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Experiments on Solitons and Electron Holes in a Pure Electron Plasma Paper

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Abstract

Solitons and electron holes are excited in a cylindrical pure electron plasma and their propagation properties are investigated experimentally. Through many reflection at both ends of plasma, solitons and electron holes do not change their propagation speed and propagate as if in a infinitely long column. Solitons behave as KdV solitons with Landau damping. Electron holes go and back in the plasma more than several hundred times but damp away in short time compared with the Coulomn collision time.

Keywords:

pure electron plasma, soliton, electron hole

1. Introduction

A pure electron plasma confined in the Penning-Malmberg type trap has a very long confinement time and reachs the thermal equilibrium state. It provides an ideal isolated system and is suited for experimental study on basic plasma physics [1]. In a neutral plasma, many experimental results on large amplitude electron plasma waves, such as solitons, electron holes and shock waves, have been reported by using Q-machines [2-5]. Recently, electron plasma solitons, electron holes and rarefaction waves have been observed in a cylindrical pure electron plasma [6]. For the axisymmetric perturbations in a cylindrical pure electron plasma, it is possible to use the theoretical treatments same as those in a neutral plasma and to compare the experimental results with theoretical ones reported so far in detail [7]. The most significant difference is reflection of solitons and electron holes at both ends of the plasma, which can not be observed in a neutral plasma produced in a Q-machine. Therefore, in a cylindrical pure electron plasma, propagation property of such nonlinear density perturbations can be experimentally investigated for a sufficiently long time till they damp away. In this paper, we report the experimental results on excitation and propagation of solitons and electron holes in such a cylindrical pure electron plasma.

2. Experimental Setup

The experiments are carried out in the multi-ring electrodes trap ($B_z \leq 510$G, $p_0 \geq 1 \times 10^{-7}$Pa) [8]. The trap has 39 ring electrodes (radius = 4.5cm, thickness = 1.5cm) and 2 end electrodes. They are aligned with each other precisely along the magnetic axis with 0.5cm gap. A well potential ($V_{\mathrm{well}} \leq -100$V) is applied to the end electrodes and the other electrodes are grounded through resistors of 50Ω. By the multi-pulse stacking method using the field emitter array cathode [9], the cylindrical pure electron plasma is formed for 2 second injection time, to fill the almost all the inner section of the electrodes. Then, the plasma is left isolated for more than 5 second to be relaxed and thermalized by Coulomn collisions and collisions with the residual neutral gas. Total electron number and temperature are

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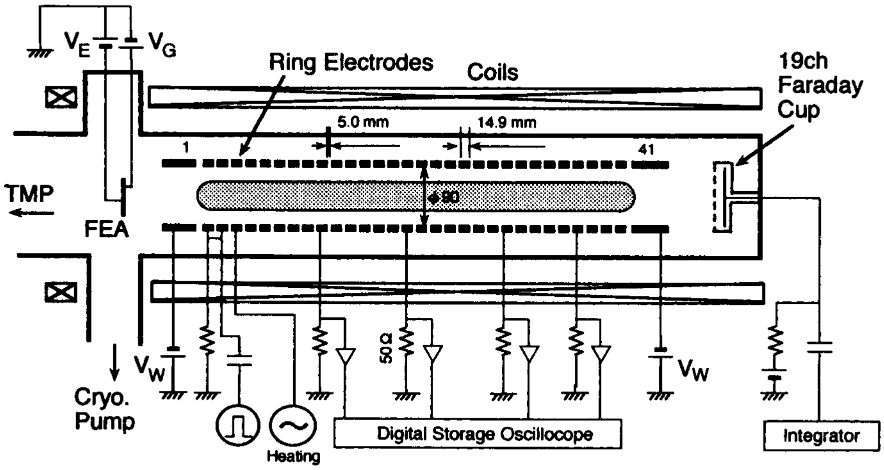

Fig. 1 Schematic drawing of the experimental setup.

measured by grounding the end electrode and introducing plasma to the 19 ch Faraday cup. The typical plasma parameters are $n \sim 3 \times 10^6\mathrm{cm}^{-3}$ and $T \sim$ 1eV. The global confinement time is about 30 sec for B_z = 400G and L_p (the plasma column length) = 78cm.

The density perturbation is excited by applying positive or negative step voltages to the two ring electrodes, EL2 and EL3, adjacent to the one of the end electrodes (Fig.1). The propagation of the density perturbation is observed by measuring the image charge signals induced on the ring electrodes. Eight signals are digitized simultaneously at 500Ms/s for 250kW/ch. Therefore the time evolution of the density perturbation can be observed for 500μs at 2ns time resolution.

Temperature can be changed from 0.5 to 6eV by applying the sinusoidal voltage to one of the ring electrode near the frequency range of electrostatic modes and heating the plasma.

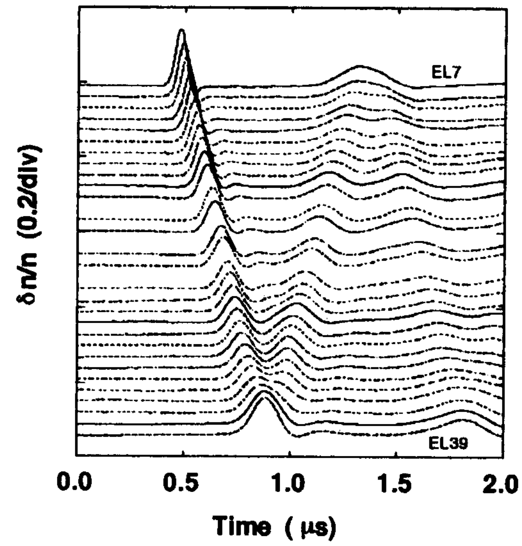

Fig. 2 Density perturbation measured at different electrodes when the negative step voltage (−6V) is applied.

