

EXPERIMENTS ON NON-NEUTRAL LONG SPHEROIDAL ELECTRON PLASMAS IN A MULTI-RING-ELECTRODE TRAP

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A non-neutral spheroidal plasma with a longer axial length can be stably trapped in a shallower electrostatic hyperbolic (or harmonic potential) well in the presence of a uniform magnetic field. This feature brings a possibility to construct a fusion reactor scheme using nonneutral plasma composed of ions only. Here, the potential well might be formed within a feasible strength of the electric field. Long spheroidal plasmas are also very useful for fundamental studies of plasma physics, especially of electrostatic waves. Traps equipped with many electrodes of a ring shape, named by Multi-Ring-Electrode Trap: MRE, have been developed for the above mentioned purpose and experiments have been performed [1-7]. This report describes experimental results obtained from a new trap named MRE-4.

1. Trap

The MRE-4 is schematically shown in Fig. 1. This trap is formed with aligned 45 ring electrodes of 7 cm inner diameter and its confinement region extends to 70.4 cm. The axially uniform magnetic field is 375 G. The hyperbolic potential is generated when a voltage allotment proportional to z^2 is applied on the ring electrodes. Figure 2 shows the applied voltages on the electrodes and the produced hyperbolic potential on the axis.

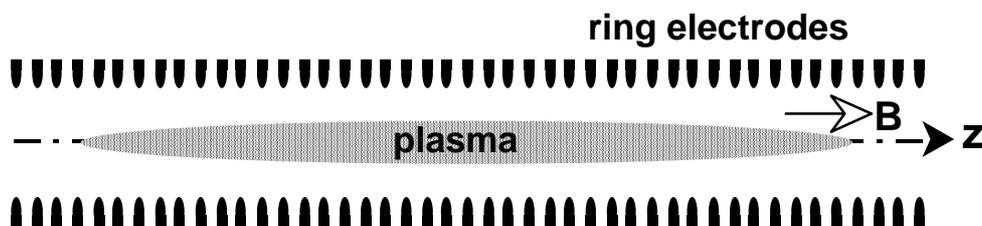


Fig.1. Multi-Ring-Electrode Trap MRE-4.

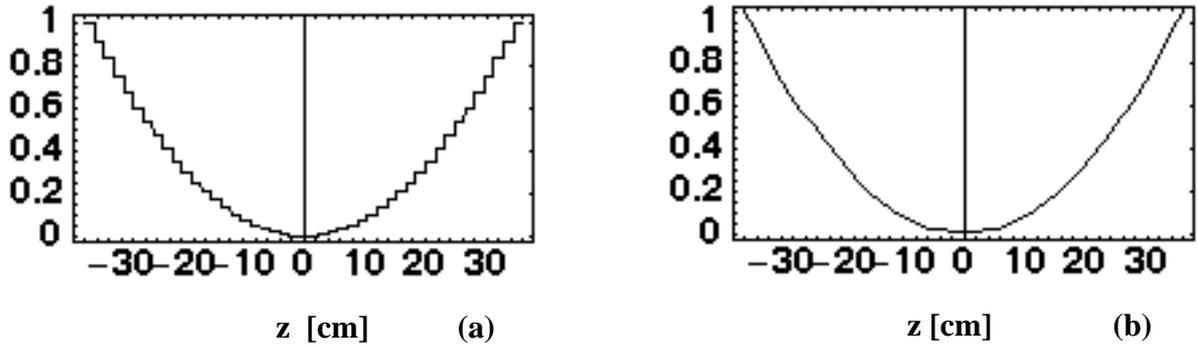


Fig. 2. (a) The applied voltages on the electrodes and (b) the generated hyperbolic potential on the axis.

2. Formation of Long Spheroidal Plasma

The elongation of a spheroidal electron plasma in an equilibrium state depends on its total angular momentum. In order to form a largely elongated spheroidal plasma, it is necessary to provide the sufficient momenta to electrons at the initial stage of the formation. Otherwise, plasmas with large aspect ratios cannot be realized as is shown in Fig. 3(a). Although the diameter of the injected pulsed electron beam along the magnetic field was reduced to be as small as 1 mm, the radius of the plasma gradually expanded with time after the injection.

