Háskóli Íslands
Rafmagns- og tölvuverkfræði

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Junction Capacitance and Solar Cell

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1 Introduction

In the depletion layer of a junction diode forms a certain charge when voltage is applied. This is called *junction capacitance* and depends on the bias voltage applied to the diode.

When light hits the pn junction of a semi-conductor the absorbed photon energy releases an electron from the n-type region and moves it to the p-type filling a hole and creating a current. The field of research related to solar cells is known as photovoltaics.

2 Instrument setup

2.1 Measurement of capacitance

A digital LCR meter was used to measure the capacitance of the junction of the diode.

2.2 Measurement of capacitance by injection

We connected an Oscillator to a diode and resistance in series. One channel of a digital oscilloscope showed us the original square wave of the power supply and another channel showed the voltage over the resistance. From the oscilloscope we were able to obtain values needed to calculate the lifetime of minority carriers in the diode.

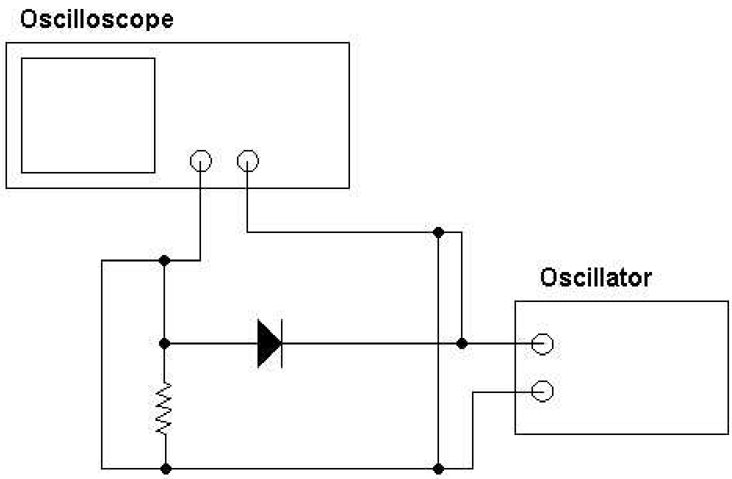

Figure 1: Measurement of capacitance by injection

2.3 Measurement of solar cells

A variable resistance was connected to a solar cell. A voltmeter was used to find the voltage the solar cell generates over the load resistance.

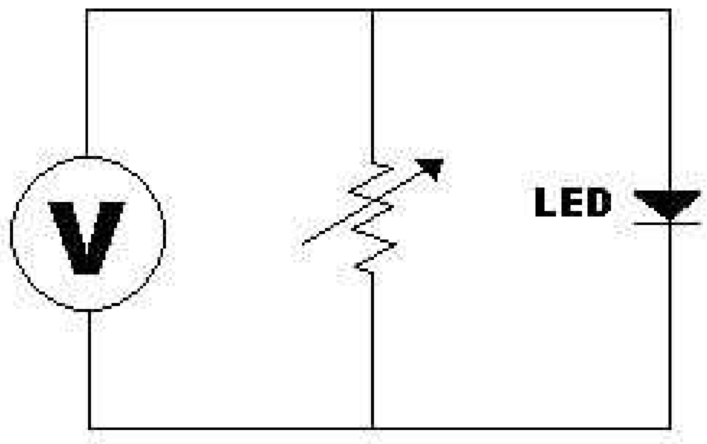

Figure 2: Measurements with solar cell

3 Theory

3.1 Junction Capacitance

The capacitance of a p-n junction is described by

$$C_j = \varepsilon A \left(\frac{q}{2\varepsilon \left(V_0 - V \right)} \cdot \frac{N_d N_a}{N_d + N_a} \right)^{1/2} \tag{1}$$

where W is the width of the depletion layer, A the junction area, V_0 the contact potential, V the bias voltage applied over the diode, N_d the donor concentration, N_a the acceptor concentration. By rewriting and squaring both sides we have:
The width, W, of the depletion layer is

$$W = \left(\frac{2\varepsilon V_0}{q} \left(\frac{N_a + N_d}{N_a N_d} \right) = \frac{2\varepsilon V_0}{q} \left(\frac{1}{N_a} + \frac{1}{N_d} \right) \right)^{1/2} \tag{2}$$

