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Anodic double layer oscillations as a source for ion-acoustic waves

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Abstract.

Experimental results are presented on ion-acoustic waves excited by self-sustained oscillations of an anode glow (AG) in a DP machine plasma. The AG is formed in front of a planar electrode placed in one chamber of the DP machine and biased higher than 150V positively with respect to the main anode. The AG turns to be either a stationary or a moving anodic double layer (ADL). In the latter case strong oscillations of the electron current to the electrode are present. Our investigations show that the anode current oscillations are accompanied either by strong oscillations of the plasma potential in the chamber where the electrode is situated or by the excitation of ion-acoustic waves in both chambers and the generation of ion-beam modes and ion-bursts in the second chamber.

Introduction.

Since the DP machine has been developed for a clear verification of ion-acoustic solitons [1], many experiments were carried out in such devices [2] or in similar ones, as e.g. triple plasma machines [3]. The excitation and propagation of linear and nonlinear ion-acoustic waves [4], ion-beam modes [5,6] or ion bursts [7] and ion holes [8] were investigated. Sinusoidal [9] and pulse excitation [4] of ion acoustic waves and solitons by an external signal, either applied to the source chamber anode or to the separating grid, or to other structures such as e.g. grids [9], probes [10] or bipotential structures [11], was also investigated. In this paper experimental recent results are presented on ion-acoustic waves, ion beam wave modes and ion-burst phenomena excited by ADL oscillations in a DP-machine plasma.

Experimental set-up.

The experiments have been carried out in the Innsbruck DP-machine presented in Fig. 1. An Argon plasma is produced in both chambers at a pressure of about 10 ^{3}mbar. Discharge voltages and discharge currents in the two chambers were almost equal as: $V_{D1} = V_{D2} =$ 80 V and $I_{D1} = I_{D2} = 20$ mA, respectively. Typical plasma parameters were: electron density $n = 5\times10^{8}$ cm^{-3} and a temperature of an almost thermalised group of electrons $T_e = 3{,}4$ eV. The anode of chamber 1 was grounded while the anode (E) of chamber 2 was biased negatively so that the plasma potential there was $V_p =$ 6,6V.

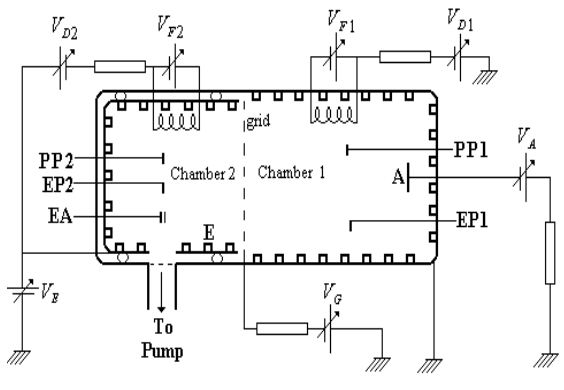

Fig. 1 Experimental set-up.

The separating grid was also biased negatively ($V_G =$ 100V) to minimise the electron coupling between the two plasmas. An anodic double layer was produced in front of an additional plane Ta-electrode A (1 cm diameter) biased positively (V_A) with respect to the ground. A was inserted on the axis of chamber 1 at a distance of 37 cm from the separating grid. Plasma parameters and ion acoustic waves were detected in both chambers by movable planar Langmuir probes (PP_1 and PP_2) and by emissive probes (EP_1 and EP_2). In addition, in chamber 2 a two-grid electrostatic analyser (EA) was used for ion beam detection. The anodic glow was also registered from one side using a fast CCD camera (sampling time 10 ^{4}s).

Experimental results and discussions.

When the anode A is biased higher than V_A = +150 V, in front of it an anodic glow may be formed. By increasing the positive bias the anodic glow becomes brighter and strong oscillations of the anode current appear.

