Solar cell

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1 Introduction

A solar cell is an electrical device that generates electricity by the photovoltaic effect. Upon exposure to illumination, the device creates voltage, which in turn gives rise to an electric current. Solar cells are becoming increasingly common as an alternative source of electricity.

A solar cell can be described as a $p-n$ junction, which is an interface between p-type material (acceptors) and n-type material (donors) inside a semiconductor. Electrons will diffuse from the n-side to the p-side, while holes will diffuse from the p-side to the n-side. At the same time, an electric field comes into existence between the diffused electrons at the p-side and the diffused holes at the n-side. Whereas the diffusion force pulls electrons to the n-side and holes to the p-side, the force from the built-in electric field will pull both electrons and holes in the opposite direction, counteracting the diffusion. Sooner or later the forces will be equal, and an equilibrium is established.

Free electron-hole pairs can be generated in a semiconductor when it is exposed to light with sufficient energy to excite electrons to the conduction band. If this happens close enough to the interface between the two sides, the electron and hole will feel the built-in electric field, and will consequently be swept in different directions. When the sides are short-circuited, electrons will flow from the n-side to the p-side to recombine with the holes. This is how solar cells generate an electric current. Note that the direction is the opposite of a diode, because we have minority carriers instead of majority carriers.

2 Experimental procedure

We used a thin-film polycrystalline silicon solar cell in this laboratory. By Kittel, the band gap of silicon is $E_g = 1.11$ eV at $T = 300$ K. It follows that the minimum frequency needed for a monochromatic light source is

$$\nu_g = \frac{E_g}{h} = 2.68 \cdot 10^{14} \text{ Hz},$$

which corresponds to the wavelength 1100 nm, which lies in the infrared spectrum. Thus, visible light will be able to drive the solar cell.

Distance [cm]	P_{max} [W]
12.5	0.07983
17.5	0.05617
22.5	0.04975
27.5	0.04169
32.5	0.03914
37.5	0.03278
42.5	0.02902
47.5	0.02727
52.5	0.02393
57.5	0.02159
62.5	0.02100

Table 1: Maximum power for different distances

A Power Cassy was used to apply a selected voltage over the solar cell and measure the current output. The Power Cassy acted as an ideal voltage source. The area of the solar cell was 2.3 cm $\times$ 6.0 cm. The solar cell was placed under the light source, a 60 W desk lamp, at distances varying between 12.5 cm and 62.5 cm.

We first made a measurement with the lamp turned off and observed that the current was next to zero, as expected; see figure 1 for reference. We next performed a measurement with the lamp turned on and observed a sine curve. This was also expected, since a standard wall outlet outputs an alternating current.

We now set the Power Cassy to produce triangular waves with amplitude 57 V and frequency 0.2 Hz. Once again, we made measurements with the lamp turned off and then with the lamp turned on. We averaged the current I_{av} over 10 ms to eliminate the sine like curve due to the wall outlet.

We finally measured the power delivered from the solar cell for each of the eleven distances using the relation $P = I_{av} \cdot U$. The power delivered to the surface of the solar cell should theoretically depend on the table-to-lamp distance d by means of the formula $P(d) = \frac{P_0}{(d/d_0)^2}$, where P_0 is a reference value at distance d_0. We later contemplated the maximal power, which depends on the total radiative power received.

3. The ideality factor can be found, which should be 1 for an ideal diode. Fit to the diode equation $I = I_{sat}\left(1 - \exp\left(-\frac{eV}{nk_BT}\right)\right)$, where n is the ideality factor.

3   Measurement results

In figure 1, least square fitting gave the values $I_{sat} = 1.78 \cdot 10^{-6}$ A and $V_0 = 0.0498$ V in the diode equation giving the ideal factor $n = \frac{eV_0}{k_BT} = 1.9$.
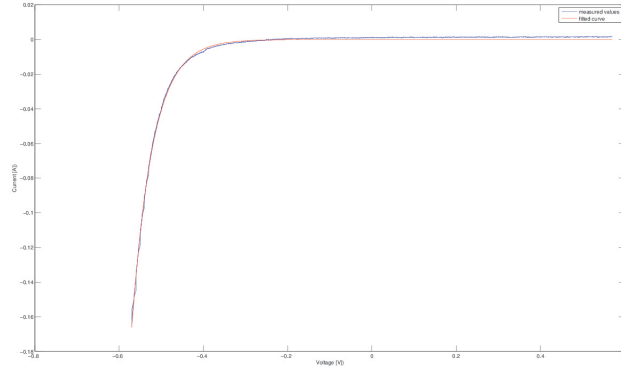
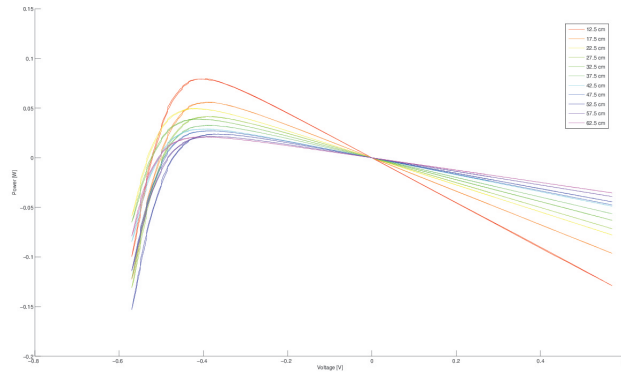Figure 1: Current as function of voltage. Fitted according to the diode equation.

