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Doppler Spectroscopy Measurement of ST Heating by Plasma Merging in UTST
UTST装置における球状トカマク合体加熱のドップラー分光計測

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The merging start-up of spherical tokamak (ST) plasma has been accomplished in UTST device using external poloidal field (PF) coils. The plasma current up to 180 kA has been attained with assistance of the center solenoid (CS) coil. In this merging start-up method, significant ion heating caused by magnetic reconnection is expected to help the formation of high-beta equilibrium. We have developed a Doppler spectroscopy system using an 8×8-channel photomultiplier tube (PMT) assembly to observe the temporal evolutions of ion temperature and flow. The bulk plasma ion temperature measured by helium II line was approximately 10 - 15 eV after plasma merging.

1. Introduction

The plasma merging method is a novel startup scheme to form a high-beta equilibrium in a short period. Plasma merging between two initial torus plasmas induces magnetic reconnection, which is a rapid conversion from magnetic energy to plasma kinetic or thermal energy. Thus, plasma merging increases the plasma thermal energy and decreases the magnetic energy, leading to a significant increase of the beta value. The merging startup method has been demonstrated in the START/MAST [1] (UKAEA) and TS-3/4 (The University of Tokyo) devices. In TS-3, two STs were merged to form a single ST with a beta value of up to 50 % [2]. The high-beta value obtained in these experiments comes mainly from significant ion heating by magnetic reconnection. In TS-3, ions are heated from 10 eV to 40 - 60 eV in 10 μs, which corresponds to a heating power of as large as 4 - 6 MW [3]. However, in these previous experiments, plasma merging startup was performed by using PF coils inside the vacuum vessel, which cannot be used in future fusion reactors. The University of Tokyo Spherical Tokamak (UTST) [4] was constructed to investigate the feasibility of merging startup of high-beta STs under a more reactor-relevant condition with no internal PF coils. To confirm the formation of a high-beta ST plasma in the UTST, ion-temperature measurement is urgently required.

2. The UTST Plasma Merging Device

A high-beta ST plasma is formed by double null merging (DNM) in the UTST. In the DNM startup method, two initial STs are generated at null points created inside the device, and they are merged to form a ST as illustrated in Fig. 1.

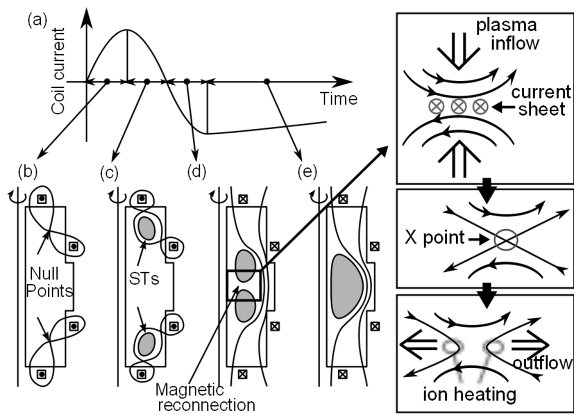

Fig.1. Schematic view of high-beta ST startup by DNM in the UTST.

During plasma merging, the tension force of the reconnected magnetic field lines accelerates the plasma to the Alfvén velocity. The accelerated ions are thermalized in the downstream area [4] by damping mechanisms such as viscosity or fast shock structure, resulting in the formation of a high-beta ST equilibrium. In the UTST device, all the coils are located outside the vacuum vessel, and the swing of the PF coil currents applies a parallel electric field at the null points to initiate the torus discharge and drive the plasma current. The plasma current is as high as 180 kA, and the pulse width is as long as 1.2 ms with the assistance of the CS coil.