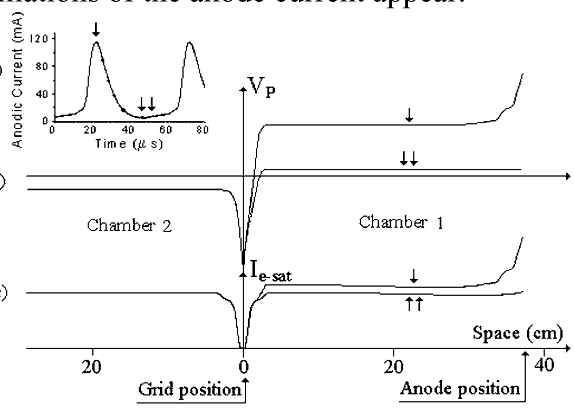

Fig. 2 Typical experimental results of the time evolution of the electron current to the anode A (a), axial distribution of the plasma potential (b) and of the electron saturation current (c) in both chambers.

The oscillations are similar to those reported by Bin Song et al. [12], but at a current about one order of magnitude smaller than in their experiment. A typical shape of the anodic current oscillations is presented in Fig. 2a. The peak current (labelled by ↓) is about one order of magnitude larger than the minimum (labelled by ↓↓) of the anodic current, which is approximately equal to the current before the formation of the anodic glow. The frequency of the oscillations depends on the plasma density and on the anode potential V_A. The axial distribution of the plasma potential (V_p in Fig. 2b) and of the electron saturation current of the probe ($I_{e\text{-}sat}$ in Fig. 2c) in both chambers are presented with respect to the grid and to the anode A, respectively.

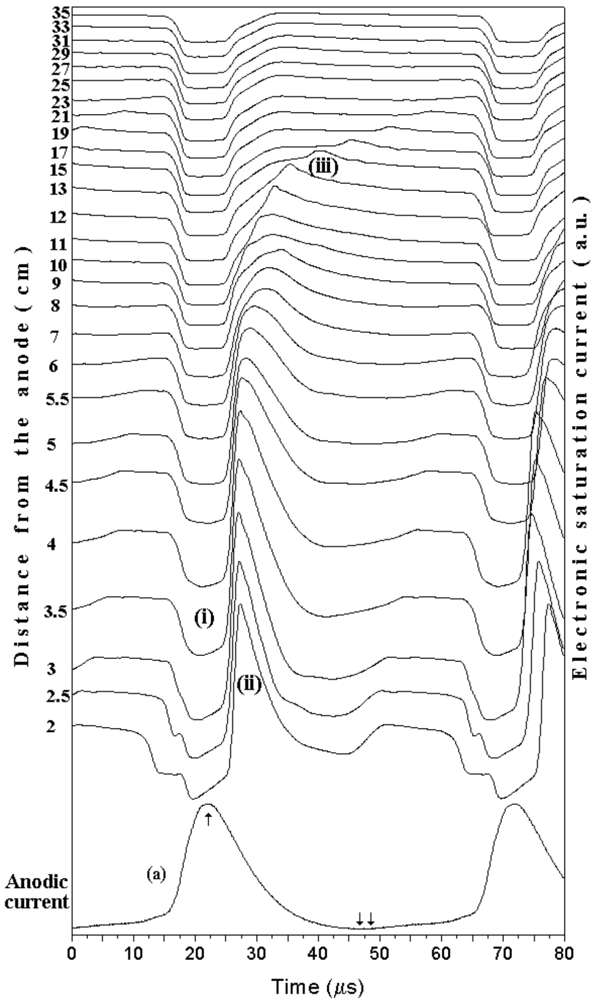

Figure 3 Time evolution of the electron saturation current of the planar probe (bias +50V) at different axial positions with respect the anode A in chamber 1 comparing with time evolution of the anodic current (a).

