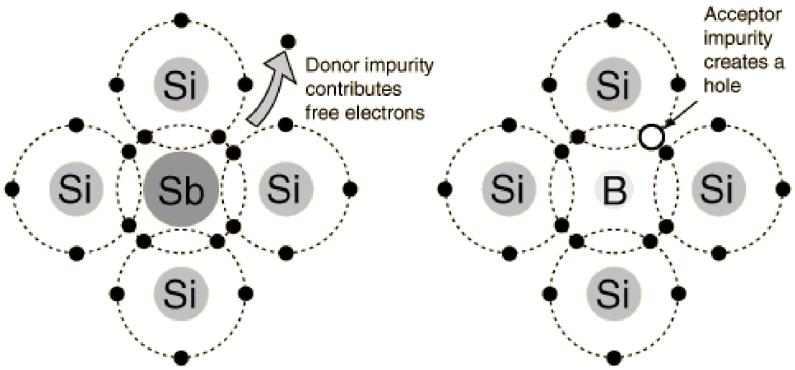

Figure 5. n-type material (left) and p-type material (right)

When you put the n-part and the p-part together, diffusion will take place. The electrons will move from the n-part to the p-part. When the electron leaves his atom, the atom becomes a positive ion which can not move. This also happens with the holes in the p-part: the holes will move to the n-part because of diffusion and the atom becomes a negative ion that can not move.

Where the holes and electrons meet (in the middle), a neutral region appears because the electrons and holes recombine. This neutral region is called the depletion region. The electrons and holes that formed the formed the depletion region, came from the ions next to the neutral region. That results in negative ions at the p-side and positive ions at the n-side. This difference in charge creates a static electric field. The electric field will stop the other electrons and holes from moving to the other side. Now there is a kind of electric field-barrier between the p-part and the n-part, called the barrier potential (Figure 4. PN junction).

5.5.1 Forward and backward bias

Diodes are made to let current only pass in one direction. To understand how that works, you have to know what forward and reverse bias includes.

We talk about forward bias when the p-type material is connected to the side of a source with a positive voltage and the n-type material to the negative voltage. The barrier potential is in the opposite direction than the forward applied voltage. This has effect on the direction of the current: the current can only flow through the PN junction when the forward applied voltage is higher than the barrier potential (Electrical4u, 2016). For silicon diodes, this is 0,7 Volt (Electrical4u, 2016). The time needed for forward applied voltage to become higher than the barrier potential is called the recovery time.

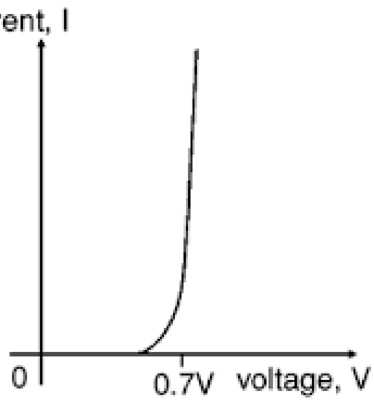

Figure 6. (I,V)-curve for silicon when forward biased

A diode is reversely biased when the positive applied voltage is connected to the n-type material. Now, no current will be able to pass the bypass diode. The depletion area is larger. The bypass diodes of solar cells are reverse biased (Honsberg & Bowden, n.d.). To ‘open the gate’ to let the current go through the bypass diode, a negative voltage is needed. If the bypass diode would be forward biased, the current always would be able to pass the solar cells, not only when shaded.

5.6 Bypass diodes

Cells in a solar panel are usually connected in series. This is done to get a high voltage and therefore a higher generation of energy. Connecting solar cells in series results in a problem when some solar cells are shaded. The resulting current over all subunits is limited determined by the unit that produces the least current. If you shade one cell of a serie, the maximum current is that of the shaded cell (Sargosis Solar & Electric, n.d.). So, actually all the solar cells in the series will virtually be shaded. This leads to a lot of energy being wasted.

To avoid these negative effects from shading, most solar cells have bypass diodes. Bypass diodes are connected parallel to the solar cells and the current is only able to go through it in one direction. Most of the time, a group up to twenty solar cells, called a string, has one bypass diode (Solar facts, n.d.). For the performance, one bypass diode per solar cell would be better, but because of the price of bypass diodes this is not practical.

Bypass diodes have two main jobs (Van Dalen, 2016):

1. Protect the efficiency of the solar panel if one of the solar cells is shaded
2. Protect the shaded solar cell from destroying and burning

When a solar cell is shaded, the current is able to go through the parallel bypass diode instead of the shaded solar cell(s). If no solar cell is shaded, the current is forced to go through the solar cells to generate more voltage. To 'open the gate' to the bypass diode, a negative voltage is needed. This negative voltage is generated when the solar panel becomes a consumer instead of a producer (E2Energie, 2012). And that is exactly what happens when a solar cell is shaded. The negative voltage is generated by the current flow from the cells before the shaded one.

For example, if the third solar cell of a serie is shaded, the first two produce a higher current than the shaded one. The current of cell 1 & 2 has to go through the third cell, which is not possible because of the shading.Trying to let high current t through the shaded cell results in a negative voltage and opens the bypass.

As outlined above, these bypass diodes prevent the solar panel for a loss of energy. But besides that, it protects the cell. When a cell is shaded, it has a maximum current that can go through the cell, but the current from the cells before the shaded one is most of the time higher than the maximum current of the shaded cell. This 'extra' current that can't pass the shaded cell, will turn into heat and this will cause a hotspot which can destroy the cell.

5.7 Pyranometer

A pyranometer measures all the solar irradiance that hits the surface in Watt per square meter. It doesn't need any current to do its work. If you install a pyranometer next to a solar panel, which is done at FOM Institute Amolf, the $G_{pyranometer}$ (Wm^{-2}) shows you the amount of solar energy that hits the solar panel and thus you can measure the efficiency, which is explained in section 5.8.1.

5.8 Efficiency

5.8.1 Explanation variables (I,V)-curves

Open-circuit voltage
The open-circuit voltage V_{oc} is measured in Volt. That's the maximum voltage when the two ends of the solar panel aren't connected.

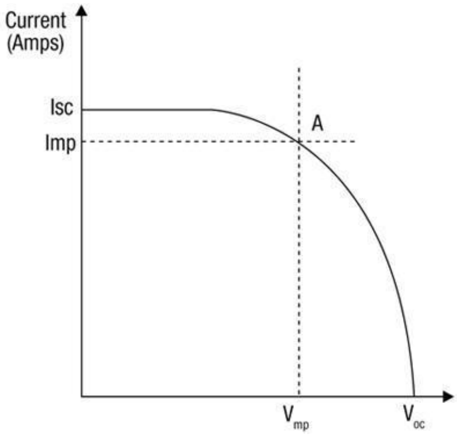

Figure 7. (I,V)-curve

Short-circuit current
The short-circuit current I_{sc} is measured in Ampère. When the two ends of a solar panel are directly connected with each other, there will be a maximum current. That's the short-circuit current.

