Further experiments on inverted fireballs

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Abstract

Fireballs are luminous phenomena, which evolve if a positively biased electrode is inserted into a thin background plasma with a sufficiently high neutral pressure. These phenomena show a wide variety of instabilities and nonlinearities and are therefore an interesting topic of fundamental plasma research. Unstable as well as stable fireballs have been studied by several authors [1-4]. Hitherto, fireballs were either seen on plane solid or gridded electrodes appearing as sharply bounded localized structures in front of the electrode [3].

1. Introduction

This work will focus on some fundamental properties of so called inverted fireballs, which are fireballs trapped inside a hollow, highly transparent grid and separated from the surrounding plasma by a nearly current free double layer [4]. This fireball configuration leads to electron oscillations at frequencies up to 100 MHz. The rf period is determined by the transit time of the electrons through the grid-sphere. Due to the fact that this frequency is far below the electron plasma frequency, no electromagnetic eigenmodes but a beam space charge wave evolves. The oscillations themselves are triggered by electrons, which are accelerated from the bulk plasma into the inverted fireball. There they ionize and accumulate in the vicinity of the grid because of the modulation of the electric field. This behaviour leads to an amplification of the electric field and eventually to periodic oscillations. This mechanism is quite similar to reflex instabilities known from klystrons or vircators. The observed instability shows some remarkable physical properties like nonlinearities or mode jumping. These properties can have different reasons such as the generation of harmonics due to the bunching of electrons, fireball relaxation oscillations or irregularities in the equipotential surface formed by the sheath around the grid wires.

The frequency properties as well as well as some basic physical parameters and nonlinearities were presented recently in two companion papers [4],[5]. In this work we will present some other fundamental features of inverted fireball such as the number of Debye lengths which are necessary to close the equipotential surface around the grid electrode and the radial plasma potential profile through the inverted fireball.

2. Experimental setup

Experiments have been carried out in the cylindrical Innsbruck Double plasma (DP) machine with a length of 0.9 m and a diameter of 0.45 m in order to determine the thickness of the Debye shielding which is necessary to trap the fireball inside the hollow electrode. To accomplish this the sheath around one grid wire has to be large enough to overlap with the sheath of the nearby wire in order to form a closed equipotential surface around the whole electrode.

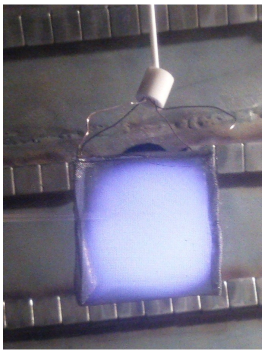

Fig. 1: Highly transparent grid electrode with an argon fireball at about 10^{-2} mbar.

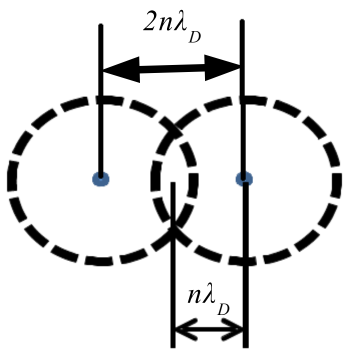

Fig. 2: Debye shield forming an equipotential surface around the grid wires of the fireball electrode.

For the confinement of the fireball a cube made of a stainless steel grid was manufactured. This cube has a grid constant of 300 μm, a transparency of ~70% and is shown in figure 1. Figure 2 shows a schematic of the Debye shielding around the wires of the grid electrode. Due to the overlap of the sheaths an equipotential surface is formed.

The electron temperature and density were measured with an ordinary Langmuir probe made of a tungsten wire with 0.2 mm diameter and 3 mm length. The working gas was argon 5.0 in a pressure range between 0.04 and 0.18 mbar. The discharge current increased from 520 mA up to 2700 mA, the discharge voltage was 60 V and the bias of the grid electrode was 100 V. The electron temperature taken at the point where the inverted fireball starts to leak out of the gridded cube was 0.6 eV. This electron temperature was determined from the logarithmic plot of the Langmuir probe characteristics.

It is emphasised that the electron temperature and density are taken in the bulk plasma because if there is a background plasma at t = 0 but no fireball there will already be a sheath around the grid wires which will then form the surfaces of equal potentials and trap the electrons. This triggers the inverted fireball therefore the Debye length properties of the bulk are taken into account rather than the plasma parameters within the inverted fireball.