3. Spectroscopic measurement system

The Doppler shift $\Delta\lambda$ of a spectral line emitted from a single traveling particle is applied to diagnose the collective behavior of plasma ions. The ion temperature T_i is calculated by the full width at half maximum (FWHM) of the line broadening and V_i is calculated from the Doppler shift of the line center $\lambda_{\text{peak}} - \lambda_0$;

$$T_i = 1.7 \times 10^8 \times A \left(\frac{\Delta\lambda_{\text{FWHM}}}{\lambda_0}\right) \quad (1)$$

where A is mass number of the ion,

$$V_i = \frac{\lambda_{\text{peak}} - \lambda_0}{\lambda_0} c. \quad (2)$$

Fig. 2 shows the schematic overview of the developed multi-channel spectroscopic measurement system. Emissions from ST plasma in the UTST device are collimated by convex lenses and introduced to eight plastic optical fibers with core diameter of 1 mm and numerical aperture of 0.5. The other ends of the optical fibers are bundled in one-dimensional vertical array and coupled with the entrance slit of a monochromator with focal length of 500 mm and grating of 2400 grooves/mm, as shown in Fig. 2 (b).

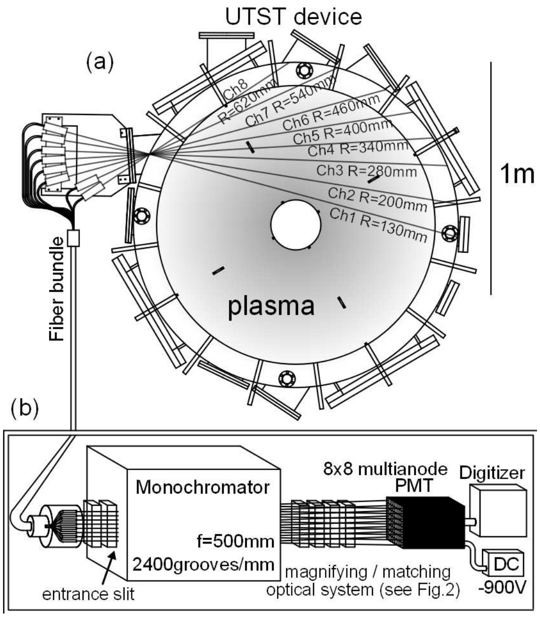

Fig.2. (a) Cross-sectional view of the UTST device and arrangement of optical fibers, (b) schematic view of the spectroscopic system with a monochromator, lenses and an 8×8 PMT assembly.

4. Experimental results

Fig. 3 (a) shows the spectral shapes of the helium impurity emission (HeII 656.0 nm) from the eight lines of sight. Ion temperature evolutions of eight spatial locations are shown in Fig. 3 (b). We successfully measured the time evolutions of ion temperature in the range of 5 - 15 eV at eight spatial locations and a temperature increase was confirmed during plasma merging time of 0.8 - 0.9 ms.

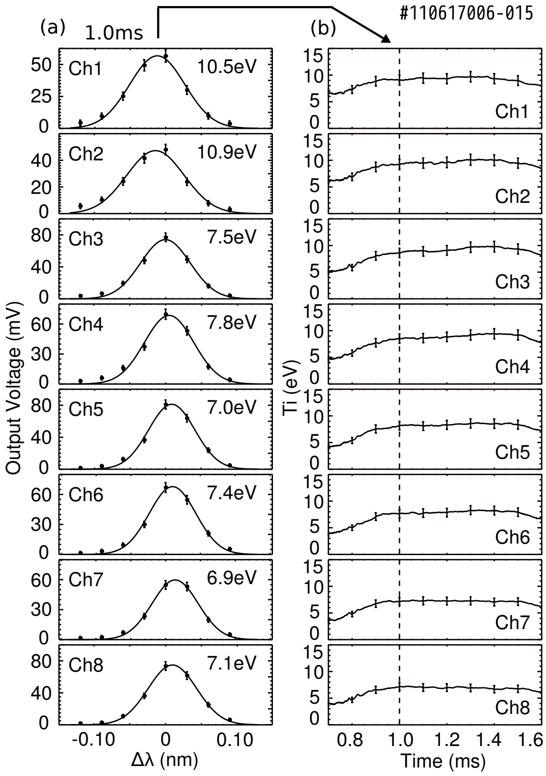

Fig.3. (a) Measured spectral distributions of HeII line emissions from eight spatial locations at t = 1.0 ms from the initiation of discharge, (b) time evolutions of derived ion temperature at eight spatial locations.

Acknowledgments

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