JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 1, February 2006, p. 128 - 131

Plasma fusion torus as a complex space charge structure

D. G. DIMITRIU[*]
Department of Plasma Physics, "Al. I. Cuza" University of Iasi, Romania

By increasing the heating power inserted into fusion plasma, first a degradation of energy and particle confinement is obtained (L-mode). Above a certain threshold value of this power, a regime of improved energy and particle confinement (H-mode) is attained. The H-mode is characterized by sharp gradients of the density and the temperature in the plasma edge region, indicating the formation of a transport barrier. This barrier leads to a reduction of the radial transport and a suppression of fluctuations. A localized radial electric field develops in the edge plasma region at the L-H transition. In this work we would like to emphasize a certain striking similarity between the L-H transition in fusion plasma and the appearance of a complex structure in low-temperature plasmas. Under some experimental conditions, a complex space charge structure can appear in form of an ion-rich plasma region confined by a plasma double layer. This structure is also characterized by steep gradients of density and temperature at the edge. A well-localized radial electric field develops in the edge region due to the double layer, which works as a radial transport engine. After the CSCC appearance, the fluctuation level decreases.

(Received October 14, 2005; accepted January 26, 2006)

Keywords: L-H transition, Double layer, Edge transport barrier, Bistability

1. Introduction

The achievement of a high density and high temperature plasma for a long confinement time constitutes the main goal of controlled thermonuclear fusion research. Experimentally it was observed that, by increasing the heating power, first a degradation of energy and particle confinement in fusion plasma is obtained (L-mode). Above a certain value of this power, a regime of improved energy and particle confinement (H-mode) is attained. The low to high confinement (L-H) transitions in tokamaks were first observed over twenty years ago in the AxySymmetric Divertor EXperiment (ASDEX) tokamak [1]. The power threshold appears to increase with density, magnetic field and the size of tokamak [2]. The H-mode is characterized by sharp gradients of the density and the temperature in the plasma edge region, indicating the formation of a transport barrier [3-5]. This barrier leads to a reduction of the radial transport and a suppression of fluctuations [6-8]. A localized radial electric field develops in the edge plasma region at the L-H transition [8-10]. The transition can be triggered by edge gradients of ion and electron temperature and pressure [11], as well as by radial electric fields [12-14]. The L-H transition is a sharp one, which suggests a bifurcation between two plasma states [2]. Despite of the fact that many theories for the L-H transition have been developed [2], the basic mechanism of this phenomenon is still elusive [15].

In a previous paper [16] we have shown that using the scenario of self-organization suggested by low temperature plasma experiments it is possible to explain the emergence of metastable complex space charge configurations and their ordered spatial distribution in dc micro-discharges.

In this work we would like to emphasize a certain striking similarity between the L-H transition in fusion plasma and the appearance of a complex structure in low-temperature plasma. Under particular experimental conditions, a **c**omplex **s**pace **c**harge **c**onfiguration (CSCC) can appear in form of an ion-rich plasma region confined by an electrical **d**ouble **l**ayer (DL) [17,18]. This CSCC is also characterized by steep gradients of density and temperature at the edge. Upon its appearance, a well-localized radial electric fields develops in the edge region due to the DL, which work as a radial transport engine [19]. The high density inside the structure is maintained by the electric field, which enhances the rate of electron-neutral impact ionizations. After the appearance of the CSCC the fluctuation level decreases. Similar phenomena were observed in the magnetized plasma of a Q-machine [20]. Experimental results proved that the appearance and dynamics of the CSCC can be easily controlled by external circuit elements [21]. This feature stays at the basis of some very efficient methods to control the chaos in plasma devices, which may be adapted also for fusion devices in order to control or even eliminate some electrostatic instabilities or turbulence.

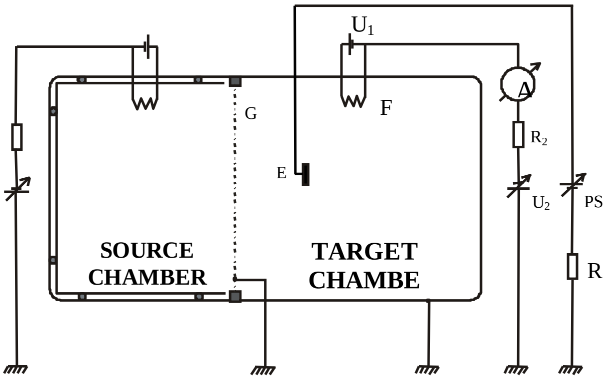

Fig. 1. Schematic of the University of Innsbruck DP machine (F – filament, G – grid , E – electrode, PS – power supply).

