36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.33E, P-4.052 (2009)

Experimental Investigation of the Ion Induced *l=2* Diocotron Instability in an Electron Plasma

M. Romé[1], G. Bettega[1], F. Cavaliere[1], B. Paroli[1,2], R. Pozzoli[1]

[1] *I.N.F.N. Sezione di Milano and Dipartimento di Fisica, Università degli Studi di Milano, Italy*

[2] *Dipartimento di Energia, Politecnico di Milano, Italy*

Malmberg-Penning traps allow to confine plasmas with a single sign of charge by means of electro- and magnetostatic fields for very long times. Particles may be lost at the wall of the confining chamber due to a slow radial diffusion caused by fields errors (imperfect alignment of the electrodes, magnetic field irregularities) and collisions with the residual neutral gas, which determine a loss of the plasma angular momentum. The confinement may also be limited by unstable collective oscillations, in particular by the $l = 1$ diocotron instability consisting in an off-axis rotation of the center of charge with an increasing radial offset, which may drive the plasma against the wall even before a significant radial diffusion has occurred.

In the absence of a positive ion contamination, the diocotron modes in an electron plasma are expected to be either neutrally stable (for $l = 1$) or damped (for $l = 2, 3, \dots$) by Landau resonance on electrons corotating with the diocotron waves [1]. Previous experiments [2, 3] showed that the fundamental diocotron mode in an electron plasma is destabilized when a small fraction of positive ions created by ionizing electron-neutral collisions is present. This instability was investigated theoretically for the case of trapped ions [4] and related to the resonant interaction between the averaged motion of the positive charges with the collective diocotron plasma oscillation. The case of untrapped (transient) ions was investigated later both experimentally [2] and theoretically [5]. Transient ions appeared to cause linear rather than exponential growth, and over a somewhat broader region around the resonance.

Higher order diocotron modes in an electron plasma can also be destabilized by the presence of ions. In previous experiments [6] an exponential growth of the lowest order diocotron modes was found, with a rate linearly proportional to the neutral pressure and to the ionization rate. The latter was obtained by measuring the frequency change of the $l = 1$ diocotron mode, keeping the mode amplitude small enough in order to neglect nonlinear effects.

Here the attention is focused on the evolution of the $l = 2$ diocotron mode, consisting in an elliptical deformation of the plasma cross section. The experiments have been performed in the Malmberg-Penning trap ELTRAP [7]. A scheme of the device is shown in Fig. 1-(a). A low density ($n \simeq 10^{12} - 10^{13}$ m^{-3}) and temperature ($T \simeq 1 - 10$ eV) plasma is contained within a stack of hollow cylindrical electrodes with radius $R_W = 4.5$ cm. The electrons are trapped

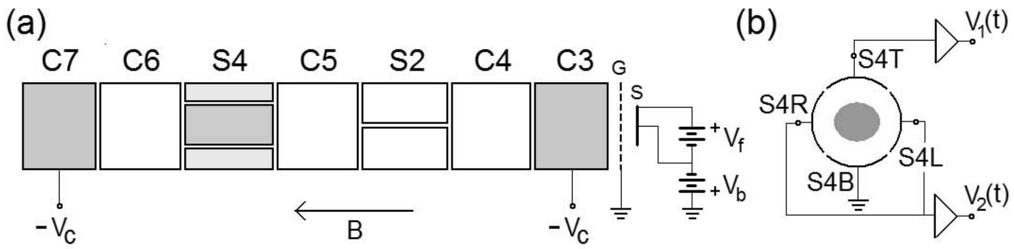

Figure 1: (a) Schematic of the ELTRAP device. The plasma is confined between electrodes C3 and C7, for a total length of $\simeq 60$ cm. The S2 and S4 electrodes are azimuthally sectored with two and four patches, respectively. The electrons are generated by a tungsten filament S, heated with a constant current and negatively biased with respect to a grounded grid G. (b) Electrical connections of the S4 electrode for the diagnostic of the $l = 1,2$ diocotron modes.

axially by two fixed negative voltages and radially by an axial magnetic field ($B \leq 0.2$ T). The device is kept under ultra high vacuum (UHV) conditions (residual gas pressure p of a few 10^{-9} mbar). A high resolution CCD camera records the light produced on a phosphor screen collecting the particles ejected from the device when the potential barrier is removed. The image on the screen represents the axially averaged plasma density distribution.