Fill factor
The fill factor FF says something about the quality of solar cells. Equation 1 shows how to calculate the fill factor (Honsberg & Bowden, n.d.):

$$FF = \frac{V_{mpp} * I_{mpp}}{V_{oc} * I_{sc}} = \frac{P_{mpp}}{V_{oc} * I_{sc}} \qquad \text{(Equation 1)}$$

The V_{mpp} is the Maximum Power Point Voltage and the I_{mpp} is the Maximum Power Point Current. Actually these are the coordinates of the point in a (I,V)-curve where the line bends, also known as the knee of the curve. You can see this point in the Figure 7. The closer the Vmpp and the Impp are to the Isc and the Voc, the higher the fill factor. The Maximum Power Point is the point used if the solar cell is used for electricity generation.

Intensity pyranometer
$G_{pyranometer}$ is the intensity of sunlight in Wm^{-2}.

Module temperature
T_{module} in °C is the temperature of the solar panels, not the outside air temperature. This is important for the semi-conductor. When the temperature is high, the semi-conductor will functionate as a conductor. With a low temperature, the semi-conductor behaves as an insultor.

The efficiency (η) is measured by Equation 2 (Honsberg & Bowden, n.d.):

$$\eta = \frac{V_{oc} * I_{sc} * FF}{P_{in}} \qquad \text{(Equation 2)}$$

Combination of Equation 1 and 2 shows that upon multiplying FF with the Voc and the Isc together, you get the Vmpp times the Impp. This is the knee point in the I-V curve, also the Pmpp. The power that goes into the solar panel can be measured with a pyranometer. You can then divide the Pmpp with the power measured with the pyranometer.

The two formulas 1 and 2 together form a basic formula to find the efficiency:

$$\eta = \frac{P_{mpp}}{P_{in}} \qquad \text{(Equation 3)}$$

5.9 Theoretical limit of efficiency

The Shockley-Queisser limit is the maximum efficiency of a solar cell made of a single pn-junction. The maximum efficiency lies somewhere around 33,7 percent, using a band gap of 1,4 eV (Queen Mary University of London, n.d.). The maximum of efficiency depends on the band gap as shown in Figure 8.

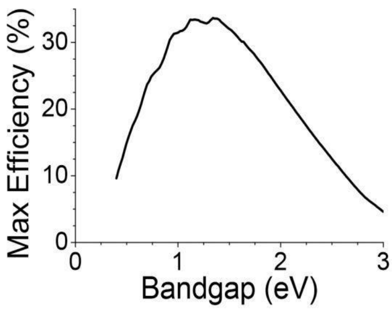

Figure 8. Maximum Efficiency

5.10 Differences in solar cells

5.10.1 Polycrystalline solar cells

The first solar cells that were made for the industry were polycrystalline solar cells. Unlike the monosilicon panels, the silicon for the polycrystalline panels doesn't have to be cut so the panels are much cheaper because less silicon gets wasted (Alternative Energy, n.d.). Instead of cutting, the polycrystalline solar cells are being heated and poured into a mold (Alternative Energy, n.d.). Because the silicon that is used isn't as pure, the efficiency rate is lower than the monocrystalline panels (Alternative Energy, n.d.). The characteristics of polycrystalline solar panels are shown in Figure 9.

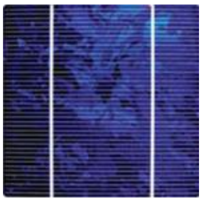

Figure 9. Polycrystalline solar cell

5.10.2 Monocrystalline solar cells

There is a broad range of different types of solar cells. First you have monocrystalline silicon solar cells. These solar cells consist of silicon crystals. These silicon crystals precisely to form a crystal lattice. The monocrystalline solar cells are made in a cylinder, from which thin circles are cut. These circles are the solar cells, but to waste as little area as possible, the circles are cut into octogans. The waste of solar cell material is less worse than the waste of area (Elmes, 2016). The shape of a mono-Si solar cell can be seen in Figure 10.

Figure 10. Monocrystalline solar cell

Monocrystalline silicon panels prove to be the most efficient solar panels (Alternative Energy, n.d.). The efficiency rate goes up to 24 percent. They also take up the least amount of space. Another advantage is the durability of the panels. They can work up to 25 years (Alternative Energy, n.d.).). But with all those benefits comes a price tag. These panels are very expensive to produce. The reason is the four side cutting way that is used, leading to waste of silicon, sometimes more than half of it (Alternative Energy, n.d.).

5.10.3 Thin film solar cells

Thin film solar cells are cells of at least one layer of semi-conducting material. The layers are layered on top of each other. A thin film solar panel only exists of one solar cell, whereas normal silicon-panels exist of somewhere around sixty cells. A benefit of this method is that thin film solar cells are cheaper than silicon cells (Alternative Energy, n.d.). The thin film cells are much easier to mass-produce. A negative feature is their space-efficiency. Thin film solar cells take up more space than other cells for the same power output. A benefit is that heat and shading have a lower negative impact on thin film solar cells (Alternative Energy, n.d.). Thin film solar cells can also also flexible.

Figure 11. Thin film solar cell

5.10.3.1 CdTe solar cells

One kind of a thin film solar cell is the cadmium telluride (CdTe) solar cells. It is the most widely spread thin film solar cell. CdTe solar cells come the closest to the theoretical optimum of efficiency. They can reach an efficiency up to 18 percent under normal test conditions (Bokalič & Topič, 2015). There are concerns however, regarding the used materials. Telluride is a very rare material in the earth's crust and furthermore, cadmium is seen as highly toxic. (Bokalič & Topič, 2015). CdTe solar cells are heterojunction cells. They have a bandgap of 2.4 eV. (Bokalič & Topič, 2015).

6 Methodology

The commercial solar cells we used to shade are located at FOM Institute AMOLF in Amsterdam. They stand outside, next to the building. In total four different types of solar cells were available. We used three of them. The solar cells are located in southern direction with an angle of 30 degrees.

These are the three modules located at AMOLF:
Module 2: CdTe
Module 3: poly-Si
Module 4: mono-Si

We have performed measurements on three different types of solar panels. The panels include: cadmium telluride (CdTe), polycrystalline silicon (poly-Si) and monocrystalline silicon (Mono-Si) solar cells. The CdTe panel is a thin film solar panel, Poly-Si is a polycrystalline solar panel and Mono-Si is a monocrystalline solar panel.

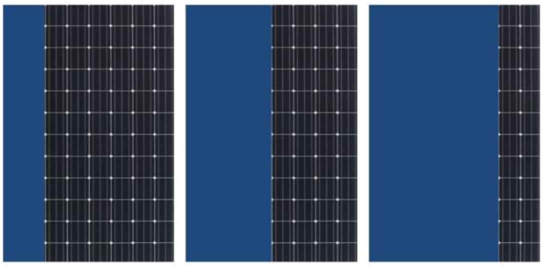

Figure 12. Horizontal shading (25%, 50%, 75%)

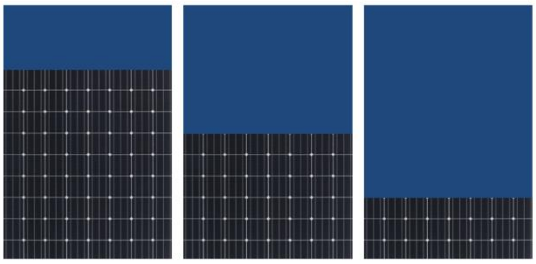

Figure 13. Vertical shading (25%, 50%, 75%)