2. Experimental results

The experiments were performed in the **d**ouble **p**lasma (DP) machine of the University of Innsbruck, schematically represented in Fig. 1. The DP-machine consists from a large cylindrical non-magnetic stainless steel tube (about 1 m longer and 0.6 m diameter), evacuated by a preliminary pump and a diffusion pump. A metallic grid (marked by G in Fig. 1) separates the tube in two chambers: the source chamber (left hand of the tube in Fig. 1) and the target chamber (right hand of the tube in Fig. 1). In each of the chambers the plasma is created by an electrical discharge between a hot filament (marked by F in Fig. 1) as cathode and the grounded tube as anode. Because of the small dimensions, the filaments will collect just a negligible part of the ions, most of them diffusing in the middle of the tube. The positive space charge will attract many electrons in this region. In this way, a high ionization degree plasma appears. To avoid plasma loses, at the walls there is some magnetic traps, generally in form of permanent magnets ($B \cong 1$ T at the surface) with alternate polarity.

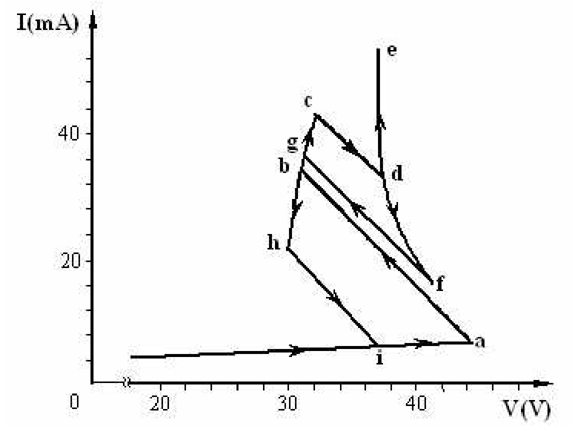

Fig. 2. Static current-voltage characteristic of the electrode E.

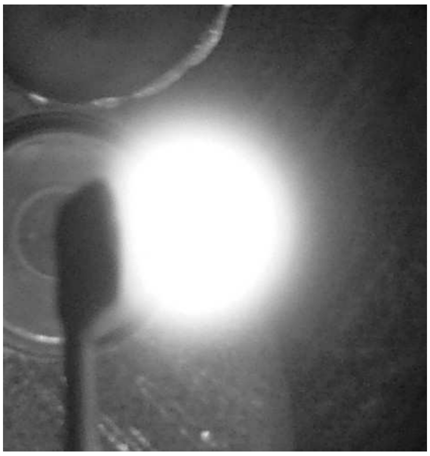

Fig. 3. Photo of a CSCC obtained in cold plasma.

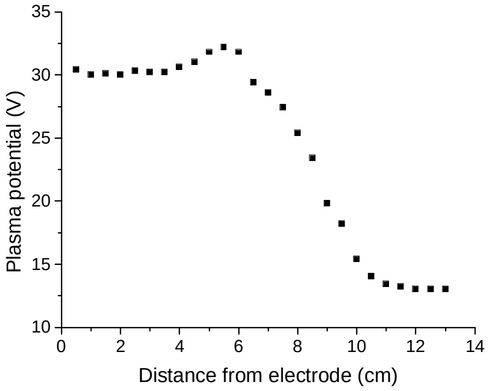

Fig. 4. Radial profile of the plasma potential in front of the electrode E.

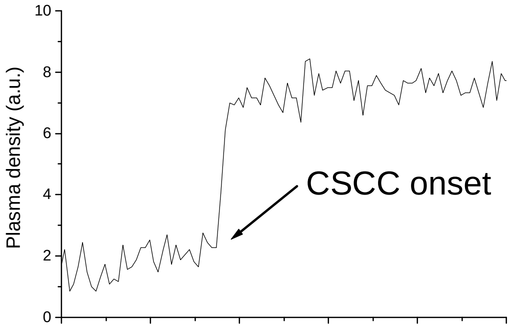

Fig. 5. Sudden increase of the plasma density after the CSCC appearance.

