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Temporal evolution of an m = +1 helicon discharge

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1. Introduction

Although many investigations on helicon discharges have been carried out in the past, the basic understanding of these discharges is still relatively poor. This holds, in particular, for the dominant rf absorption mechanism(s) closely related to the effectiveness of helicon discharges as well as the excitation of the Trivelpiece-Gould waves which may compete with the helicon modes as a significant fraction of the rf power can be deposited in the plasma via these waves [1,2]. In this paper, we study the temporal evolution of a pulsed m=1 helicon discharge which gives some insight in the discharge physics. In particular, we focussed on the transition from the inductively coupled plasma (ICP) concentrated on the region under the antenna to the axially asymmetric discharge sustained by m = +1 helicon modes.

2. Experiment

The investigations have been carried out on a pulsed large-volume m=1 helicon discharge HE-L [2]. The plasma is produced by RF power pulses (P_{RF} < 4 kW, f_{RF} = 13.56 MHz, τ_{pulse} = 2 - 3 ms , f_{pulse} = 25 Hz, typically) via an m=1 helical (Shoji type) antenna consisting of two helical current paths with opposite directions of the *rf* current (180° turn over the antenna length L_a = 22 cm). The plasma parameters measured by standard methods (electric probe diagnostics and 1 mm and 8 mm interferometry) were $n_e < 2 \times 10^{19}$ m^{-3} , T_e = 3 - 4 eV, B_0 < 0.1 T, p = 0.1 - 2 Pa argon gas, r_p = 7.4 cm and L_p = 200 cm.

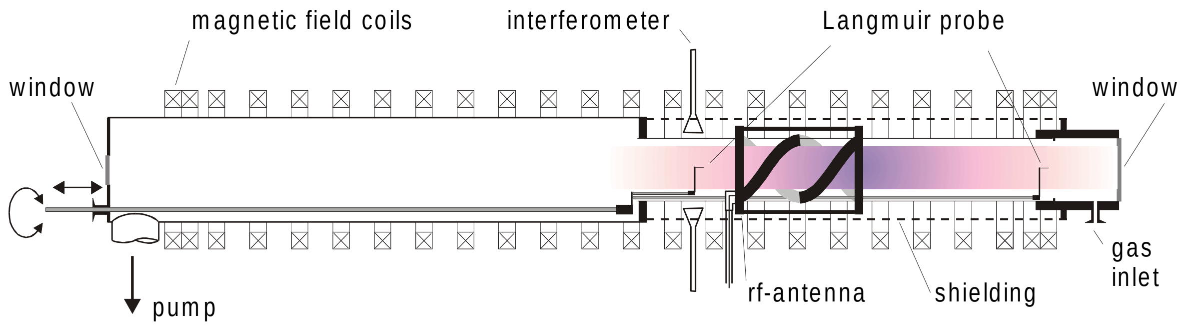

Fig. 1 : Experimental set-up of HE-L

The helicon wave field was measured by a movable array of magnetic (B-dot) probes picking up all the three components of the *rf* magnetic field. An *rf* double probe (tip distance 1.1 mm) was employed to sense the small-scale fluctuations of the *rf* electric field. The double probe data were evaluated by cross-correlation analysis.

3. Results

Temporal evolution of the density and the rf field profiles: A characteristic feature of the helicon discharge is the close relation between the plasma production, i.e., the formation of the density profile, and the wave propagation. First, we show in Fig. 2 the temporal evolution of the *rf* power distribution. During the first half millisecond the *rf* fields are mainly concentrated near the helical windings of the antenna. After about 0.6 ms a maximum originates on the tube axis which steadily increases. Finally, the profile forms a largely extended crest due to the m=+1 helicon mode travelling in positive magnetic field direction (see second contribution on this conference).

