

# Experimental investigation of the interaction between two fireballs in low-temperature plasma

C. Ionita<sup>1</sup>, S.A. Irimiciuc<sup>1,2</sup>, D.G. Dimitriu<sup>2</sup>, S. Popescu<sup>2</sup>, M. Agop<sup>3</sup>, R.W. Schittwieser<sup>1</sup>

<sup>1</sup>*Institute for Ion Physics and Applied Physics, University of Innsbruck, Innsbruck, Austria*

<sup>2</sup>*Faculty of Physics, “Alexandru Ioan Cuza” University, Iasi, Romania*

<sup>3</sup>*Department of Physics, “Gheorghe Asachi” Technical University, Iasi, Romania*

## 1. Introduction

Mesoscale science has to bridge the gap between nanoscience and the macroscopic world. Collective behaviour of large numbers of atoms, molecules and nanoscale components enables the creation of macroscopic systems and their control [1].

In plasma physics, fireballs represent typical examples of macroscopic self-organized structures. Their appearance and dynamics are determined by mesoscopic collective interactions, which, in turn, originate from atomic quantum processes, like excitations and ionizations. Fireballs are intensely luminous complex space charge structures consisting of a positive core (ion-rich plasma), confined by an electrical double layer which sustains a potential jump, i.e. an electric field [2]. The stability of the double layer is assured by electrostatic forces that act as long-range correlation forces between the two adjacent opposite space charge accumulations (electrons and positive ions). When this stability cannot be assured, two situations were observed, depending on the experimental conditions. In the first case, the fireball passes into a dynamic state, consisting of periodic disruptions and re-aggregations of the double layer, giving rise to strong oscillations of the plasma parameters (plasma potential and density, current through plasma, etc.) [2,3]. In the second case, a more complex structure develops in front of the exciting electrode, consisting of several concentric luminous shells, known as concentric multiple double layers [4,5], or as a network of fireballs, located near each other, almost equally distributed on the electrode surface, known as non-concentric multiple double layers [4,6]. At high values of the voltage applied on the exciting electrode, the multiple double layers (concentric and non-concentric as well) evolve towards a chaotic state, following different routes [5,6]. As a possible cause for this evolution to chaos the un-correlation between the dynamics of the individual double layers composing the multiple structures was considered [5]. This hypothesis is very difficult to be investigated because of the common exciting electrode.

Here we report on experimental investigations of the interaction between two fireballs in dynamic states, simultaneously excited on two different electrodes immersed into the same

plasma, as a first step to elucidating the way by which these dynamics can become correlated or not. The two fireballs in dynamic states interact through the fluxes of charged particles released at the disruption. Moreover, a dynamic fireball perturbs all the plasma parameters.

## 2. Experimental results and discussion

The experiments were carried out in the target chamber of the **double plasma machine (DP)** of the University of Innsbruck, schematically represented in Fig. 1. The usual separating grid was removed in order to obtain a larger homogeneous plasma volume. Two tantalum disk electrodes

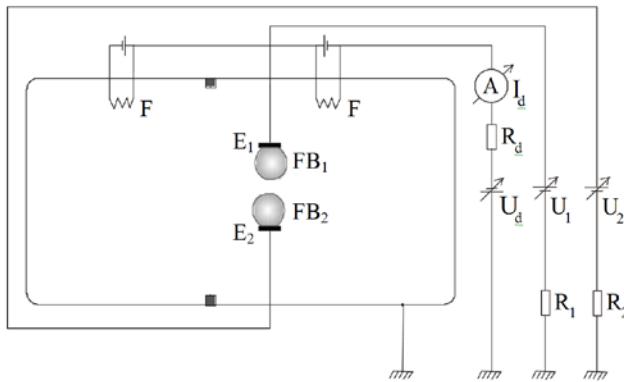


Fig. 1: Schematic of the experimental setup (F - filament, E<sub>1</sub> and E<sub>2</sub> – electrodes, U<sub>1</sub> and U<sub>2</sub> – power supplies for electrode bias, R<sub>d</sub>, R<sub>1</sub> and R<sub>2</sub> – load resistors, FB<sub>1</sub> and FB<sub>2</sub> – fireballs

(E<sub>1</sub> and E<sub>2</sub> in Fig. 1), with the same diameter 1,5 cm, were introduced into the diffusion plasma region and were positively biased with respect to the plasma potential. The distance between the electrodes can be changed by moving the electrode E<sub>1</sub> with respect to the electrode E<sub>2</sub>, which is fixed. When the voltage applied to an electrode surpasses a critical value, a fireball develops in front of the electrode, first being stationary. At a second critical value of the voltage, the fireball passes into a dynamic state, showing oscillations of the current collected by the electrode with a frequency of the order of kHz or tens of kHz.

