Gas breakdown — when the medium changes from an insulating phase to a conducting phase — is a spectacular phenomenon that takes place every time upon the initiation of any gas discharge [1, 2]. Contrary to this, breakdown is an unwanted phenomenon in electrical insulation, but in both cases the detailed understanding of the relevant physical effects is of utmost importance. Its simplest form, i.e., the Townsend breakdown in a dc electric field has been investigated for many decades. Whereas, the breakdown process under radio-frequency (rf) excitation exhibits its complexity, and most of relevant studies have been devoted to determination of a “breakdown curve”, which describes the dependence of the breakdown voltage on the product of the gas pressure and the electrode gap. Details of the gas breakdown process, e.g., time evolution of electrical and plasma characteristics, under rf excitation are far from being well understood [2].

In this work, time evolution of the electrical and plasma characteristics since the beginning of the excitation pulse is studied on the nanosecond time scale by a synergistic combination of experiments (performed in a parallell-plate pulsed capacitively coupled rf discharge in Argon with the use of multifold diagnostics), kinetic simulations (based on the particle-in-cell approach coupled with Monte Carlo collision) and an analytical model.

During the breakdown process the system is found to undergo a sequence of distinct electron power absorption modes, i.e. “avalanche”, “overshoot”, “DA”, and α modes, which were found to be highly correlated with the rapid changes of the system impedance as the plasma is building up. Figure 1 shows the time evolution of the voltage, $V_{RF}$, the current amplitudes: the total, conduction and displacement current, $I_{RF}$, $I_c$ and $I_d$, respectively, the relative phase between $V_{RF}$ and $I_{RF}$, $\phi_{vi}$. $I_c$ and $I_d$ are provided in the center of the electrode gap.

The time axis is divided into three phases in Figure 1: (i) pre-breakdown ($t < t_1$), (ii) breakdown ($t_1 < t < t_2$), and (iii) post-breakdown ($t > t_2$). During the pre-breakdown phase, the system behaves like a gas-filled capacitor. The charge density is so low that $I_c$ is negligible compared to $I_d$. $\phi_{vi}$ remains at 90° for dozens of rf cycles after an initial rise, and $I_d$ follows closely the increasing $V_{RF}$. This indicates a pure capacitive impedance, so that rf power is hardly deposited. During breakdown phase, $I_c$ contributes increasingly to $I_d$, while $I_d$ decays, because the externally applied potential is gradually shielded by the formation of space charge regions adjacent to the electrodes. Shortly after $t_1$, $I_d$ increases quickly, due to the rapidly growing $I_c$, while $V_{RF}$ drops slightly in the experiment. The opposite trends of $I_c$ and $I_d$ lead to a fast drop of $\phi_{vi}$, from 90° to a minimum of 62°, corresponding to an increased resistance of the system. In the post-breakdown phase, the increase of $I_{RF}$ slows down, and $I_d$ is now dominated by $I_c$ due to the attenuation of $I_d$.

Besides, the effects of changing the afterglow duration of a pulsed discharge on re-ignition process have also been studied. By decreasing the afterglow duration, it was found that the re-ignition process gradually deviates from the breakdown.

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References
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