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Different Features of Electron Plasma Confinement of Rectangular and Harmonic Electric Potential Wells

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Introduction

Nonneutral plasmas have been extensively studied mainly in three kinds of traps: Penning trap[1], Malmberg trap (cylindrical trap)[2] and Paul trap[3]. Other modified traps such as nested trap[4] and multi-ring electrode trap[5] have been served for experiments in many fields such as antimatter physics[6], plasma physics[7,8], and atomic physics[9]. Many experiments so far have shown that harmonic potential wells are superior to rectangular ones in regard to plasma confinement. The multi-ring electrode trap can generate axially symmetric electric potentials, including either pure harmonic potential or rectangular one and intermediate ones between them. In this report, features of the harmonic potential well (HPW) on plasma confinement are experimentally compared with those of the rectangular potential well (RPW), using a multi-ring electrode trap: MRE-4 at Kyoto University.

Possible potential in multi-ring electrode trap

Figure 1 shows the multi-ring electrode trap with 45 ring-electrodes of the radius R=3.5 cm. The axial length of the trap region is 70.4 cm. The electrostatic field of the trap can be changed by allocating an appropriate voltage onto each electrode. A harmonic potential well (HPW) with the width L is produced by applying voltage proportional to z^2 up to the electrodes at $z=L$. Here, cylindrical coordinates (r, θ, z) are used. The longest HPW is shown in fig.1 where L=35.2 cm. In addition, a rectangular potential well (RPW) can be formed by distributing a rectangular voltage with the flat bottom length 2L to the electrodes. It should be noted that the shape of RPW approaches to HPW as L becomes shorter, as shown in fig.2. Therefore, we can survey a variety of configurations for plasma confinement: HPW, RPW and the intermediate between the two.

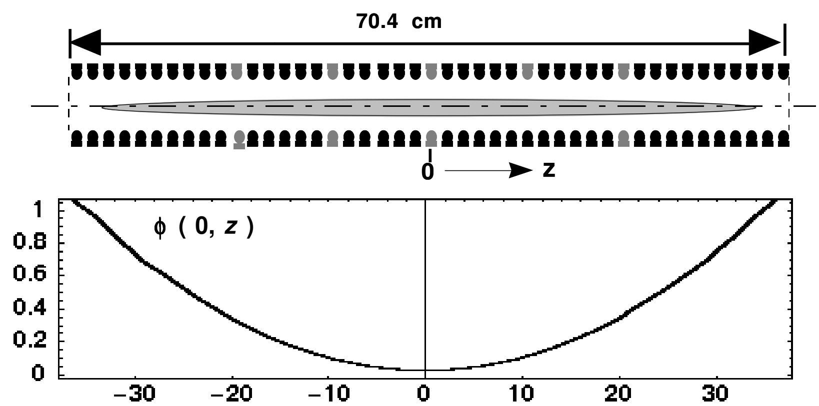

Fig.1 Multi-ring electrode trap: MRE-4 and the axially longest harmoni potential.

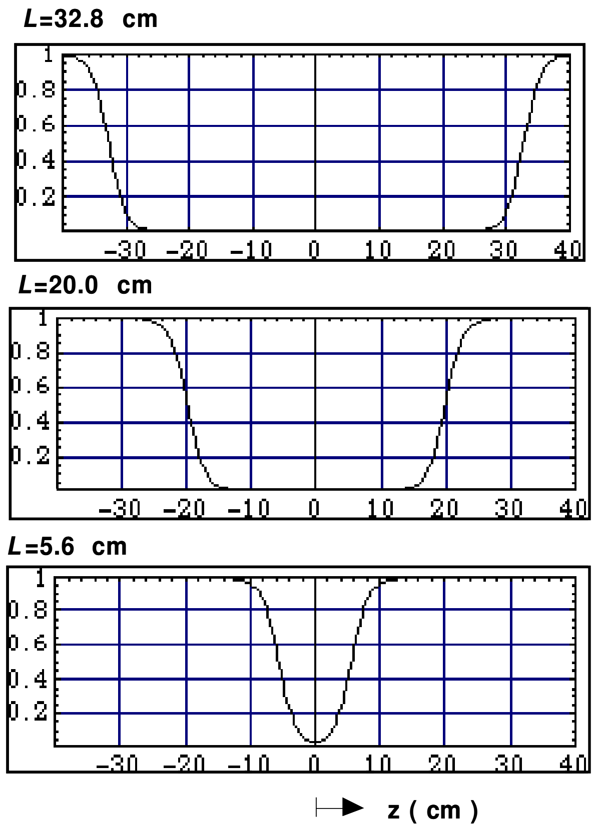

Fig.2 Rectangular wells for different L. The shape approaches HPW as L decreases.