These values are plotted for the extremes of the anode current, at the ↓ maximum and the ↓↓ minimum, respectively. A fast recording camera shows that the anode oscillations are the result of the formation and destruction of double layers at a distance of about 7 cm from the anode A, similarly to an on-off discharge system. The result corresponds to previous space-time resolved measurements of the plasma potential distribution in front of the anode A [12]. Synchronously to the current oscillations, the plasma potential in the entire chamber 1 changes from a rather high positive value (some tens of volts curves↓, Fig. 2b), to the usual value of the plasma potential of about two volts (curve ↓↓, Fig. 2b). The former distribution corresponds to the peak of the anode current while the latter corresponds to its minimum, which is almost the identical to the plasma potential when A is not biased. In this latter case a quasistationary ion-beam enters chamber 2 because of the difference of the plasma potentials between the two chambers.

Fig. 3 shows the temporal evolution of the electron saturation current to Langmuir probe PP1 for different axial positions from A, towards the grid. Three phenomena can be observed: (i) a decrease of the probe current in phase with a rapid increase of the anode current, i.e., a direct-coupling effect (curve (a) Fig3); (ii) a strong, almost in-phase increase of the probe current which follows the previous signal over a distance of about 7 cm from A, i.e., up to the distance where the double layer is formed. It represents a local compression of the plasma density because ions are released from the AG and accelerated toward the background plasma before the destruction of the DL; (iii) an ion-acoustic wave which propagates from the edge of the double layer towards the separation grid during the minimum of the anode current. During the anode current increase, the AG develops in front of the anode simultaneously with the increase of both, the potential and the density. The DL moves from the anode surface into the plasma until the AG quenches approximately 7 cm from the anode. The resulting ion-acoustic perturbation is therefore a compressive one. The fact that ion-acoustic waves are excited at the boundary of the anode double layer is also confirmed in Fig. 4 where a linear extrapolation of the ion-acoustic wave signal (iii) yields that the wave is excited at the same distance of about 7 cm from the anode A.

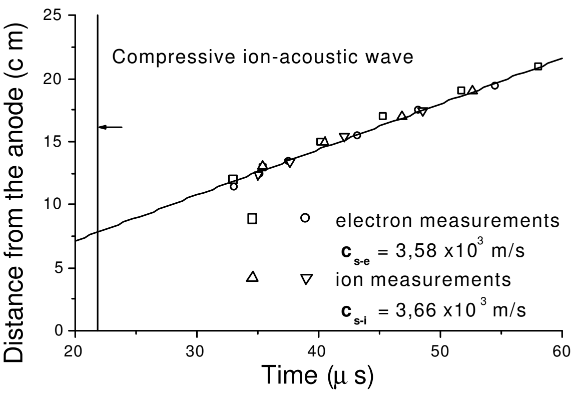

Fig. 4 Axial propagation of the ion-acoustic signal in chamber 1, taken from the maximum trace of Fig. 3 and minimum trace of the ion saturation current of the planar probe.

In Fig. 5 the time evolution of the electron saturation current is presented for different probe positions in the chamber 2 together with the evolution of the anode current (Fig. 5a). Both, oscillations of the plasma potential in the chamber 1 and the ion-beam injection into chamber 2, produce very complex phenomena in this plasma region. These phenomena consist of: (j) a pseudo-shock produced by the fast increase of the plasma potential in chamber 1 and the consecutive injection of ions with higher and higher speeds until both, the anode current and the potential in chamber 1 reach their maximum (↓ Fig. 5a).

After propagation through the pre-sheath region of about 5,5 cm, this signal splits in a very fast beam mode (VFB) with its precursor (pr) and in fast (fb) and slow (sb) beam modes, respectively. The VFB corresponds to very fast ions injected in the first stage of the increasing anodic current. A similar signal was observed some time ago in a Q-machine plasma [13]. The (fb) and (sb) modes correspond to the coupling of the ion-acoustic mode (jj) with the quasi-steady beam produced between the peaks of the anode current when both, the anode current and the plasma potential in chamber 1, reach a minimum value. The full lines correspond to values of v_{fb} and v_{sb}, obtained from the formula (4) given by Nagasawa and Nishida [6]. Both curves show a rather good agreement with the experimental points.

