Application of the Capacitance-Voltage curve to photovoltaic cell characterizations

I – INTRODUCTION

Capacitance measurement is widely used to carry out semiconductor characterization such as photovoltaic (PV) cells. For example, this measurement is used to determine the doping concentration.

In EC-Lab® & EC-Lab® Express software, it is possible to directly plot the capacitance (directly means without any post-process). The capacitance can be obtained with all the Electrochemical Impedance Spectroscopy (EIS) techniques *i.e.* Potentio EIS (PEIS), Galvano EIS (GEIS), Staircase PEIS (SPEIS), Staircase GEIS (SGEIS), "Wait" technique that allows user to follow up the modulus of Z *vs* time (PEISW) techniques.

Depending on the model circuits considered, two types of capacitance, C_s or C_p, are calculated. The capacitance C_s corresponds to the capacitance of the R+*C* (in **s**eries) circuit and C_p corresponds to the capacitance of the R/*C* (in **p**arallel) circuit (Fig. 1)

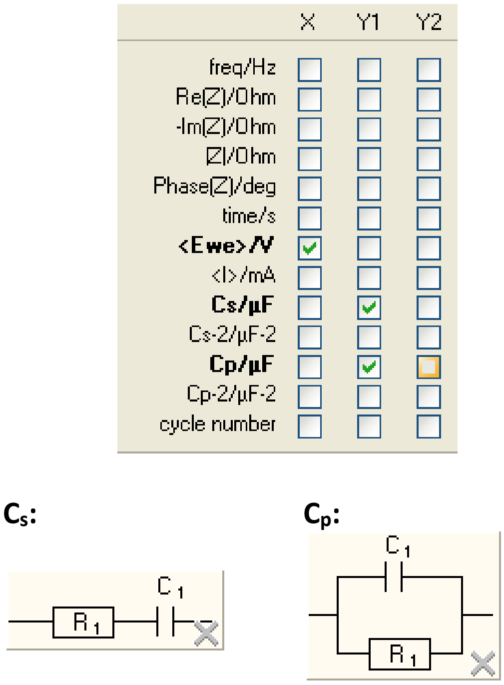

Figure 1: The two equivalent circuits offered for direct capacitance plotting.

This note exhibits how to plot Capacitance *vs.* Voltage (*C-V*) curve. Firstly, the different options offered to plot the capacitance are shown with a varia-capacitor[1] as an experimental model system. Selection of the circuit model and comparison between values of capacitance fitted with Zfit and the capacitance directly available in the technique are discussed. Secondly, typical *C-V* characterizations of PV cell are described.

II – EXPERIMENTAL CONDITIONS

Investigations are carried out with a SP-200 equipped with the Ultra Low Current option or with SP-300 and EC-Lab® software. For both systems (*i.e.* varia-capacitor and photovoltaic cell), investigations are done with a standard two-electrode connection.

The characteristic of the varia-capacitor is the following:

– low voltage variable capacitance double diode (BB201 from NXP).

– The capacitance is in the range of 10 to 120 pF for a voltage range of 0.5 to 11V.

The *C-V* characterization of the PV cell has been performed on a cell irradiated by a Xenon lamp of 150 W (light source of MOS-200 powered by ALX-150 power supply).

III – VARIA-CAPACITOR INVESTIGATIONS

III - 1 R/C OR R+C EQUIVALENT CIRCUIT?

To choose the appropriate equivalent circuit among R/C or R+C, an EIS measurement on a wide frequency range *i.e.* 3 MHz to 1 mHz is performed. Settings are displayed in Fig. 2.

The EIS measurement leads to a semicircle (Fig. 3), so the R/*C* model (C_p variable) is considered for the *C-V* investigations. The

[1] capacitor whose capacitance may be intentionally and repeatedly changed mechanically or electronically

fitted values of R and *C* are 70 Ohm and 145 pF (Fig. 4), respectively.