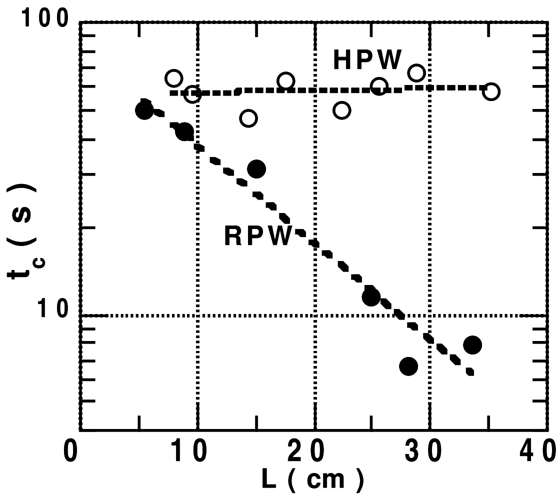

Fig.3 Dependence of global confinement time t_c on L for HPW and Rocument Error^^^

Overall confinement time

The confinement time, t_c, in RPW was measured for different L in the uniform magnetic field of 473 G. Here, the average electron number per axial unit length, n_A was adjusted to be nearly constant as n_A~5 x 10^6 cm^{-1}. The confinement was greatly degraded with the length L, as is noticed in fig 3. This trend had been reported by UCSD group[10]. The potential in RPW approaches the pure harmonic potential as L decreases (see the lower case in fig.2). Therefore, the reason why the confinement is improved at lower L relys upon the confinement features of HPW, at least in this experimental condition L/R<10.

The dependence of t_c on L in HPW was also measured in the same condition as mentioned above. The results are plotted in fig.3. There is no clear change in t_c over the wide range of L, though the plots fluctuate a little. Besides, t_c for different L was always longer than those in the case of RPW. A conslusion from these results is such that the confinement improvement in RPW with shorter L is caused by the approach of the potential well towards HPW which has good features for plasma confinement.

Evolution of internal density distribution

Measurement of the internal density distribution may more clearly elucidate the origin of the observed difference in confinement time between HPW and RPW. The radial distribution of line-integrated density along magnetic field, $nl(r, t)$, was taken with a movable

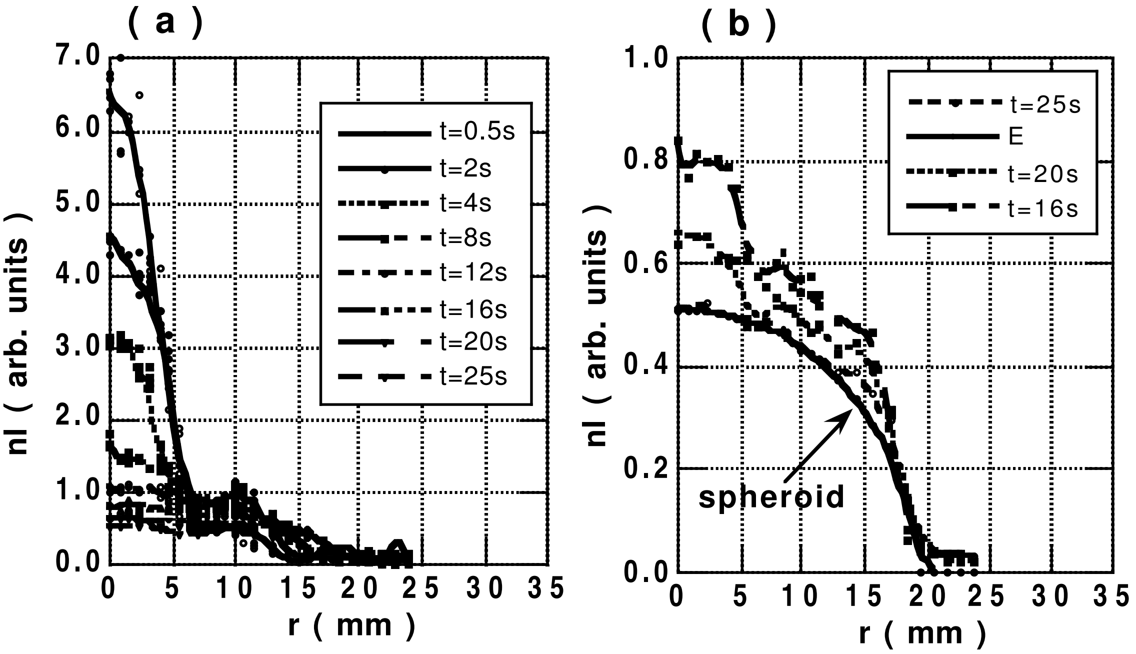

Fig.4 Time evolution of line-density profile *nl* (*r,t*) for the case of HPW.
(a) from 0.5 s to 25 s. (b) at later time: t > 16 s.

tiny Faraday cup. Pulsed electron beams of the small diameter of 0.5 mm were injected along the axis to clearly observe the radial expansion of the stacked electrons.

