Characterization of photovoltaic energy conversion device by DC and frequency resolved techniques (IMPS/IMVS)

A solar cell or photovoltaic cell is a device that converts light energy into electrical energy. Dye-sensitized solar cells (DSSC) are currently subject of intense research in the framework of renewable energies as a low-cost photovoltaic (PV) device. Electricity generated from a PV produces zero emissions, is modular, and can produce energy anywhere the sun shines.

The standard characterization technique of a PV device consists in the determination of the DC Current-Voltage curves under different incident light intensities.

DC techniques do not provide any information about the internal dynamics of the PV device. Therefore, additional information can be obtained using time dependent and frequency dependent measurements.

The application of small perturbations drives the system out of equilibrium and the measurement of the transient during response provides information about internal processes. Similarly, the application of a small amplitude AC perturbation of variable frequency provides information about the different time constants of the internal processes.

Two particular frequency domain characterization methods can be used to study PV devices:

- **IMPS** – Intensity modulated photocurrent spectroscopy: measurement of the transfer function between modulated light intensity and generated AC current.
- **IMVS** – Intensity modulated photovoltage spectroscopy: measurement of the transfer function between modulated light intensity and generated AC voltage.

This application note illustrates the use of the Autolab PGSTAT302N/FRA2 in combination with a controlled light source (LED) to perform DC and AC characterization of a PV device.

Hardware setup

The measurements described in this application note require the Dynload interface (Order code: LOAD.INT). This interface is used to set both the DC and the AC light intensity of the light source. The light source is driven by a voltage-to-current converter, using the input voltage of the Dynload interface to define the light intensity. The DC light intensity is defined by the DAC164 output voltage and AC light modulation is defined by the FRA2 DSG output voltage. The amplitude of the AC light modulation was 10% of the DC light intensity.

Experimental conditions

All the measurements were performed on a dye-sensitized solar cell, using the N719 dye. The light source was a single LED driven by a voltage to current converter with a 0-10 V analog input. All the measurements were carried out with the NOVA software.

Photocurrent-voltage measurements

The photocurrent-voltage measurements (IV curves) can be obtained by applying a potential scan, from 0 V (short-circuit conditions) to the open-circuit potential, under constant illumination.

The light intensity was controlled by setting the voltage output of the DAC164 to the required value during the measurement.

Figure 1 shows the measured IV curves with increasing light intensity. As the light intensity increases, the maximum short-circuit current, I_{sc} and the open-circuit voltage V_{oc} increase.

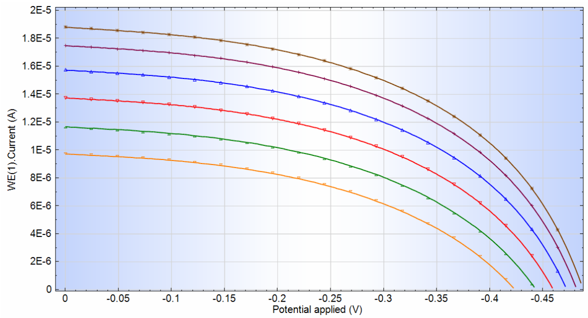

Figure 1 – Photocurrent-voltage profiles obtained using different illumination levels

From the photocurrent-voltage curves, the following parameters can be obtained:

- I_{sc} (Short-circuit current): the cell current measured at an applied potential of 0 V. I_{sc} is a function of the illumination intensity.
- V_{oc} (Open-circuit voltage): the cell potential measured when the current is 0 A.
- MPP (Maximum power point): the point where the maximum power is generated.
- FF (Fill factor): the ratio of the maximum power to the short and open circuit values.

Figure 2 shows the IV curve for a specific illumination level and the power profile. The maximum power point is indicated in the plot.