The number of Debye lengths is however a crude estimation because there will be a very electron rich sheath anyway.

3. Experimental results

The first results obtained in the experiments are shown in fig. 3:

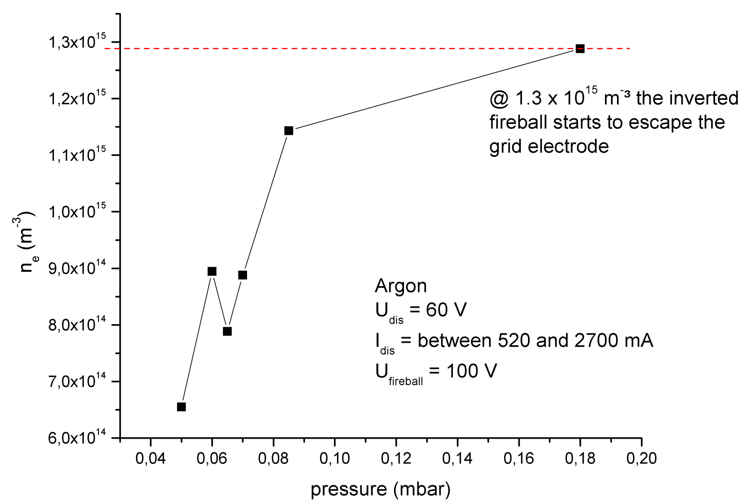

Fig. 3: Development of the electron density in dependence on the neutral gas pressure inside the chamber. The fireball leaks out from the grid cube when the particle density reaches $1.3x10^{15}/m^3$.

The fireball starts to leak out from the cube for a particle density of about $1.3x10^{15}/m^3$ and a electron temperature of 0.6 eV which corresponds to a Debye length of 160 µm. The grid space is 300 µm which leads to the conclusion that the sheath around the grid wires has to have at least a thickness in the order of 1 Debye length in order to close the equipotential surface completely.

Further measurements determined the radial plasma potential profiles within the inverted fireball. The experimental parameters were as follows: Argon at a pressure of $3x10^{-2}$ mbar, a discharge current of I_{dis} = 130mA, a discharge voltage of U_{dis} = 45V and a positive bias on the fireball electrode of $U_{fb} = 40V$. The Langmuir probe consisted of a 0.2 mm tungsten wire with a length of 3 mm. It was mounted on a step motor and moved in 2 mm steps starting 5 mm from the edge of the grid electrode. The probe was inserted into the inverted fireball through a small hole in the mesh. The results are shown in figure 4:

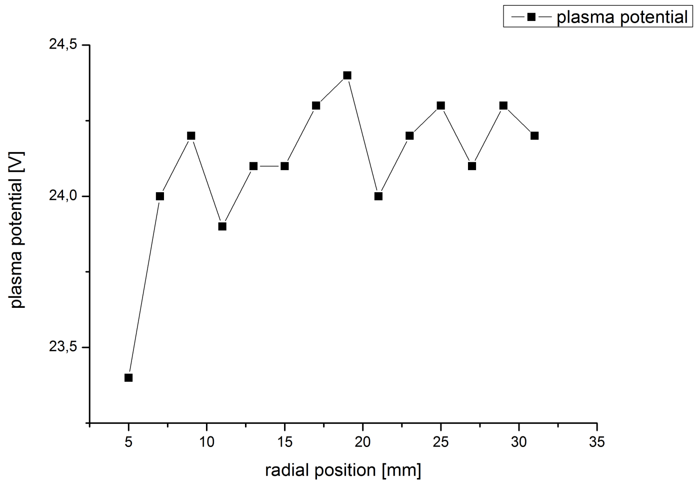

Fig. 4: Radial plasma potential profile of an inverted Argon fireball at a neutral gas pressure of $3x10^{-2}$ mbar, I_{dis} = 130 mA, U_{dis} = 45 V and a positive bias on the fireball electrode of 40 V.

The measurements reveal that the potential profile of an inverted fireball is nearly flat if the size of the fireball is very large compared to the Debye length which is only a few microns in this case. If this assumption is fulfilled, the only potential drop is located in the nearest vicinity of the surface of the fireball electrode. These data show that the plasma potential of an inverted fireball is at a much higher level than in the bulk plasma which is only slightly positive if the fireball is not present.

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