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ON THE DYNAMICAL BEHAVIOR OF A HIGH-FREQUENCY PLASMOID

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1. Introduction

Recent studies showed that well located **c**omplex **s**pace **c**harge **c**onfigurations (*CSCC*), generated in a plasma submitted to a sufficient strong external constraint, exhibit a proper dynamics [1]. This behavior can turn into a chaotic one if this constraint reaches a critical value. Controlling the dynamics of such complex systems, especially their chaotic behavior, is of a great interest in the last decade [2].

A *CSCC* appears as a plasmoid [3] in a **h**igh-**f**requency (*HF*) plasma. Its self-consistence is ensured by a **d**ouble **l**ayer (*DL*) self-assembled at its border. Under certain experimental conditions, the plasmoid reveals a proper dynamics, evidenced by periodic variations of the light emission and by a modulation of the *HF* field. In this paper we report experimental observations on the dynamics of the plasmoid depending on the external constraints applied to the *HF* discharge. Our research also proves that its dynamics can be controlled using an electron beam periodically injected in the region where the plasmoid is formed.

2. Experimental results and discussion

The experimental setup is schematically presented in Figure 1. It consists in a glass tube, 30 cm long and 5 cm inner diameter, filled with Argon a pressure of 1 Pa. The plasma is excited using two metallic parallel bars forming a Lecher line, coupled to a Hartley generator, whose frequency ν is 100 MHz. The gas pressure assures that the discharge is controlled by secondary electrons emitted by the glass wall. The energy transferred from the generator to the discharge can be controlled varying the control parameter of the system, namely the voltage U_S applied to the screen grid. As a measure of the energy absorbed by the discharge one uses the control grid current I_G. The value of this system parameter is falling when the amount of the absorbed energy is rising. The two parameters are registered using a XY plotter, obtaining the U_S - I_G characteristic (Figure 2). The dynamics of the plasmoid is investigated using a photo multiplier (*PM*). The current I_{PM} generated by the *PM* is amplified and analyzed using the first entry of a **d**igital **s**torage **o**scilloscope (*DSO*). A **t**hermo-**e**missive

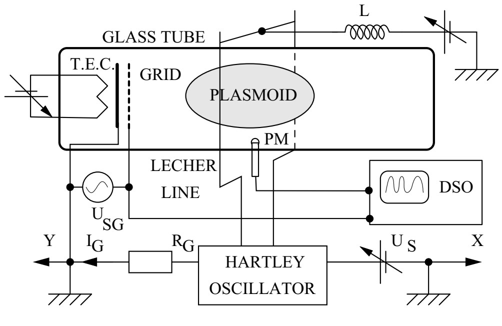

Figure 1: Experimental device

cathode (*TEC*), consisting of a heated grounded disk covered by barium carbonate, 5 mm in diameter, is placed at one end of the tube. The electrons emitted by the *TEC* are accelerated using a metallic grid, with a transparency of 60%. The grid is biased at a step voltage U_{SG} (20V in amplitude) using a signal generator. The signal is recorded using the second entry of the *DSO*.