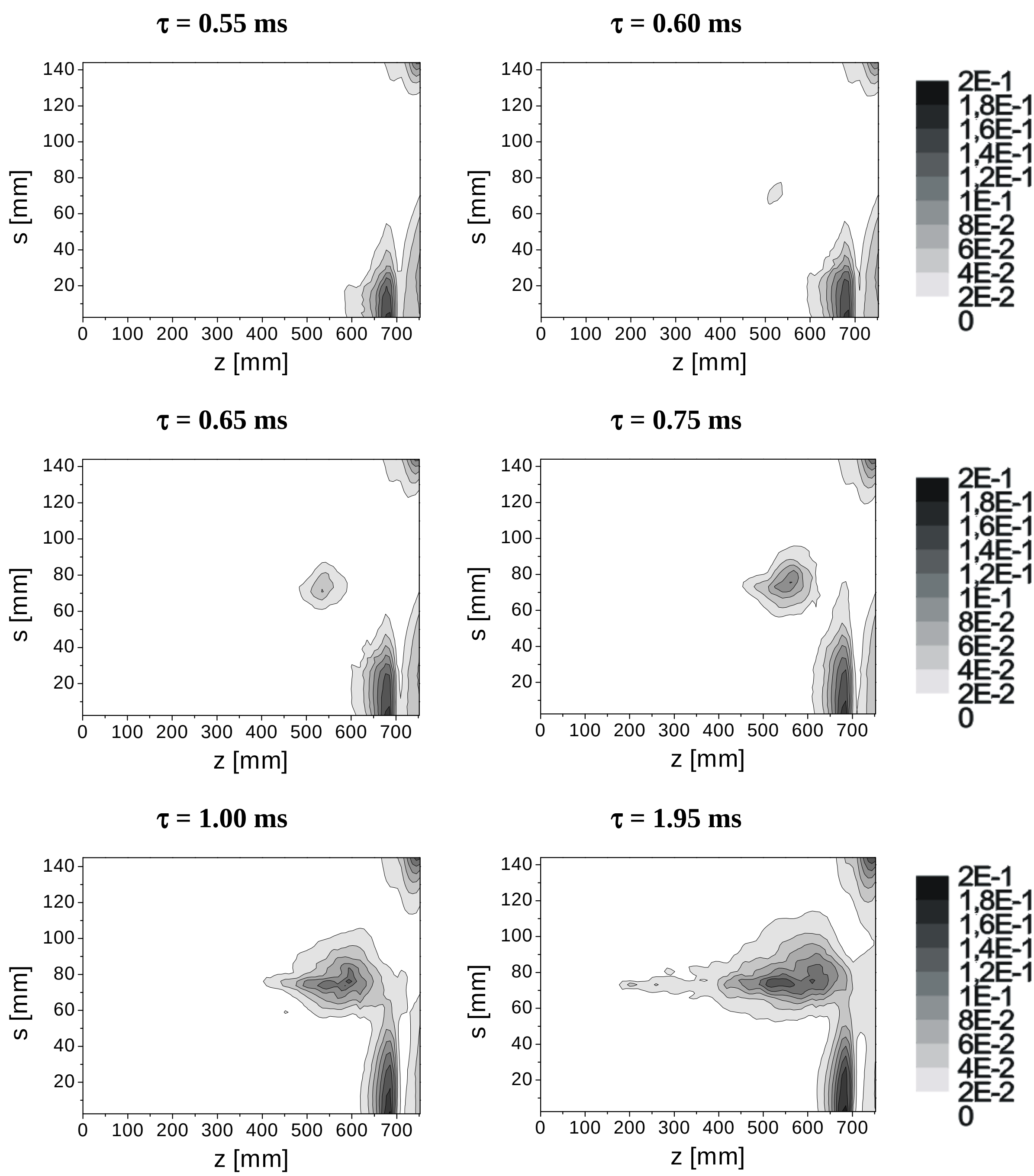

Fig. 2 : 2D-Plots of rf energy density ($|B|^2$)

Closely connected with this behaviour is the formation of the density profile (Fig. 3). In the first few tenths of millisecond one observes a broad profile which can be attributed to an inductively-coupled plasma (ICP) which is mainly located under the antenna. After that, the density strongly increases on the axis forming a profile peaked on the axis. In Fig. 4 we compare the time-evolutions of the density and the *rf* power measured on the axis. First the density rises nearly exponentially until a small plateau (ICP) is reached. Then it rises again, however, with a much shorter time constant.

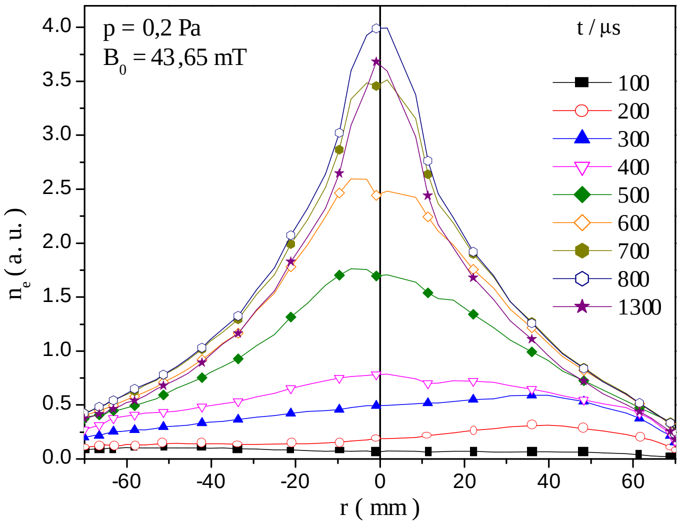

Fig. 3 : Radial density profiles

The rf energy on the axis increases nearly simultaneously with the second rise of the density. We believe that first fast electrons that can effectively ionise originate at the position of the first field maximum (Fig. 2), that is, strong ionisation sets in before the helicon modes have been established. Once the density in the region near the axis is high enough, the helicon modes build up and start propagating. To support the hypothesis of energetic electrons, we deduced from the step-like temporal increase of the density two temperatures. Of course, the second (higher) *temperature* is merely a measure of the thermal energy because the electron distribution function is far away from equilibrium. We further note that both *temperatures* decrease with growing gas pressure.