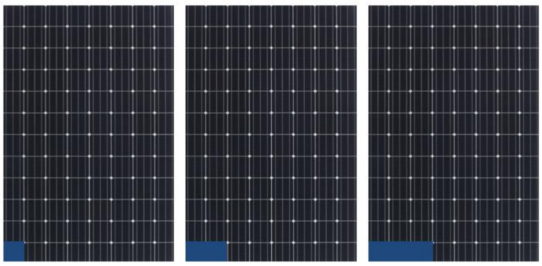

Figure 14. Shading of individual solar cells (1 cell, 2 cells, 3 cells)

We planned to shade the solar panels at the 4th of octobre. We were very lucky, because the weather was really nice for our research: only a few clouds, sunny and no rain. We have shaded each solar panel with a wooden board. We shaded the panels on three different ways as can be seen in figures 12, 13 and 14. From left to right: horizontal shading, vertical shading and we shaded an amount of solar cells. When horizontally shaded, we moved the wooden board of figure 10 each measurement more to the right which results in a higher percentage of parts shaded. When vertically shaded, the wooden board is moved each time a little bit upwards until the full solar panel was shaded. On the right, we shaded exactly an amount of solar cells. We started with 1 solar cell shaded, then 2 solar cells in a row shaded etcetera. In the end, these measurements weren't interesting enough for our results. This is not possible for the CdTe panel, because that panel has no seperated solar cells. The whole panel is one big solar cell. But besides this CdTe panel, all solar panels are shaded each way.

Figure 15. Us shading the Poly-Si panel

To make our measurements more reliable we took several zero-measurements between our measurements where we shaded the panels. So, we did one measurement shaded, one measurement non-shaded, one measurement shaded and so on. We did this to avoid that the weather would have an impact on our research. With our zero measurements, we were able to look at the difference in cell performance between shaded and non-shaded. This will give us more significant results.

We got the database, which included the parameters I_{sc}, V_{oc}, V_{mpp}, I_{mpp}, P_{mpp}, FF, T_{module} and $G_{pyranometer}$. The database can be found in section 12 Appendix. This is not the whole database we got, but the part we used for our results. After selecting the data we needed, we plotted with Excel graphs including several parameters. For calculating the efficiency, we used the formula derived in section 5.7.1:

$$\eta = \frac{P_{mpp}}{P_{in}}$$

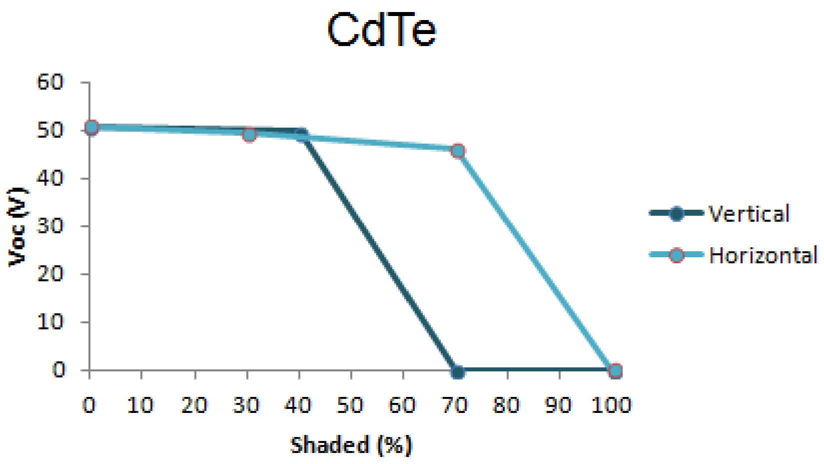

Figure 16. Effect of vertical and horizontal shading of CdTe panel on Open Circuit Voltage

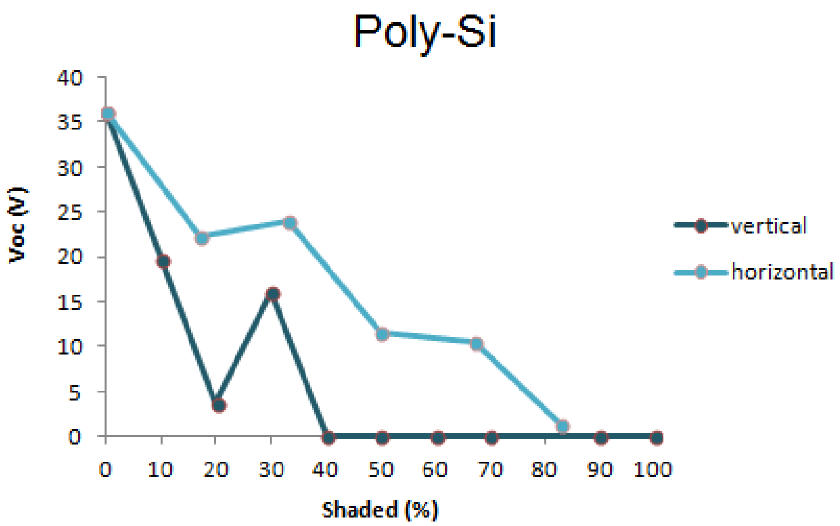

Figure 17. Effect of vertical and horizontal shading of Poly-Si-panel on Open Circuit Voltage

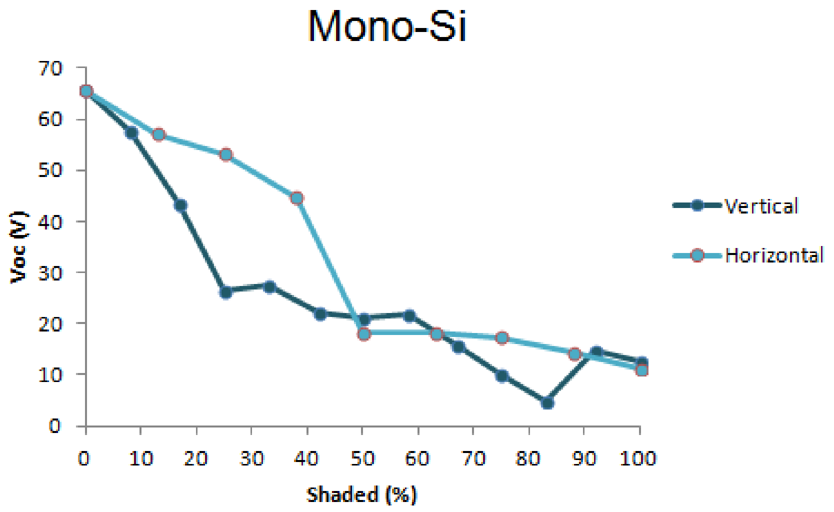

Figure 18. Effect of vertical and horizontal shading of Mono-Si-panel on Open Circuit Voltage

When a solar panel is shaded, the Open Circuit Voltage of each solar panel decreases. Obviously, the negative influence of shading on the V_{OC} is stronger in the vertical than in the horizontal mode. It depends on the solar panel how big the difference is between horizontal and vertical shading. Especially the CdTe-panel has a big gap.

