Numerical simulation of successive nanosecond pulsed discharges in air at atmospheric pressure

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In this work we present numerical simulations of point-to-point nanosecond repetitively pulsed discharges in air at atmospheric pressure and put emphasis on the crucial question of preionisation pulse after pulse. We show 2D distributions of seed charges after successive pulses and study their influence on the dynamics of repetitively pulsed discharges.

Nanosecond repetitively pulsed discharges (NRPD) are very promising for many applications such as flow control or plasma assisted combustion. At very high repetition frequency (10-30 kHz), the preionisation level at the beginning of each new pulse may be as high as 10^{10} cm^{-3} as the recombinaison of ions between pulses is quite slow. Diffusion processes tend to decrease this large amount of seed charges and then it is important to take into account the ambipolar diffusion of charged species between pulses. In order to study these different aspects of nanosecond repetitively pulsed discharges, we use a discharge code based on a 2D axisymmetric fluid model described in [1]. Rates and transport parameters are taken from [3] and are functions of the reduced electric-field. During the interpulses, we solve the chemistry of the charged species coupled with their diffusion in the gas, assuming that charged species diffuse at the velocity of positive ions. The geometry used in this study is a point-to-point geometry with two hyperbolic electrodes with 300 μm radius of curvature at the tip and a gap size of 2.5 mm. We have computed 10 pulses at a frequency of 10 kHz and at a temperature of 1000 K with an applied voltage of 5 kV. The pulse duration is about 5 ns with a rise-time and a decrease-time of 2 ns and a plateau at 5 kV during 1 ns. As initial condition, we have considered a low uniform preionisation of 10^4 cm^{-3}. Photoionisation is taken into account in these simulations and we have checked that it has a significant influence for the first pulse but its influence becomes negligible for other pulses.

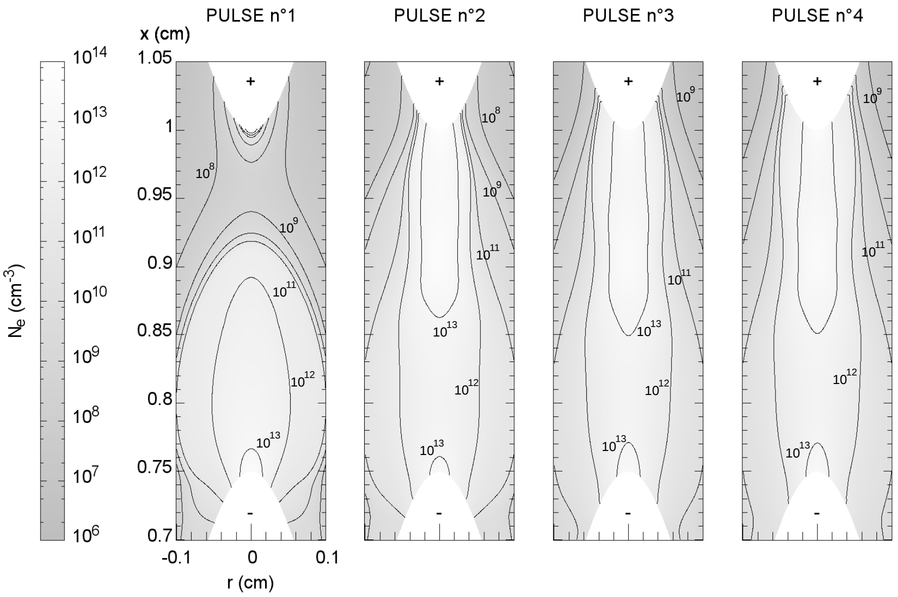

Fig. 1: Cross-sectional views of the electron density at the end of the first four pulses of a NRPD in air at atmospheric pressure at 10 kHz and 1000 K. The pulse duration is 5 ns, the applied voltage is 5 kV, and the inter-electrode gap is 2.5 mm.

Figure 1 shows the 2D distributions of the electron density for 4 pulses just before the decrease of the applied voltage. We note that the discharges are almost identical after the three first pulses which means that a permanent regime is obtained very quickly. It is a consequence of the fact that the final preionisation level obtained at the end of an interpulse is almost independent of charged species densities obtained during previous pulses. As explained in [2], the final positive ion density $n(T_i)$ at the end of an interpulse of duration T_i is given by $n(T_i) \simeq (\beta T_i)^{-1}$ where β is the recombinaison rate of charged species and then $n(T_i)$ is independent on n_0, the positive ion density obtained during the pulse. In our case for air at atmospheric pressure : $\beta \simeq 2.10^{-7} cm^3 s^{-1}$ [3] and $n_0 \simeq 10^{13}$ cm^{-3} for discharges at 1000 K. This approximation is correct as long as $T_i * \beta >> n_0^{-1}$. Then this is verified if the interpulse duration T_i is much longer than 0.5 μs which corresponds to frequencies much smaller than 2 MHz. NRPD verify this condition most of the time with frequencies in the range 1 kHz-100 kHz. Consequently in our simulation (10 kHz), the dynamics of the discharge is only changing during the first pulses of the NRPD and then remains always the same. Figure 1 shows that during the first pulse, there is no connection between the positive and the negative discharges. Connection occurs during the second pulse because the discharge is able to ignite a little earlier thanks to the increase of the preionisation level due to the first discharge. In a previous work [4], we have shown that this could correspond to a transition from a corona to a glow regime, as described experimentally in [5]. Pulse after pulse, the preionisation left by previous discharges diffuses and spreads radially. We have checked that the negative discharge is barely affected by this spreading of the preionisation. For the positive discharge, Figure 2 shows that it ignites in a medium highly preionized over a radius of about 2 mm, larger than the diameter of the discharge. These results validate the assumption of a uniform preionisation of the gas used in our previous simulations of NRPD [4].

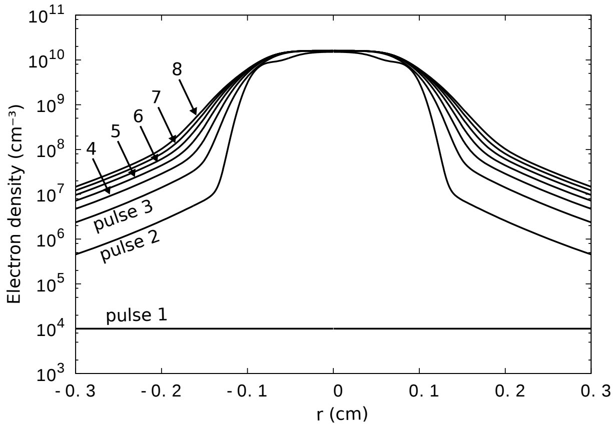

Fig. 2: Sliced view of the distribution of the electron density at the begining of each pulse of a point-to-point nanosecond repetitively pulsed discharge at 10 kHz and 1000 K at 0.5 mm from the tip of the anode .

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