



**Exercise  
104**

**PHOTOVOLTAIC EFFECT – SOLAR CELL**

**Measurement procedure**

**1. List of equipment**

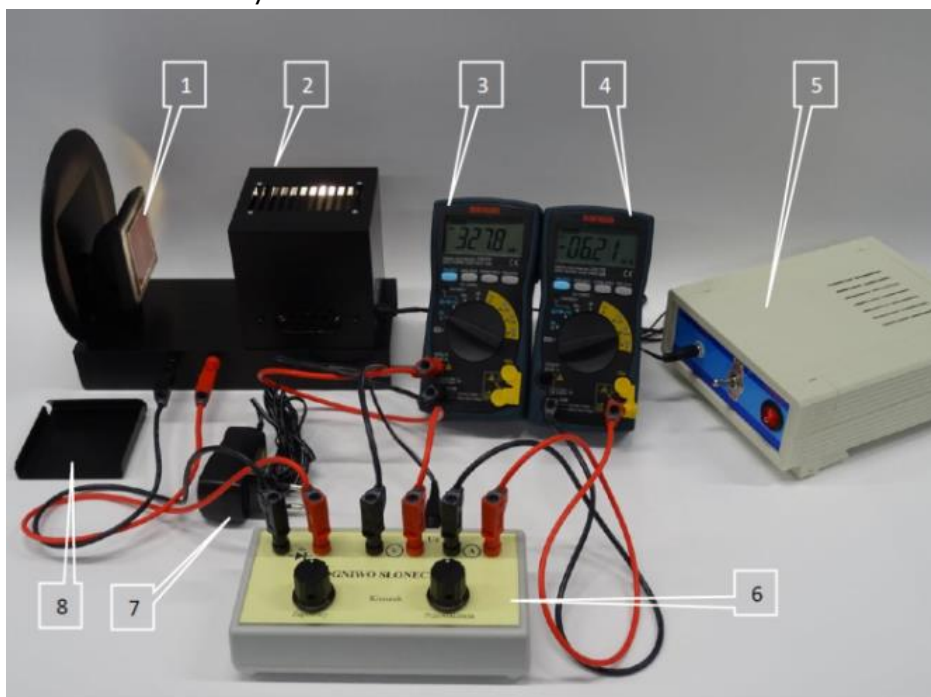
1. Solar cell panel (PV panel)
2. Halogen lamp
3. DC voltmeter
4. DC milliammeter
5. Stabilized power supply of a halogen lamp
6. Setup to apply a voltage bias to the panel
7. Power supply of the voltage bias setup
8. Iris of the panel

**2. Goal**

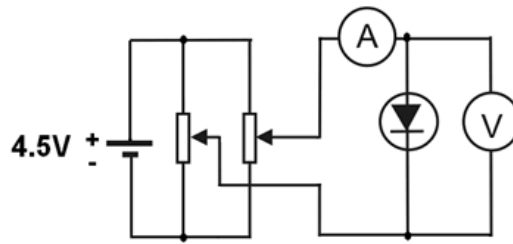
- 1) Determination of the dark and light I-V characteristic of the PV panel
- 2) Determination of the built-in voltage using dark I-V characteristic of the panel.
- 3) Determination of the fill factor (FF) of light I-V characteristic of the panel.

**3. Measurement setup**

In Fig.1 the experimental setup used to measure I-V characteristics of a PV panel is shown. The PV panel (1) is located on the optical bench. In front of the panel the halogen lamp (2) is set. The power supply of the lamp (5) enables the choice of two alternative light intensities. Voltmeter (3) and ammeter (4) serve to perform measurements of voltage and current in the PV panel circuit, respectively. Setup (6) enables polarization of the panel with the help of the potentiometers located in this system.



**Fig.1.** Experimental setup to perform the measurements of the PV panel I-V characteristics.



**Fig. 2.** Electric circuit of a PV panel voltage bias setup.

### 3 Experimental procedure

#### 3.1. Measurements of the dark I-V characteristic

a) Assemble the measuring system according to the diagram shown on Fig. 1 and 2. In the setup (6) there are several sockets.