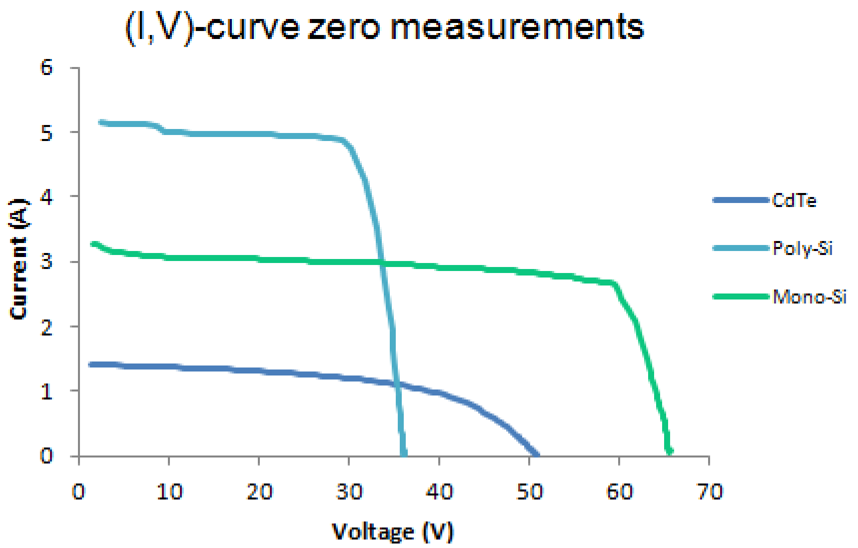

Figure 19. Relation between voltage and current at zero measurement (0% shading)

	V_{mpp} [V]	I_{mpp} [A]	P_{mpp} [W]	Area [m^2]	$G_{pyranometer}$ [Wm^{-2}]	Efficiency [%]
CdTe	36,607	1,0758	39,38	0,72	816,6	4,822434
Poly-Si	30,141	4,7451	143,025	1,7	829	17,25271
Mono-Si	59,515	2,6463	157,494	1,6	809,1	19,46533

Table 1. Maximum Voltage, Current & Power of the 3 panels

The Mono-Si panel has the highest V_{mpp} and the Poly-Si panel the highest $I_{mpp.}$ On average is the Mono-Si panel the best performer, because it has the highest P_{mpp}/m^2.

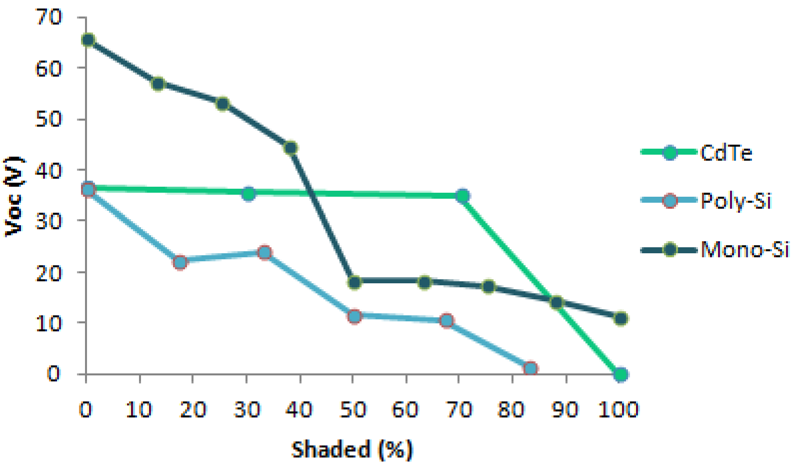

Figure 20. Effect of horizontal shading on the VOC of the different types of solar cells

When horizontal shaded, the CdTe panel works quite well until 70% shading, the other panels lose voltage earlier. When 100% shaded, the Mono-Si still has an V_{OC}, which is interesting.

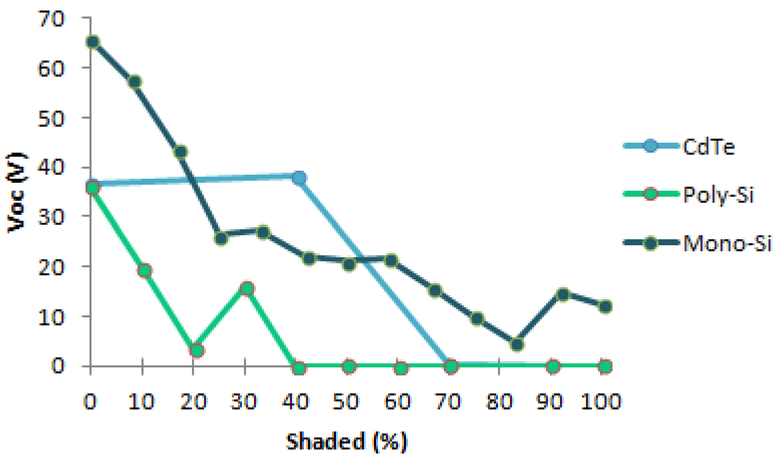

Figure 21. Effect of vertical shading on the VOC of the different types of solar cells

When vertical shaded, the CdTe panel doesn't lose voltage until about 40% shaded. This is in contrast to the Mono-Si and Poly-Si panel, which V_{OC} is affected immediately by the shading. The top from Poly-Si at 30% shading can't be explained by the $G_{Pyranometer}$ and the T_{Module}, which seem normal.

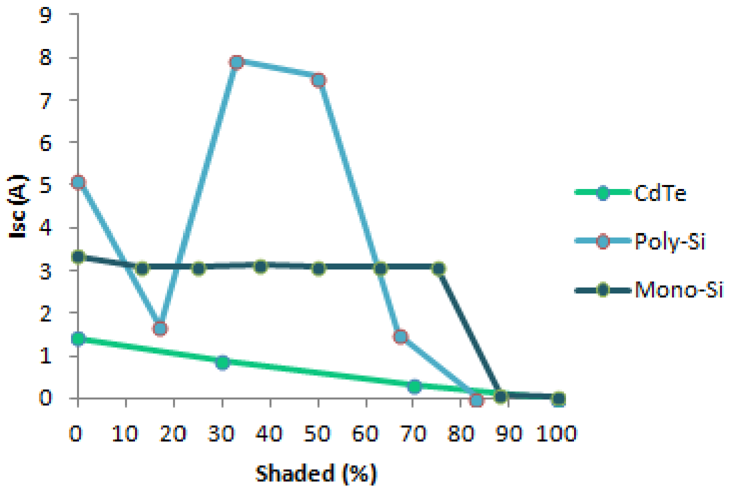

Figure 22. Effect of horizontal shading on the ISC of the different types of solar cells

Horizontal shading hasn't much influence on the I_{SC} of the CdTe panel and the Mono-Si panel until 70% shaded, then especially the I_{SC} from the Mono-Si panel decreases a lot. The low I_{SC} from the Poly-Si at 17 and 67% shading can be explained by the $G_{Pyranometer}$. The value of these is much lower than the $G_{Pyranometer}$ of the other points (194,1 and 215,4 instead of about 900). This means the weather conditions changed between these measurements and thus this line of Poly-Si isn't useful.

