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Production and Confinement of Lithium Ion and Electron Plasmas Applied to Two-Fluid Plasma Experiments
2流体プラズマ実験用リチウムイオンおよび電子プラズマの生成制御

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An experiment of producing a two-fluid plasma by merging Li^+ and e^- plasmas is prepared. Using a pair of positive and negative electrostatic potential wells, those plasmas are successfully confined. For the planned experiment, those plasmas needs to be treated as fluid plasmas, which thus requires to confine each of them longer than the time reaching thermal equilibrium. Also, the density of the Li^+ plasma must be controlled because a skin depth where two-fluid effects appear depends on it. In this paper, we present confinement properties of Li^+ and e^- plasmas in optimized shapes of electrostatic potential wells.

1. BXU Experiment

We proposed a new experiment [1] using positive and negative non-neutral plasmas (NNPs) to test the two-fluid plasma model, and have developed a linear device, BXU. The machine is one of Penning-Malmberg type traps. To confine NNPs in it, a uniform magnetic field B is applied, and positive and negative electrostatic potential wells are externally created with multi ring electrodes. A remarkable thing is that both Li^+ and e^- plasmas are not only produced separately but also confined simultaneously in BXU [2]. In the chamber, four electrodes separated azimuthally are installed to measure time evolutions of image currents from which the plasma shift is obtained [3]. Besides, through the separated electrodes, rotating electric fields can be applied to NNPs [4]. At one end of the machine, a Faraday cup with a fluorescent screen is placed to measure the two dimensional density profile of the e^- plasma after it is ejected from the potential well [5].

After the plasma confinement is completed, the non-neutral plasma exhibits $\boldsymbol{E}\times\boldsymbol{B}$ rigid rotation. Currently, we experiment on relaxing NNPs into thermal equilibrium to treat them as fluid plasmas [6]. This is crucial to the next merging experiment of producing a two-fluid plasma. To attain thermal equilibrium, NNPs must be confined longer than the energy relaxation time. Another requirement before merging NNPs is to control the ion density n_i. This is because the ion skin depth, where two-fluid effects are considered to appear, depends on n_i [7].
In this paper, we present optimized shapes of electrostatic potential wells along with the first data of confinement times of NNPs in them [8,9].

2. Confinement of Li^+ Plasma

Figure 1 shows typical numerical equilibrium [10] of oblate spheroidal Li^+ plasmas confined in BXU. In this calculation, the plasma radius is assumed to equal the radius of the ion source, which is about 1.0 cm. The top of the electrostatic potential wall V_t is fixed to 20 V. On the other hand, the bottom of the well V_b is varied from (a) 0 V to (b) 5 V. Numbers of Li^+ plasmas N_i are also numerical parameters; N_i is set to be (a) 6.9×10^7 and (b) 4.7×10^7.

With those potential values used to calculate the numerical equilibrium, we experiment to confine Li^+ plasmas. The typical vacuum pressure is 3×10^{-9} Torr. The acceleration energy of the Li^+ beam has been fixed to be 11 eV. Figure 2 shows time

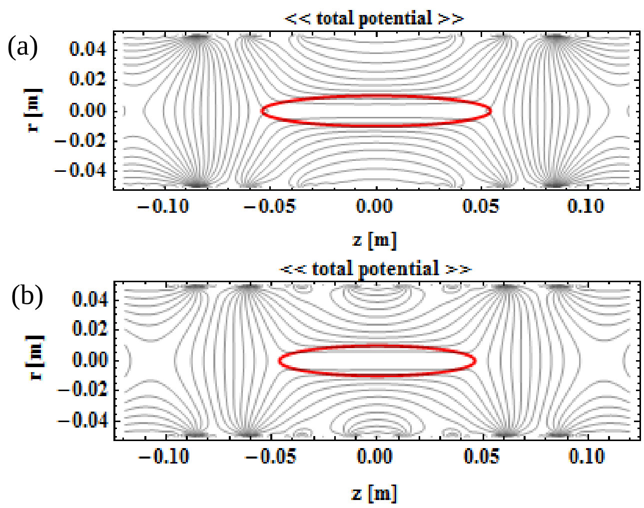

Fig. 1. Calculated equilibrium of oblate spheroidal Li^+ plasmas for cases of (a) V_b = 0 V, and (b) 5 V.

