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Evaluation of Electron Heating during Strong Guide-Field Magnetic Reconnection in UTST Merging Experiment

UTST 装置における高ガイド磁場リコネクション時の電子加熱の評価

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In UTST device, magnetic reconnection with strong guide field (typically $B_t \sim 15B_p$) takes place during the ST merging period. We developed a novel slide-type 2-dimensional Thomson scattering measurement system to evaluate electron heating during strong guide-field magnetic reconnection in the UTST device. We observed strong electron heating (from 8 to 27[eV]) and formation of a round-shaped high electron temperature area in sharp contrast with radially-elongated current sheet during strong guide-field magnetic reconnection. The effective resistivity was higher than Splizter resistivity in fast reconnection phase and then, the strong electron heating was observed at the X-point, suggesting that the magnetic energy was released when fast reconnection phase started and that electrons are accelerated by reconnection electric field and thermailzed by effective resistivity at the X-point.

1. Introduction

Recent theoretical and numerical studies have revealed kinetic effects of both ions and electrons play an important role in collison-less magnetic reconnection. Generation of non-thermal particles and their behavior often govern local reconnection dynamics in particle-in-cell (PIC) simulations, however, the entire energy conversion mechanism including particle acceleration and thermalization still remains unclear. On the other hand, strong electron heating during plasma merging was observed in MAST spherical tokamak experiment by using 1-dimensional (radial) multi-channel Thomson scattering system[1]. This result suggest that detailed electron measurement in plasma merging experiment might account for the electron energy conversion mechanism during strong guide field reconnection. In this paper, electron heating mechanism in UTST plasma merging experiment will be presented based on the results from newly developed 2-dimensional Thomson scattering measurement system.

2. Experimental setup

In UTST merging experiment, the initial spherical tokamaks (STs) is formed by PF coils in both upper and lower sections and then, these 2 initial plasmas merge together through magnetic reconnection simultaneously with energy conversion of the upstream magnetic energy to the plasma kinetic/thermal energy.

The merging process was observed by magnetic probe array with 162 channels in the central section to measure the magnetic field B_t and B_z directly inside the vacuum vessel. Under the assumption of toroidal symmetry, the poloidal magnetic flux, the toroidal current density and the toroidal electric field are obtained.

To investigate the energy conversion mechanism of magnetic reconnection, we developed a novel slide-type 2-dimensional Thomson scattering measurement system[2] to evaluate electron heating in strong guide field magnetic reconnection in UTST spherical tokamak device. This system can measure an axial profile of electron temperature and density in a single discharge and its radial scan allows us to measure their 2-D profiles.

3. Experimental results

We observed electron heating (from 8 to 27[eV]) as well as a slow density fluctuation at the X-point during strong guide-field (GF) magnetic reconnection (Fig.1 (d), (e)) while the electron temperature outside current sheet (z=± 3[cm]) was clearly lower than that at the X-point.

Figure 1 shows the effective resistivity was higher than Splizter resistivity when the magnetic flux increased faster during magnetic reconnection (fast reconnection phase) and then, the strong electron heating was observed at the X-point, suggesting that the magnetic energy was released during fast reconnection phase and that electrons are accelerated by reconnection electric field and thermailzed by effective resistivity.

Figure 2 shows the 2-dimensional profile of electron temperature and toroidal current density measured at t=816[μs] after fast reconnection phase. High electron temperature area was found to have a round shape with radius of 2[cm], in sharp contrast with radially-elongated shape of current sheet. Furthermore, the scale length of high temperature area of 2[cm] is smaller than the current sheet width of 7[cm], suggesting that the kinetic effect plays an important role during strong GF magnetic reconnection.

The increment in electron thermal energy is about 2.2 J, which is about 15% of the dissipated magnetic energy of 13.6 J measured by 2-D magnetic probe array. This conversion ratio in the strong guide field magnetic reconnection was higher than that in the weak guide field ($B_t \sim 5B_p$) experiment in TS-3 device, suggesting that accelerated fast electrons by parallel electric field might provide additional heating via some thermalization mechanism in strong guide-field reconnection.

4. Conclusion

By using slide-type 2-D Thomson scattering measurement system, we observed strong electron heating at the X-point which forms round-shaped high electron temperature area in sharp contrast with highly-elongated current sheet. The observed energy conversion ratio of the strong guide-field magnetic reconnection was higher than that observed in the previous weak guide-field experiment, suggesting that the thermalization of toroidally accelerated fast electrons may contribute to the total energy conversion toward electrons.

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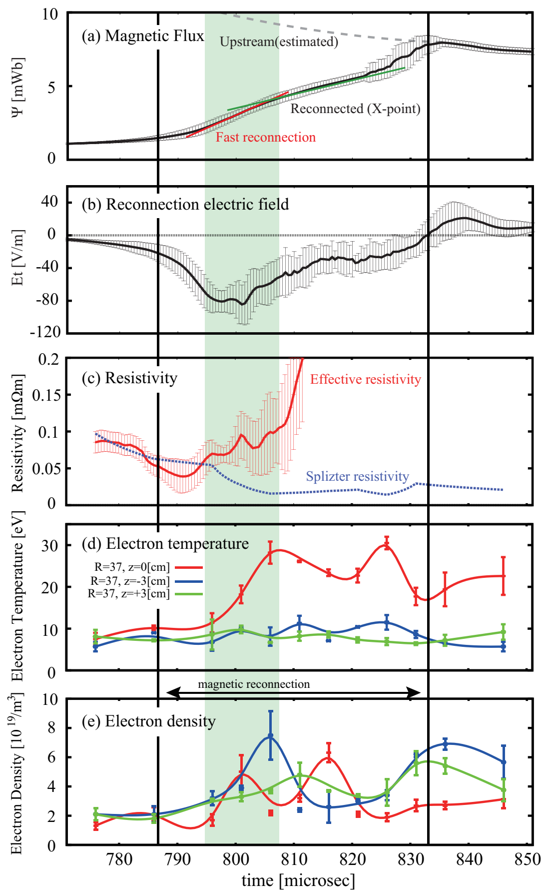

Fig. 1. Time evolutions of reconnected magnetic fluxes (a), reconnection electric field (b), effective and Splizter resistivity (c) at X-point, electron temperature (d) and density (e) at X-point (red) and upstream (blue and green).

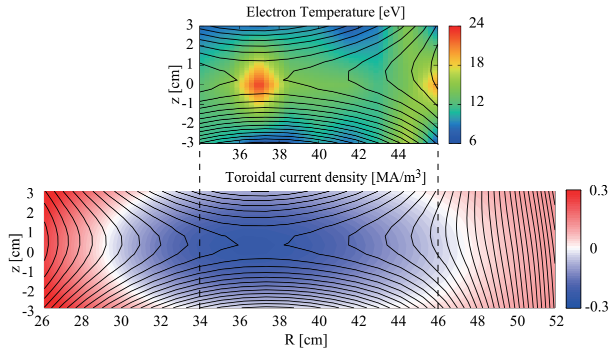

Fig. 2. R-Z contours of poloidal flux (line), electron temperature (top) and toroidal current density (bottom) at t=816[μs].

References

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