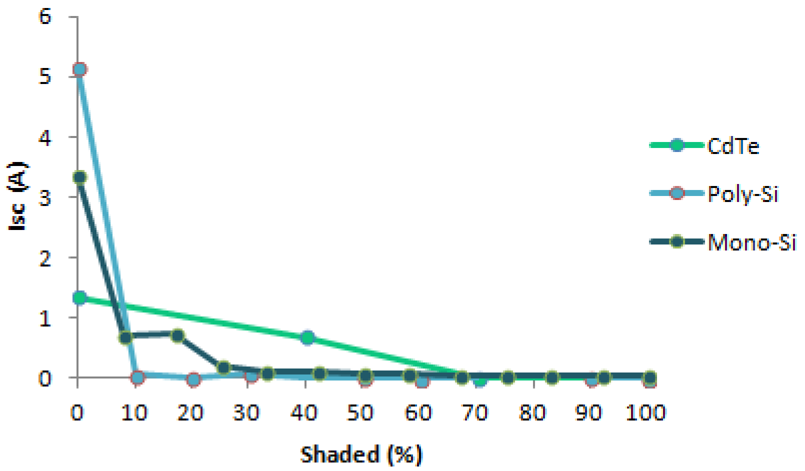

Figure 23. Effect of vertical shading on the ISC of the different types of solar cells

Vertical shading has directly a lot of influence on the I_{SC} of the Poly-Si and Mono-Si panels. The CdTe panel experiences less influence. The Poly-Si and Mono-Si panels have lost all their Short Circuit Current at 40% shading.

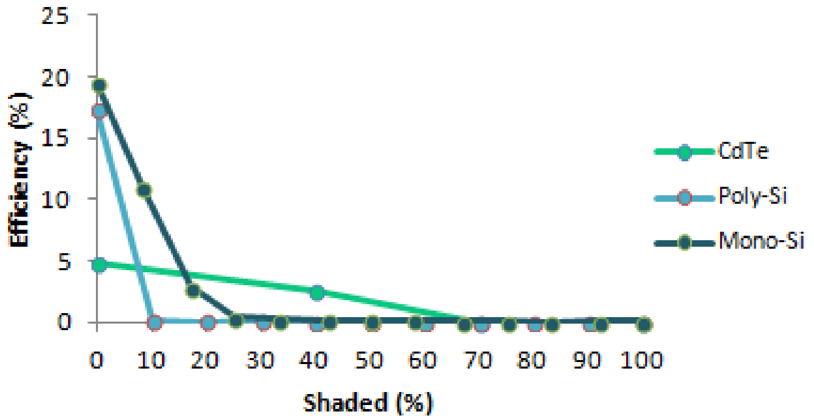

Figure 24. Effect of vertical shading on the efficiency

The efficiency of all solar panels is affected by shading.

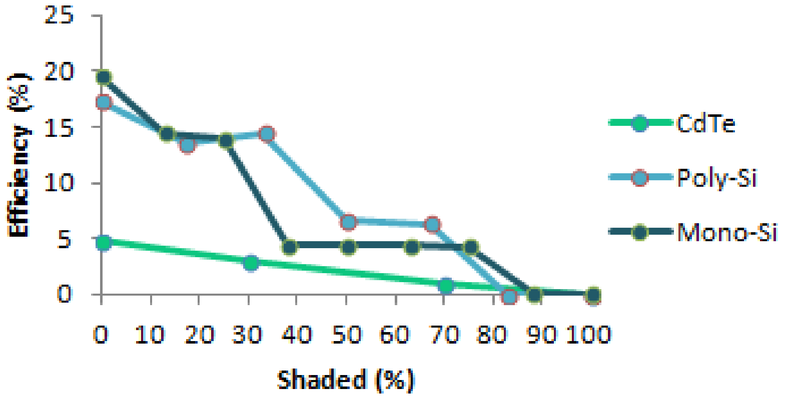

Figure 25. Effect of horizontal shading on the efficiency

The Poly-Si and Mono-Si cells are like stairs. The CdTe cell is more linear.

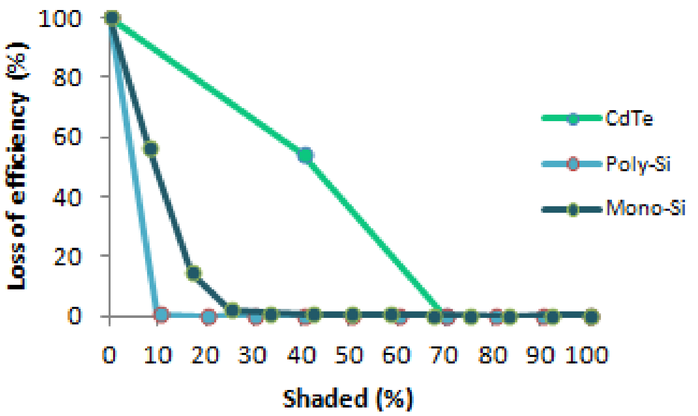

Figure 26. Loss of efficiency when vertical shaded

Shading has much more influence on the Poly-Si and Mono-Si cells than on the CdTe cells, which have still an efficiency above 0 till 70% shaded.

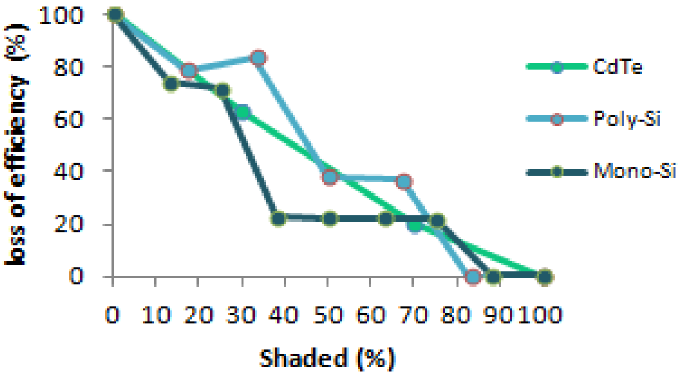

Figure 27. Loss of efficiency when horizontal shaded

When horizontal shaded, the different solar cells do react almost the same on the shading.

8 Conclusion

8.1 Without shading

The (I,V)-curves at the zero measurements (Figure 19), show which solar panel works the best. You can clearly see that the CdTe panel is worse than the other two because both the voltage and the current are lower. You can't really see the difference between the poly-Si and the mono-Si. The current with the Poly-Si is higher, but the voltage lower. In table 1 you can see the maximum power of the modules. Mono-Si has a higher maximum power than Poly-Si. The efficiency of the Mono-Si solar panel is also higher. This is in line with our literature study. (section 1.9)

8.2 With shading

8.2.1 Vertical shading

When the panels were shaded vertically, you can clearly see that the effect of shading on Poly-Si and Mono-Si is worse than CdTe. Especially Poly-Si has lost its efficiency fast, after only ten percent of vertical shading. (Figure 26)

When we look at Figure 24, with the total efficiency, Poly-Si and Mono-Si start out with the highest efficiency. Mono-Si has the highest efficiency when shaded vertically from 0 to 20 percent. From 20 to 70 percent, the efficiency of CdTe the highest, it is around 4 percent. After 70 percent of vertical shading, the panels produce hardly any power.

