23P105-P

Ion Heating Characteristics of Magnetic Reconnection in Torus Plasma Merging Experiment
トーラスプラズマ合体実験を用いた磁気リコネクションのイオン加熱機構の検証

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For the past ten years, we have developed a novel 2-D ion temperature measurement by use of computer tomography and studied the ion heating characteristic of magnetic reconnection. The 2-D ion temperature measurement revealed that the dissipated magnetic energy of two merging compact toroids heats ions in the downstream area of magnetic reconnection, indicating ion outflow energy is converted to ion thermal energy through viscosity damping and fast shock. The dependency of ion heating efficiency on the angle θ of reconnecting field line is investigated by changing the guide magnetic field and have a maximum in counter helicity case (θ =180°).

1. Introduction

Magnetic reconnection is a topological rearrangement of magnetic field lines that converts magnetic energy to plasma thermal and kinetic energy. For the past decades, violent plasma acceleration and heating due to the process has been reported in the observation of solar corona, the magnetized plasmas and various laboratory fusion plasma experiments. However, because of the line-integrated effect for passive Doppler spectroscopy, the detailed local spatial profile of ion heating has not been investigated yet. To study the detailed heating characteristics, we have developed a novel local 2-D ion Doppler diagnostics by use of computer tomography. It revealed where and how ion is heated during reconnection. The section 2 describes the 2-D local ion Doppler diagnostics and the experimental results in the torus plasma merging device TS-3 are shown in the next.

2. Tomographic 2-D ion Doppler Measurement

As shown in Fig. 1, our 2-D ion Doppler measurement system was designed for torus plasma whose major radius R and aspect ratio A are 200mm and 1.5. The 7×5 chords of collecting lens systems (f=50mm, D=10mm) are installed on the cylindrical vacuum vessel to measure a R-Z profile of line spectrum emissions integrated over 35 lines of viewing chords. This 2-D projection composed of the 35 channels of line spectrum emissions is transported through 35 optical fibers and is realigned to 35×1 array for 50cm polychromator connected with ICCD image sensors (1024×256 pixel, 26μm^2/pixel, 0.00400nm/pixel) through magnifying optics (meridional:×4.3, sagittal:×0.7).

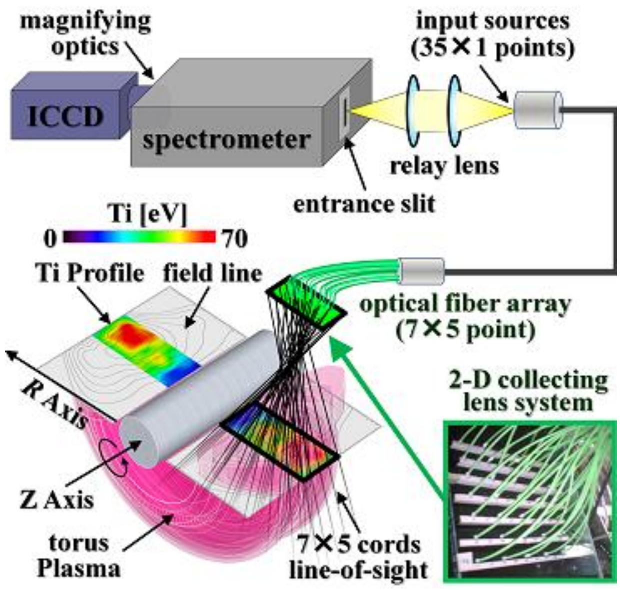

Fig.1. Schematic view of tomographic 2-D ion Doppler measurement system. A 2-D projection of discrete line spectrum emissions is collected by 7 × 5 chords of optical fibers and is connected with the spectrometer with an ICCD camera by realigning 35 fibers into 1-D array.

The measured 35 line-integrated spectrums of H_β line which are collected by 7×5 (2-D) optical fibers. The 35 line spectrums with 17×256 pixel for each chord are extracted from the ICCD image, and then are realigned to the 7×5 array equivalent to the original view position on the computer. The crosstalk is smaller than 0.3%.

In order to measure local 2-D (*r*-*z*) ion temperature from the 35 chord-integrated spectra, we utilize the slice-by-slice Abel inversion technique [1]. The inversion is applied as follows:

- Ti: line-integrated spectra $\xrightarrow{\text{inversion}}$ local spectra $\xrightarrow{\text{Gauss fitting}}$ local Ti profile[2]

The reconstruction fidelity by the method is shown in the numerical simulation results (Fig. 2). In 280mm < r < R_{edge} in the 7 chords system, reconstruction error Δ exceeds 30% but it is suppressed smaller than 20% in the 8 chords system. In the region of 70mm < r < 280mm, both of 7 and 8 chord systems keep Δ smaller than 15%. Therefore, in 7 chords system, the measurement area is limited at 70mm < r < 280mm.