If we want to calculate W and we only know one of two, donor or acceptor concentration, we can assume that either $N_a \gg N_d$ or $N_a \ll N_d$. Our selection of which constant is significantly greater depends solely on how our sample is doped. The relation between $N_{a/d}$ and W is

$$\frac{1}{N_a} + \frac{1}{N_d} = \frac{W^2 q}{2\varepsilon V_0} \tag{3}$$

If we assume that $N_d \gg N_a$ for the Schottky diode we get

$$N_d = \frac{2\varepsilon V_0}{W^2 q} \tag{4}$$

3.2 Injection Capacitance

The relation between storage delay time t_{sd}, lifetime of excess carriers τ_p, and the currents I_f and I_r, the forward and reverse currents, respectively, is

$$t_{sd} = \tau_p \ln\left(1 + \frac{I_f}{I_r}\right) \tag{5}$$

Ohm's law states that $V = IR$ and if the resistance is constant we can rewrite this as

$$t_{sd} = \tau_p \ln\left(1 + \frac{V_f}{V_r}\right) \tag{6}$$

Rewriting for τ_p gives

$$\tau_p = \frac{t_{sd}}{\ln\left(1 + \frac{V_f}{V_r}\right)} \tag{7}$$

3.3 Solar cell

The maximum power from a solar cell is

$$P_{\max} = I_m \cdot V_m \tag{8}$$

where I_m and V_m are the values of current and voltage that give us the greatest power. The fill factor, ι, is defined by

$$\iota = \frac{P_{ideal}}{V_m \cdot I_m} \tag{9}$$

where $P_{ideal} = I_{max} \cdot V_{max}$.

4 Measurements and results

4.1 Measurement of capacitance

A digital LCR meter was used to measure capacitance as function of voltage for three types of diodes, two *pn*-diodes and one Schottky diode. We used our measurements to plot a graph of $\frac{1}{C^2}$ as a function of V. We then calculated a trend line through the first data points on the curve before it started to curve.

