Experimental estimation of capacitances in pulsed barrier discharges

A.V. Pipa [(*)1], T. Hoder [1], J. Koskulics [2], M. Schmidt[1] , R. Brandenburg [1]

[1] *Leibniz Institute for Plasma Science and Technology (INP Greifswald), Felix-Hausdorff-Str. 2, Greifswald 17489, Germany*

[2] *Light and Life Laboratory, Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07030, USA*

[(*)]pipa@pisem.net

The determination of electrical parameters (e.g. transferred charge and gas gap voltage) in dielectric barrier discharge (DBD) reactors relies on estimates of key capacitance values. For miniature laboratory reactors driven by fast pulsed voltage waveforms with sub-microsecond rise time, the capacitance of the dielectric barriers cannot be evaluated from a single Q-V plot because of the limited applicability of the classical theory. In this work, it is suggested to obtain capacitance of dielectric barriers from a plot of the maximal charge versus maximal voltage amplitude similar to the classical way. The method is examined for coaxial DBD in argon at 100 mbar driven by high voltage pulses.

Dielectric barrier discharges are studied extensively due to numerous applications [1]. In 1943 Manley [2] suggested plotting the charge on the DBD reactor electrodes versus the applied voltage (Q-V plot) to infer electrical properties of the discharge. Q-V plots appear as a parallelogram. A part of the parallelogram corresponding to active discharge phase can be described as [3]:

$$q(t) = C_d\left(U(t) \pm U_g\right), \tag{1}$$

where C_d is the capacitance of dielectric layers, U_g is the gas gap voltage which is constant and equal to breakdown voltage, *q(t)* and *U(t)* are measured instant charge and voltage on the DBD electrodes. The height of this part is equal to the charge transferred in the gas gap *Q* [3].

The other part of the parallelogram corresponding to dark phase can be expressed as [4]:

$$q(t) \pm \frac{q_0}{2} = C_{DBD} U(t) \tag{2}$$

where C_{DBD} is the total capacitance of the discharge cell, which is a series connection of the C_d and gas gap capacitance; q_0 is related to Q as following:

$$Q = \frac{1}{1 - \dfrac{C_{DBD}}{C_d}} q_0 \, . \tag{3}$$

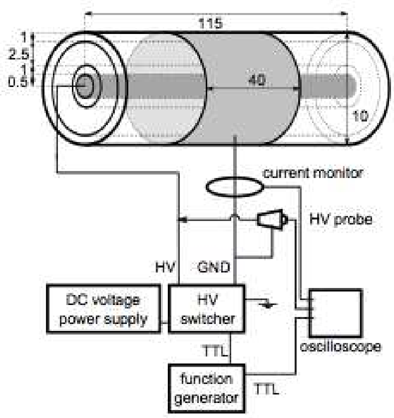

Fig. 1: Experimental setup.

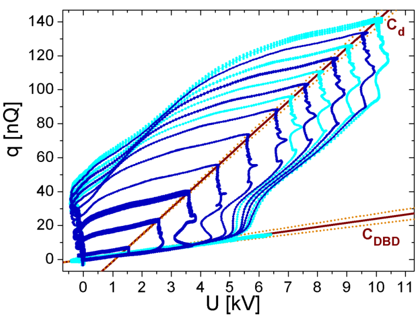

Fig. 2: Q-V plots measured for different amplitudes of applied voltages. Plots measured with increasing voltage amplitude are drawn by light lines and with decreasing amplitude by dark lines. Straight solid lines represent determined values of the C_d and C_{DBD}. .

Thus, the slope of one parallelogram side was associated with the total capacitance of DBD reactor C_{DBD} and the slope of the other side with C_d.

In present work the Q-V plots were measured in the setup shown in figure 1. The DBD is coaxial quartz glass reactor filled by argon at 100 mbar. The reactor was driven by positive high voltage pulses with amplitude up to 10 kV and rise time of 20 ns. The duration of pulse was 500 ns and repetition frequency was 100 Hz. The charge on the electrode was determined by integration of the current waveforms.

The results for different voltage amplitudes are shown in figure 2. The form of measured Q-V plots is significantly differ from classical parallelogram and could not be interpreted in classical way. Between the voltage pulses the reactor behaves as a simple capacitance and low part of the Q-V plots follows the equations (2) with q_0=0; that is shown in figure 2 by line C_{DBD}. Accurate examination of the current and voltage waveforms indicates that extinguishing of the discharge during high voltage plateau could not ensure absents of the current through the discharge gap. The current can be caused by redistribution of the space charge. Thus this part of the Q-V plot could not be used for determination of C_{DBD}.

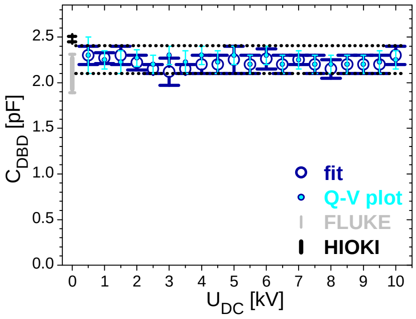

Fig. 3: Results of different approaches to C_{DBD}.

The value of the capacitance C_{DBD} evaluated in different ways: i) single Q-V plot, ii) fitting the measured current and voltage waveforms and iii) by simple measurement using RCL meters. All obtained results are shown in figure 3. Two different RCL meters are described in figure 3 as Fluke and Hioki. The results are in a good agreement.

The known value of the C_{DBD} allows evaluate the displacement current as a product of applied voltage derivative and C_{DBD}. The difference between measured and displacement current proportional to the discharge current. Thus the active part of the discharge can be identified. At low voltage amplitude the discharge develops at constant voltage and the corresponded part of the Q-V plot appears as a vertical line that in framework of classical theory can be misinterpreted as infinite value of C_d. At higher voltage amplitudes the corresponded parts of the Q-V plots could not be approximated by straight lines at all. Thus for small-scaled fast pulsed DBD U_g could not be assumed to be constant, see equation 1, and the evaluation of the C_d from single Q-V plot is impossible.

Actually, the dielectric barriers limit the maximum charge transferred through the gas gap. The amount of charge depends on the geometry of the reactor, applied voltage and the voltage across the gas gap. A plot of maximum charge Q_{max} detected on the reactor electrode versus maximum applied voltage V_{max} ($Q_{max} - V_{max}$ plot) gives an additional opportunity for determination of the C_d. In classical case U_g=*constant* and C_d can be determined either from Q-V plot or $Q_{max} - V_{max}$ plot [2].

In present work we suppose the gas gap voltage U_g at the moment when the charge transfer is finished $U_g(Q_{max})= U_{res}$ remains constant for different voltage amplitudes. Then the $Q_{max} - V_{max}$ plot can be expressed as:

$$Q_{\max} = C_d \left(V_{\max} - U_{res} \right) \qquad (4)$$

where the V_{max} is defined as $q(V_{max}) = Q_{max}$. The C_d line on the figure 2 follows the equation (4). Linear proportionality of the Q_{max} and V_{max} measured in this work provide evidence in favor of the suggested method. Q-V plots for different voltage amplitudes are also shown in [5]. We note that $Q_{max} - V_{max}$ plot follows the straight line as well. Nevertheless, verification of the assumption about independence of U_{res} on amplitude of the applied voltage requires additional investigations.

References

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