As a first general observation, when the two fireballs are in dynamic states in front of the two electrodes E<sub>1</sub> and E<sub>2</sub>, their dynamics carry on with the same frequency. The second general observation is that interesting phenomena appear when the two fireballs are in contact with each other. For our experimental conditions, the diameter of the fireballs is typically around 3 cm and because of this special attention was given to the investigation of the phenomena that occur when the distance between the two electrodes is approximately  $d = 6$  cm.

In the first experiment, the dependence of the dynamical fireball frequency on the distance between the electrodes was investigated under the following experimental conditions (see Fig. 2): Argon pressure  $p = 10^{-3}$  mbar, discharge current  $I_d = 90$  mA, voltages applied on the two electrodes  $U_1 = U_2 = 122$  V. The distance between the two electrodes was increased from 3,6 cm to 23 cm. For  $d = 3,6$  cm the two fireballs overlap, the frequency of their oscillations being about 3 kHz. By increasing the distance between the electrodes, the frequency strongly

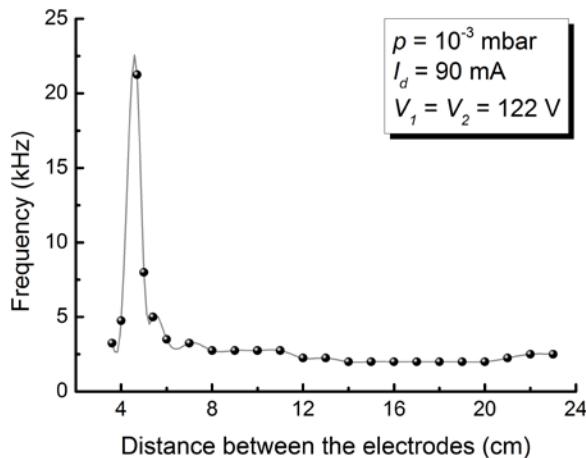


Fig. 2: Frequency of the current oscillations collected by the electrodes  $E_1$  and  $E_2$  versus the distance between the two electrodes.

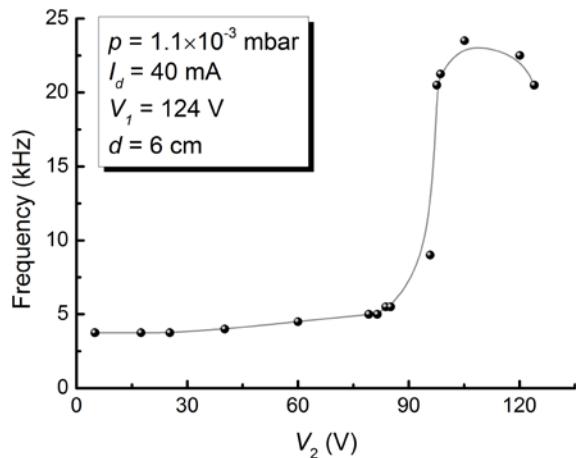


Fig. 3: Frequency of the current oscillations collected by the electrodes versus the voltage applied on the electrode  $E_2$ .

increases, attaining a maximum of 21,25 kHz for  $d = 4,7$  cm (Fig. 2). At this distance the fireballs are still in contact with each other. From now on, increasing the distance between the two electrodes leads to a decrease of the current oscillations frequency, as observed in Fig. 2. For  $d = 5$  cm the two fireballs can be distinctly observed, but touching each other. Up to about  $d = 7$  cm the frequency remains almost constant up to approximately 2,5 kHz (Fig. 2), while the fireballs are completely separated.