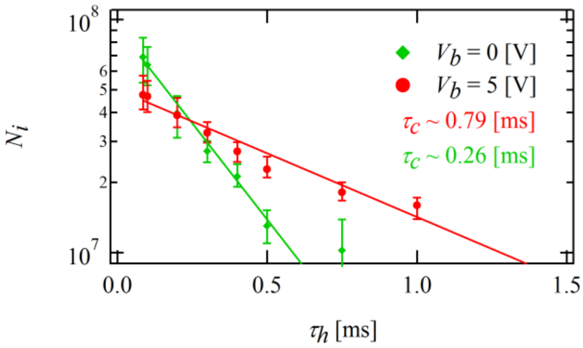

Fig. 2. Time dependences of particle numbers of Li$^+$ plasmas. Values of τ_c are obtained from the fitting lines.

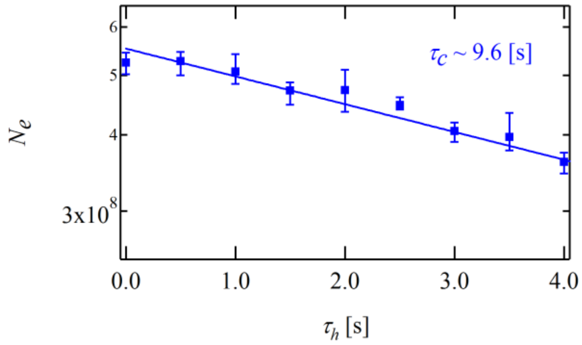

Fig.4. A time dependence of the particle number of the e$^-$ plasma. The value of τ_c is obtained from the fitting line.

dependences of total ion numbers for the two cases of V_b. From these data, the confinement time τ_c can be obtained. As recognized, the confinement time τ_c becomes longer from 0.26 ms to 0.79 ms with changing V_b from 0 to 5 V. However, this τ_c is still shorter than the ion-ion collision times, which is calculated to be about 2 s for $n_i \sim n_B$. Here, n_B is the Brillouin ion density.

3. Confinement of e$^-$ Plasma

Regarding the numerical equilibrium for e$^-$ plasmas, a typical result is described in Fig. 3. In this calculation, the plasma radius is set to be 0.35 cm. Also, V_t and V_b are 120 and 0 V, respectively, and the electron number N_e is 3×10^8. Using these parameters, the value of electron density n_e is calculated to be 4×10^8 cm^{-3}.

Similar to the experiment of Li$^+$ plasmas, time dependences of N_e are measured. In experiments, the acceleration energy of e$^-$ beams is 41 eV. The vacuum pressure is 6×10^{-9} Torr. The obtained data are plotted in Fig. 4. As seen from the fitting line, τ_c is 9.6 s, which is longer than the electron-electron collision time: ~ 14 ms. Therefore, the confinement of e$^-$ plasmas is ready for the next merging

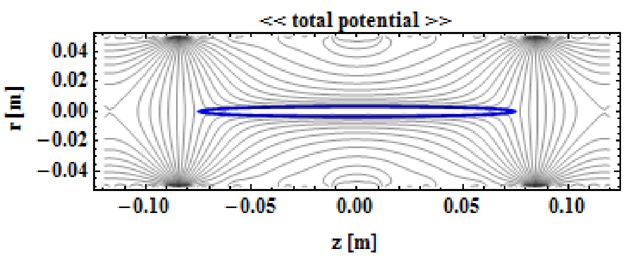

Fig. 3. A typical calculated equilibrium of an oblate spheroidal e$^-$ plasma.

experiment.

4. Summary

In this work, we have been performing confinement experiments of NNPs. Potential wells are numerically determined by an equilibrium code. Data show that τ_c of e$^-$ plasmas attain much longer than the electron-electron collision time. On the other hand, for the case of Li$^+$ plasmas, τ_c is still shorter than the binary collision time. More studies for lasting Li$^+$ plasmas longer will be started soon.

Acknowledgments

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