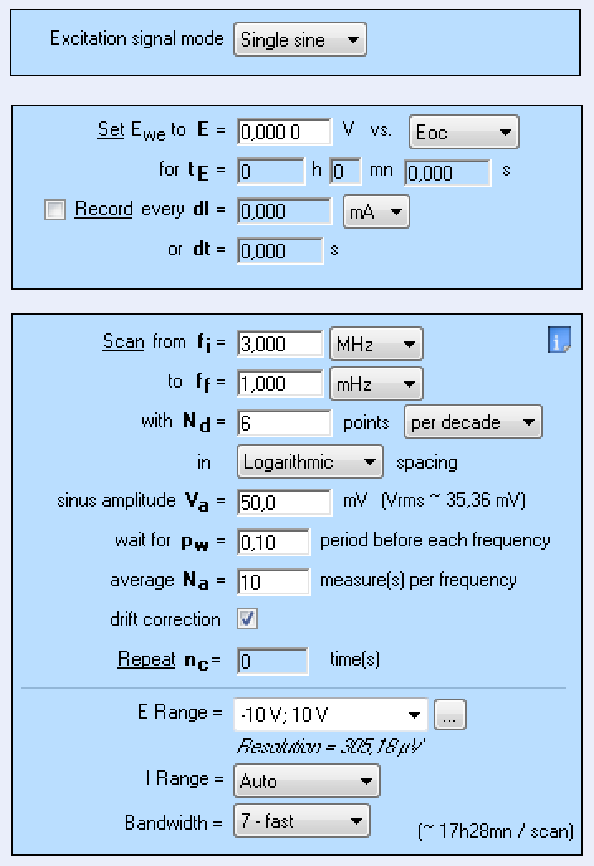

Figure 2: Settings for the EIS characterizations of the varia-capacitor.

III - 2 *C-V* INVESTIGATIONS

Two SPEIS techniques are performed. One in the frequency range from 7 MHz to 1 Hz (setting displayed in Fig. 5) and one at one frequency (similar settings than shown in Fig. 5 with f_i equal to f_f). Measurements are performed at a frequency of 323 kHz because above this frequency the responses of the varia-capacitor is dependent on the frequency (Fig. 6). The experiments are named $SPEIS_{7MHz\ 1Hz}$ and $SPEIS_{323kHz}$, respectively. The voltage scan starts at 0V and goes up to 10V with steps of 200 mV.

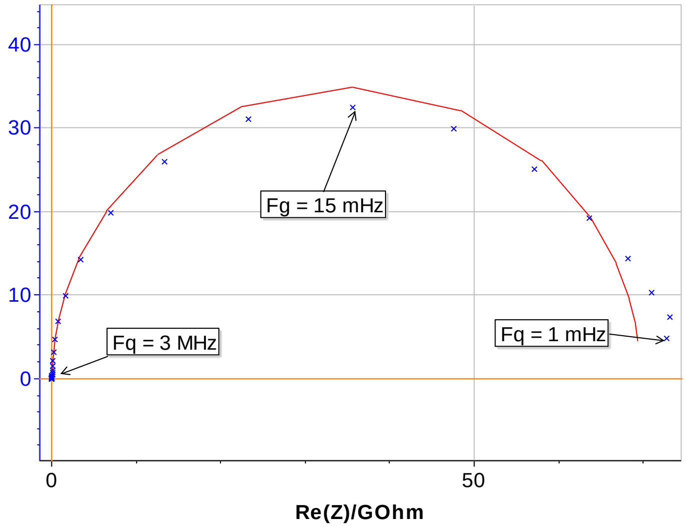

Figure 3: Nyquist plot of varia-capacitor (Exp data fitted data).

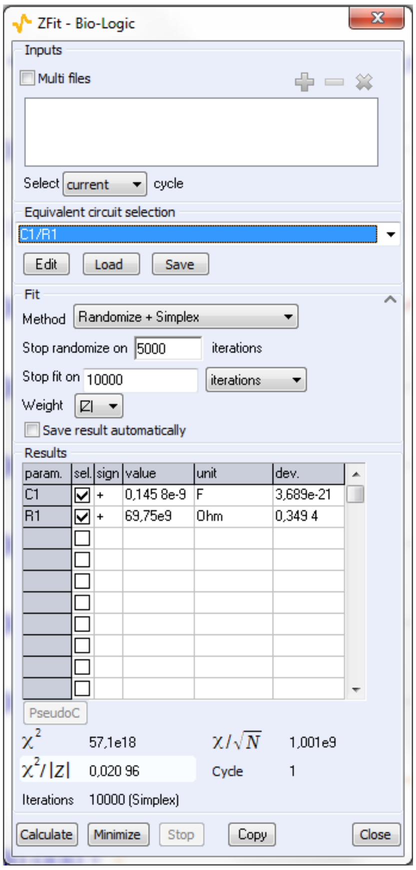

Figure 4: Values of the Zfit process.

