High-Voltage Nanosecond Pulse Discharge in a Low-Pressure Preionized Medium

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A disharge, created by superposition of a steady-state RF electric field and single high-voltage pulses, is being studied. RF field sustains a capacitively coupled weakly-ionized low-pressure plasma, to which the high-voltage pulses are applied. It is demonstrated, that this discharge evolves through two main phases. In the first phase strong electric field of the pulse sweeps significant part of the plasma electrons out of the discharge gap and the residual quasi-stationary electric field of the ion cloud gives rise to the rapid increase of plasma density and intensity of the emission. In the second phase the discharge becomes dark due to the screening of the RF electric field by the high-density plasm, formed in the first phase. Different physical mechanisms, underlying the observed phenomena, are discussed.

Interaction of short (tens ns) high-voltage (kV to tens of kV) pulses with the weakly ionized low-pressure plasma of RF discharge is investigated. Such pulses are at present a very common tool in the low-temperature plasma physics and are used for e.g. fast ignition of the reactive gas mixtures [1] or in DBD discharges in plasma medicine [2]. They were also used to manipulate the microparticles, levitating in DC [3] and RF discharges [4].

The experiments are performed in a modified GEC reference cell. Two disc-shaped electrodes of 15 cm diameter are separated by a 5 cm gap. Top electrode is grounded via a 50 Ω resistor. To the bottom electrode sinusoidal RF signal (13.56 MHz, 50-100 V peak-to-peak), sustaining a steady-state discharge, is applied. In addition, to the top electrode single pulses of 20 ns duration and 1-17 kV amplitude are coupled. Experiments are performed in argon in the pressure range of 0.07-3 Pa. The discharge was characterized both electrically (by measuring RF voltage and current) and optically (by observing its image with the ICCD videocamera).

We performed 1D3V particle-in-cell simulations, based on the code from [5] according to the following procedure: fisrt a steady-state RF discharge was obtained, then a high-voltage pulse was applied to the discharge gap and evolution of the plasma was tracked. RF voltage was kept constant all through the process.

Both experiment and simulation exhibit similar evolution of the plasma after the pulse. During the pulse majority of the electrons are swept away from the discharge gap by the strong electric field of the pulse. After removing the pulse voltage the discharge is restarted due to the high electric field, created by the ions, which are practically not affected by the pulse. Within several hundred ns the excessive ions leave the discharge gap. Quasineutral plasma with the density much higher, than that of the steady-state discharge, is formed. This results also in the rapid increase of the brightness of the discharge. In several s the discharge enters a dark phase, where the plasma density is still high, but the average electron energy is too small to efficiently produce the excitation of argon atoms. The dark phase lasts for several hundred s and finishes with the relaxation to the steady-state RF discharge.

According to the simulation the bare cloud of positive ions, formed in the discharge gap after the removal of the high voltage from the electrodes, will create a strong electric field (positive potential in the kV range), which lives long enough to produce excessive ionization in the discharge gap. This is confirmed by the experimental observation of a strong overshoot of the emission intensity, starting right after the pulse is over (Fig.1a). An important role of photoelectron emission due to the vacuum UV, radiated by excited argon atoms, in the formation of this overshoot was demonstrated. Role of

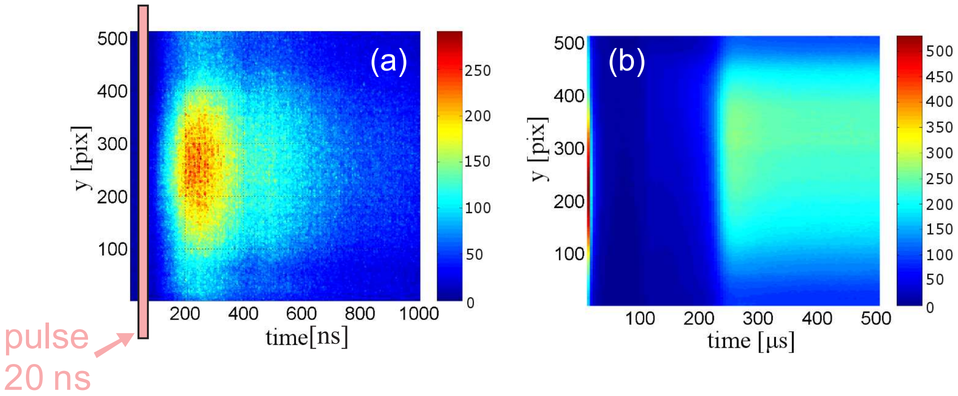

Fig. 1: Time-space map of the emission intensity of the nanopulse discharge on different timescales: (a) behavior of the discharge right after the pulse; (b) dark phase

the bremsstrahlung, radiated by the energetic electrons, hitting the surface of the electrode, was on the contrary shown to be negligible.

The dark phase (Fig.1b) was revealed not to be connected with the redistribution of RF voltage in the external circuit of the discharge. In a standard situation the reduction of the RF voltage on the discharge gap during the relaxation of the plasma is about 15%. We intentionally added additional impedance into the external circuit so that the reduction of the RF voltage became 50%. This resulted, however, in a very small change in the depth of the dark phase. In the simulations the dark phase is obtained without any variation of the RF voltage at all. The mechanism of the dark phase formation is therefore provided by the screening of the RF field by the high density plasma, created in the overshoot.

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