The ion-acoustic wave evolves later from the ion-hole [8] produced by a pseudo-shock. This ion-acoustic wave is a depressive one and it is presented in Fig. 6 (line (jj) with the speed C_s).

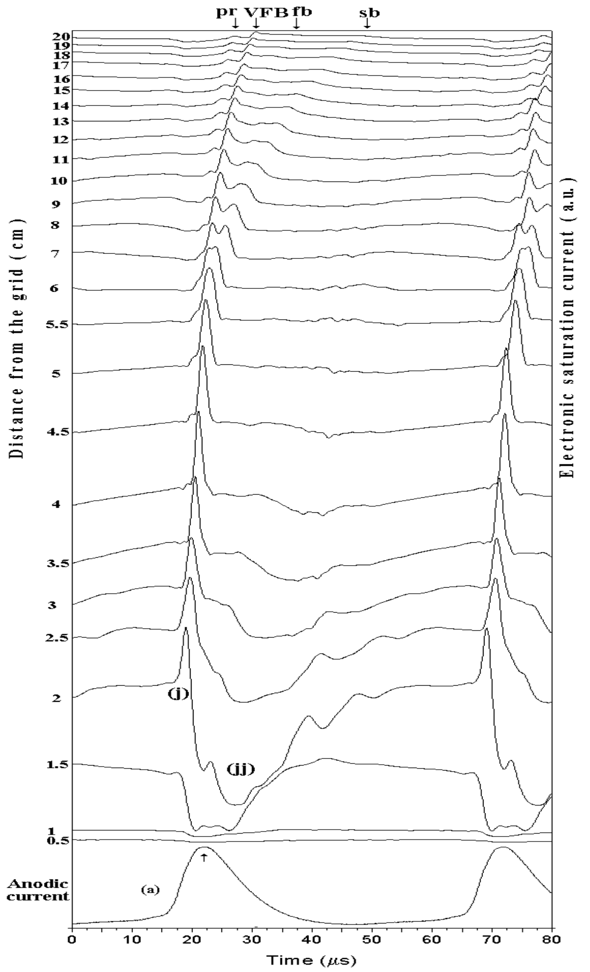

Fig. 5 Time evolution of the planar probe electron saturation current (bias +50V) at different axial positions with respect to the separation grid in chamber 2 compared to the time evolution of the anode current (a).

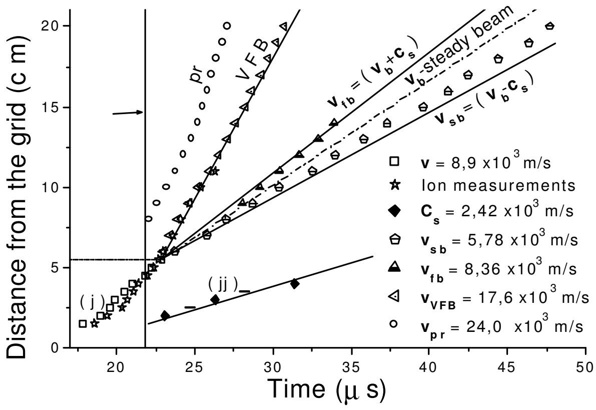

Fig. 6 Axial propagation from the grid into chamber 2 of the following signals taken from fig. 5: ion acoustic wave (jj), slow (sb) and fast (fb) beam mode, very fast (VFB) beam mode and precursor (pr).

Conclusions.

The experimental results show that the oscillation of the AG in one chamber of a DP-machine may produce rather complex plasma response: an ion-acoustic wave and synchronous plasma potential oscillations in the chamber where the AG is formed; a pseudo-shock, different ion beam modes and an ion-acoustic wave in the second chamber of the machine.

Acknowledgements.

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