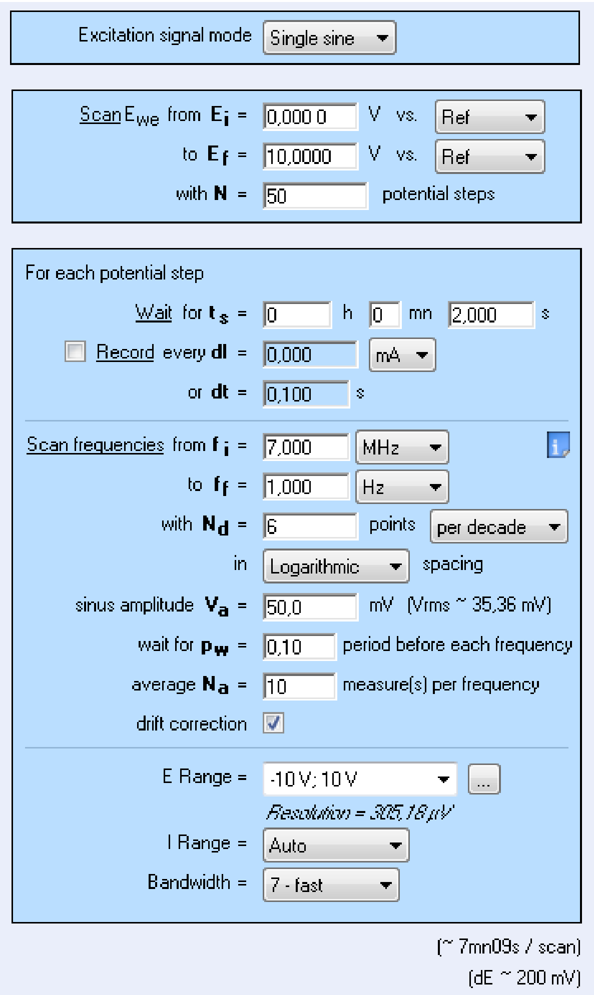

Figure 5: SPEIS settings for varia-capacitor characterizations.

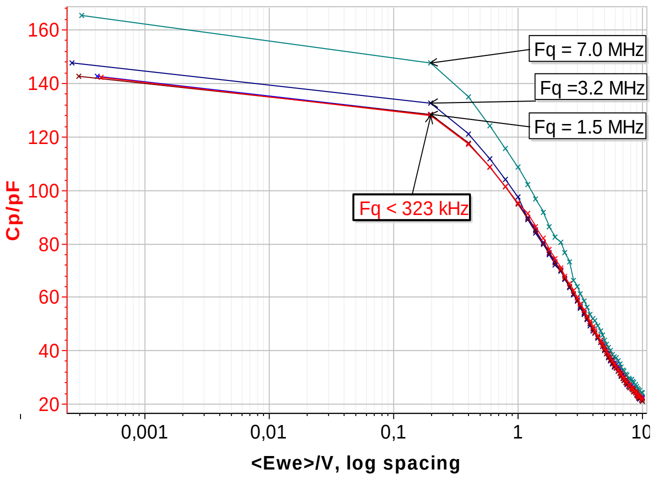

Figure 6: *C-V* characterization at different frequencies.

The $SPEIS_{7MHz\text{-}1Hz}$ allows user to fit the capacitance value, C_1 with the Zfit tool at the different frequencies (window of frequency selection is displayed in Fig. 7). C_1 is compared in Fig. 8 to the value of C_p that is already calculated during the experiments $SPEIS_{7MHz\text{-}1Hz}$ and $SPEIS_{323kHz}$. C_1 and C_p lead to similar value around 140 pF at low voltage and 20 pF at high voltage. So, the comparison shows that the C_1 calculated with Zfit and C_p determined directly in the EIS technique are identical.