Voltmeter should be connected with the socket  $\textcircled{V}$  and the ammeter with the  $\textcircled{A}$  socket.

The PV panel should be connected with the socket  $\textcircled{\text{PV}}$ .

b) Set both potentiometers of the setup (6) in the left extreme position.

c) Check if the output voltage of the power supply connected with the setup (6) is set at 4.5V and plug it in.

d) Perform the measurements of the dark current-voltage characteristic of the PV panel, i.e. the dependence of current vs voltage for the PV panel obscured by the iris.

- In the reverse bias change the voltage bias up to -4V with the step of 0.2V using relevant potentiometer (labeled "zaporowy"). For each value of a voltage bias read the value of current, using the least ammeter range.
- After the measurement, turn the potentiometer into the extreme left position.
- In the forward bias (potentiometer labeled "przewodzenia") vary the current from 0mA to 10mA with the 1mA step and from 10mA to 100mA with 5mA step. For each value of the current read the value of voltage bias.
- After the measurement, turn the potentiometer into the extreme left position.

#### 3.2. Measurements of the light I-V characteristic

1) Repeat steps 3.1 a)-c)

2) Remove the aperture of the solar panel.

3) Turn on power supply of a halogen lamp. Set the switch in the power supply (5) in the lower position. This position corresponds to the reduced light intensity. The upper position corresponds to the higher light intensity.

4) Measure the current-voltage characteristics for the illuminated panel.

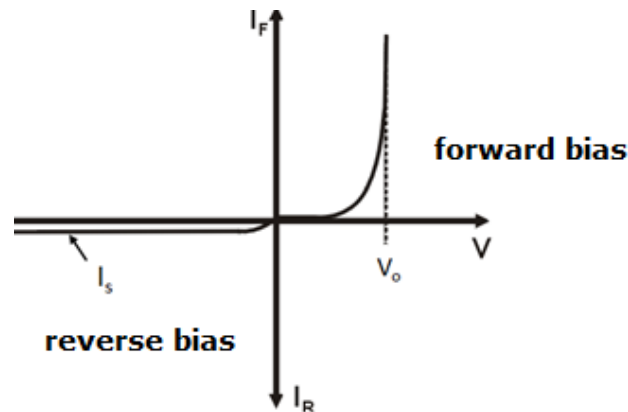
- For reverse bias change voltage bias from 0V with the step of 0.05 V up to a value equal to -0.6 V. For each value of a voltage bias read the current value, using the least range of the ammeter (the maximum short circuit current equals only several mA). Keep in mind that this is a reverse current, so the ammeter should indicate the "-I".
- For forward bias ( $> 0V$ ) change the current with the step of 0.1mA until the current achieves value a little higher than 0mA (this value corresponds to the open - circuit voltage) but less than +0.2mA. Then the characteristic will be clearly visible in the fourth quadrant of the I-V chart (cf. Fig. 4). For each value of current, read the value of the voltage.

5) Repeat the measurement of I-V characteristics for greater illumination. To do this, switch the power supply of lighting set in the upper position and repeat point 4).

#### 4. Calculations and analysis of the results

##### 4.1. Determination of dark I-V characteristics and built-in potential

- 1) Plot a graph of the dark I-V characteristics of the solar panel.
- 2) For a few selected points draw a rectangle of uncertainty assuming the uncertainties of  $I$  and  $V$  to be equal to the uncertainties of the ammeter  $\Delta_p I$  and voltmeter  $\Delta_p V$ .
- 3) Read from the I-V plot the built-in potential  $V_0$  from the intercept of the best linear fit to the I-V plot, in the range of large currents in the forward bias, with voltage axis (cf. Fig.3).



