Measuring the Optical Power of your LED

Purpose of This Note

When performing experiments with dye solar cells, light is focused on the cell and its current response is measured. The generated current depends strongly on the intensity of the light.

In order to calculate the efficiency of a solar cell, the optical power of the incident light has to be known. This technical note explains how to measure and calculate the optical power of your light source.

Introduction

IMPS/IMVS setup

Gamry's IMPS/IMVS setup allows you to perform various experiments with dye solar cells (DSCs).

Our current Framework version enables cyclic voltammetry, potentiostatic EIS, and potentiostatic experiments under constant illumination. In addition, IMPS (intensity modulated photocurrent spectroscopy) and IMVS (intensity modulated photovoltage spectroscopy) experiments can be performed.

> **Note**: For more information on experiments with dye solar cells, see Gamry's application notes at www.gamry.com:
>
> **Dye Solar Cells: Part 1 – Basic principles and measurements**

Figure 1 shows the setup of Gamry's IMPS/IMVS system. It consists of a bench top which supports a rail system. The photodiode and light source are mounted on optical posts. Dye solar cells are mounted on the cage system using a special holder. The construction allows simple and reproducible adjustment of the distance between solar cell/photodiode and light source.

In order to perform experiments with dye solar cells, two synchronized potentiostats of the same family are needed. The "master" potentiostat controls the LED. The "serf" potentiostat is used for measuring.

The photodiode is used as dummy cell. It allows measurement and calculation of the optical power from the light source. This parameter is needed to calculate the efficiency of your cell.

The active area of the photodiode has a diameter of 0.9 cm, which gives a sample area of 0.636 cm^2. The photodiode also includes an adapter cable for connecting a potentiostat.

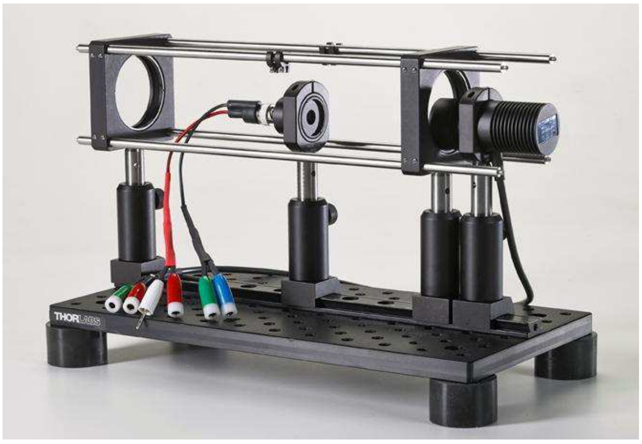

Figure 1 – Gamry's IMPS/IMVS setup with LED and photodiode. For details, see text.

The light source is optional. You may either provide your own light source or use one of Gamry's LEDs. Table 1 lists up all six LEDs available from Gamry.

LED color	wavelength [nm]
blue	470
green	530
amber	590
orange	617
red	625
warm white	3000 K[1]

Table 1 – Gamry's LEDs for the IMPS/IMVS setup.

All LEDs are galvanostatically controlled with a maximum rated current of 1 A. Their power output is typically between 170 mW and 770 mW. The LEDs provide four banana jacks for connecting a potentiostat.

[1] color temperature

Theory

Optical Power

The intensity I of a light source depends strongly on the distance. Imagine a light bulb that emits light equally in all directions (see Figure 2). The intensity is greatest at the center and decreases with increasing distance r.

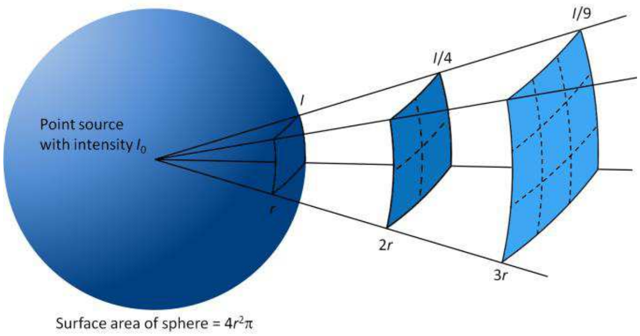

Figure 2 – Schematic drawing illustrating the inverse-square law of light. For details, see text.

The decrease of intensity follows the inverse-square law of light (see also equation 1). This means that at a distance twice as far from the light source, light is spread over an area which is four times bigger. Hence intensity is only one-fourth of the initial intensity I_0.

$$I = \frac{I_0}{4r^2\pi} \qquad \text{Eq. 1}$$

The same is true when measuring dye solar cells. Only a small portion of light that is emitted from the LED reaches the active area of the DSC.

However, the intensity of the incident light – from now on referred to as optical power P_{in} – is needed in order to calculate the efficiency η of the DSC (see also equation 2).

$$\eta = \frac{P_{max}}{P_{in}} \cdot 100\% \qquad \text{Eq. 2}$$

P_{max} is the power maximum of a DSC at constant light intensity. This parameter can be obtained from I-V curves.

Responsivity of a photodiode

A photodiode can be used to calculate the optical power P_{in} of light.