These values are in agreement with the specification described in the datasheet of the varia-capacitor.

Moreover, $SPEIS_{7MHz\text{-}1Hz}$ and $SPEIS_{323kHz}$ last 6 200 s and 150 s, respectively. So it is possible to save time by performing SPEIS at one frequency.

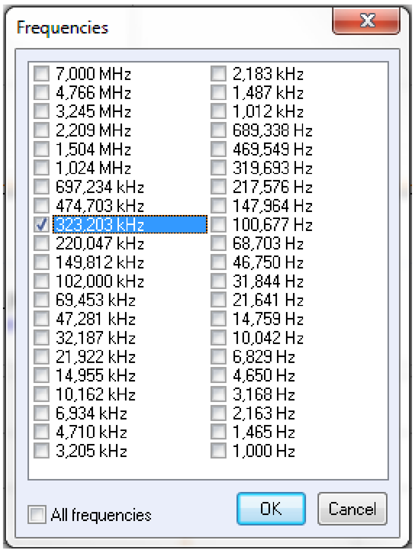

Figure 7: Frequency selection.

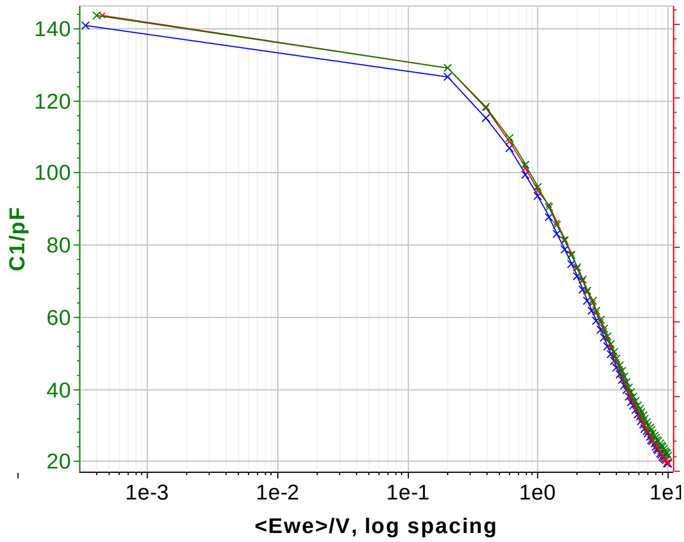

Figure 8: semi logarithmic *C-V* curves of varia capacitor. C_p *vs E* of $SPEIS_{323kHz}$; C_p *vs. E* of $SPEIS_{7MHz\text{-}1Hz}$ and C_1 (from Zfit) *vs. E* of $SPEIS_{7MHz\text{-}1Hz}$.

IV – *C-V* CURVE OF PHOTOVOLTAIC CELL

For the PV cell characterization, the voltage is scanned between 3 and 7.5 V and the frequency of the signal is 100 kHz (Fig, 9). According to the application note #24 [1], R/C model is considered. So C_p *vs* *V* curve is plotted (Fig. 10).

The *C-V* curve exhibits 3 regions:

- *E* < 4V: accumulation region
- 4V < *E* <6V: depletion region
- *E* > 6V: Inversion region

