Letter: Influence of inhomogeneous electrode biasing on the plasma parameters of inverted H_2 fireballs

J. Gruenwald[1], J. Reynvaan[2] and P. Geistlinger[2]

[1] *Gruenwald Laboratories, Taxberg 50, 5660 Taxenbach, Austria*
[2] *University of Graz, Institute of Physics, Universitaetsplatz 5, 8010 Graz, Austria*

(Received: 09. April 2018, Accepted: 04. May 2018, Published online: 01. July 2018)

In this letter we present measurements of the influence on inhomogeneous electrode biasing on the basic plasma parameters of inverted fireballs in a hydrogen plasma. The measurements were performed in hydrogen because it is often used in many reactive plasmas, which are very important for technical or industrial applications. The dependence of the plasma parameters on voltages and currents on the electrodes are described in this work. It will be shown that the density profiles and the plasma potentials inside an inverted fireball can be shaped to a certain extend by asymmetric potentials on the anode.

DOI: 10.31281/hat5v156

[1] jgruenwald@g-labs.eu

I. Introduction

In recent years inverted fireballs (FBs) have been proven to be viable tools for surface modifications [1-5] but only little data has been published on the basic plasma parameters of inverted FBs [6,7]. Additionally, some more recent work has been done to understand the energy deposition and plasma creation in inverted FBs using sophisticated particle-in-cell simulations [8,9]. Inverted FBs provide a very homogeneous plasma over a large area with high plasma densities. However, it will be demonstrated in this letter that it is possible, to a certain extent, to shape the profiles of the plasma potential, the electron temperature and the plasma density with asymmetric biasing of the FB anode, i.e. applying different potential on different sections of the grid electrode.

II. Experimental setup

All experiments have been conducted in a hot filament UHV vacuum chamber with a base pressure of 10^{-8} mbar and equipped with a standard movable Langmuir probe system with a 10 mm long tungsten tip with 0.15 mm diameter. Both have been described in more detail in [7]. The inverted FBs haven been created in hydrogen at a working gas pressure of 5×10^{-2} mbar. The Langmuir probe was inserted from the side into the inverted FB through a hole on the side of the 10 x 10 x 10 cm^3 gridded anode (grid wire: 60 μm diameter and 130 μm grid spacing). This so-called ‘bottom’ electrode was electrically insulated from the rest of the grid and could, thus, be biased independently. An inverted FB is created by accelerated electrons from the background plasma that are oscillating through the grid. A photograph of the gridded cube and a sketch of the Langmuir probe tip are depicted in Fig. 1.

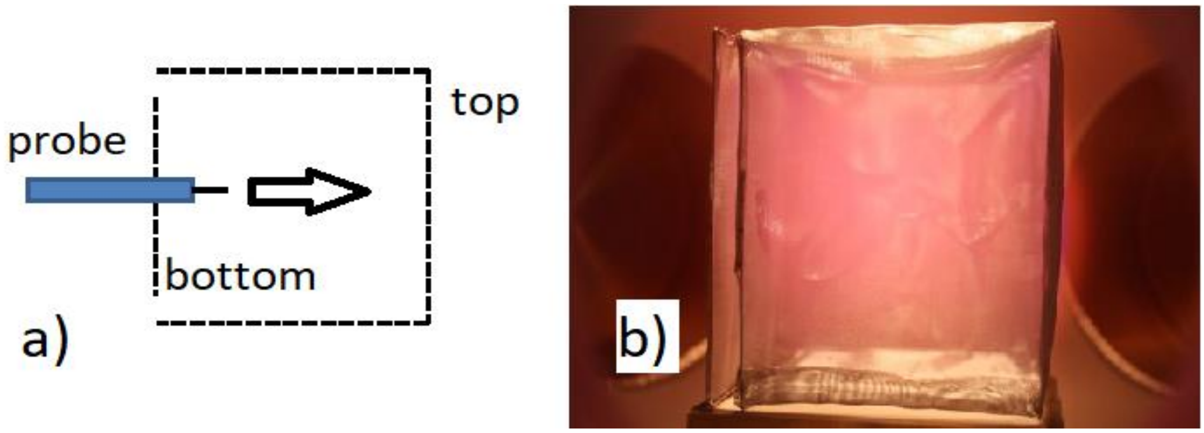

Figure 1 A photograph of the electrode configuration [a)] and a sketch of how the Langmuir probe was inserted into the inverted FB [b)]. The hot cathode was located 50 cm above the gridded electrode in all of the experiments.