In the second experiment the influence of the voltage applied to the electrodes on the frequency of the fireballs dynamics was investigated (Fig. 3). The experimental conditions were: Argon pressure  $p = 1,1 \cdot 10^{-3}$  mbar, discharge current  $I_d = 40$  mA and distance between the electrodes  $d = 6$  cm. The voltage applied on the electrode  $E_1$  was kept constant  $U_1 = 124$  V, while the voltage applied on the electrode  $E_2$  was increased from 0 V to 124 V. When  $U_2 = 0$  V, a fireball appears only in front of electrode  $E_1$ , the frequency of its oscillations being about 3,75 kHz (Fig. 3). When the voltage applied on the electrode  $E_2$  reaches the critical value  $U_2 = 83,8$  V, a diffuse fireball appears in front of it, the frequency of the current oscillations in this case being 5,5 kHz. From now on, the frequency starts to increase strongly, until it reaches a maximum value of 23,5 kHz for  $V_2 = 105,1$  V (Fig. 3). Starting from  $U_2 = 97,6$  V the two fireballs are in contact with each other and with almost the same dimension. A further increase of the voltage on the electrode  $E_2$  leads to a slight decrease in the frequency (Fig. 3), while the fireball developed in front of the electrode  $E_2$  becomes dominant (more luminous) with respect to the fireball still existing in front of the electrode  $E_1$ .

In the third experiment the dependence of the fireballs dynamics frequency on the discharge current, which is approximately proportional to the plasma density, was investigated

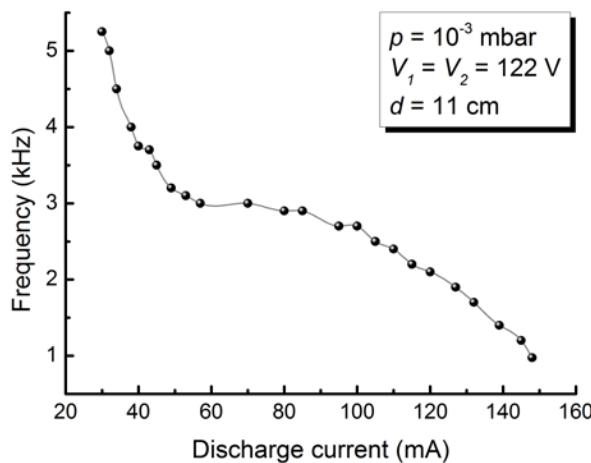


Fig. 4: Frequency of the current oscillations collected by the electrodes versus the discharge current

discharge current. This region of the curve is followed by a plateau and a region of slower decrease of the frequency. By increasing the discharge current, dimension and luminosity of the fireballs decrease too.

### 3. Conclusion

The interaction between two fireballs simultaneously excited on two electrodes immersed into a low-temperature discharge plasma was experimentally investigated. In dynamic states the two fireballs are always synchronized. The oscillation frequency depends on the plasma density, the distance between the electrodes and the voltages applied on the electrodes.

### Acknowledgment

This work was supported by the CEEPUS network AT-0063 and by the Austrian-Romanian Scientific-Technical Collaboration project RO 05/2012 (in Austria) and 747/2014 (in Romania).

### References

- [1] *From Quanta to Continuum: Opportunities for Mesoscale Science*, Report for the Basic Energy Science Advisory Committee, Mesoscale Science Subcommittee, US Department of Energy, September 2012.
- [2] R.L. Stenzel, C. Ionita, R. Schrittwieser, *Plasma Sources Sci. Technol.* **17** (2008) 035006.
- [3] O. Niculescu *et al.*, *Phys. Plasmas* **17** (2010) 042305.
- [4] D.G. Dimitriu *et al.*, *Plasma Phys. Control. Fusion* **49** (2007) 237.
- [5] D.G. Dimitriu *et al.*, *Plasma Source Sci. Technol.* **22** (2013) 035007.
- [6] M. Agop *et al.*, *Phys. Scripta* **87** (2013) 045501.

under the following experimental conditions: Argon pressure  $p = 10^{-3}$  mbar, distance between the electrodes  $d = 11$  cm, voltages applied on the electrodes  $U_1 = U_2 = 122$  V. The discharge current was varied between 30 mA and 150 mA by modifying the heating currents of the filaments. The obtained dependence is shown in Fig. 4. Three distinct regions can be observed on this curve. At small values of the discharge current, the frequency strongly decreases with increasing