Measurements of the ion energy distribution function during the creation of a fire-rod in a weakly magnetized discharge plasma column

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1. Introduction

A fire-rod is a cylindrical localized space charge structure of a certain length that can appear in a weakly ionized magnetized plasma in front of a sufficiently positively biased additional electrode [1,2] (often simply called anode). In an unmagnetized plasma the structure has a spherical shape and is called fireball [3,4,5]. Both structures are bounded by a double layer (DL) consisting of two adjacent layers of opposite space charge. DLs create a spatially localized electric field extending for several Debye lengths, separating two quasi neutral-plasmas with different parameters including space potential [6]. Also in usual glow discharges, phenomena like fireballs or fire-rods can appear in front of the actual anode [7], often called anode DLs.

The positive bias of the anode accelerates electrons from the background plasma to energies sufficient to create an additional localized discharge – the fireball – in front of the anode by impact ionization of neutrals. The fireball plasma has a higher space potential, density and luminosity than the background plasma.

2. Experiment

Experiments are performed in the linear magnetized discharge plasma device at the Jožef Stefan Institute, Ljubljana, Slovenia. The length of the device is 1,5 m and its diameter is 17 cm (Fig. 1). Plasma is produced in argon by a DC discharge between hot cathode filaments, heated by direct current, and the wall. The argon pressure is 0,2 Pa, discharge voltage U_d = 50

V, discharge current I_d = 1 A and magnetic field density B = 7 mT. The resulting plasma drifts into the magnetised tube region through a circular limiter and forms a plasma column of 5 cm diameter with a Gaussian radial density profile.

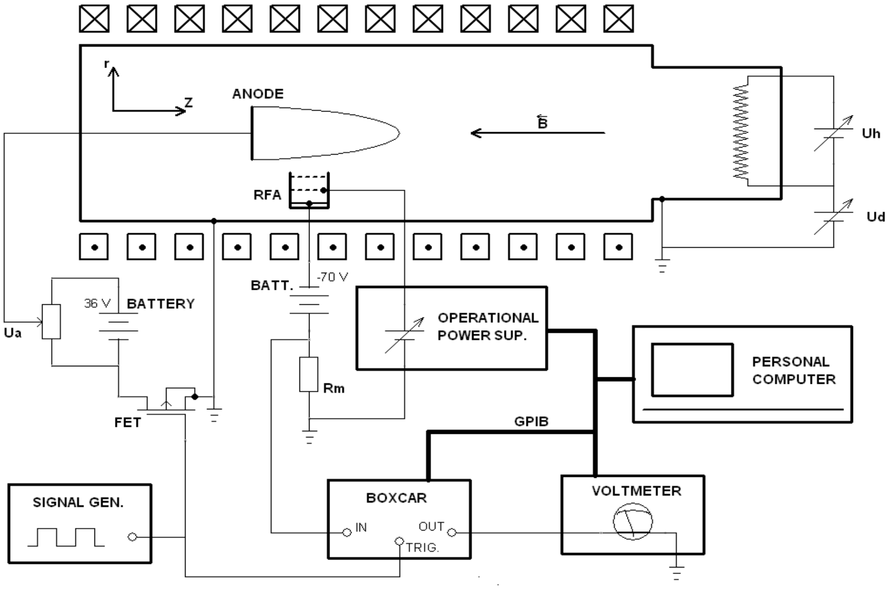

Figure 1: Schematic of the experimental set-up.

Typical electron temperatures are kT_e = 1,5 – 3 eV and typical plasma density on the main axis are $n = 2 - 6 \cdot 10^{15}$ m^{-3}. The Larmor radius for electrons is around 0,1 mm, while the Larmor radius for the positive ions is more than 1 cm. An additional planar anode with 2 cm diameter is immersed into the plasma column with its surface perpendicular to the magnetic field lines. If the anode is biased positively a fire-rod can be created. An example of the current-voltage characteristics of this anode is shown in Fig. 2. The fire-rod is created when the anode bias U_a reaches approximately +25 V with respect to the grounded vacuum vessel and the electron saturation current jumps suddenly, showing hysteresis when the voltage is decreased again.

