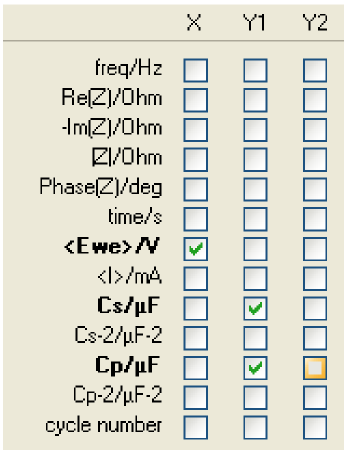
Application of the Capacitance-Voltage curve to photovoltaic cell characterizations

I- Introduction

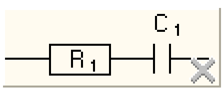
Capacitance measurement is widely used to carry out semiconductor characterization such as photovoltaic (PV) cells. For example, this measurement is used to determine the doping concentration.

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)



C_s:



C_p:

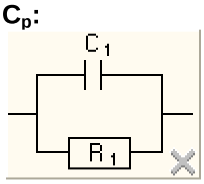


Fig. 1: The two equivalent circuits offered for direct capacitance plotting.

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* 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.

*capacitor whose capacitance may be intentionally and repeatedly changed mechanically or electronically

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).

Note: All settings and raw data files presented hereafter are available in the Data Sample folder of EC-Lab® Software as filename_C_V charact.mpr,

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

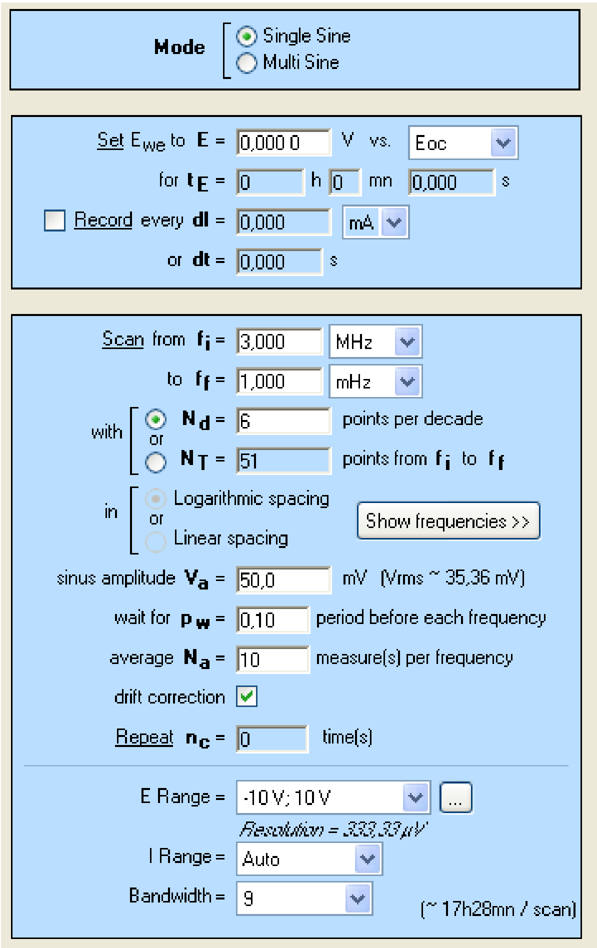


Fig. 2: Settings for the EIS characterizations of the varia-capacitor.

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 $SPEIS_{7MHz\text{-}1Hz}$ and $SPEIS_{323kHz}$, respectively. The voltage scan starts at 0V and goes up to 10V with steps of 200 mV.

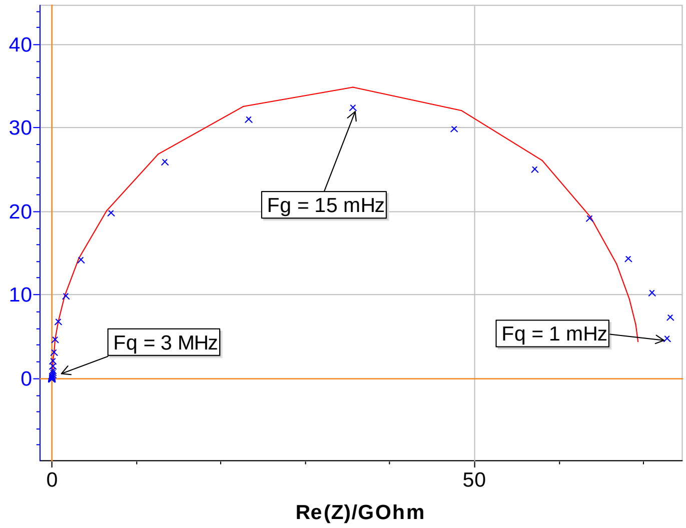


Fig. 3: Nyquist plot of varia-capacitor (Exp data fitted data).