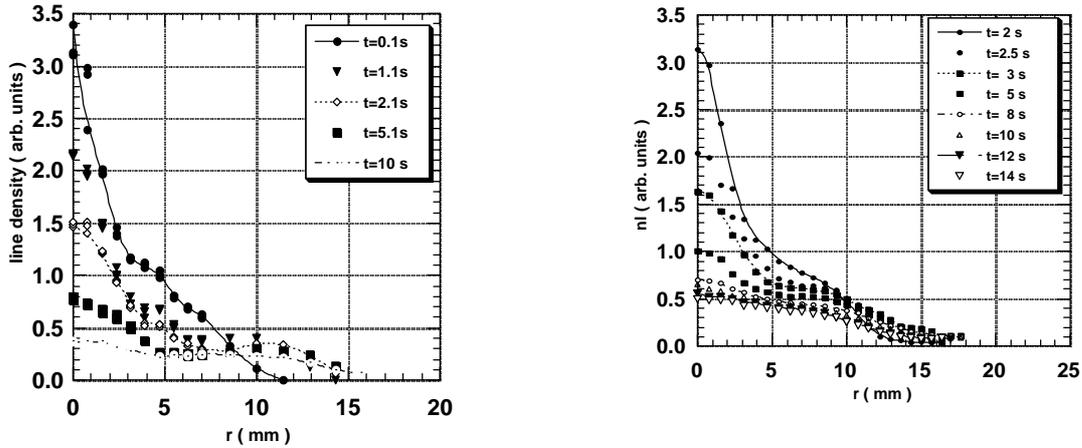


Fig. 3. Evolution of axial line-density profiles: (a) the case without REF and (b) after the cease of REF where the diameter of the injected beam was 2 cm.

To give the angular momenta, an azimuthally rotating electric field (REF) of single phase, i.e., $m=1$, was applied to two rings with four sectors, set 9.6 cm apart from the well bottom on the both sides. Figure 3(b) shows a typical evolution of the line-density profile when the REF of 1.55 MHz was applied for 2 s after the electron stacking. Though injected electron beam was 2 cm in this case, the profile was radially much compressed by the REF. Then, it settled down to the profile which was very close to that of a spheroidal plasma. In Fig.4, the profile obtained at $t = 12$ s is fitted by a curve $\{1-(r/a)^2\}^{1/2}$, where a is the principal radius of the spheroid. In this case, $a = 12.5$ mm, the temperature was less than 0.1 eV and the

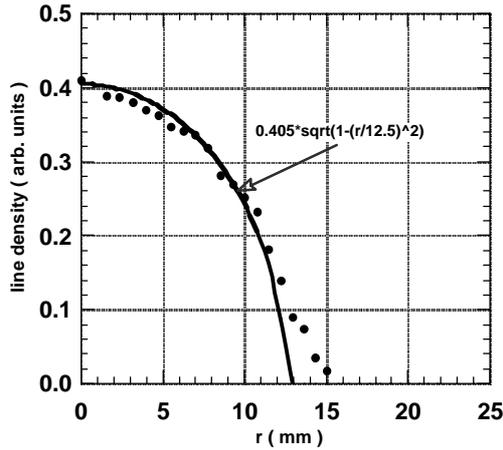


Fig. 4. Relaxed line-density profile measured 12 s after the cease of the REF.

3. Electrostatic Waves

Many axisymmetric electrostatic modes were distinctly excited and observed in long spheroidal electron plasmas trapped in the MRE-4 since their wavelengths became sufficiently long even for higher modes. The axial phase difference and the position of nodes of a wave were inferred from induced signals on the many electrodes. Figure 5 shows the observed mode frequencies up to the axial mode number of $n=17$, i.e., (17,0) mode.

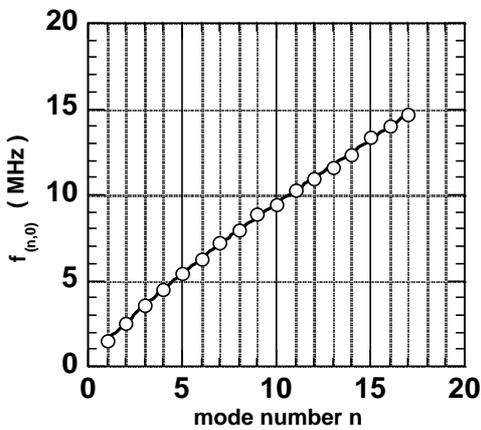


Fig. 5. Mode frequencies observed in MRE-4 where $N=1.5 \times 10^9 \text{ cm}^{-3}$, $a=3 \text{ cm}$ and $2b=54 \text{ cm}$.