III. Results and Discussion

During the experiments the following physical parameters were recorded: The current and voltage on the 'top' electrode (I_{top}, U_{top}), the current and voltage at the 'bottom' electrode (I_{bot}, U_{bot}) and the plasma current in the chamber (I_{fil}, U_{fil}). Furthermore, the plasma potential U_{pl}, the electron temperature T_e and the electron density n_e have been measured with the Langmuir probe system. From the latter two the Debye length has been calculated The following Table 1 shows these parameters for a series of four measurements.

The parameters in Table 1 have been chosen because it was observed that the confinement of the inverted FB was best at these values. The first important quantity to look at is the plasma potential. Its profile along the trail of the probe is shown in Fig. 2a). It can be seen that the plasma potential is very homogeneous within the inverted FB at a quite high level. As the potential jump in a FB occurs in the double layer, which forms its border [10] this is a good indication of the actual spatial size of such a FB. The magnitudes of the potential jumps are as follows:

From 42.3 V to 59.5 V (= 17.2 V) in 1

From 44.5 V to 60.0 V (= 15.5 V) in 2

From 59.2 V to 75.2 V (= 16.0 V) in 3

From 76.7 V to 81.2 V (= 4.50 V) in 4

Measurement	U_{bot} [V]	I_{bot} [mA]	U_{top} [V]	I_{top} [mA]	U_{fil} [V]	I_{fil} [mA]
1	30.8	7	58.2	546	-13.5	484
2	50	48	58.7	541	-11.5	505
3	74.2	106	72.2	278	-18.2	322
4	79.8	322	74.5	376	-7.5	543

Table 1: Measured potentials (with respect to ground) and currents.

Fig. 2b) shows the electron temperature as obtained from the I-V probe traces. As the incoming electrons gain a lot of kinetic energy in the double layer surrounding the FB, their temperature will increase accordingly there. However, this energy is rapidly dissipated by the numerous inelastic collisions within the FB which causes the electron temperature to decrease very fast inside the surface of the inverted FB. In the following Fig. 2c) the electron density is displayed. The peak density as well as the onset of the density increase tends to shift towards the inside of the cage due to the slightly higher positive potential on the "top" monotonically. The electron density in measurement 4 rises by a factor of up to nearly 100 in the center of the FB compared to the background plasma, which is produced by the DC discharge (from 6.6 x 10^{13} to 8.2 x 10^{15} m^{-3}). Furthermore, the position of the raise in plasma potential and electron density shifts towards the 'bottom' anode with increasing positive bias. Hence, it was shown that there is the possibility of shaping the density profile and the range of plasma potential homogeneity to some extend with asymmetric biasing of certain areas of an inverted FB electrode. This might lead to interesting new possibilities in the