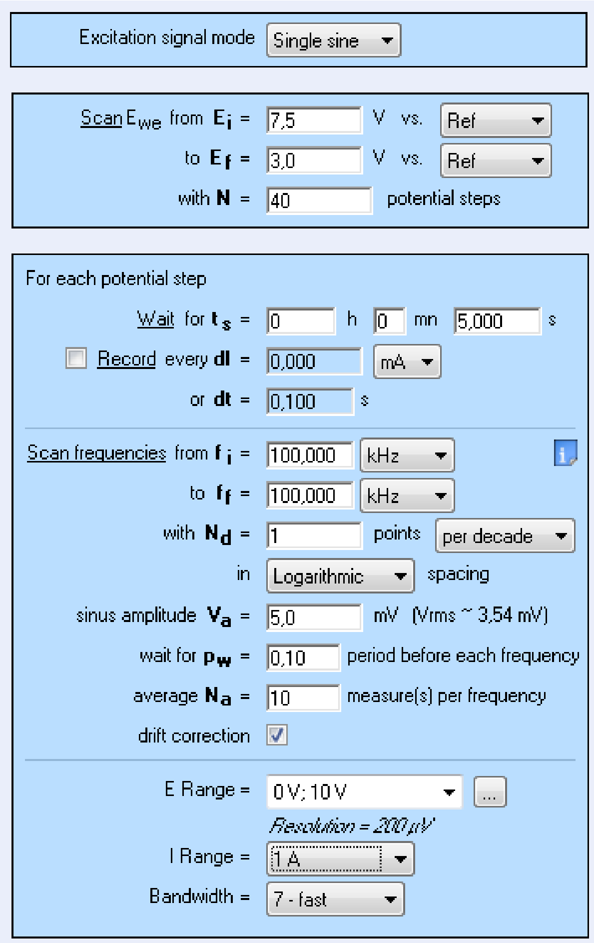

Figure 9: *C-V* curves settings of PV cell characterization.

The doping concentration N can be determined thanks to the following relationship:

$$N = \frac{2}{e\varepsilon\varepsilon_0 A^2 \left(\frac{d\left(\frac{1}{C^2}\right)}{dE} \right)} \qquad (1)$$

Where *e* is the electron charge (1.60 x 10^{-19} C)
ε_0 is the semiconductor permittivity (1.03 x 10^{-12} F/cm for silicon)
A is the surface of the photovoltaic cell, 21 cm^2
C is the capacitance (F) and *E* the voltage (V).

As C^{-2} variable is also available in the list of available variable (Fig. 1), it is also possible to plot C^{-2} *vs. E*. The slope of this curve leads to the doping concentration.

In this case, the slope (determined by linear fit) is 3.53 x 10^{15} F/V, so the doping concentration is 1.64 x 10^{14} cm^{-3}. This value is in agreement with a value previously given [1].

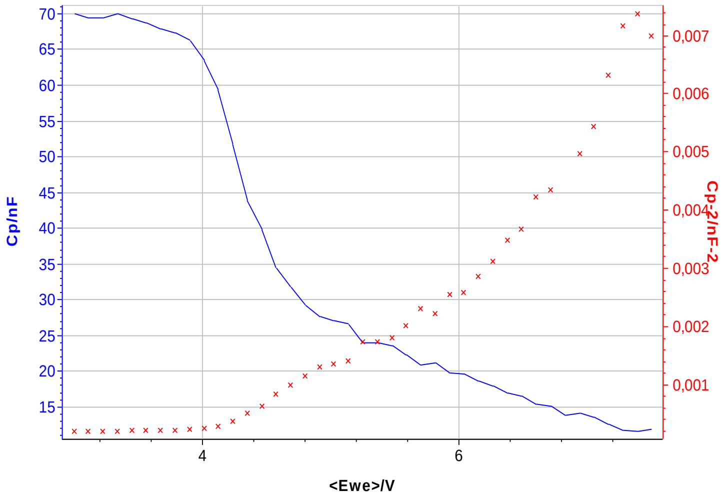

Figure 10: *C-V* curves of photovoltaic cell. C_p *vs. E* and C_p^{-2} *vs. E*.

IV – CONCLUSION

The note shows how to perform capacitance measurement without any fitting process. Several advantages:

- Quick measurement, only one frequency is needed to determine C_p or C_s. No need of the full EIS spectra.
- No post-treatment: no impedance fitting process is needed

- The graphic package of EC-Lab allows one to plot different types of graph such as *C vs. E* in log spacing, C^{-2} *vs. E*, and even more…

It is possible to follow up the capacitance change that can be carried out with the PEISW technique. This technique is also of interest for sensor applications.

Data files can be found in :
C:\Users\xxx\Documents\EC-Lab\Data\Samples\Photovoltaic\X_C_V_Charact

REFERENCES

1) Application Note #24 “Photovoltaic Characterizations: Polarization and Mott-Schottky plot”

Revised in 07/2018