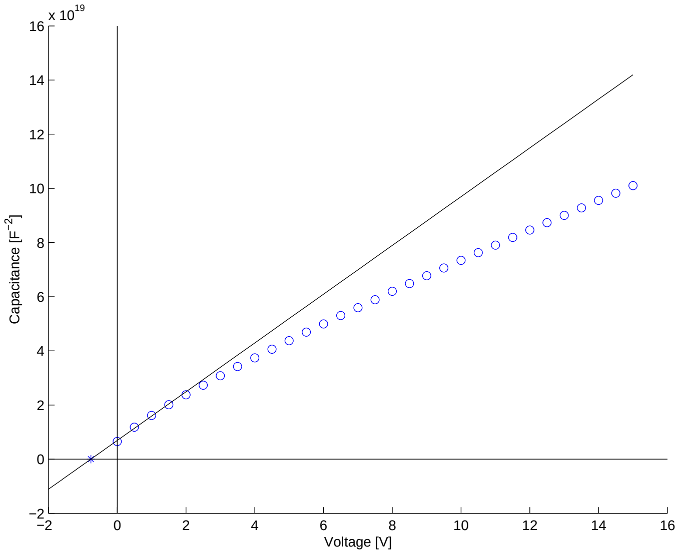

Figure 3: $\frac{1}{C_j^2}$ as a function of V for *pn*-diode # 1

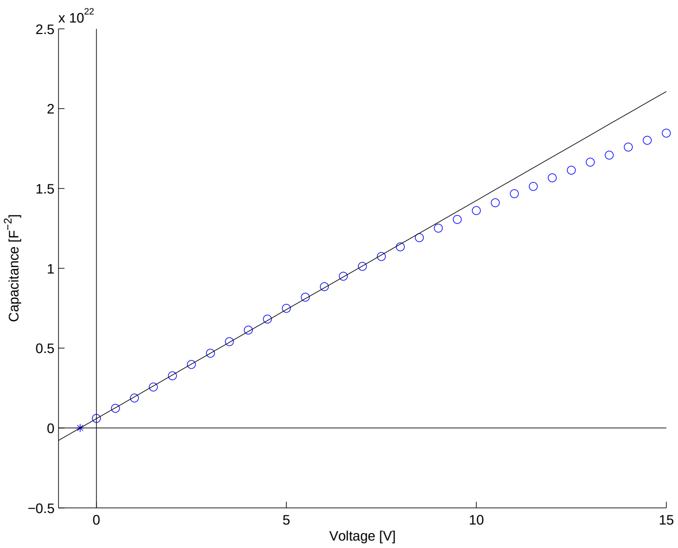

Figure 4: $\frac{1}{C_j^2}$ as a function of V for *pn*-diode # 2

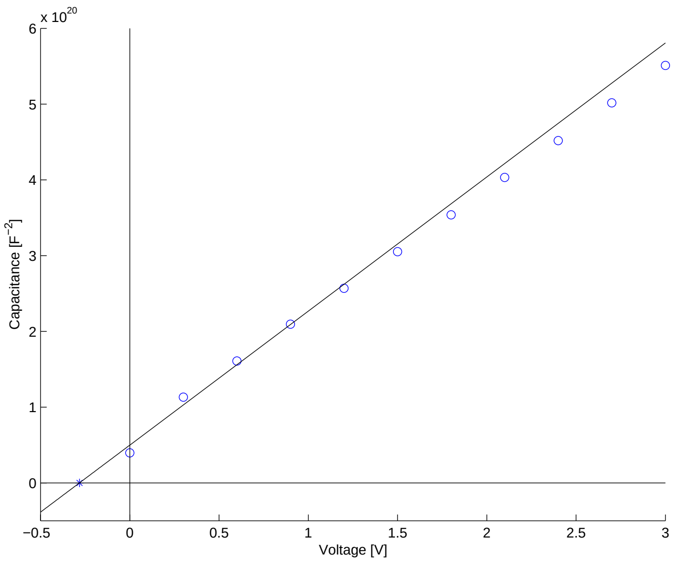

Figure 5: $\frac{1}{C_j^2}$ as a function of V for Schottky diode

Table 1: *Values of* V_0 *for three types of diodes, also,* W *and* N_d *for the Schottky diode.*

	$V_0[V]$	$W[\mu m]$	$N_d\ [cm^{-3}]$
pn-diode [#] 1	0.7655	-	-
pn-diode [#] 2	0.4272	-	-
Schottky diode	0.2815	15	$1.689 \cdot 10^{12}$

4.2 Capacitance by injection

The storage delay time, t_{sd}, was measured by inspecting the image on the scope's monitor. The image was very much like figure $5-29b$ in [1]. We needed three sets of different values for each diode we tested. To do that we varied the resistance connected to the diode.
We were unable to measure t_{sd} for the Schottky diode simply because the oscilloscope didn't have enough resolution to measure the storage delay time.

Table 2: *Values of* V_f, V_r, t_{sd} *and* τ_p *for pn-diode # 1*

$V_f[V]$	$V_r[V]$	$t_{sd}[\mu s]$	$\tau_p[\mu s]$
10	11.4	3.68	5.84
5.2	6.4	3.44	5.78
8.6	10	3.52	5.67

Table 3: *Values of V_f, V_r, t_{sd} and τ_p for pn-diode # 2*

$V_f[V]$	$V_r[V]$	$t_{sd}[\mu s]$	$\tau_p[\mu s]$
10	11.8	7.68	12.51
7.6	9	8.16	13.33
4.8	6	7.64	12.99

From these tables we see that the value of carrier lifetime τ_p does not change though we alter the resistance, frequency or the amplitude of the voltage. From that we conclude that the carrier lifetime is a property of the diode itself, and is constant.