The time evolution of the plasma has been investigated for different values of p, using the optical diagnostics. In order to change p, the trap is at first isolated from the pumping system by closing gate valves. The pressure reaches a value of $\approx 5 \cdot 10^{-7}$ mbar due to the outgassing from the inner structures of the device. By opening the gate valves again, p decreases to UHV conditions with a time constant of the order of a few minutes. During this period, several cycles of plasma inject-hold-dump are operated, recording the value of p. In the experiments the energy of the emitted electrons has been set to $\simeq 17$ eV, just over the first ionization energy of the H_2 molecule, which represents the major component of the residual neutral gas, so that only single ionization events are expected to occur. The evolution at $p \simeq 1.4 \cdot 10^{-7}$ mbar is shown in Fig. 2. The plasma undergoes a radial expansion due to electron-neutral collisions, as expected for this high pressure regime, and develops on the time scale of hundreds of ms an evident elliptical deformation, which forms nonlinear structures.

Due to the rapid development of a non-linear saturation due to spatial Landau damping in the radial edge of the plasma column, the use of the electrostatic diagnostic is limited to relatively low pressures, where the instability rate of the $l = 2$ mode is not too big. The evolution of the mode is investigated in this case analyzing the induced current signals collected on two opposite, electrically connected patches of an azimuthally four-sectored electrode [see Fig. 1-(b)].

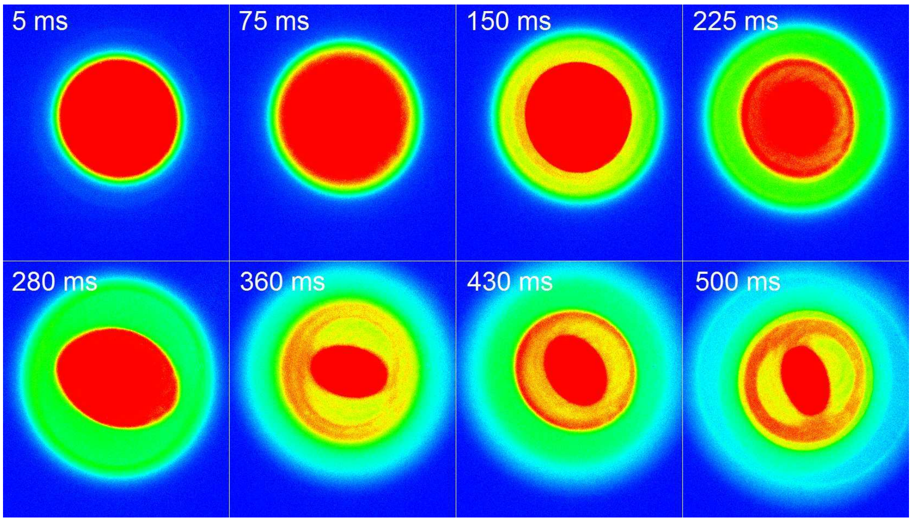

Figure 2: Time evolution of the plasma density distribution at $p \simeq 1.4 \cdot 10^{-7}$ mbar. The false color map evidences the density gradients.

The use of high gain and low-noise transimpedance amplifiers [8] avoids the destabilization of the diocotron modes due to resistive effects [9]. The induced signals are digitized at 500 kSamples/s and Fourier transformed using a time window of 8192 points ($\Delta t \simeq 16.4$ ms), for a frequency resolution of $\Delta f = 61$ Hz. The frequency and amplitude of the modes are followed with a peak detector. Fig. 3 shows an exponential growth of the signal amplitude detected on the quadrupole antenna at $p \simeq 1.2 \cdot 10^{-8}$ mbar. A similar behavior, but with a smaller growth rate, is observed for the evolution of the $l = 1$ mode amplitude, measured using a single patch of the same sectored cylinder. The figure also shows for comparison the amplitude of the $l = 2$ mode obtained for a lower residual gas pressure.

