Experimental and theoretical studies on plasma fireballs interactions

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Abstract. The interaction of two distinct plasma fireballs is experimentally determined and theoretically modeled using the fractal approximation and assimilating the plasma column which separates the structures to an elastic beam, whose extremities are free or simply "supported" or "embedded". The experimental results and the theoretical outcome find themselves in a very good agreement.

Introduction. When an electrode immersed into an equilibrium plasma is positively biased up to a threshold value, a complex space charge structure in form of an intense luminous, almost spherical plasma body appears in front of it. This structure consists of a positive nucleus (ion enriched plasma) confined by an electrical double layer [1]. In certain experimental conditions, a more complex structure can appear, in form of multiple concentric or non-concentric double layers (MDLs) [1, 2]. In the case of the non-concentric MDLs, the interaction between the individual component double layers seems to be responsible for the transition to chaos of the MDLs dynamics.

Experimental results. The experimental set-up is presented in Fig. 1. The discharge is fired between the hot filament (F in Fig. 1) as cathode and the grounded chamber wall as anode. The argon plasma parameters, measured by means of plane Langmuir probes, are: $n_{pl} \cong 10^8$ cm^{-3}, electron temperature $T_e \cong 2$ eV for the pressure $p = 5\times10^{-3}$ mbar. The discharge voltage was fixed at $V_d = 60\text{V}$, and the discharge current was kept constant at $I_d = 90\,\text{mA}$. In the diffusion plasma, two identical Tantalum disk electrodes having 1.4 cm in diameter (E_1 and E_2 in figure 1) were inserted. The electrodes are facing each other and are positively biased as against the plasma potential. The voltages applied to E_1 and E_2 were kept constant at $V_1 = 59\text{V}$ and respectively $V_2 = 39\text{V}$, values for which, in front of both electrodes, two stationary state fireballs are present.

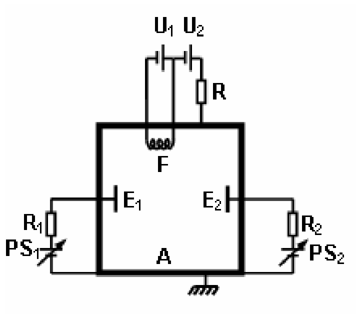

Fig. 1: Setup: (A – anode, F – filament, E_1,E_2 – supplementary electrodes, PS_1,PS_2 – power supplies for biasing the electrodes, U_1, U_2 - power supplies for heating and respectively for biasing the filament, R, R_1, R_2 – load resistors