Similar to DSCs, photodiodes generate current when light shines on them. The amount of current depends on the light power as well as wavelength of the incident light. This relationship is called responsivity (R_{PD}). It is generally measured under short-circuit conditions (0 V) and is typically indicated in the data sheet of a photodiode.

Figure 3 shows the responsivity curve for the photodiode of Gamry's IMPS/IMVS setup. The graph is provided by Thorlabs Inc. Note that R_{PD} strongly depends on the wavelength of the light source.

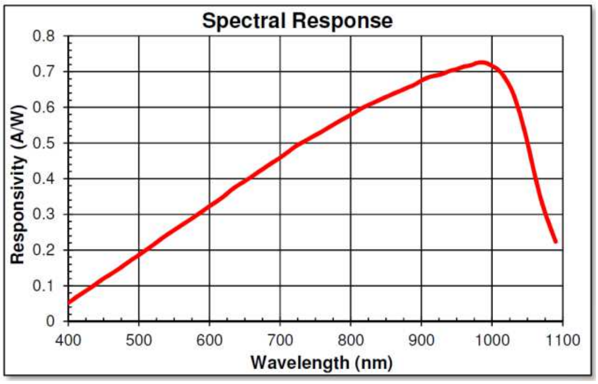

Figure 3 – Spectral response curve of the photodiode for Gamry's IMPS/IMVS setup (source: Thorlabs Inc).

Table 2 lists single responsivity values for all colored LEDs which Gamry offers for the IMPS/IMVS setup.

LED color	R_{PD} [A/W]
blue	0.147
green	0.230
amber	0.309
orange	0.346
red	0.359

Table 2 – Selected responsivity values for all color-LEDs provided by Gamry.

The responsivity R_{PD} can be used to calculate the optical power density p_{PD} of the light that shines on the active surface area of the photodiode.

$$p_{PD} = \frac{i_{PD}}{R_{PD}} \qquad \text{Eq. 3}$$

Here i_{PD} is the generated current density from the photodiode under constant illumination.

The optical power P_{in} of the light that shines on a DSC can then be calculated (see equation 4). A_{DSC} is the active area of the dye solar cell.

$$P_{in} = p_{PD} \cdot A_{DSC} \qquad \text{Eq. 4}$$

Generally, photodiodes are only used for narrow-band light sources (see Table 2) in order to measure the optical power.

Broadband light sources (e.g., warm-white LEDs) perform poorly with photodiodes because the responsivity depends on the wavelength. Only relative power changes can be measured. Typically, thermal power sensors are used for broadband LEDs to measure the optical power output. At the moment, Gamry Instruments does not provide thermal power sensors.

Experiment

The photodiode replaces the dye solar cell when measuring p_{PD}. The distance between photodiode and light source should be similar to experiments with real DSCs. We recommend that you darken the environment around the setup in order to block ambient light which can falsify the results.

Figure 4 shows a series of potentiostatic experiments under constant illumination. The potential of the photodiode was set to 0 V (short-circuit conditions) and its current response was measured. The distance between photodiode and light source was adjusted to 3 cm.

A red LED (625 nm) was used as light source. The LED current was set to 100 mA, 300 mA, 500 mA, 700 mA, and 900 mA respectively.

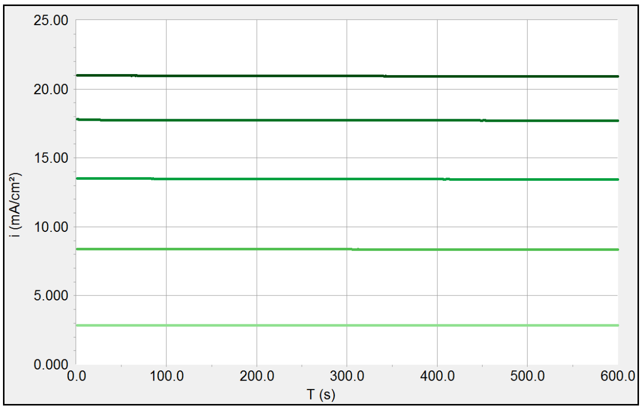

Figure 4 – Current curves of the photodiode with increasing light intensities (from bright to dark). For details, see text.

The current density is automatically calculated by the Echem Analyst. As expected, current increases with increasing light intensities.

Keep in mind that the LED warms up the photodiode. This can lead to changes in current. We recommend running a single experiment until the measured current is constant in order to get correct results.

Table 3 lists the results from the previous measurements. Only the last measured current density was used for calculations. The responsivity factor R_{PD} for this LED is 0.359 (see also Table 2).

LED current [mA]	i_{PD} [mA]	p_{PD} [mW/cm^2]
100	2.85	7.93
300	8.35	23.27
500	13.44	37.43
700	17.71	49.34
900	20.91	58.26

Table 3 – Measured current densities i_{PD} and calculated optical power densities p_{PD} of the photodiode at different light intensities.

With these results, P_{in} (Eq. 4) of the incident light and the efficiency (Eq. 2) of your DSC can be calculated.

Summary

This technical note gives a short overview on Gamry's IMPS/IMVS setup.

It is described how to use the photodiode as dummy cell. The photodiode allows measuring the optical power output of your light source. This parameter is needed in order to calculate the efficiency of your dye solar cell.

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