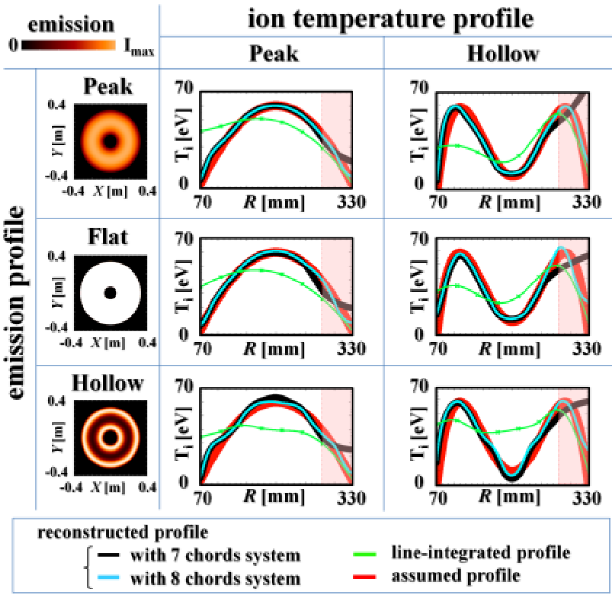

Fig.2. Numerical simulation results of the proposed reconstruction of 2-D line spectrums with six different ion temperature and emission profile. The ion temperature profile of before and after inversion and models are compared with 7 and 8 viewing chords measurement.

3. Experiment of Ion Acceleration and Heating

We installed the 2-D Doppler system in the TS-3 torus plasma merging device. The 2-D projection of H_β line spectrum was measured at $r_{tangential}$ = 70, 105, 140, 175, 210, 245, 280mm and z = − 48, − 29, − 10, 9, 28mm using hydrogen torus plasma experiments in TS-3. The H_β spectral line is used for the measurement because the charge exchange time between H and H^+: 0.1 μsec[3] is much shorter than the MHD timescale of plasma motions.

Figure 3 shows the measured temperature profile during magnetic reconnection in counter-helicity spheromak merging. Two clear hot spots of ion temperature increase are observed at the downstream area of magnetic reconnection. These measured results indicate the existence of outflow damping by viscosity and first shock.

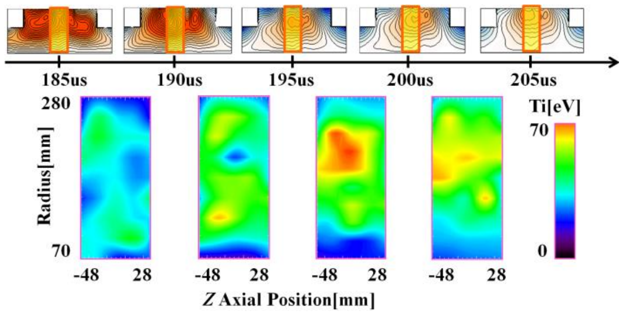

Fig.3. Time evolution of the 2-D ion temperature measurement. Two clear hot spots are observed at the downstream area of magnetic reconnection (reference flux profiles are measured by magnetic probe array).

Figure 4 shows radial ion temperature profile on the mid-plane (z = 0) of the vessel when we control the angle θ of reconnecting field angle. The heating efficiency strongly depends on an angle θ of reconnecting field lines and have the maximum in counter-helicity case (θ =180°).

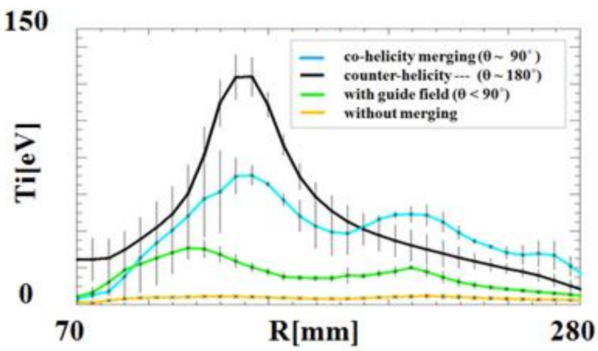

Fig.4. The ion heating of reconnection increases with the angle θ of reconnecting field lines

4. Summary

Local ion heating of reconnection has been studied clearly using the tomographic 2-D ion Doppler measurement. The measured 2-D ion temperature profile has two clear hot spots in the downstream area of magnetic reconnection, indicating that ion outflow energy is converted to ion thermal energy through viscosity damping and/or fast shock. The ion temperature increases after the reconnection depends on the angle θ of reconnecting field lines and decreases inversely with the toroidal magnetic field. More detailed investigation in tokamak merging experiment is discussed in our presentation.

References

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[3] Y. Ono *et al*, *Earth Planets Space*,**53**, 521 (2001)