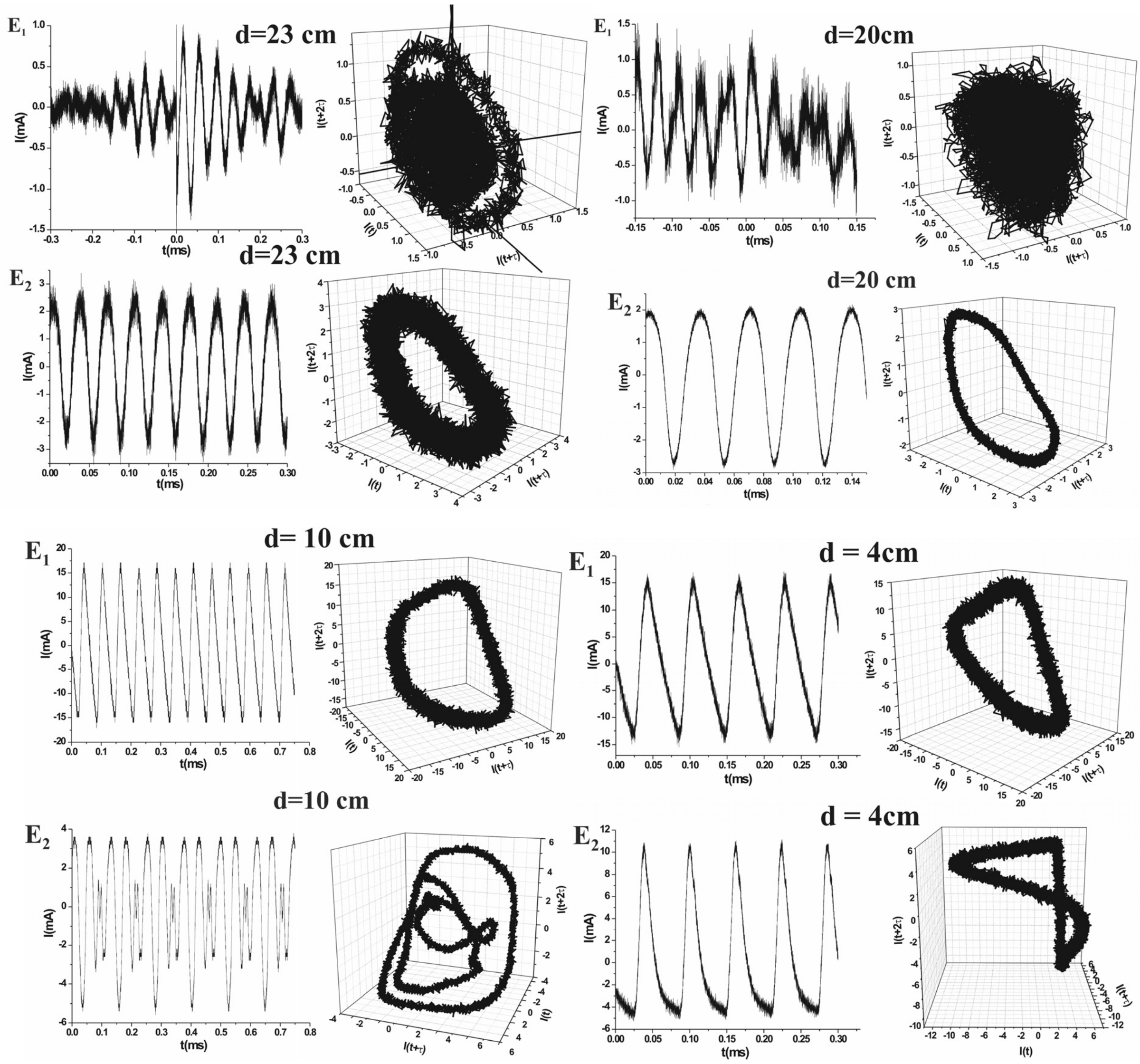

Fig. 2: Time series and reconstructed phase space attractors corresponding to the fireballs dynamics when the distance between the electrodes decreases (d=23 cm, d=20 cm, d=10 cm, d=4 cm)

The experimental data were recorded by only varying the distance between the two electrodes from 25 cm to 2 cm. Initially, when the electrodes are 25 cm apart, both fireballs in front of them are in stationary states. When the distance is reduced to 23 cm, both structures spontaneously transit into dynamical states (see figure 2).

We notice that with decreasing distance, the dynamics of both fireballs become more and more ordered (see figure 2) until, at 4 cm, their dynamics become correlated, the collected currents oscillating with the same frequency but having different amplitudes. By concluding, when the plasma structure passes into dynamical state, the double layer at its border periodically disrupts and re-aggregates, releasing in the surrounding plasma bunches of initially trapped particles. These particles fluxes are responsible for the interaction between the two structures, inducing changes in their dynamics and, thus, in the oscillation regime of the current collected by the two electrodes [3, 4].

Theoretical model. We note that for movements on fractal curves, the small (deterministic) perturbations at a given scale can be perceived as patterns at another scale [5]. In this case, the small perturbations equation can be written in the form:

$$D^2\nabla^4 n(\boldsymbol{r},t)+\frac{\partial^2}{\partial t^2}n(\boldsymbol{r},t)\equiv 0 \tag{1}$$

where D is a coefficient which corresponds to the fractal - non-fractal transition and n is the plasma density perturbation. We notice that this equation is similar to the standard equation from the elastic beams theory so thus, we can assimilate the plasma with such a beam.

Let us now analyze the free vibrations of a l linear length beam, whose extremities are free or simply “supported” or ”embedded”. We assume that the one dimensional solution for the motion equation is:

$$w(x,t)=u(x)\exp(i\omega t) \tag{2}$$

where ω represents the plasma pulsation [6].

Also, we assume that the beam is embedded in the x = 0 section and simply “supported” by the section $x = \mathrm{l}$ and we calculate the particular pulsations using the formula:

$$\omega_r=\frac{D}{l^2}\beta_r^2,\quad r=1,2,...\infty \text{ where } \beta_r=\frac{\pi}{4}(4r+1),\quad r>5 \tag{3}$$

Considering that l is the distance between the two fireballs and D = 3 m^2/s is the ambipolar diffusion coefficient [7] we obtain (for l = 20 cm and β = 19.63 (for the fundamental frequency corresponding to r = 6)): $\omega_6 \cong 28.5$ kHz. This result corresponds to the experimental data presented in figure 2.

Conclusion. Assuming that the plasma column behaves like a simply ”embedded” beam, we were able to explain the interaction between two fireballs when the distance between them is varied. The mathematical model and the experimental results are in a very good agreement.

Acknowledgment

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, project number PN-II-RU-PD-2011-3-0069.

References

[1] M. Aflori, G. Amarandei, L. M. Ivan, D. G. Dimitriu, and M. Sanduloviciu 2005 Experimental Observation of Multiple Double Layers Structures in Plasma—Part I: Concentric Multiple Double Layers *IEEE Trans. Plasma Sci.* **33** 542-543;

[2] L. M. Ivan, G. Amarandei, M. Aflori, M. Mihai-Plugaru, C. Gaman, D. G. Dimitriu, and M. Sanduloviciu 2005 Experimental Observation of Multiple Double Layers Structures in Plasma—Part II: Nonconcentric Multiple Double Layers *IEEE Trans. Plasma Sci.* **33** 544-545;

[3] O. Niculescu, S. Chiriac, D. G. Dimitriu – On the interaction between complex space charge structures in plasma, *34th EPS Conference on Plasma Physics*, Warsaw, Poland, 2007;

[4] O. Niculescu, D. G. Dimitriu, V. P. Paun, P. D. Matasaru, D. Scurtu, M. Agop - Experimental and Theoretical Investigations of a plasma fireball dynamics, *Physics of Plasmas*, Vol. 14, Issue 4, Article Number 042305, 2010;

[5] M. Agop, P. Nica, O. Niculescu, D. G. Dimitriu - Experimental and Theoretical Investigations of the Negative Differential Resistance in a Discharge Plasma, *J. Phys. Soc. Jpn.*, Vol. 81, 064502, 2012;

[6] M. Agop, P. Nica, S. Gurlui, C. Focsa, *Fractal hydrodynamic model of high-fluence laser ablation plasma expansion*, International High-Power Laser Ablation Conference, Santa Fe, USA, 2010;

[7] S. Gurlui, M. Agop, M. Strat, G. Strat, S. Bacaita – Experimental and theoretical investigations of anode double layers, *Jpn. J. Appl. Phys.*, Vol. 44, no. 5A, pp. 3253-3259, 2005.