In our experiments we used only the target chamber of the DP-machine of the University of Innsbruck. The plasma created in the target chamber was pulled away from thermal equilibrium by gradually increasing the voltage applied on a tantalum disk electrode (E in Fig. 1), with 2 cm in diameter, under the following experimental conditions: argon pressure p = 0.5 N/m^2, plasma density $n = 10^{15}$ m^{-3}. The voltage is delivered by a power supply

(PS in Fig. 1) through a load resistor $R = 500\ \Omega$. An *XY* recorder was used to register the static current-voltage characteristic of E. The plasma potential was measured by an emissive probe. A plane Langmuir probe, with 2 mm in diameter, was used to measure the plasma density inside the structure.

Fig. 2 shows the static current-voltage (*I*-*V*) characteristic of the electrode E, obtained by gradually increasing and decreasing the voltage from PS. The appearance of two current jumps, associated with hysteresis effects, was observed. After the first current jump (**a** → **b** in Fig. 2) a very luminous, almost spherical structure appears in front of the electrode (see Fig. 3). The probe measurements prove that this structure consists from a positive nucleus (an ion-rich plasma) bordered by an electrical DL (see the axial profile of the potential in front of E from Fig. 4). Fig. 4 emphasizes that the voltage across the DL slightly exceeds the ionization potential of the used gas (argon). Because of this, the electrons accelerated to the electrode can reach enough energy to produce electron-neutral ionization impacts. In this way, a high plasma density is maintained inside the structure. After the second jump of the current (**c** → **d** in Fig. 2), the structure passes into a dynamic state, in which the double layer periodically disrupts and re-aggregates [17]. A dynamic technique was used in order to analyze how the plasma density in front of E and the level of the current fluctuations through plasma conductor, respectively, change when the CSCC emerges. For this, we recorded the ionic saturation current collected by a small planar Langmuir probe, inserted in front of E, as well as the AC component of the current collected by E, simultaneously with the increase of the voltage on E with a slope of 100 V/s. The results are shown in Figs. 5 and 6, respectively. We observe that, after the CSCC emergence, the plasma density inside it increases and the level of the current fluctuations decreases.

3. Discussion

The experimental results obtained in cold plasma when a complex space charge configuration appears show qualitative similarities with the results obtained in hot fusion plasma at the L-H transition. Thus, the CSCC in cold plasma appears simultaneously with a jump of the current collected by the electrode (Fig. 2). A similar current jump was obtained when the L-H transition was triggered by applying a potential on an electrode immersed in the edge region of the tokamak plasma [12]. After the CSCC appearance, a radial electric field develops at the edge region of the structure (Fig. 4), just as in the case of the L-H transition [2, 8-10, 12]. The electron and ion densities (Fig. 5), as well as the electron temperature increase inside the CSCC and their gradients become sharp in the edge region, a similar behaviour being observed at the L-H transition in tokamak plasma [3-5]. The fluctuation level of the current collected by the electrode (Fig. 6), as well as of the plasma potential, strongly decreases after the CSCC appearance, similar as in the case of the L-H transition [6-8].

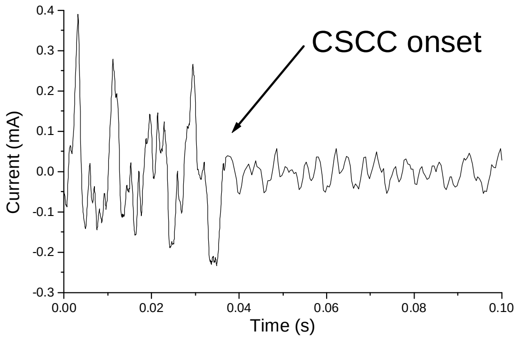

Fig. 6. Sudden decrease of the current fluctuations after the appearance of CSCC.

All similarities are just in qualitative agreement, any quantitative comparisons being almost impossible because of the very different types of plasma. The experimental results seem to suggest that a double layer appears at the edge region of fusion plasma in the H mode. It acts as a barrier for the radial transport, suppressing the fluctuations. In this case, the H mode plasma torus in fusion devices can be analyzed as a complex structure, similar to those obtained in cold plasma. Further investigations are needed, especially on the dynamic phase of the CSCC, in connection with the edge localized modes (ELMs). These investigations could be useful for the understanding of fusion plasma turbulence and disruption.

4. Conclusion

Experimental results prove the existence of a certain striking similarities between two phenomena which occur in very different types of plasma: the L-H transition in fusion plasma and the appearance of a complex space charge configuration in cold plasma. The observations can lead to the development of a new phenomenological model for the H mode of fusion plasma.

Acknowledgement

This work was supported in part by the National University Research Council, Romanian Ministry of Education and Research, under grant no. 33373, cod CNCSIS 70, and by the University of Innsbruck.

References

[1] F. Wagner, ASDEX Team, Phys. Rev. Lett. **49**, 1408 (1982).
[2] J. W. Connor, H. R. Wilson, Plasma Phys. Control. Fusion **42**, R1 (2000).
[3] T. N. Carlstrom, K. H. Burrell, R. J. Groebner, A. W. Leonard, T. H. Osborne, D. M. Thomas, Nucl. Fusion **39**, 1941 (1999).
[4] W. M. Stacey, Phys. Plasmas **9**, 3082 (2002).

[5] H. Punzmann, M. G. Shats, Phys. Rev. Lett. **93**, 125003 (2004).

[6] I. García-Cortés, C. Hidalgo, J. R. Martín-Solís, S. Ali-Arshad, S. Clement, S. J. Davies, J. Lingertat, A. Loarte, G. F. Matthews, R. D. Monk, Plasma Phys. Control. Fusion **38**, 2051 (1996).

[7] H. Xia, M. G. Shats, Phys. Rev. Lett. **91**, 155001 (2003).

[8] E. J. Doyle, R. J. Groebner, K. H. Burrell, P. Gohil, T. Lehecka, N. C. Luhman Jr., H. Matsumoto, T. H. Osborne, W. A. Peebles, R. Philipona, Phys. Fluids B **3**, 2300 (1991).

[9] V. Rozhansky, M. Tendler, Phys. Fluids B **4**, 1877 (1992).

[10] A. Moleti, Phys. Plasmas **3**, 1284 (1996).

[11] R. J. Groebner, D. M. Thomas, R. D. Deranian, Phys. Plasmas **8**, 2722 (2001).

[12] J. A. Heikkinen, T. P. Kiviniemi, A. G. Peeters, Phys. Rev. Lett. **84**, 487 (2000).

[13] K. H. Burrell, E. J. Doyle, P. Gohil, R. J. Groebner, J. Kim, R. J. La Haye, L. L. Lao, R. A. Moyer, T. H. Osborne, W. A. Peebles, C. L. Rettig, T. H. Rhodes, D. M. Thomas, Phys. Plasmas **1**, 1536 (1994).

[14] R. J. Taylor, M. L. Brown, B. D. Fried, H. Grote, J. R. Liberati, G. J. Morales, P. Pribyl, D. Darrow, M. Ono, Phys. Rev. Lett. **63**, 2365 (1989).

[15] P. N. Guzdar, R. G. Kleva, R. J. Groebner, P. Gohil, Phys. Plasmas **11**, 1109 (2004).

[16] M. Sanduloviciu, D. G. Dimitriu, L. M. Ivan, M. Aflori, C. Furtuna, S. Popescu, E. Lozneanu, J. Optoelectron. Adv. Mater. **7**(2), 845 (2005).

[17] B. Song, N. D'Angelo, R. L. Merlino, J. Phys. D: Appl. Phys. **24**, 1789 (1991).

[18] M. Sanduloviciu, E. Lozneanu, Plasma Phys. Control. Fusion **28**, 585 (1986).

[19] M. Sanduloviciu, C. Borcia, G. Leu, Phys. Lett. A **208**, 136 (1995).

[20] D. G. Dimitriu, V. Ignatescu, C. Ionita, E. Lozneanu, M. Sanduloviciu, R. Schrittwieser, Int. J. Mass Spectrom. **223-224**, 141 (2003).

[21] D. G. Dimitriu, C. Gaman, M. Mihai-Plugaru, G. Amarandei, C. Ionita, E. Lozneanu, M. Sanduloviciu, R. Schrittwieser, Acta Phys. Slovaca **54**, 89 (2004).

---

[*] Corresponding author: dimitriu@uaic.ro