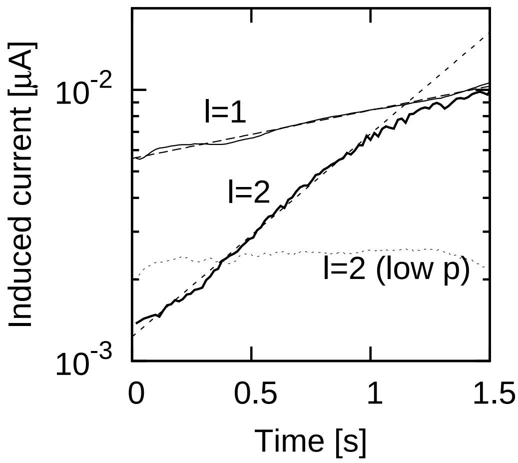

Figure 3: Time evolution of the amplitude of the $l = 1, 2$ modes at $p \simeq 1.2 \cdot 10^{-8}$ (solid lines, exponentially fitted with growth rates $\simeq 0.41$ s^{-1} and $\simeq 1.72$ s^{-1}, respectively), and of the $l = 2$ mode at $p \simeq 2.9 \cdot 10^{-9}$ mbar (dotted line).

Since the total light intensity on the phosphor screen is proportional to the total trapped charge, its time variation has been used to estimate the ionization rate. The time behavior during the first 100 ms of evolution of the number of trapped electrons for different pressures is shown in Fig. 4-(a). The ionization rate ν^{+} turns out to be roughly proportional to the neutral gas pressure, as shown in Fig. 4-(b), in agreement with previous results [6].

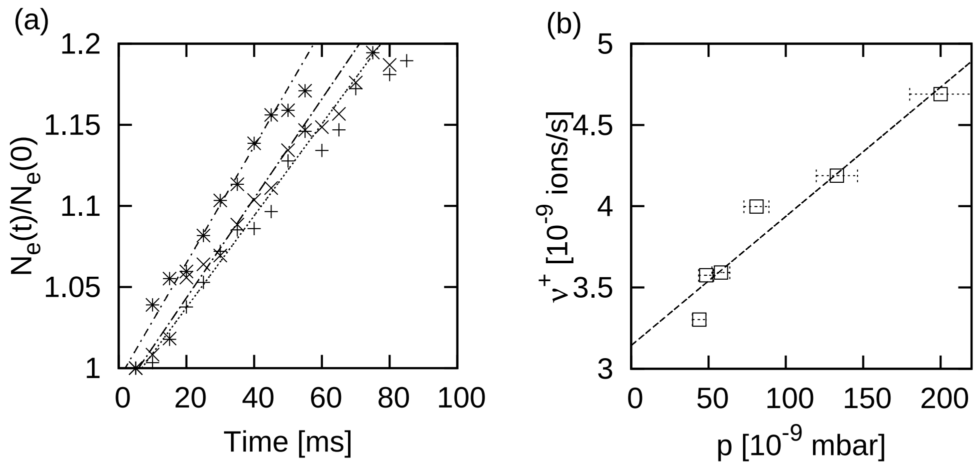

Figure 4: (a): Time evolution of the number of trapped electrons normalized to its initial value $N_e(0)$ for $p \simeq 4.4 \cdot 10^{-8}$ mbar (plus symbols), $p \simeq 4.9 \cdot 10^{-8}$ mbar (crosses) and $p \simeq 1.3 \cdot 10^{-7}$ mbar (asterisks). (b): Estimated ionization rate ν^+ as a function of the residual gas pressure.

This work was supported by the Italian Ministry for University and Scientific Research 'PRIN-2007' funds.

References

[1] R. J. Briggs, J. D. Daugherty and R. H. Levy, Phys. Fluids **13**, 421 (1970)

[2] A. J. Peurrung, J. Notte and J. Fajans, Phys. Rev. Lett. **70**, 295 (1993)

[3] G. Bettega, F. Cavaliere, M. Cavenago, A. Illiberi, R. Pozzoli and M. Romé, Plasma Phys. Control. Fusion **47**, 1697 (2005)

[4] R. H. Levy, J. D. Daugherty and O. Buneman, Phys. Fluids **12**, 2616 (1969)

[5] J. Fajans, Phys. Fluids B **5**, 3127 (1993)

[6] A. A. Kabantsev and C. F. Driscoll, on Non-Neutral Plasma Physics V (edited by M. Schauer et al.), AIP Conf. Proc. **692**, 61 (2003)

[7] M. Amoretti, G. Bettega, F. Cavaliere, M. Cavenago, F. De Luca, R. Pozzoli and M. Romé, Rev. Sci. Instrum. **74**, 3991 (2003)

[8] G. Bettega, B. Paroli, R. Pozzoli, M. Romé and C. Svelto, Meas. Sci. Tech. **19**, 085703 (2008)

[9] G. Bettega, F. Cavaliere, B. Paroli, R. Pozzoli, M. Romé and M. Cavenago, Phys. Plasmas **15**, 032102 (2008)