Figure 4(a) shows $nl(r, t)$ in HPW, where t =0 is the time of the cease of the electron injection. In this case, the well depth was 20 V, L=17.6 cm and the total electron number at t =0.5 s was 7.1 x 10^7. The profile in the earlier phase was peaky near the axis, and then a bump appeared at an outer location. Figure 3(b) shows enlarged profiles in the later phase. This bump did not disappear until nl coincided with a curve in the form $(1-(r/a)^2)^{1/2}$, *i.e.*, the line-density profile of a spheroidal plasma with the minor radius a. Such an evolution of the profile was always observed in other cases of different L. These results suggest that a cloud of injected and stacked electrons in HPW is apt to relax towards a state where the plasma is spheroidal.

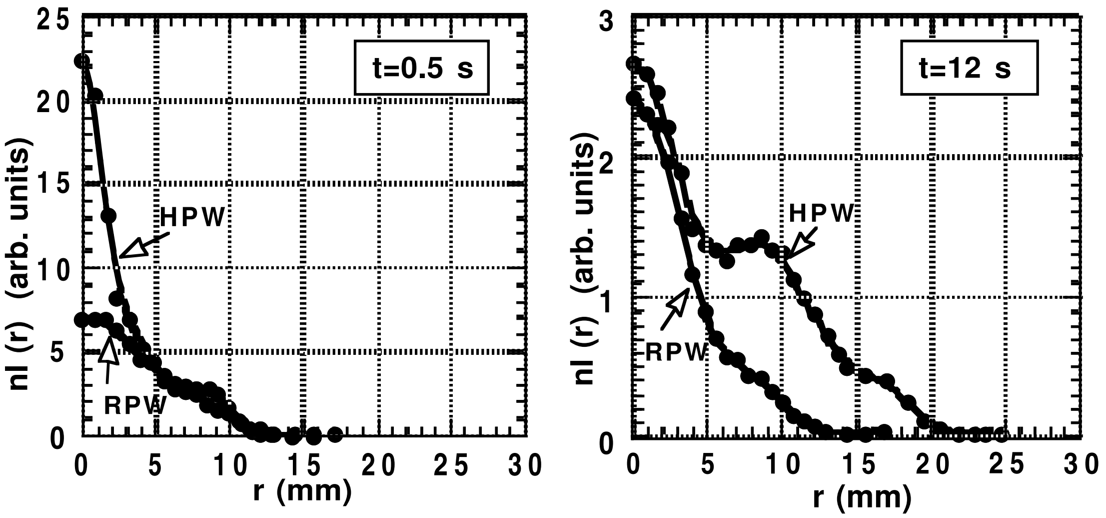

Fig.5 Line-density nl for HPW and RPW at t =0.5 s and t =12 s.

The radial change in *nl* -profile evolves in different ways in the cases of HPW and RPW. This difference becomes larger as L increases. Figure 5 shows the *nl* -profiles at t =0.5 s and t =12 s in the case that L =25.6 cm, the well depth=20 V and the total number of stacked electrons was 1 x 10^8. The overall confinement time was 50 s for HPW, while it was only 6 s for RPW. At the earlier time t =0.5 s, the central density in RPW fell down and the plasma began to spread to the wall. Then, the outer plasma was being scraped off and, thereby, the central core became more slim as noticed in the profile at t =12 s. On the contrary, for the case of HPW, the outer plasma near the bump stayed and the central part decayed supplying electrons to the outer region to make a smooth density distribution. The profile in HPW, in this way, approached to that of a spheroidal plasma.

Cooperative phenomena

Both the total kinetic energy, K_t, and the total canonical angular momentum, P_θ, of the plasma reflect the above mentioned difference. The decay of K_t in HPW was much slower than that in RPW, probably due to the difference in particle losses. The decay of P_θ also behaved in the similar fashion. The decay rate of P_θ for HPW was about 0.09 s^{-1}, which was less than a half of the rate for RPW. Measurement of internal density fluctuations in frequency range up to 90 MHz was tried but their signals were at too low levels to catch them even in the case of RPW. Otherwise, fluctuations, if present, must have been of shorter wave lengths or of higher frequencies where the used instruments did not fulfil their functions.

Conclusive remarks

Through the experiments described in this report, it has been perceived that the harmonic potential well has superior functions for nonneutral plasma confinement even if it stretches its axial length.

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