4.3 Solar cell

Excitation by light source causes current to run in the solar cell, and when we connected a load to the solar cell a voltage was generated. The voltage originating from the solar cell was measured over different values of resistance. We use two types of light source; ordinary room light and a desk lamp at two distances, $15cm$ and $30cm$. Our measurements enabled us to calculate both the maximum power from the cell and the fill factor ι. The results of the measurements were plotted and the values of current and voltage that maximize the power, I_m and V_m, were found by iteration in Matlab.

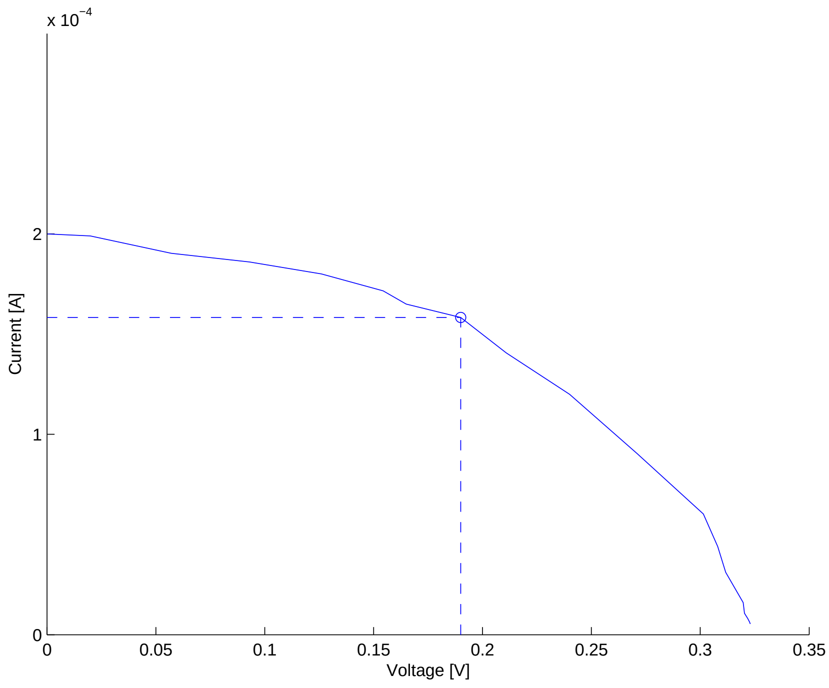

Figure 6: I vs. V for solar cell excited by room light

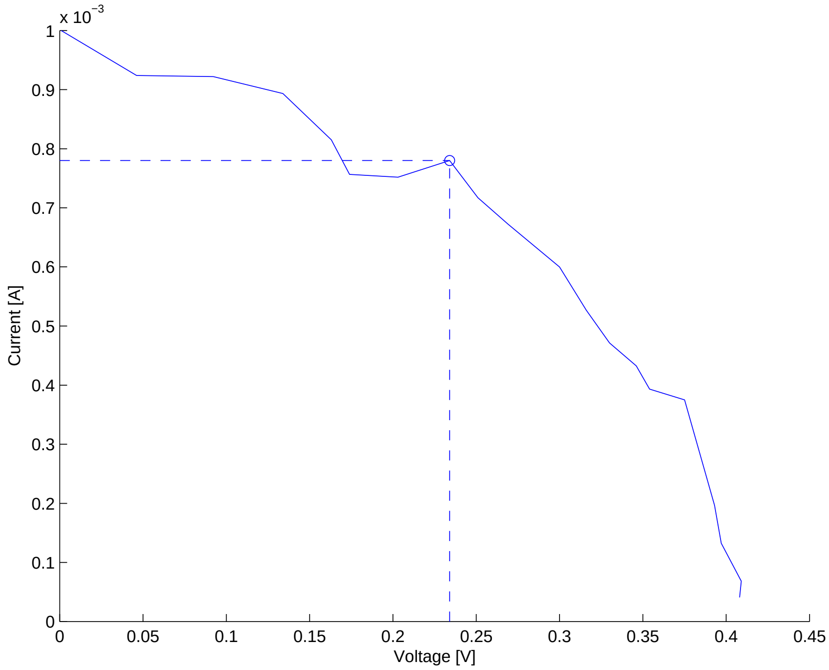

Figure 7: I vs. V for solar cell excited by desk lamp 30cm above

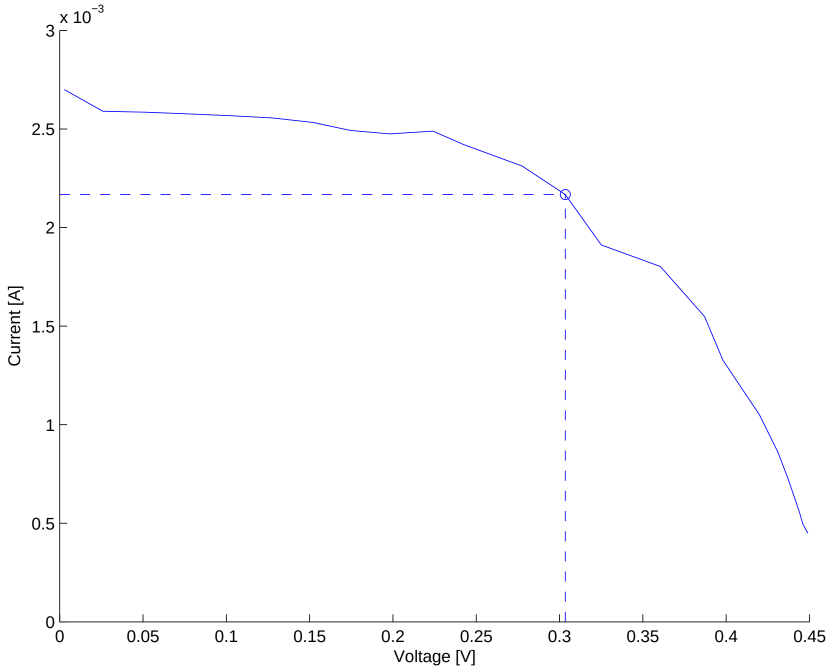

Figure 8: I vs. V for solar cell excited by desk lamp 15cm above

Table 4: *Maximum power and fill factor, ι, for solar cell excited by different light source*

Light source	Maximum power $P_{max}[W]$	Fill factor ι
Room light	$3 \cdot 10^{-5}$	0.47
Desk lamp (30 cm)	$1.83 \cdot 10^{-4}$	0.45
Desk lamp (15 cm)	$6.58 \cdot 10^{-4}$	0.54

4.3.1 The power plant problem

The density of radiation from the sun just outside Earth's atmosphere is $1.37k\frac{W}{m^2}$. Let us assume that the density is $D_A = 1k\frac{W}{m^2}$ on the surface of the Earth directly below the Sun. What is the maximum power from a power plant run by $A = 1km^2$ of solar cells with $\eta = 15\%$ efficiency?

The maximum power will be

$$P_{max} = D_A \cdot A \cdot \eta = 1k\frac{W}{m^2} \cdot 1km^2 \cdot 15\% = 150kW$$

5 Discussion

In the first part we measured capacitance as a function of reverse voltage. With this data we were able to calculate V_0, the contact potential for each diode. For the Schottky diode we could also calculate the donor concentration N_d and W, the width of the depletion layer. In the second part several measurements were made to get different values of lifetime of excess carriers for same three diodes. The calculations gave almost the same value for each diode. In the third part the maximum value of power was calculated in *Matlab* and from those calculations we base the values of the fill factor ι.

References

[1] Streetman, Ben G. and Banerjee, Sanjay. 2000. *Solid State Electronic Devices*. Prentice Hall International, New Jersey USA.