8.2.2 Horizontal shading

When shaded horizontally, a different effect occurred. The loss of efficiency was on all modules less than when shaded vertically. This can have several reasons. Firstly, the cells are connected in vertical groups. When we shade a column, only one group is affected. When we shade a row, however, all groups are affected, even though less. This is still worse than only one column so the performance of the solar panels are better when shaded horizontally. Secondly there are bypass diodes positioned on the top and bottom of the Poly-Si and Mono-Si panels. (verwijzing literatuuronderzoek). This can be seen in the stair shaped graph. At first, the efficiency decreases because of the shading. Then, a bypass diode starts working and skips the first group of solar cells which consists typically of a few columns. When you shade the second column also, which belongs to the same group as the first column, the efficiency won't decrease further because the group of these two columns was already skipped by the bypass diode. And this continues when you shade any further. With CdTe, no such pattern has been found, because it has no bypass diodes. (Figure 25)

Looking at the loss of efficiency (Figure 27), there is hardly any difference between the three modules. When you look at the total efficiency, however, you can clearly see that CdTe has an efficiency far lower than Poly-Si and Mono-Si. Thus when horizontally shaded, Poly-Si and Mono-Si are better.

8.3 Summary

Overall, our hypothesis was correct. At our measuring conditions, so without shading, Mono-Si is the best performing panel with an efficiency of 19.5 percent. Poly-Si is second, with an efficiency of 17.3 percent. CdTe is for below that, with an efficiency of 4.8 percent. Our research question was: *What is the influence of both horizontal and vertical shading on CdTe, Mono-Si and Poly-Si solar panels?* Shading vertically has less of a negative impact on CdTe than the other two panels, but horizontally there is not really a difference between the three. So CdTe reacts better on shading vertically, but in absolute numbers the efficiency is still low. Horizontally the three panels react about the same, but CdTe has a lower starting efficiency. So with that, we answered our research question.

9 Discussion

During our measurements the weather wasn't completely stable. It was mostly sunny but sometimes a cloud prevented us for a good measurement. To make sure this didn't affect our results, we did a lot of zero-measurements.

At one point during our measurements, abusively the solar panel wasn't completely covered, while it should have been. We expected that this didn't influence our results significantly, but of course it would have been more precise, had we covered the panel completely.

During our measurements, we covered the solar panels completely. We laid the wooden board directly on the panels. When doing this, you block all the light. In a real situation however, not all of the light would have been blocked. When for instance a chimney causes a shadow to fall on the solar panels, not all light would have been blocked. The direct light from the sun gets blocked, but you also have diffuse light. So, we didn't study all different kinds of shading.

We did want to use the measurements from the weather station, to explain any deviating measurements. The weather station unfortunately, wasn't available when we were measuring. So we weren't able to use the weather data to compare to our own measurements.

The solar panels we used for measurements weren't clean. Especially on the mono-Si solar panel laid a lot of dust, this could have affected our results (Figure 28). The glass from the CdTe panel, was broken. Because rain came into the panel, a part of the panel was destroyed. (Figure 28) This wasn't a very large part but it might have affected our results.

Figure 29. Broken CdTe solar panel

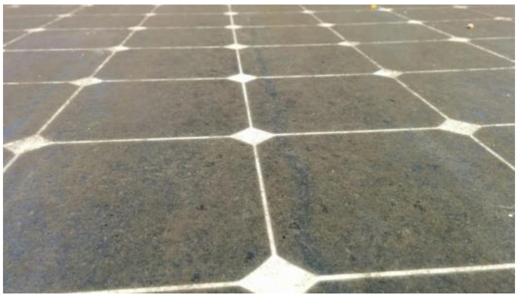

Figure 28. Dust on Mono-Si panel

Of course, our study would have been more precise, if we had been able to do more measurements. This especially holds for module 2, the CdTe panel.

9.1 Suggestions future research

When we shaded the panels, we stopped both the direct and the diffuse light. Maybe it is interesting to find out what would happen to the (I,V)-curves and efficiency when only stopping the direct light was stopped. Another option would be to shade not the entire solar cell, but only half of it, for example.

10 Sources

1. Alternative Energy. Common types of solar cells. Used on 16-09-16, from http://www.altenergy.org/renewables/solar/common-types-of-solar-cells.html

2. Bokalič, M; Topič, M (2015). Spatially Resolved Characterization in Thin-Film Photovoltaics.

3. Dalen van, A (2016). Bypass diodes for solar panels. Used on 5-11-2016, from http://www.avdweb.nl/tech-tips/pv-panels/bypass-diodes.html

4. E2Energie (2012). Bypass diodes in zonnepanelen. Used on 18-10-16, from http://www.e2energie.nl/bypass-diodes-zonnepanelen

5. Electrical4u (2016). Working principle and types of diode. Used on 5-11-2016, from http://www.electrical4u.com/diode-working-principle-and-types-of-diode/

6. Elmes, S (2015). What's the difference between polycrystalline and monocrystalline solar panels? Used on 13-11-2016, from http://www.yougen.co.uk/blog-entry/2521/What'27s+the+difference+between+polycrystalline+and+monocrystalline+solar+panels'3F/

7. Encyclopaedia (2016). Photovoltaic effect. Used on 21-09-16, from https://www.britannica.com/science/photovoltaic-effect

8. Honsberg, C; Bowden, S. PV Education, from http://pveducation.org/

9. IOP, date unknown. How do solar cells work?. Used on 5-11-2016, from http://www.physics.org/article-questions.asp?id=51

10. Queen Mary University of London. date unknown. The Shockley-Queisser limit. Used on 15-10-16, from http://ph.qmul.ac.uk/sites/default/files/u75/Solar%20cells_environmental%20impact.pdf

11. Sargosis Solar & Electric. How shade affects a solar array. Used on 17-10-16, from http://sargosis.com/how-shade-affects-a-solar-array/

12. Solar facts. date unknown. Blocking and By-Pass diodes in solar panels. Used on 19-10-16, from http://www.solar-facts.com/panels/panel-diodes.php

10.1 Sources figures

Figure 1: http://pvcdrom.pveducation.org/SEMICON/SEMICON.HTM

Figure 2: http://solarcellcentral.com/junction_page.html

Figure 3: http://www.universetoday.com/87943/absorption-of-light/

Error! Reference source not found.: http://www.electrical4u.com/diode-working-principle-and-types-of-diode/

Figure 5 : http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html

Figure 6 : http://openwetware.org/wiki/20.309:DiodePrimer

Figure 77: http://www.digikey.com/en/articles/techzone/2011/nov/optimal-power-management-techniques-in-energy-harvesting-designs

Figure 8: http://openwetware.org/wiki/20.309:DiodePrimer

Figure 9: https://en.wikipedia.org/wiki/Shockley%E2%80%93Queisser_limit

Figure 10: http://www.solarcloset.com/understanding-solar-equipment/difference-between-monocrystalline-polycrystalline-and-amorphous-thin-film-solar-cell/

Figure 1011: http://www.solarcloset.com/understanding-solar-equipment/difference-between-monocrystalline-polycrystalline-and-amorphous-thin-film-solar-cell/

Figure 1112: http://www.solarcloset.com/understanding-solar-equipment/difference-between-monocrystalline-polycrystalline-and-amorphous-thin-film-solar-cell/