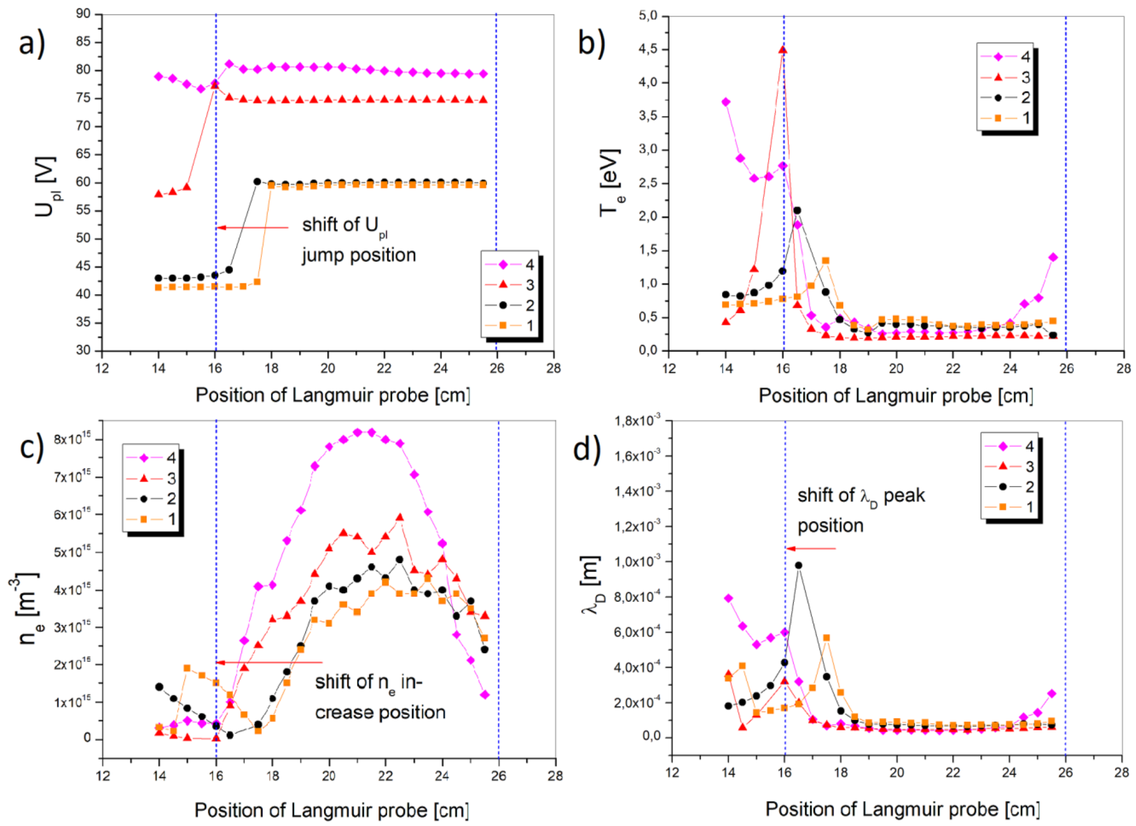

Figure 2: Plasma potential [a)], electron temperature [b)], electron density [c)] and the Debye length [d)] in dependence on the probe position in the vacuum chamber.

electrode. The same behaviour is to be seen in the positions of the plasma potential jumps in Fig. 2a). When the potential difference is small like in curve 4, the shape of the density distribution will become more symmetric and the maximum density is reached at the maximum value of I_{bot}. This is indeed interesting, since the currents on the 'bottom' electrode do not behave as field of plasma enhanced chemical vapour deposition technologies.

The Debye length λ_D, which is the crucial parameter for the confinement of the inverted FB also peaks near the vicinity of the grid inside the inverted FB. This peak shifts as well towards the mesh with increasing U_{bot}. Since λ_D has to be at least half of the grid constant in the plane of the anode mesh in order to trap the inverted FB, the trapping mechanism will become more inefficient if this length becomes too small or moves too far away from the grid. This sets a physical limitation to the tailoring of the shape of electron densities and plasma potentials inside an inverted FB and has to be kept in mind, especially when it comes to technical applications, such as deposition or other forms of surface modification where the plasma homogeneity over a large area is of importance.

IV. References

[1] J. Gruenwald, J. Reynvaan and P. Knoll, "Creation and characterization of inverted fireballs in H_2 plasma", Phys. Scripta (T161) 014006 (2014). DOI: 10.1088/0031-8949/2014/T161/014006

[2] P. Knoll, J. Reynvaan, M. Mayer et al. "PECVD of carbon by inverted fireballs: From sputtering, bias enhanced nucleation to deposition", Diam. Rel. Mater. 65, 96-104 (2016). DOI: 10.1016/j.diamond.2016.02.021

[3] M. Mayer, J. Reynvaan, J. Gruenwald et al., "Diamond like carbon deposition by inverted fireballs", Mater. Today: Proc. **3**, S184-S189 (2016).
DOI: 10.1016/j.matpr.2016.02.031

[4] J. Reynvaan and J. Grünwald, "Plasma-assisted chemical gas separation method having increased plasma density and device for implementing the method", US Patent 9,490,121 (2016)

[5] J. Reynvaan, J. Gruenwald, M. Mayer and P. Knoll, "Multiple Fireballs in a Reactive H_2/CH_4 Plasma", IEEE Trans. Plasma Sci. **42** (10), 2848 (2014).
DOI: 10.1109/TPS.2014.2301494

[6] J .Gruenwald, R. Stenzel, C. Ionita and R. Schrittwieser, "Further experiments on inverted fireballs", Proc. 38th EPS Conference on Plasma Physics, (2011)

[7] J. Gruenwald, J. Reynvaan and P. Geistlinger, "Basic plasma parameters and physical properties of inverted He fireballs", Plasma Sources Sci. Technol. **27** (1), 015008 (2018). DOI: 10.1088/1361-6595/aaa332

[8] D. Levko and J. Gruenwald, "On the energy deposition into the plasma for an inverted fireball geometry", Phys. Plasmas, **24**, 103519 (2017). DOI: 10.1063/1.4998548

[9] D. Levko, "Unmagnetized fireballs in the hollow cathode geometry", Phys. Plasmas, **24**, 053514 (2017). DOI: 10.1063/1.4983323

[10] A. Lefort and P. Andanson, "Characteristic Parameters of the Anode Spot", IEEE Trans. Plasma Sci. **13** (5):296-299 (1985) DOI: 10.1109/TPS.1985.4316424