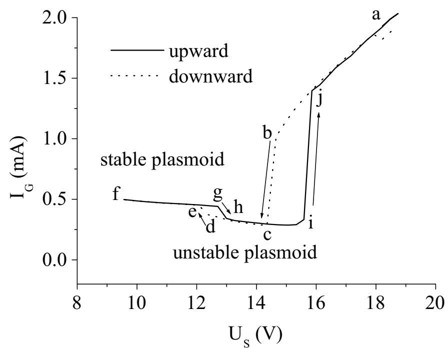

Figure 2: U_S-I_G characteristic of the plasmoid

The plasmoid is obtained by setting U_S at a value for which an usual *HF* discharge appears in the glass tube (point a in Figure 2). Decreasing U_S a well-localized *CSCC* suddenly appears inside the tube having the appearance of a luminous ellipsoidal body, namely the plasmoid. Its spontaneous self-assemblage is accompanied by a sudden fall of I_G (point b in Figure 2) indicating a strong energy absorption and therefore a passage to a resonant state [3]. Simultaneously, both I_G and I_{PM} evidence periodic variations with a frequency f_m of about 25 kHz. A further decrease of U_S determines an increasing of f_m up to 45 kHz. At a certain critical value of U_S (point *d* in Figure 2), I_G increases indicating that less energy is absorbed by the plasmoid. Its border becomes more sharply, his luminosity increases and I_{PM} becomes constant, indicating that the plasmoid is in a stable state. If U_S is further decreased, no significant modification can be observed in the behavior of the plasmoid. For a critical value of U_S (point *f* in Figure 2) the plasmoid disappears.

If the critical point *f* is not reached U_S can be increased without disabling the plasmoid. After a decrease of I_G (branch *g-h*) the plasmoid becomes diffuse and I_{PM} periodically varies again. The temporal series observed in the variation of I_{PM} are analyzed using their power spectra. One can remark that, for lower values of U_S (13.79V), the power spectrum exhibits one frequency f_1 with its harmonics (Figure 3a). When U_S reaches 14.33 V, a second incommensurate frequency f_2 with its harmonics emerges (Figure 3b). Since the control parameter is still low (U_S=14.82V), the two frequencies are present (Figure 3c). If U_S is raised (15.08V), the magnitude of f_2 becomes insignificant (Figure 4 d).

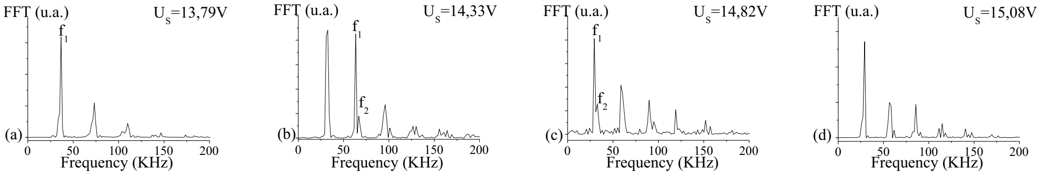

Figure 3 Power spectra of the signal generated by the plasmoid

This behavior is determined, as already shown [3], by the dynamics of *DL*s successively generated at the border of the plasmoid. The scenario of this dynamics involves elementary processes, namely excitation and ionization of neutrals by electron collisions. These processes are taking place in two adjacent regions, determining the accumulation of opposite space charges and the genesis of a *DL* that borders the plasmoid. At a critical value of the absorbed energy, the region where electrons experience excitation is shifted away from the border of the plasmoid and the *DL* is moving toward the wall, where it disrupts. This process is triggered by electrons released by the previous *DL* disruption so that it becomes periodic. The frequency f_1 emerging in the power spectrum of I_{PM} can be determined by the shelling off process of the *DL*. The second frequency f_2 can be correlated, in our opinion, with the formation and the dynamics of a second *DL* at the border of the plasmoid. Experiencing their own dynamics, the two *DL*s meantime created determine the co-existence of two frequencies in the power spectrum until the strong value of the external constraint determines a coupling between the two *DL*s and the disappearance of f_2 from the spectrum. A similar behavior was reported in the case of a *DC* plasma [1].