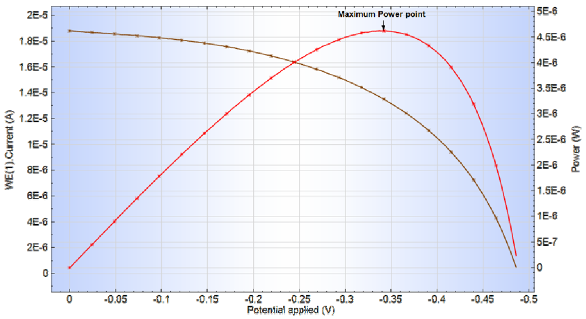

Figure 2 – Photocurrent-voltage (brown) and power profile (red) obtained for a specific illumination intensity. The MPP is shown in the plot

According to the Schottky equation, both the short-circuit current, I_{SC}, and the open-circuit voltage, V_{oc} are dependent on the light intensity. The current at short circuit increases linearly as the light intensity increases, since the photon-to-current conversion rate increases. On the other hand, the open-circuit voltage increases logarithmically, following the distribution of the energy states in the semiconductor.

Figure 3 shows the variation of the I_{sc} and V_{oc} as a function of the light intensity, respectively.

IMVS measurements

The intensity-modulated photovoltage spectroscopy measurements provide additional information on the internal dynamics of the cell. The IMVS data corresponds to the values of the transfer function, H_{IMVS}, between the modulated light intensity and the measured AC potential of the cell, at open-circuit.

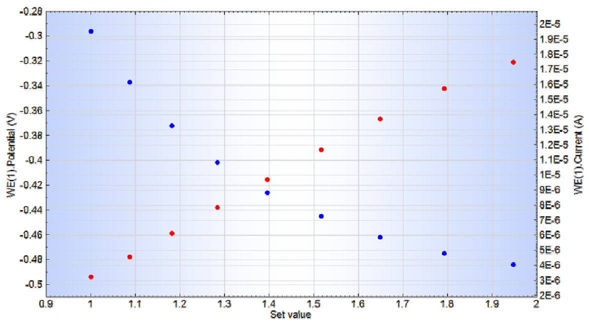

Figure 3 – Evolution of the I_{sc} (red) and V_{oc} (blue) as a function of illumination intensity

$$H_{IMVS} = \frac{\Delta V}{\Delta \Phi} \exp(i \cdot \varphi)$$

Where H_{IMVS} is the transfer function, ΔV is the variation of the cell voltage, $\Delta\Phi$ is the variation of the photon flux and φ is the phase angle. IMVS measurements provide information about the electron lifetime and electron-hole recombination dynamics under open-circuit conditions. Figure 4 shows a schematic overview of the IMVS measurements.

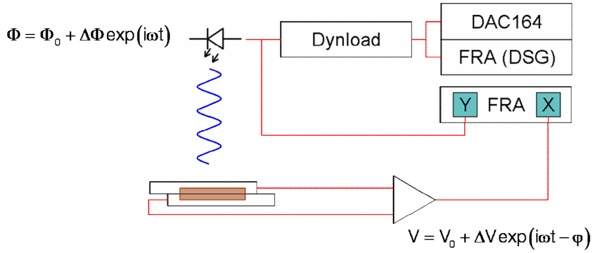

Figure 4 – Overview of the setup of the IMVS measurements. The DAC164 and the FRA (DSG) define the DC and AC components of the photon flux, respectively

Figure 5 shows complex plane IMVS data recorded under different DC light intensities.

As light intensity increases, the semi-circle radius decreases. The frequency corresponding to the minimum in the complex plane increases as the light intensity increases, which indicates that the electron lifetime decreases. Therefore, the electron recombination is more pronounced at high illumination intensities. The same conclusion can be inferred from the plot of the imaginary component versus the frequency (see figure 6).

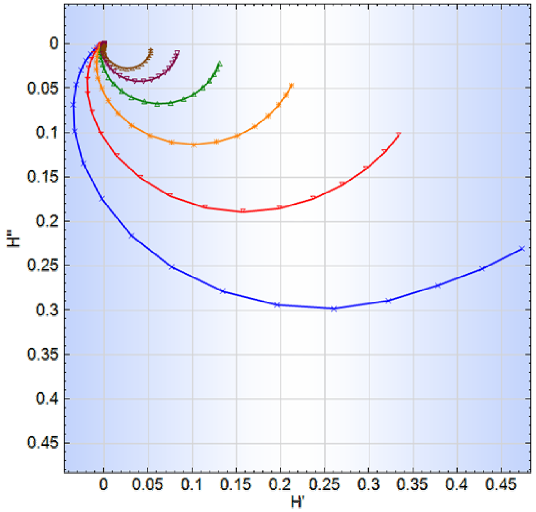

Figure 5 – IMVS measurements performed at different DC light intensities

An increase of DC light intensity leads to an increase in the characteristic frequency of the electron recombination, which indicates a decrease of electron lifetime.