Furthermore, by raising the perturbation more, such a mode transition became of a cascade type where the lower modes were successively excited from the higher ones. Figure 6 shows a typical observed cascade transition when the mode (7,0) was excited first as a pump wave. The power spectra were obtained using FFT. The pump wave decayed within $50 \mu\text{s}$ and, during its decay, the lower modes (6,0) and (5,0) rose up but the amplitude of the of the mode (5,0) was still lower than that of the mode (6,0). Then, the mode (5,0) became dominant. Such a sequential transition continued until the mode (1,0) remained only.

total electron number was $N = 6.6 \times 10^8$. The deviation of plots from the curve is about ten times the Debye length. The plasma is nearly spheroidal with the axial length $2b = 58 \text{ cm}$ and the aspect ratio of 23. This length was also confirmed by measuring the position of the nodes of excited electrostatic waves of ($n=3, m=0$) mode. Through these experiments, it has been proved that a long spheroidal plasma can be formed by supplying sufficient amount of momentum to plasma particles.

A burst of weak rf-perturbations were applied, the excited wave was only the resonated one with the imposed frequency. However, when the excited wave amplitude was increased by applying larger perturbations, there appeared a mode transition from the excited mode, i.e., pump wave, to lower modes. This transition was normally three wave transition.

Furthermore, by raising the perturbation more, such a mode transition became of a

The time history of this cascade transition can be seen more clearly from the time dependence of the peak amplitude of each mode. Figure 7 shows the dependence for the same case of Fig. 6.

Similar transition was also observed for pump waves of mode number higher than 9. The transition became more complicated as the pump wave of higher mode was excited. In this case, many modes arose simultaneously and they tended to lower ones on the whole.

When the pump wave of a large amplitude was excited, the cascade transition to the lowest mode was accelerated and completed in a short time. The MRE trap can axially extend the confinement region, keeping the good confinement characteristic of Penning trap. The other configurations such as cylindrical trap and so on can be generated in the same apparatus. Owing to the many electrodes, performance of basic experiments on non-neutral plasma is easy. More detailed non-linear phenomena in non-neutral plasma will be studied in this MRE-4.

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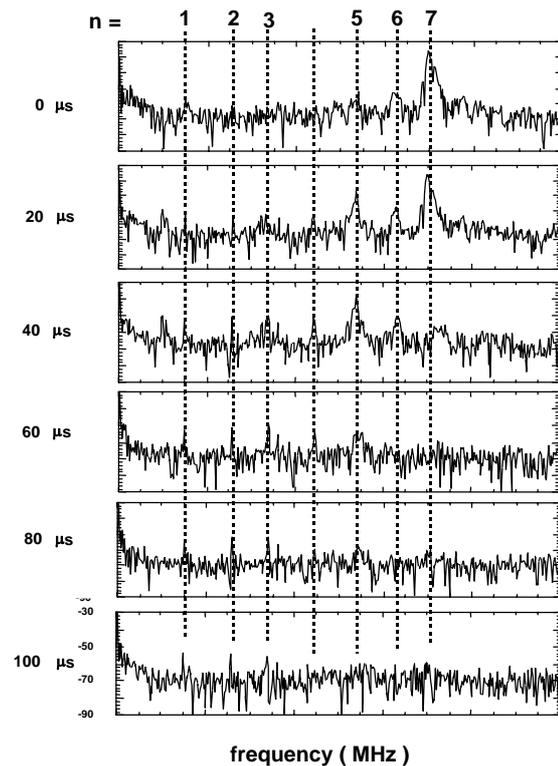


Fig. 6. Cascade mode transition in a spheroidal electron plasma where mode (7,0) of 6.9 Mhz was resonantly excited as a pump wave. Amplitude is indicated by dB.

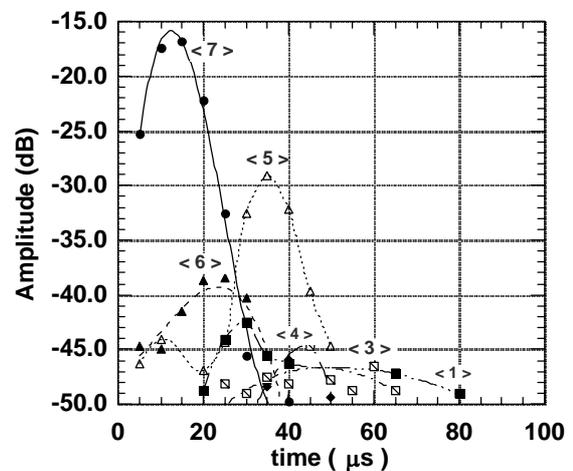


Fig. 7. Time variations of modes during the cascade transition. <n> shows the mode number.