In this paper some results of pulsed experiments are presented. Using a fast transistor switch the anode bias is pulsed from floating potential to a selected positive value. The temporal evolution of the ion energy distribution function (IEDF) perpendicular to the magnetic field lines is measured with an ion energy analyzer and boxcar integrator. The IEDF is proportional to the first derivative of the current-voltage characteristics of the analyzer. In Fig. 3 two examples of such characteristics are shown: one with fire-rod and the second without it. The analyzer is located at r = 20 mm, i.e. a few mm out of the current channel of the collector. It can be seen clearly how the positive ions are pushed out in radial direction, when the fire-rod is created. This process is similar to that known from the electrostatic ion-cyclotron instability exited by a positively biased collector at the end of the magnetized collisionless plasma column of a Q-machine. In this case an ion ring beam is formed during the two dimensional potential relaxation of a cylindrical double layer [8,9,10].

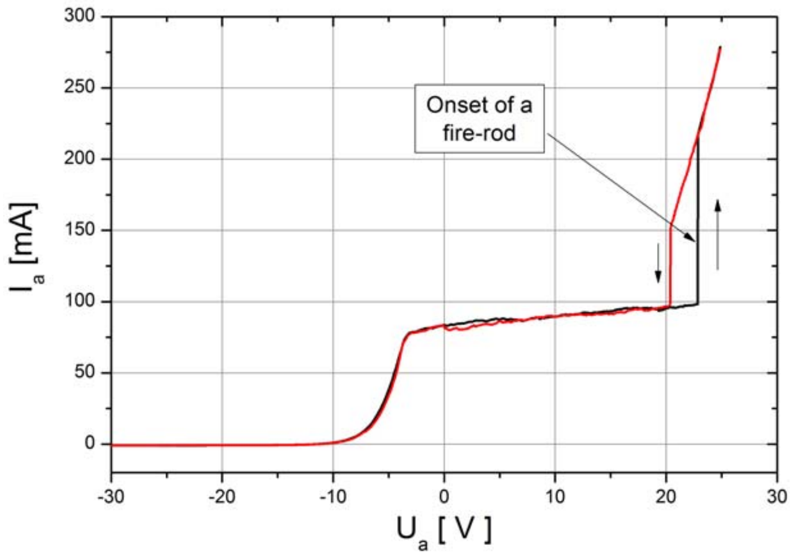

Figure 2: Example of a current voltage characteristic of the 2 cm diameter anode.