11 Logboek

31-5-2016	L&S	Gesprek met De Nijs	2x60	120
5-6-2016	L	PWS deel 1	120	120
4-6-2016	S	PWS deel 1 en inlezen literatuur	60	60
6-6-2016	S	PWS deel 1	50	50
6-6-2016	L	inlezen literatuur	30	30
7-6-2016	L&S	Afspraak mr Mann	2x30	60
1-7-2016	L&S	PWS 1 bespreken	2x45	90
4-7-2016	L&S	PWS 1 verbeteren	2x160	320
1-9-2016	S	Pyton leren programmeren	180	180
3-9-2016	S	Python leren programmeren	210	210
4-9-2016	L	Python leren programmeren	290	290
5-9-2016	L	Python leren programmeren	90	90
7-9-2016	L	Grafieken leren maken	270	270
9-9-2016	L	Grafieken leren maken (DJIA)	100	100
11-9-2016	S	Grafieken leren maken	60	60
16-9-2016	L&S	Gesprek met Benjamin en co	2x90	180
17-9-2016	S	Literatuur onderzoek	150	150
20-9-2016	L&S	Literatuur onderzoek	2x240	480
23-9-2016	L	Literatuuronderzoek	90	90
23-9-2016	S	Literatuuronderzoek	135	135
27-9-2016	L	Literatuuronderzoek	235	235
28-9-2016	L	Bronnen zoeken	25	25
4-10-2016	L&S	Onderzoek op Amolf	2x250	500
5-10-2016	L	Anaconda & Literatuuronderzoek	120	120
6-10-2016	S	Anaconda & Literatuuronderzoek	125	125
7-10-2016	L	Gegevens analyse	190	190
8-10-2016	L	Gegevens analyse	160	160
10-10-2016	S	Literatuuronderzoek	240	240
14-10-2016	L	Excel	60	60
17-10-2016	L	Verbeteren literatuuronderzoek	240	240
18-10-2016	L&S	Alles een beetje	2x360	720
19-10-2016	L&S	Resultaten verwerken	2x620	1040
20-10-2016	L&S	Conclusie	2x380	760
22-10-2016	S	Afwerken eerste versie	245	245
23-10-2016	L	Afwerken eerste versie	320	320
29-10-2016	S	Bronnen ordenen en aanvullen	120	120
5-11-2016	L&S	Verslag verbeteren	2x120	240
6-11-2016	L	Verbetering & afronding	440	440
13-11-2016	L&S	Verbetering & afronding	2x210	420
Total (hours)				140,4166667

12 Appendix

12.1 Module 2 – CdTe

Station no.	Shaded [%]	Date	Time	Vmpp [V]	Impp [A]	Pmpp [W]	Voc [V]	Isc [A]	FF [%]	G [W/m²]	Tmodul [°C]	G_pyranoı [W/m²]	V Range	I Range	Scan Rate [S/sec.]	Efficiency [%]	Efficiency max [%]
↔																	
2	100	04.10.2016	11:52:03	-0,019	-0,0021	0	0,028	0,0002	871,6	738,7	25,5	763,7	2	0	800	0	0
2	70	04.10.2016	11:54:03	0,157	0,0064	0,001	0,024	0,0041	1010,1	736,9	26,1	763	2	0	800	0,00013106	0,00272813
2	40	04.10.2016	11:56:03	38,039	0,5289	20,12	49,694	0,6926	58,5	742,9	27,1	768,3	2	0	800	2,61876871	54,5113164
2	0	04.10.2016	11:58:03	36,507	1,025	37,419	50,571	1,3495	54,8	752,6	28,2	778,9	2	0	800	4,80408268	100
↔																	
2	100	04.10.2016	12:00:03	0,077	0,0007	0	0,044	0,0001	2072,6	764,7	27,7	790,5	2	0	800	0	0
2	70	04.10.2016	12:02:03	35,056	0,2186	7,663	46,21	0,3218	51,5	756,9	28,8	783	2	0	800	0,97867178	20,37166802
2	30	04.10.2016	12:04:03	35,676	0,6589	23,509	49,4	0,8622	55,2	749,5	29,3	778,9	2	0	800	3,01823084	62,82637163
2	0	04.10.2016	12:06:03	36,607	1,0758	39,38	50,811	1,4157	54,7	789,7	28,5	816,6	2	0	800	4,82243448	100,3820043

12.2 Module 3 – Poly-Si

Station n	Shaded	Date	Time	Vmpp	Impp	Pmpp	Voc	Isc	FF	G	Tmodul	G_pyranc	V Range	I Range	Scan Rat	Efficiency	Efficiency maximum
	[%]			[V]	[A]	[W]	[V]	[A]	[%]	[W/m²]	[°C]	[W/m²]			[S/sec.]	[%]	[%]
↕																	
3	100	04.10.201	12:10:08	0,086	0,0138	0,001	0,062	0,0009	2021	770,3	25	797,3	1	2	3200	0,00012542	0,00073
3	90	04.10.201	12:12:08	0,036	0,0087	0	0,026	0,01	118,9	785,9	24,8	813,8	1	2	3200	0	0
3	80	04.10.201	12:14:08	-0,033	-0,0066	0	-0,027			778,4	25,4	803,4	1	2	3200	0	0
3	70	04.10.201	12:16:08	0,067	0,0143	0,001	0,023	-0,006	-675,3	785,9	26,2	811,8	1	2	3200	0,00012318	0,00071
3	60	04.10.201	12:18:08	0,055	0,0076	0	0,008	0,0009	6235,4	808,9	26,6	836,1	1	2	3600	0	0
3	50	04.10.201	12:20:08	0,08	0,0153	0,001	0,053	0,0087	261,9	794,9	27,7	822	1	2	3200	0,00012165	0,00071
3	40	04.10.201	12:22:08	0,086	0,0158	0,001	0,01	-0,0005	-25110,2	815,6	26,6	841,3	1	2	3600	0,00011886	0,00069
3	30	04.10.201	12:24:08	16,188	0,0474	0,767	16,154	0,095	50	823,5	26,4	851,2	1	2	3600	0,09010808	0,52228
3	20	04.10.201	12:26:08	3,665	0,0285	0,105	3,637	0,0219	131,5	841,3	27,3	864,4	1	2	3600	0,01214715	0,07041
3	10	04.10.201	12:28:08	19,407	0,0596	1,157	19,725	0,0704	83,3	887,7	28,5	915,2	1	2	3600	0,12642045	0,73276
3	0	04.10.201	13:42:08	30,141	4,7451	143,025	36,106	5,1486	76,9	628,6	23,4	829	1	1	2800	17,2527141	100
↔																	
3	1 cell	04.10.201	13:41:08	19,352	5,2642	101,873	36,055	5,5016	51,4	681,6	22,6	845,6	1	2	3600	12,0474219	69,8291
3	2 cell	04.10.201	13:43:09	19,695	3,9655	78,101	31,055	4,2727	58,9	526	24	725,2	1	1	2800	10,7695808	62,4225
3	3 cell	04.10.201	13:45:13	9,054	1,6069	14,548	26,13	1,7098	32,6	215,3	22,5	223,4	1	0	1200	6,51208594	37,7453
3	1 cell	04.10.201	13:47:13	19,448	2,1577	41,962	32,954	2,2855	55,7	288,3	22,1	289,8	1	0	1200	14,4796411	83,9267
3	2 cell	04.10.201	13:49:13	19,08	2,1632	41,274	34,771	2,2815	52	283,1	23	279,8	1	0	1200	14,7512509	85,501
3	3 cell	04.10.201	13:51:07	9,316	6,9075	64,347	25,59	7,662	32,8	934,4	23,8	961,7	1	2	4000	6,69096392	38,7821
3	0	04.10.201	13:42:08	30,141	4,7451	143,025	36,106	5,1486	76,9	628,6	23,4	829	1	1	2800	17,2527141	100
↔																	
3	100	04.10.201	12:10:08	0,086	0,0138	0,001	0,062	0,0009	2021	770,3	25	797,3	1	2	3200	0,00012542	0,00073
3	83	04.10.201	13:56:08	1,406	0,027	0,038	1,38	0,024	114,6	877,5	27,4	908,2	1	2	3600	0,0041841	0,02425
3	67	04.10.201	14:04:43	8,663	1,4207	12,308	10,607	1,4928	77,7	184,1	24,8	194,1	1	0	800	6,34106131	36,754
3	50	04.10.201	14:00:08	8,735	6,932	60,549	11,619	7,5453	69,1	886,1	24,4	916,8	1	2	3600	6,60438482	38,2803
3	33	04.10.201	14:07:38	19,275	7,2383	139,521	23,997	7,9236	73,4	948,9	22,7	967,8	1	2	4000	14,416305	83,5596
3	17	04.10.201	14:10:43	18,781	1,5587	29,273	22,288	1,6808	78,1	206,2	21,9	215,4	1	0	1200	13,590065	78,7706
3	0	04.10.201	13:42:08	30,141	4,7451	143,025	36,106	5,1486	76,9	628,6	23,4	829	1	1	2800	17,2527141	100

