Not Only Independently Producing but Simultaneously Confining of Lithium and Electron Plasmas

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In order to test extended MHD models experimentally, we develop a new linear machine in which pure ion and electron plasmas are not only produced separately but also trapped simultaneously. At the first series of experiments, both lithium ion and electron plasmas are successfully confined at the same time. Values of density of those plasmas are in each range of critical values where ion and electron fluids could keep their own motions independently as a two-fluid plasma.

Keywords: non-neutral plasma, lithium ion plasma, electron plasma, extended MHD model, two-fluid plasma

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Recently, extended MHD models [1] are proposed in both theoretical and computational works of plasma physics. Those models have been applied to explain recent experimental observations such as high-β equilibrium [2] and magnetic reconnections [3]. In fact, those phenomena can be never understood by the conventional MHD model. However, no experimental tests for the extended MHD models have ever been conducted yet. One of possible reasons why no experiment has been carried out is due to the scale length of ion skin depth λ_i where the extended MHD plasma state is expected to appear. In usual plasmas, λ_i is too short to be measured clearly. This means we need to expand the scale length of λ_i. To do that, we proposed a new experiment [4] in which positive and negative non-neutral plasmas (NNP) [5] were used to test the extended MHD plasmas.

For the proposed experiment, there are two technical issues to be solved. Firstly, pure ion and electron plasmas must be produced separately, and moreover, have been confined simultaneously until the two plasmas relax in thermal equilibrium. Secondly, both ion and electron guns to produce NNP must be installed together in the one side of the machine. This actually makes it possible to place plasma measuring instruments on the other side of the machine. To answer these, we have just developed a linear machine called BX-U. And, at the first series of experiments, both lithium ion (Li^+) and electron (e^-) plasmas are successfully produced and confined at the same time. In this paper, we report the first data showing the result.

Figure 1 shows a schematic diagram of the experiment on BX-U. Both Li^+ and e^- guns are mounted on a metallic holder that is located on the most left-hand side of the chamber. The Li^+ gun is adjusted to fit its axis to the machine one of BX-U. On the other hand, the e^- gun consists of four micro filaments that are equally placed 22 mm apart from the machine axis. Li^+ ions and electrons are produced by thermionic emission and injected by applying negative and positive potentials to the extractors, respectively. Typical ion and electron beam currents are 0.4 μA and 0.3 mA, respectively. In experiments, at first, electrons are injected for 0.1 s from the e^- gun and the negative potential gate on the left-hand side is repeatedly opened for storing more electrons. An e^- plasma is then produced on

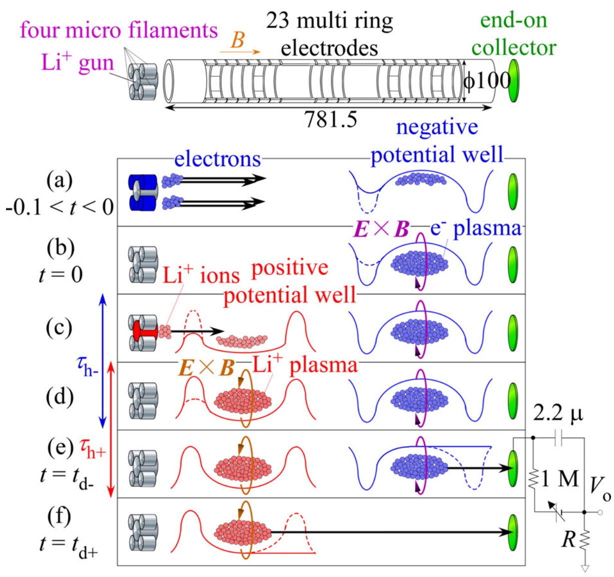

Fig. 1 A schematic diagram of the experiment producing and confining both lithium ion (Li^+) and electrons (e^-) plasmas simultaneously.

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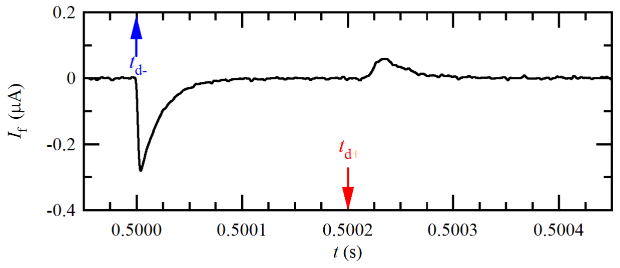

Fig. 2 A typical waveform of I_f. The data is smoothed. At $t = t_{d-}$, the e$^-$ plasma is flowing out, while the Li$^+$ plasma is extracted at $t = t_{d+}$.