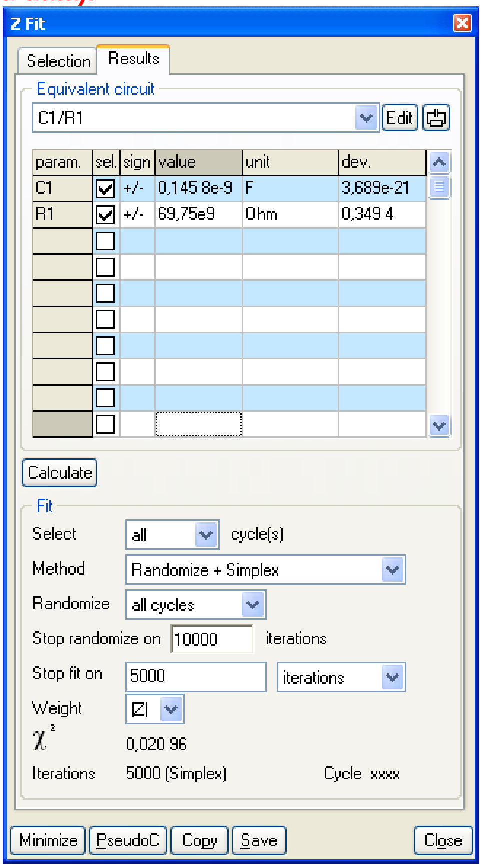


Fig. 4: Values of the Zfit process.

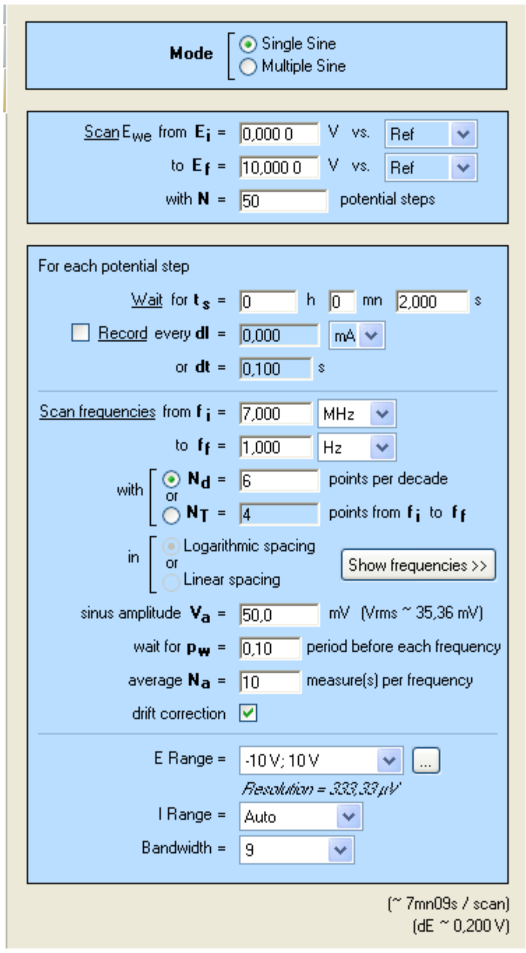


Fig. 5: SPEIS settings for varia-capacitor characterizations.

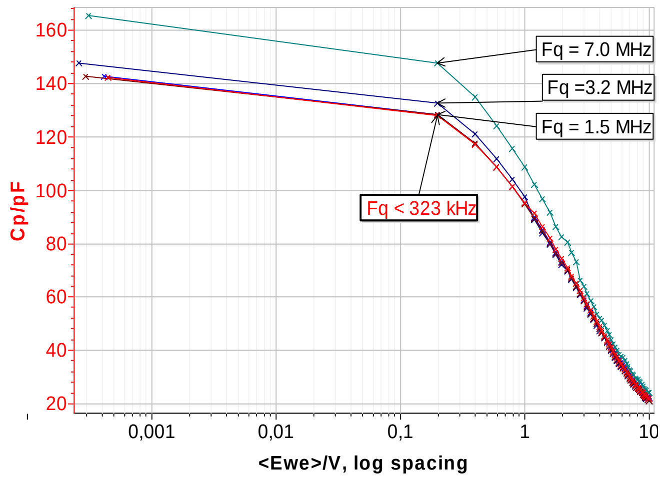


Fig. 6: C-V characterization at different frequencies.

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.

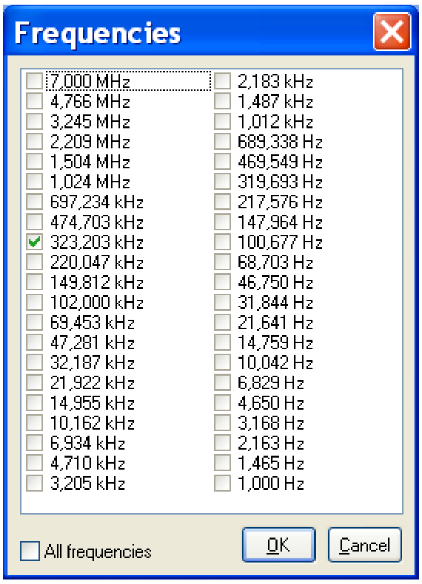


Fig. 7: Frequency selection.