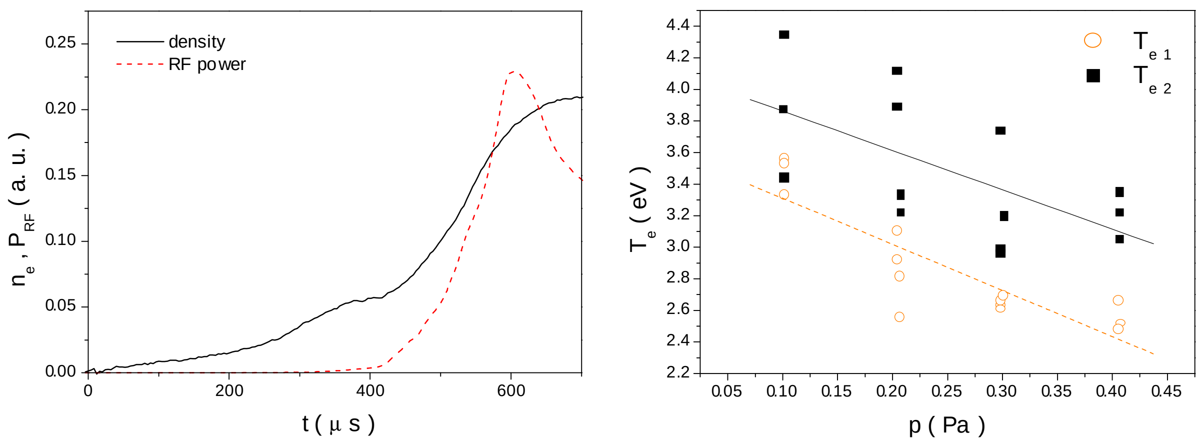

Fig.4 : Evolution of density and magnetic energy density (left), calculated electron temperature (right)

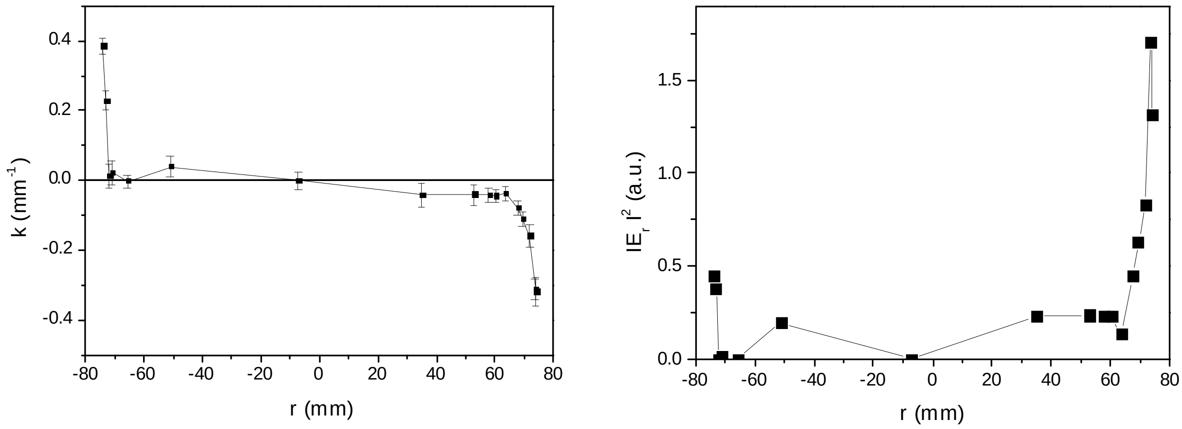

Fig. 5: Mean wave number (left) and electric energy density (right) vs. plasma radius

Measurements of the rf electric fields: The rf probes measure essentialy the rf potentials, i.e. the quasi-static part of the helicon modes as well as the TG (potential) waves. The latter are clearly more interesting inasmuch as they cannot be diagnosed by magnetic probes. Fig. 5 shows the mean radial wave number $<k_r>$ obtained from the cross-correlaton analysis of the *rf* double probe signals (mainly from the cross-phase). It can clearly be seen that $<k_r>$ increases strongly at the plasma edge. Apparently we observe small-scale waves close to the tube wall. Moreover, these waves propagate to the plasma edge as it is expected for the TG modes and their rf electric energy density is much larger than that of the helicon modes. Our findings are also qualitatively supported by computations from a fully electromagnetic antenna-plasma model that covers the excitation of both the helicon modes as well as the TG modes [3]. Up to now the TG modes could only detected at smaller magnetic field strengths (not for the best discharge conditions, i.e., high electron densities at high magnetic field).

4. Conclusions

We found that the formation of the helicon discharge is mainly determined by m = +1 helicon modes. These modes originate after strong ionisation has set in on the discharge axis. Furthermore there is some evidence that Trivelpiece-Gould modes are exited at the plasma edge. It has to be clarified in future investigations whether these modes play a dominant role for the *rf* power deposition in the present discharge.

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