**Fig.3.** Sample dark I-V characteristic of a solar cell/panel.

To do this determine the slope coefficient  $A$  and intercept  $B$  (and their uncertainties  $u(A)$  and  $u(B)$ ) with the axis  $I_F$  of the best linear fit to the I-V plot using the method of linear regression. Then the built-in voltage can be determined from the equation:

$$V_0 = -\frac{B}{A}. \quad (1)$$

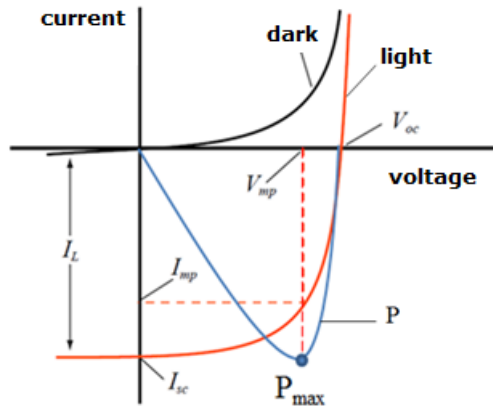
The uncertainty  $u(V_0)$  can be found from the formula:

$$u_c(V_0) = \sqrt{\left(\frac{u(B)}{A}\right)^2 + \left(\frac{u(A)B}{A^2}\right)^2}. \quad (2)$$

##### 4.2. Determination of the light I-V characteristics, the maximum power and the fill factor

- 1) Draw up light I-V characteristics of the I-V solar panel for two different light intensities.
- 2) For a few selected points draw a rectangle of uncertainty assuming the uncertainties of  $I$  and  $V$  to be equal to the uncertainties of the ammeter  $\Delta_p I$  and voltmeter  $\Delta_p V$ .
- 3) Tick on the plots: short-circuit current,  $I_{sc}$ , open circuit voltage  $V_{oc}$  and the maximum current  $I_{mp}$  and voltage  $V_{mp}$  corresponding to the maximum power point (cf. Fig.4).
- 4) For the IV-th quadrant of the I-V characteristic draw the  $P = I \cdot V = f(V)$  plot.
- 5) For a few selected points draw a rectangle of uncertainty. Assume the voltage uncertainty equal to  $\Delta_p V$  while the power uncertainty calculate using equation:

$$u_{cp}(P) = \sqrt{[u_p(I) \cdot V]^2 + [u_p(V) \cdot I]^2}. \quad (3)$$



**Fig.4.** Sample dark and light  $I=f(V)$  and power vs voltage  $P(V)$  characteristics of the solar cell

6) Using eq. (4) determine fill factors for both light intensities using formula:

$$FF = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}} = \frac{P_{max}}{I_{sc}V_{oc}} \quad (4)$$

6) Calculate uncertainties of the fill factors using equation:

$$u_c(FF) = \sqrt{\left(\frac{u(I_{mp})V_{mp}}{I_{sc}V_{oc}}\right)^2 + \left(\frac{I_{mp}u(V_{mp})}{I_{sc}V_{oc}}\right)^2 + \left(\frac{u(I_{sc})I_{mp}V_{mp}}{I_{sc}^2V_{oc}}\right)^2 + \left(\frac{u(V_{oc})I_{mp}V_{mp}}{V_{oc}^2I_{sc}}\right)^2} \quad (5)$$

where  $u(x) = \frac{\Delta_p x}{\sqrt{3}}$ .

## 6. Proposed tables

### 6.1. Dark characteristic

$I$	$u_p(I)$	$U$	$u_p(U)$	$V_0$	$u_c(V_0)$
[A]	[A]	[V]	[V]	[V]	[V]

### 6.2. Light characteristics

$I$	$u_p(I)$	$U$	$u_p(U)$	$P$	$u_{cp}(P)$	$I_{sc}$	$u(I_{sc})$	$U_{oc}$	$u(U_{oc})$	$I_{mp}$	$u(I_{mp})$	$U_{mp}$	$u(U_{mp})$	$FF$	$u_c(FF)$
[A]	[A]	[V]	[V]	[W]	[W]	[A]	[A]	[V]	[V]	[A]	[A]	[V]	[V]	[%]	[%]

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