Figure 2: Power as function of voltage for different distances from lamp to solar cell.

4   Discussion of the results and conclusions

The power delivered to the solar cell should of course satisfy $4\pi R^2 \Phi = P$, where P is the effect. (We measured the maximal effect P_{max}). Hence, if we fit the curve according to the formula $P_{max} = kf(d)/f(0)$, where k is a proportional constant, $f(d) = \frac{1}{(d+x_0)^2}$ and d the distance from the lamp to the solar cell, we should obtain something that is linear, see figure 4. We introduced x_0 in order to compensate for systematic errors and found that $k = 1.76 \cdot 10^{-6}$ Wm^2 and $x_0 = 4.98$ cm, however some differences still remain; some possibly arising from the fact that the lamp is not a perfect sphere.

As a way to check the results, consider the following: Approximate the solar cell together with the Power Cassy as a simple circuit, where the solar cell and the Power Cassy has resistance R_0 and R, respectively. By Ohm's law, we know
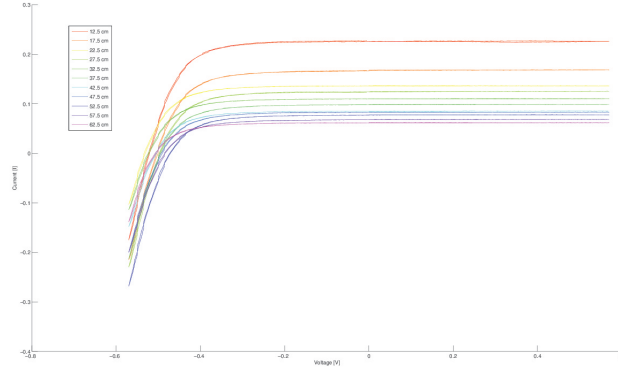
Figure 3: Current as function of voltage for different distances from lamp to solar cell.
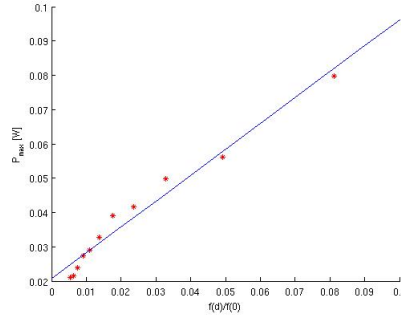

Figure 4: Current as function of voltage for different distances from lamp to solar cell.

that $U = RI$ and $P = IR^2$. Then, since $U_0 = (R + R_0)I$, it follows that $P = RI^2 = R\left(\frac{U_0}{R+R_0}\right)^2$. The voltage at maximum power it therefore given by

$$0 = \frac{dP}{dR} = -\frac{U_0^2(R - R_0)}{(R + R_0)^3} \iff R = R_0.$$

In this case, the voltage is also maximal and given by $U_{max} = R_0 I = R_0 \frac{U_0}{R_0 + R_0} = \frac{U_0}{2}$. From figure 2, we see that $U_{max} \approx -0.4$ V and from figure 3, we see that $U_0 \approx -0.5$ V, which does not at all agree with theory. So either the model is too crude or our values are bad.

The most ideal solar cells are of course those whose energy gap coincide with the sun. Now, from theory, we know that the maximum efficiency is given by $E_g/(k_B T) \approx 2.3$ and since the temperature of the photosphere is approximately 5800 K, the best solar cells are those with an energy gap of around 1.15 eV. Our solar cell with an energy gap of around 1.11 eV at 300 K is therefore an excellent choice.

4

We considered a 60 W light bulb with an effective temperature of around 3000 K. This implies that $E_g/(k_B T) \approx 4.3$, so that theory gives us an upper limit on the efficiency to be 25%. Obviously, we do not reach 25%, in fact, it is considerably lower as the following shows: The area of the solar cell was 13.8 cm^2 and as a rough approximation, assume that the wavelength of the 60 W light bulb is 1100 nm. Then elementary physics implies that it emits approximately $3.3 \cdot 10^{20}$ photons per second. Assuming that they are distributed spherically and perfectly aligns with the solar cell, at a distance of 37.5 cm, $13.8/(4\pi 37.5^2) \approx 7.8 \cdot 10^{-4}$ of the photons hit the solar cell per second. Thus, the efficiency is

$$\frac{7.8 \cdot 10^{-4} \cdot 3.3 \cdot 10^{20} \cdot 6.6 \cdot 10^{-34} \cdot 3 \cdot 10^8}{1100 \cdot 10^{-9} \cdot 0.033} \approx > 1 WRONG!!!!$$

We also note that our methodology was not free of errors. We approximated the distribution of the light from the lamp as spherical, while in reality a lampshade focused the light into a cone.