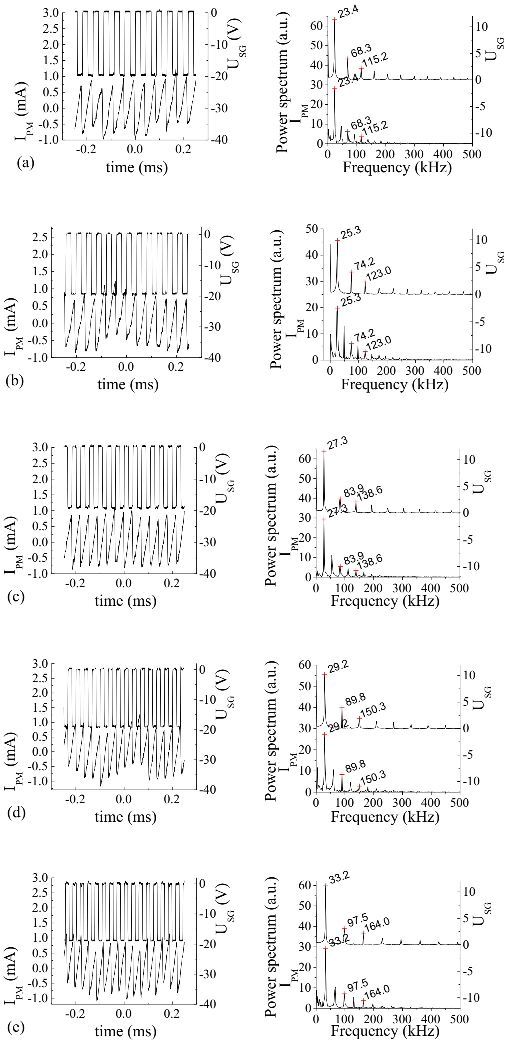

Figure 4: Signals and power spectra generated by I_{PM} and U_{SG}

In the following we propose an experiment demonstrating that this mechanism can be controlled using electrons from an external source. After the formation of the plasmoid, U_S is decreased to about 13 V in order to obtain an unstable state when the light emission (evidenced by I_{PM}) periodically varies with a frequency ν_P of 27.3 kHz. In the following, all the parameters concerning the discharge are maintained constant. A positive step voltage U_{SG} (20 V in amplitude) is applied to the grid (Figure 4 c). In this way, a pulsed electron beam is injected toward the plasmoid. The frequency ν_{SG} of the bias voltage is chosen to be close to the proper frequency ν_P of the unstable plasmoid. The *DSO* evidences that the two signals become coupled.

If ν_{SG} is modified, the *DSO* evidences that the modulation frequency ν_P of the plasmoid is entrained, following the first one. The first column in Figure 4 shows that the signals generated by U_{SG} and I_{PM} are strongly coupled, even if ν_{SG} is decreased (Figure 4 a,b) or increased (Figure 4 d,e). The same is evidenced by the power spectrum of the two signals (second column in Figure 4), showing that the two frequencies and their harmonics have identical values. The registered data show that the entrainment band is about 15% of ν_P (between 23.4kHz and 33.2kHz). If ν_{SG} passes these limits, ν_P suddenly regains its initial value, namely 27.3kHz.

This experiment evidences that a modulated electron beam can determine variations of the proper frequency of the plasmoid in a certain domain, confirming that electrons are at the origin of the triggering mechanism of the *DL*s shelling off process. If the electrons from the beam are arriving before the *DL* disruption ($\nu_{SG} > \nu_P$), they are injected in the region where a new DL is forming, determining its shelling off process with the frequency of the beam injection. If $\nu_{SG} < \nu_P$, the electrons from the beam are modifying the electric field in the region where the *DL* just starts its disruption and they are delaying the resulting electrons to gain the new forming *DL*. In this way, the frequency of the *DL* dynamics is controlled on a limited band. If the limits of the entrainment band are exceeded, the plasmoid retrieves its proper dynamics. Modifying ν_{SG} in order to return in this band one can remark that the plasmoid can be entrained only if the frequency of the beam is decreased under the upper limit or is increased over the lower limit of the entrainment band.

3. Conclusions

In this paper we report experimental observations on the dynamics of a *HF* plasmoid. Varying the amount of the energy injected in the *HF* discharge one can evidence the transition of the plasmoid in an unstable state, characterized by temporal variations of the *HF* field and also of the emitted light. Our experiment also demonstrates that the proper dynamics of a plasmoid can be controlled using a modulated electron beam. Taking into account the similarities between the plasmoid and *CSCC*s formed in *DC* plasma devices [4], we consider that this method could be applied to control the dynamics of such structures, even in the case when their behavior becomes chaotic.

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