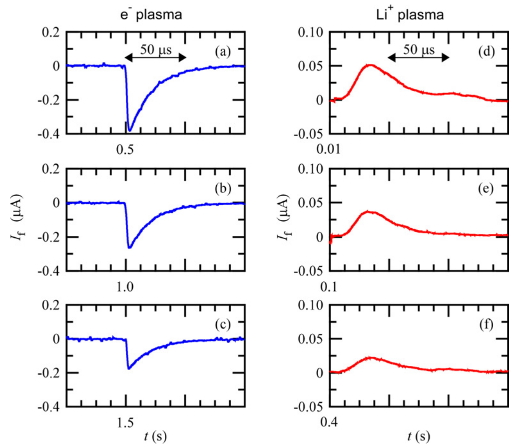

Fig. 3 Time evolutions of I_f measured by the end-on collector for both e$^-$ and Li$^+$ plasmas.

the machine axis through a self-organization process [6] and confined in the bottom of the negative potential well by applying independent potentials to 23 multi-ring electrodes [7] (see also shown in Fig. 1). On the other hand, the radial constraint is attained by a homogeneous magnetic field of $B_0 = 0.1$ T. Subsequently, during confinement of the e$^-$ plasma, the Li$^+$ gun is fired to produce a Li$^+$ plasma in the bottom of the positive potential well on the left-hand side. Typical vacuum pressure is $\sim 2 \times 10^{-8}$ Torr in this first experiment.

Simultaneous confinement of Li$^+$ and e$^-$ plasmas is clearly observed. Figure 2 shows a typical time history of the collector current I_f (= V_o/R, where R = 51 k) that flows out from the end-on collector used to measure the number of particles of both Li$^+$ and e$^-$ plasmas. About 0.5 s after the multiple injection of electrons is completed at $t = 0$ (see also Fig. 1), the negative potential gate (-120 V) on the most right-hand side is, at first, pulsed to 0 V. This potential gate rises up/down in ~ 0.3 μs. This dump allows the remaining electrons to stream out axially along the magnetic field lines for collection and analysis. Because of the negative charge of electrons, the measured I_f results in negative, as recognized at $t = t_{d-}$ in Fig. 2. Following the e$^-$ plasma extraction, the right-hand positive potential gate (+120 V) is pulled down to 0 V in order to take out the remaining Li$^+$ ions. Contrary to the case of the e$^-$ plasma, the sign of charge is positive for Li$^+$ ions. Thus, the measured I_f turns to be positive in case of the extraction of the Li$^+$ plasma, as seen at $t = t_{d+}$ in Fig. 2.

Such simultaneous confinement has been attained even for the case where the polarities of the potential wells are completely flipped each other. In this case, the Li$^+$ plasma has been firstly produced on the right-hand side near the end-on collector in Fig. 1, while the e$^-$ plasma secondly done on the left-hand one. As expected, the resulting first signal of I_f has been positive and the second one negative. From these results, we conclude that both pure Li$^+$ and e$^-$ plasmas are certainly confined in separate positive and negative potential wells simultaneously.

Since the two NNP need to be in thermal equilibrium for the forthcoming extended MHD experiments, the question would be asked on what the confinement time τ_N is attained. Figure 3 shows two typical sets of $I_f(t)$ for both e$^-$ and Li$^+$ plasmas. These data are obtained with changing the time to open potential gates on each right-hand side systematically. By time-integrating $I_f(t)$, the number of remaining particles N can be obtained as $N = (1/q) \int I_f \, dt$ at each time, where q is the elementary charge. Using the obtained N, τ_N can be determined as the 1/e decay time of N. From these calculations, values of τ_N of e$^-$ and Li$^+$ plasmas are so far $\tau_{N-} \sim 1.2$ s and $\tau_{N+} \sim 0.47$ s, respectively [8]. These seem to be hardly short to become equilibria.

Regarding the plasma density, the rest value of N_e is calculated to be 4.5×10^7 for the case of Fig. 3 (a), for example. Here, from the end-on collector measurements, we assume that the e$^-$ plasma is spheroidal and its minor and major axes are 0.7 and 24 cm, respectively. Then, the electron density n_e is calculated to be 7.3×10^6 cm^{-3}, which is much smaller than its Brillouin density n_{B-}: $n_{B-} = 4.9 \times 10^{10}$ cm^{-3} for $B = 0.1$ T. Similarly, the ion density n_i is about 4.1×10^5 cm^{-3}, which is an order of magnitude smaller than n_{B+}: $n_{B+} = 3.8 \times 10^6$ cm^{-3}. Therefore, as for the dependence of the size parameter $S^* \equiv L/\lambda_i$ where L is a typical scale length of a plasma and $\lambda_i = \sqrt{m_i/\mu_0 e^2 n}$ is the ion skin depth, the value of S^* is calculated to be about 8×10^{-6}, which is enough small to move on the next experiment for testing the extended MHD models, especially the two-fluid plasma state predicted by theoretical works [9].

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[1] N. Nakajima *et al.*, J. Plasma Fusion Res. **85**, 105 (2009).
[2] H.Y. Guo *et al.*, Phys. Rev. Lett. **97**, 235002 (2006).
[3] M. Yamada *et al.*, Phys. Plasmas **13**, 052119 (2006).
[4] H. Himura, IEEJ Trans. FM **130**, 977 (2010).
[5] E.M. Hollmann *et al.*, Phys. Plasmas **7**, 2776 (2000).
[6] Y. Kiwamoto *et al.*, Phys. Rev. Lett. **99**, 115002 (2007).
[7] A. Mohri *et al.*, Jpn. J. Appl. Phys. **37**, 664 (1998).
[8] H. Himura *et al.*, submitted to the Proceedings of 22nd International Toki Conference (2012).
[9] H. Yamada *et al.*, Phys. Plasmas **9**, 4605 (2002).