Lab #24: Photo-Voltaic Converters

Goal:
Study the performance parameters of an amorphous silicon photo-voltaic converter. Determine the power output as a function of the load resistance, the irradiance, the angle of incidence, and the temperature.

Equipment:
Solarex, SA-1, amorphous silicon converter module, Hubbard insolation meter, digital multimeter.

1 Physics:
1.1 Photodiodes
Electronically, the converter behaves like a photodiode. The current $I$ through a photodiode and the voltage $U$ across it are related by the so-called Shockley equation

$$I = I_d \left( e^{\alpha U} - 1 \right) + I_g,$$

where the dark current $I_d$ and the constant $\alpha$ in the exponent are parameters that depend on the temperature and on the type of diode, and $I_g$ is the photo-generated current (i.e., $I_g=0$ without illumination). Note, that the photo-current is in the reverse direction, i.e., $I_g$ is a negative number. The voltage across the diode when no current is flowing is called open-circuit voltage $U_{oc}$, and the current that flows when the diode is shorted is called short-circuit current, $I_{sc}$. A typical diode characteristic ($I$ versus $U$) is shown in fig.1.

![Characteristics of a diode](image)

Fig.1: typical diode characteristics ($I$ versus $U$) for an illuminated photodiode (solid, red). The same without light is shown as a dashed, blue line. The curves have been calculated from eq. 1.
The open-circuit voltage \( U_{oc} \) and the short-circuit current, \( I_{sc} \) follow from eq.1:

\[
I_{sc} = I_g ,
\]

\[
U_{oc} = \frac{1}{\alpha} \ln \left( 1 - \frac{I_g}{I_d} \right) ,
\]

1.2 Power output

A resistor \( R \) across the diode represents a load. The dissipated power \( P \) is then \( P = U \cdot I \), and Ohm’s law states that \( U = R \cdot I \). The power \( P \) as a function of the load resistance is shown in fig.2 (log-log plot).

For small \( R \), \( I \rightarrow I_{sc} \) (constant), and for large \( R \), \( U \rightarrow U_{oc} \) (constant). For the dissipated power, this means

\[
P(R \rightarrow 0) = I_{sc}^2 \cdot R , \quad P(R \rightarrow \infty) = U_{oc}^2 / R
\]

This represents the asymptotic behavior, shown in fig.2 as dashed, black lines. The intercept of these lines defines \( P_{max0} = U_{oc} \cdot I_{sc} \). The actually observed maximum power output \( P_{max} \) is lower. The ratio between the two values is called the ‘fill factor’, \( F_f \):

\[
F_f \equiv \frac{P_{max}}{I_{sc} \cdot U_{oc}} ,
\]
The crosses in fig.2 represent actual data, and the solid, red curve is calculated from eq.1 with the parameters $I_d = 0.8 \ \mu A$, $\alpha = 0.6 \ \text{V}^{-1}$, $I_g = -0.6 \ \text{mA}$. For a simple diode that is made from a p-n junction, the parameter $\alpha$ is expected to be $q/kT$, where $q$ is the elementary charge, $k$ is the Boltzmann constant, and $T$ is the temperature (in K). This corresponds to $\alpha \sim 38 \ \text{V}^{-1}$. This shows that the photo-voltaic cell behaves different from a simple diode.

An approximate theoretical estimate of the fill factor is given by [STO93]

$$F_f \approx \frac{\alpha U_{oc} - \ln(\alpha U_{oc} + 0.72)}{\alpha U_{oc} + 1.0}.$$  \hspace{1cm} (6)

## 2 Experiment:

1. Connect a variable load resistor across the converter. Expose the converter to constant irradiance (light box). Determine $I_{sc}$, $U_{oc}$, and measure the voltage across the diode as a function of the load resistance. Make a plot analogous to fig.2. Determine empirically the fill factor. Fit the data with eq.1 and determine the parameters $I_d$, $\alpha$, and $I_g$. Knowing these, calculate the theoretical values for $U_{oc}$ from eq.3 and for the fill factor $F_f$ from eq.6, and compare with your measured data.

2. Stick a thermometer into the light box. The temperature is probably rising because of the dissipated lamp power. Measure $I_{sc}$ and $U_{oc}$ for a while and try to determine its temperature dependence. Does the maximum power increase or decrease with increasing temperature? How does the temperature dependence affect the first measurement?

3. Let’s hope, the sun is shining. In direct sunlight, measure $I_{sc}$ and $U_{oc}$ as a function of the angle of incidence. For normal incidence determine the maximum power output with a variable load. At the same time determine the solar flux with the insolation meter. Calculate the efficiency of the converter at normal incidence. Determine the fill factor and compare with the value from the box measurement.

4. Plot $I_{sc}$ and $U_{oc}$ versus the angle of incidence. Can you explain the result?

## 3 References:
