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Similarities between the L-H transition in fusion plasma and the appearance of a self-organized structure in low-temperature plasma

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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. By increasing the heating power, 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 [1,2]. This barrier leads to a reduction of the radial transport and a suppression of fluctuations [3]. A localized radial electric field develops in the edge plasma region at the L-H transition [4]. This transition was considered a remarkable self-organization phenomenon in tokamak plasmas [5].

In this work we would like to emphasize a certain striking similarity between the L-H transition in fusion plasmas and the appearance of a complex structure in low-temperature plasmas. Under particular experimental conditions, a complex space charge configuration (CSCC) can appear in form of an ion-rich plasma region confined by a plasma double layer [6]. This CSCC is also characterized by steep gradients of density and temperature at the edge. Upon its appearance, a well-localized radial electric field develops in the edge region due to the double layer, which works as a radial transport engine [7]. The high density inside the structure is maintained by the electric field, which enhances the rate of electron-neutral impact ionization. After the appearance of the CSCC the fluctuation level decreases. Similar phenomena were observed in the magnetized plasma of a Q-machine [8].

2. Experimental results

The experiments were performed in the target chamber of the DP (double plasma) machine of the University of Innsbruck, schematically presented in Fig. 1. The background argon pressure was $p \cong 5\times10^{-3}$ mbar and the plasma density $n \cong 10^{10} - 10^{11}$ cm^{-3}. The plasma was pulled away from its steady state by gradually increasing the voltage to a circular tantalum disk electrode (E in Fig. 1) with 2 cm diameter. The voltage is delivered by a power supply (PS in

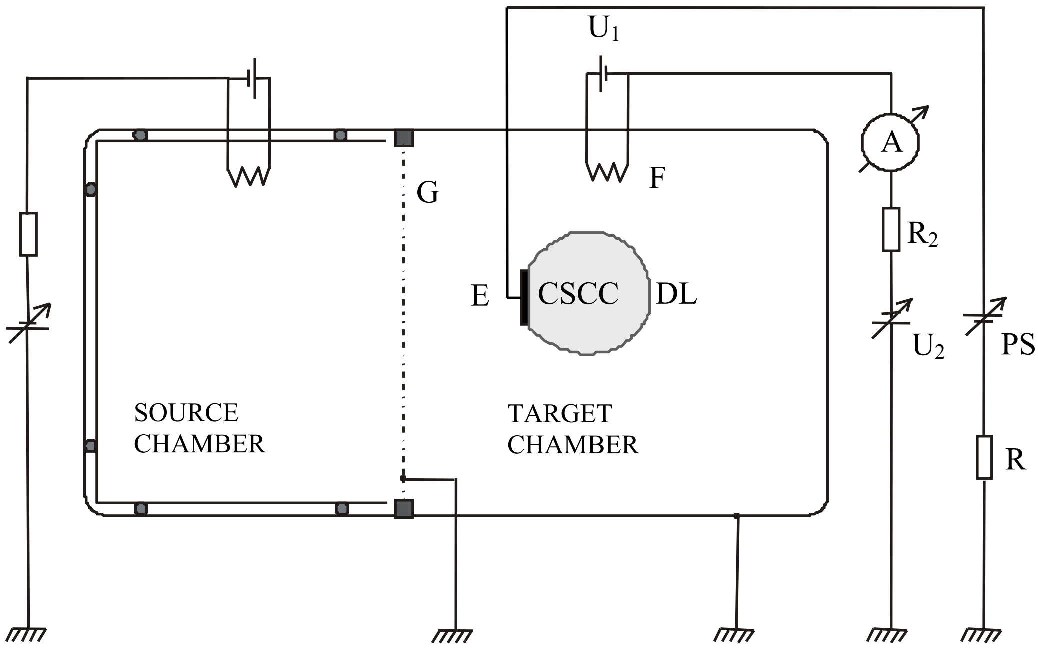

Fig. 1: Schematic of the Innsbruck DP machine. G – grid, F – filaments, E – electrode, PS – power supply, R – load resistor

Fig. 1) through a load resistor R = 500 Ω. An XY recorder was used to register the static current-voltage characteristic of E. The ac component of the electrode current was recorded by a digital computer-controlled oscilloscope. The plasma potential was measured by an emissive probe.

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. Probe measurements prove that this structure consists of a positive nucleus (an ion-rich plasma) bordered by an electrical double layer.9 After the second jump (c → d in Fig. 2), the structure passes into a dynamic state, in which the double layer periodically disrupts and re-emerges [10]. Fig. 3 shows the radial profile of the plasma potential in front of the electrode E. The

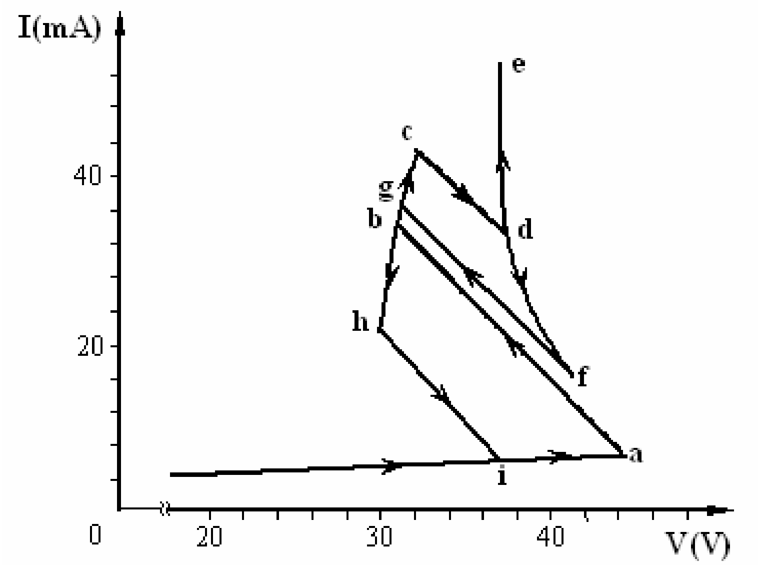

Fig. 2: Static upward and downward characteristic of the electrode E

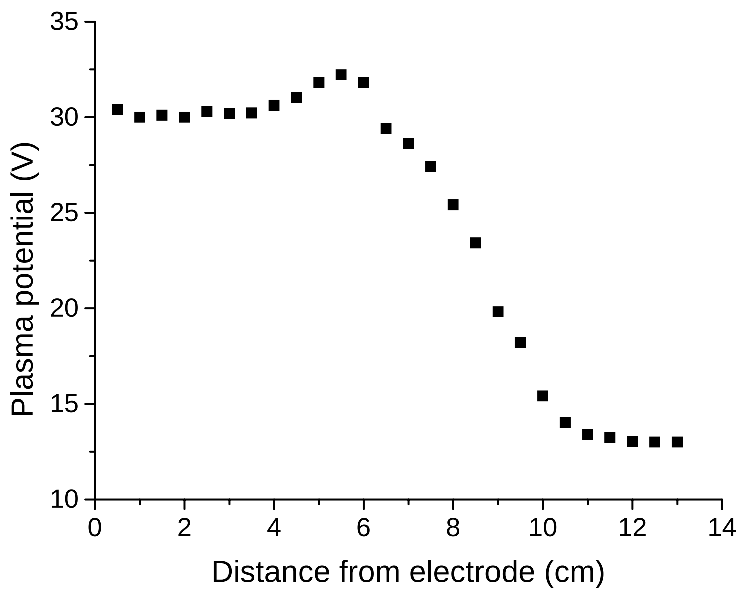

Fig. 3: Radial profile of the plasma potential in front of the electrode E

voltage across the double layer slightly exceeds the ionization potential of the gas. 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. Fig. 4 emphasizes the decreasing of the fluctuations level of the current collected by the electrode E after the appearance of the CSCC. Similar decreasing was recorded also for the fluctuations level of the plasma potential.

3. Discussion

The experimental results obtained in a cold plasma when a self-organized space charge structure appears, show qualitative similarities with the results obtained in hot fusion plasma at the L-H transition, as follows:

(i) The CSCC in a cold plasma appears simultaneously with a jump of the current collected by the electrode. 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 [4].

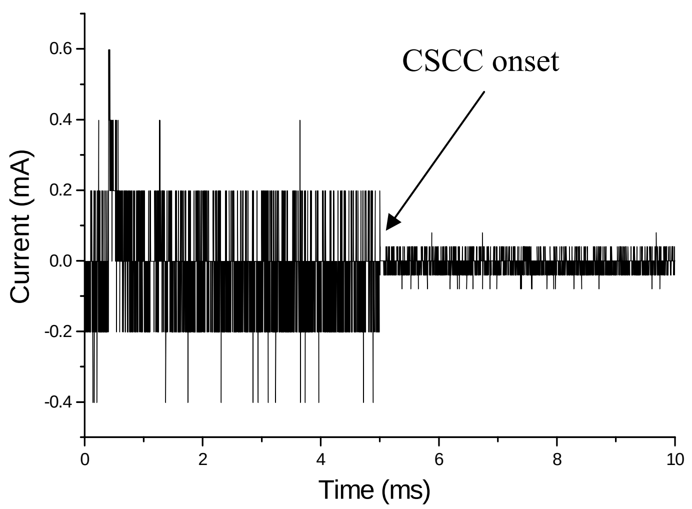

Fig. 4: The decreasing of the current fluctuations at the onset of the CSCC

(ii) After the appearance of the CSCC, a radial electric field develops at the edge region of the structure, just as in the case of the L-H transition [1,4].

(iii) The electron and ion density, 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 [2].

(iv) The fluctuation level of the current collected by the electrode, as well as of the plasma potential, strongly decreases after the CSCC appearance, similar as in the case of the L-H transition [3].

All similarities are just qualitatively, any quantitative comparison being almost impossible because of the extremely different types of plasma. The experimental results seem to suggest that a double layer appears at the edge region of the 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 self-organized structure, similar to that obtained in a cold plasma. Further investigations are needed, especially on the dynamical phase of the CSCC, in connection with 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. These observations can lead to the development of a new model for the H mode of fusion plasma, based on self-organization.

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