3. Soliton

When the negative step voltage is applied to the ring electrodes at one end of the plasma column, the bell-shaped positive pulse ($\delta n/n > 0$) propagating along the axis is excited. Figure 2 shows the time evolution of the density perturbation observed at different electrodes. Here four identical shots data are plotted in one figure. It is seen that the positive pulse propagates, reflects at the ends of the plasma several times and damps away.

The peak position z (folded after the reflections), normalized amplitude $\delta n/n$ and width t_w are plotted as a function of time in Fig. 3. The peak position z increases linearly with time through reflections. The normalized amplitude varies as $(1 + \nu t)^{-2}$, except around the ends of plasma. The least-mean-squre-fitted value of ν is $7 \times 10^5\mathrm{s}^{-1}$ in this case.The width becomes wide as the amplitude decreases and finally disappears. The propagation speed tends to increase with increasing its amplitude. The propagation properties are in good accordance with those of KdV solitons observed in the neutral electron column [2].

When the plasma is heated by applying the sinusoidal voltage near the frequency range of electrostatic modes, the pulses propagate faster and the damping rate increases. When the pulse is excited at $\tau =$

250ms after the heating (i.e., τ is longer than the Coulomn collision time $\tau_{ee} \sim$ 10ms), the propagation speed and the damping rate are nearly the same as those predicted by the theory for the KdV soliton under the Landau damping [3]. On the other hand, when the pulse is excited at τ = 0.5ms after the heating and the energy distribution function is not a Maxwellian, the propagation speed and the damping rate are different.

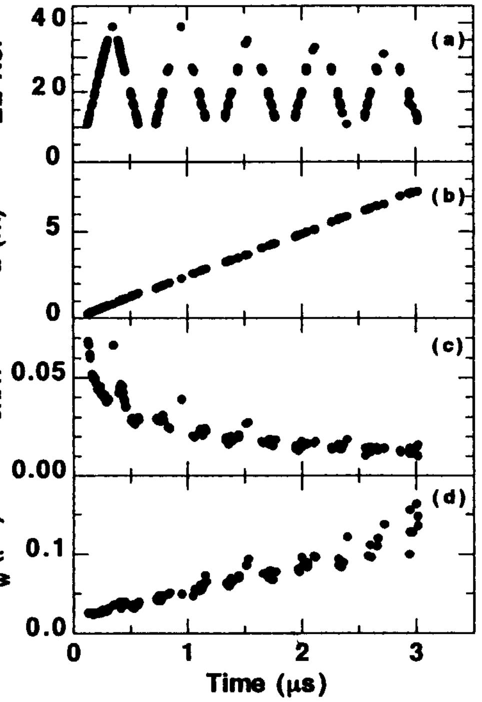

Fig. 3 Time evolution of the peak position, normalized amplitude and width.

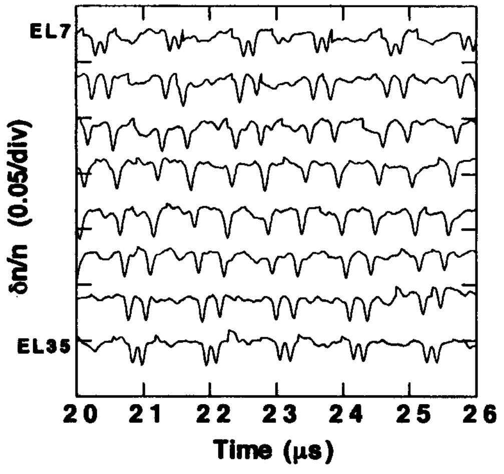

Fig. 4 Density perturbation measured at different electrodes when the positive step voltage (+6V) is applied.

After solitons damp away, several axisymmetric modes of electrostatic waves (T-G mode) are excited. Their amplitude is large when the amplitude of solitons is large.

4. Electron Hole

When the positive step voltage is applied, the electron hole ($\delta n/n < 0$) is excited. Figure 4 shows the time evolution of the density perturbation observed at different electrodes in one shot. The electron hole is very stable and propagates back and forth more than 300 times in the plasma column. As solitons, electron holes do not change their propagation speed at the reflection. The propagation speed tends to increase with decreasing its amplitude. Because the amplitude of electron holes decreases gradually as they pass through the plasma column, the propagation speed increases progressively. The damping rate is about 1/50 shorter than the Coulomb collision time. After electron holes is damped away, several axisymmetric modes of electrostatic waves are excited, similar to the case of solitons.

Two counter-streaming holes pass through each other as solitons do, while two co-streaming holes whose relative speed is small merge together. The merging time is about 4 μs.

5. Conclusions

In this work, the characteristics of solitons and electron holes propagating in a cylindrical pure electron plasmas are investigated exprimentally. Solitons and electron holes are excited when the negative or positive step voltage is applied to the ring electrodes at one end of the plasma column. They propagate back and forth through reflections at the both ends of plasmas, and finally damp away. After that, several axisymmetric modes of electrostatic waves are excited. Solitons behave as KdV solitons with Landau damping. Electron holes are much more stable than solitons, but damp away in short time compared with the Coulomn collision time.

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