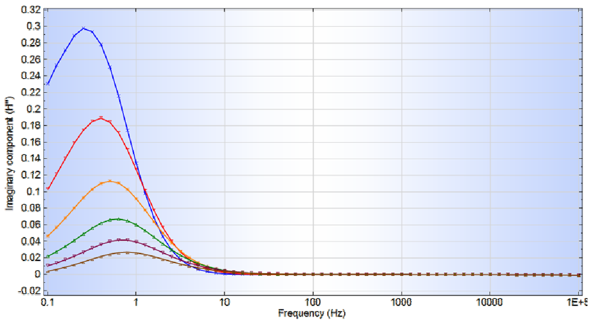

Figure 6 – Imaginary component of H_{IMVS} versus the frequency at different DC light intensities

IMPS measurements

The intensity-modulated photocurrent spectroscopy measurements provide complementary information on the internal dynamics of the cell. The IMPS data corresponds to the values of the transfer function, H_{IMPS}, between the modulated light intensity and the measured AC current of the cell, at short-circuit.

$$H_{IMPS} = \frac{\Delta I}{\Delta \Phi} \exp(i \cdot \varphi)$$

Where H_{IMPS} is the transfer function, ΔI is the variation of the cell current, $\Delta\Phi$ is the variation of the photon flux and φ is the phase angle. IMPS measurements provide information about the electron lifetime and electron-hole recombination dynamics as well as the equivalent mass transport of the charge carriers. Figure 7 shows a schematic overview of the IMPS measurements.

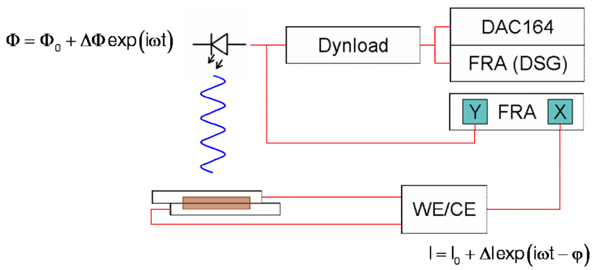

Figure 7 – Overview of the setup of the IMPS measurements. The DAC164 and the FRA (DSG) define the DC and AC components of the photon flux, respectively

Figure 8 shows complex plane IMPS plot.

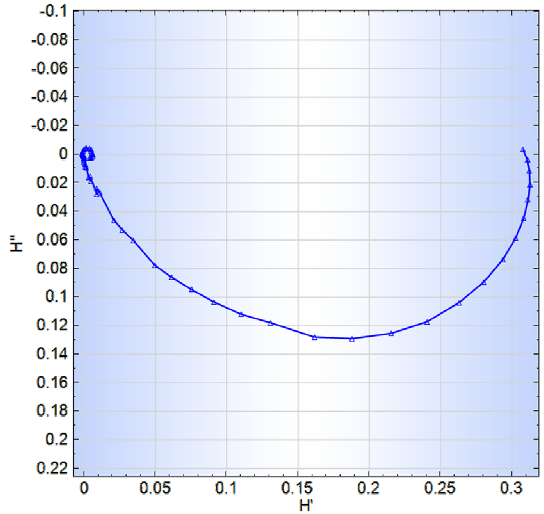

Figure 8 - IMPS measurement performed at constant illumination

The IMPS data is similar to the data obtained in the IMVS measurements. At high frequencies the modulated photocurrent approaches zero, indicating that the modulation frequency is faster than the relaxation of the charge carrier density by transport to the contacts and back reaction.

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