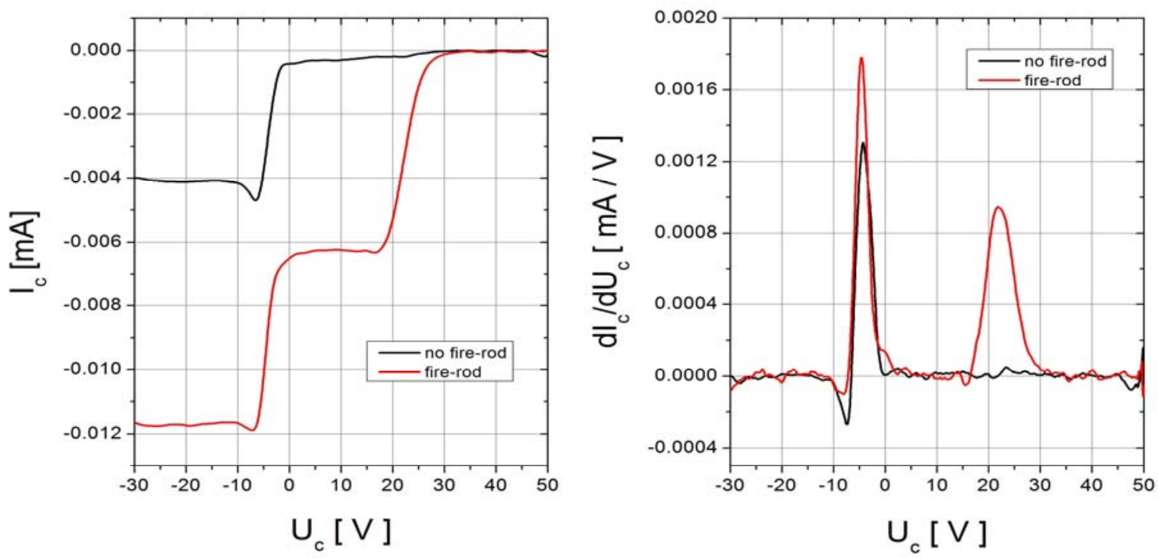

Figure 3: Examples of current voltage characteristics of the ion energy analyzer without (black line) and with fire-rod (red line). The analyzer is located at z = 5 mm and r = 20 mm from the anode.

In Fig. 4 an example of the temporal evolution of the IEDF is shown for two positive voltage steps applied to the collector. At U_a = 15 V the fire-rod is not yet created but it can be noticed that positive ions are pushed out of the current channel between 6 and 16 μs. At higher voltage steps a fire-rod starts to form about 6 μs after the application of the voltage step to the collector and it is formed in a few μs.

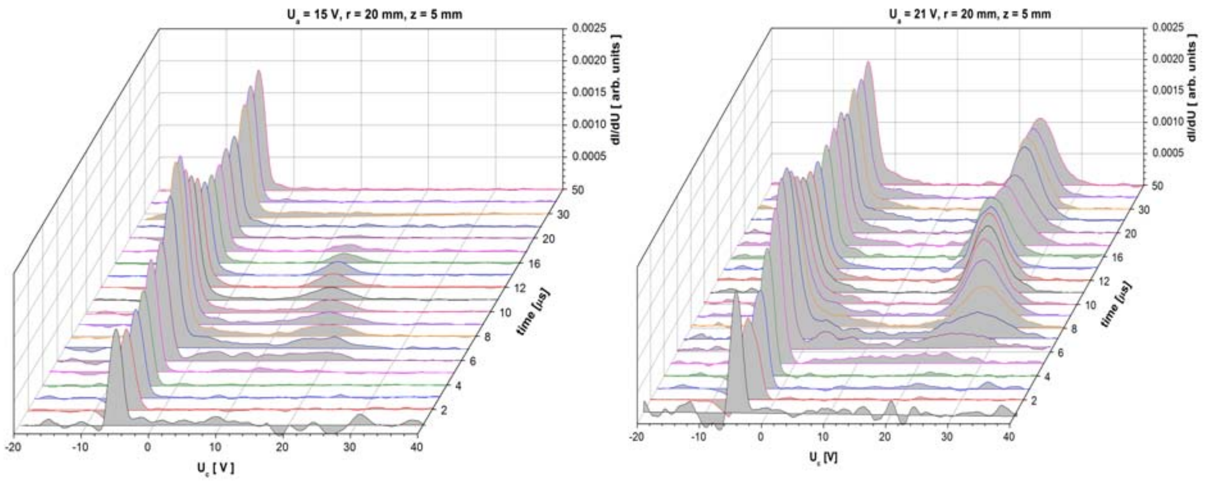

Figure 4: Temporal evolution of the ion energy distribution function after the application of a positive voltage step to a collector: U_a = 15 V, no fire-rod, left and U_a = 21 V, fire-rod is created, right. The analyzer position is z = 5 mm and r = 20 mm.

Conclusions

A fire-rod was produced in front of a positively biased plane electrode, placed in a magnetized discharge plasma column. The ion energy distribution function was measured by an ion retarding field energy analyzer. Extensive and systematic measurements of the spatial and temporal evolution of the ion energy distribution function were performed. In the plasma region surrounding the fire-rod the presence of both, thermal plasma ions and of an ion beam was observed. The ion beam is produced by the acceleration of ions leaving the fire-rod through the double layer, which separates the fire-rod from the surrounding plasma region. A longer paper will follow presenting more details.

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