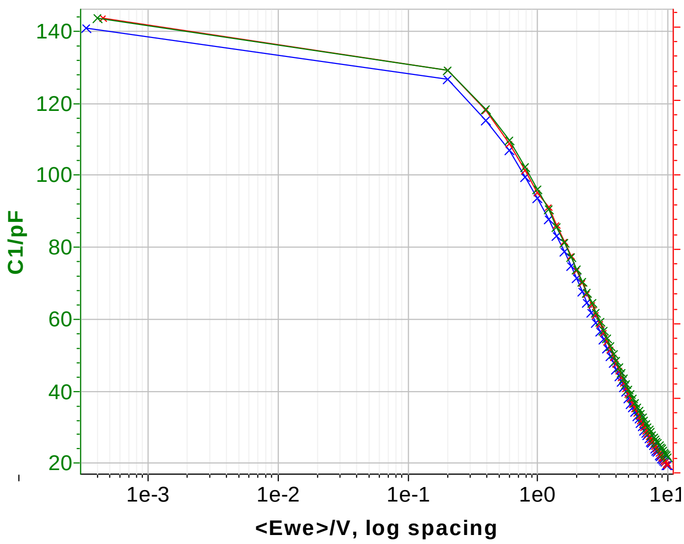


Fig. 8: semi logarithmic C-V curves of varia capacitor. C_p *vs* E of $SPEIS_{323kHz}$; C_p vs E of $SPEIS_{7MHz\text{-}1Hz}$ and C_1 (from Zfit) *vs* E of $SPEIS_{7MHz\text{-}1Hz}$.

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

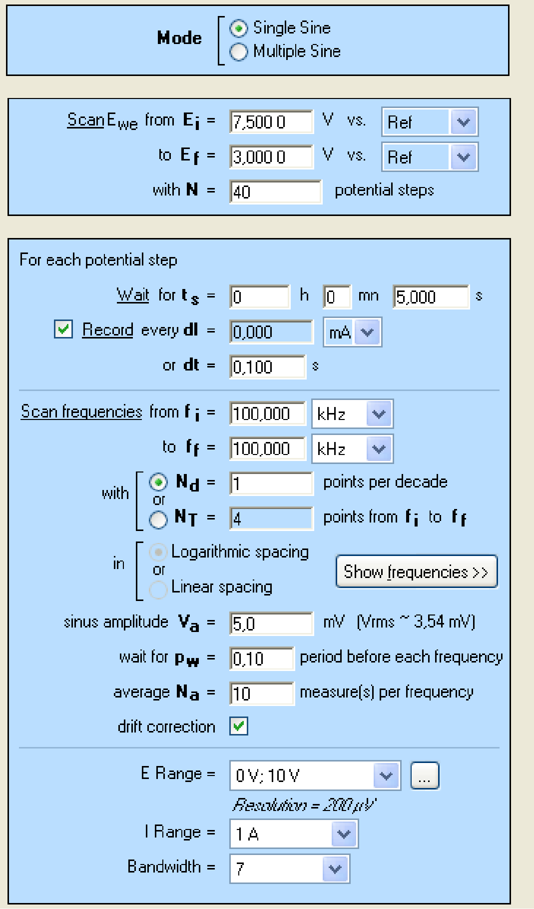


Fig. 9: C-V curves settings of PV cell characterization.

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

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

Where *e* is the electron charge (1.60 x 10^{-19} C)
$\varepsilon\varepsilon_0$ 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 the values given in the literature [1].

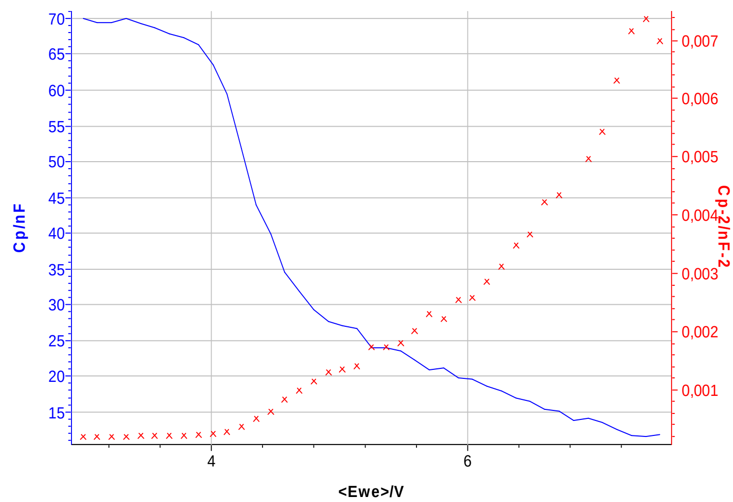


Fig. 10: C-V curves of photovoltaic cell. C_p vs E and C_p^{-2} vs E.

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.

References

[1] Photovoltaic Characterizations: Polarization and Mott Schottky plot, Application Note #24, http://www.bio-logic.info/potentiostat/notes.html