12.3 Module 4 – Mono-Si

Station n	Shaded	Date	Time	Vmpp	Impp	Pmpp	Voc	Isc	FF	G	Tmodul	G_pyran	V Range	I Range	Scan Ra	Efficienc	Efficiency maximum
	[%]			[V]	[A]	[W]	[V]	[A]	[%]	[W/m²]	[°C]	[W/m²]			[S/sec.]	[%]	[%]
4	100	04.10.2016	14:17:11	12,385	0,0418	0,518	12,57	0,0452	91,1	863,1	31,2	890,9	2	1	3600	0,0581	0,2987
4	92	04.10.2016	14:18:11	14,556	0,0477	0,694	14,765	0,0545	86,2	836,6	31,1	867,8	2	1	3600	0,08	0,4108
4	83	04.10.2016	14:19:11	4,72	0,055	0,26	4,735	0,0532	103,1	874,6	31,7	902,5	2	1	3600	0,0288	0,148
4	75	04.10.2016	14:20:11	9,951	0,0621	0,618	10,102	0,0629	97,2	784,5	32,3	852,8	2	1	3200	0,0725	0,3723
4	67	04.10.2016	14:21:11	15,773	0,056	0,883	15,832	0,0553	100,8	712,7	33,1	866,4	2	1	3200	0,1019	0,5236
4	58	04.10.2016	14:22:11	21,817	0,0777	1,696	21,846	0,0868	89,4	934,1	32,8	964,6	2	1	4000	0,1758	0,9033
4	50	04.10.2016	14:23:11	21,38	0,0741	1,583	21,183	0,0829	90,2	934,6	33,7	960,5	2	1	4000	0,1648	0,8467
4	42	04.10.2016	14:24:11	22,054	0,0723	1,595	22,163	0,1055	68,3	908,5	34,7	941,3	2	1	4000	0,1694	0,8705
4	33	04.10.2016	14:25:11	27,455	0,0794	2,181	27,523	0,1203	65,8	858,3	34,5	863	2	1	3600	0,2527	1,2983
4	25	04.10.2016	14:26:17	26,408	0,0515	1,361	26,416	0,2159	23,9	284,1	33,1	308,8	2	0	1200	0,4407	2,2642
4	17	04.10.2016	14:28:17	13,952	0,4304	6,005	43,583	0,7405	18,6	202,7	31	210,2	2	0	1200	2,8568	14,676
4	8	04.10.2016	14:30:22	32,063	0,6095	19,543	57,732	0,6993	48,4	171	27,6	176,6	2	0	800	11,066	56,851
4	0	04.10.2016	14:54:11	59,515	2,6463	157,49	65,605	3,3507	71,6	782,1	30,3	809,1	2	1	3200	19,465	100
↔																	
4	100	04.10.2016	14:36:16	11,165	0,0364	0,407	11,159	0,0385	94,6	788,3	28,4	685,7	2	1	3200	0,0594	0,3049
4	88	04.10.2016	14:38:11	14,341	0,0381	0,547	14,445	0,0651	58,2	802,4	28,4	827,4	2	1	3600	0,0661	0,3396
4	75	04.10.2016	14:39:11	13,39	2,6355	35,291	17,363	3,0986	65,6	798,3	27,9	824,7	2	1	3200	4,2793	21,984
4	63	04.10.2016	14:40:11	12,841	2,8122	36,113	18,313	3,0899	63,8	795,7	27,4	822,4	2	1	3200	4,3912	22,559
4	50	04.10.2016	14:41:11	12,668	2,8012	35,486	18,203	3,0835	63,2	792,4	26	819	2	1	3200	4,3328	22,259
4	38	04.10.2016	14:42:11	13,127	2,8024	36,788	44,738	3,1392	26,2	806	26,1	832,9	2	1	3600	4,4169	22,691
4	25	04.10.2016	14:43:11	44,426	2,5766	114,47	53,219	3,0993	69,4	795,3	25,8	822,9	2	1	3200	13,911	71,463
4	13	04.10.2016	14:44:11	43,967	2,6893	118,24	57,117	3,0879	67	789,3	26,1	820	2	1	3200	14,42	74,078
4	0	04.10.2016	14:54:11	59,515	2,6463	157,49	65,605	3,3507	71,6	782,1	30,3	809,1	2	1	3200	19,465	100
↔																	
4	0	04.10.2016	14:54:11	59,515	2,6463	157,49	65,605	3,3507	71,6	782,1	30,3	809,1	2	1	3200	19,465	100
4	1 cell	04.10.2016	14:46:11	56,156	2,6367	148,07	65,913	3,1679	70,9	802,8	26,8	828,6	2	1	3600	17,87	91,804
4	2 cell	04.10.2016	14:47:11	52,422	2,5126	131,72	65,604	3,1054	64,7	789,9	27,9	821,5	2	1	3200	16,033	82,369
4	3 cell	04.10.2016	14:48:11	44,847	2,7553	123,57	65,387	3,2173	58,7	825,8	28,6	845,1	2	1	3600	14,621	75,115
4	4 cell	04.10.2016	14:49:11	40,891	2,8191	115,27	65,229	3,2557	54,3	847,2	29,1	872,6	2	1	3600	13,21	67,866
4	5 cell	04.10.2016	14:50:11	40,335	2,7367	110,39	65,119	3,2464	52,2	833,9	29,7	862,1	2	1	3600	12,804	65,78
4	6 cell	04.10.2016	14:51:11	36,469	2,7247	99,368	64,839	3,2107	47,7	820,5	30,3	848,5	2	1	3600	11,711	60,163
4	7 cell	04.10.2016	14:52:11	30,888	2,7998	86,479	59,751	3,0391	47,6	780	30,1	804,8	2	1	3200	10,745	55,203
4	8 cell	04.10.2016	14:53:11	27,308	2,7438	74,926	61,393	3,0287	40,3	776,8	29,8	811,8	2	1	3200	9,2296	47,416