Observations of toroidal plasma rotation from X-ray imaging crystal spectrometer for KSTAR

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1. INTRODUCTION

Two high-resolution X-ray imaging crystal spectrometers (XICS) [1-3], which can record temporally and spatially resolved spectra of helium-like Ar, have been successfully utilized for the measurement of the ion and electron temperature profiles, and toroidal rotation velocity profiles in 2010 KSTAR experimental campaign. The XICS has been applied with pure Ohmic plasmas as well as plasmas with ECRH, ICRH, and NBI heating sources.

2. EXPERIMENTAL ARRANGEMENT AND RESULTS

The experimental arrangement and photo of two XICS at KSTAR are shown in Fig. 1. Both spectrometers' central diffraction plane is parallel to the horizontal mid-plane of KSTAR. The radial XICS was installed perpendicular to the magnetic axis of KSTAR, which mainly provides the ion and electron temperature profiles. The tangential XICS was installed 14° tangentially to the magnetic axis of KSTAR in order to measure the Doppler shifts of the spectra, which can provide the toroidal plasma rotation velocity profiles. Both spectrometers are equipped with a spherically bent 110 quartz crystal with a 2*d* spacing of 4.91304 Å. The crystal is a circular disk with a diameter of 100 mm and a radius of curvature of 5294 mm for the radial XICS and 3760 mm for the tangential XICS, respectively. The mean Bragg angle for the observed spectral range is θ=54°, which extends from the Ar XVII resonance line **w** at 3.9494 Å to the Ar XVII forbidden line **z** at 3.9944 Å.

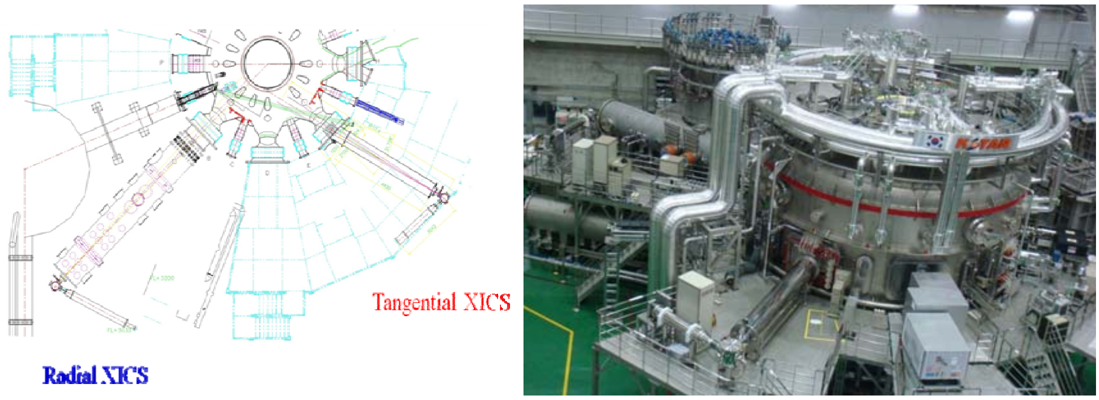
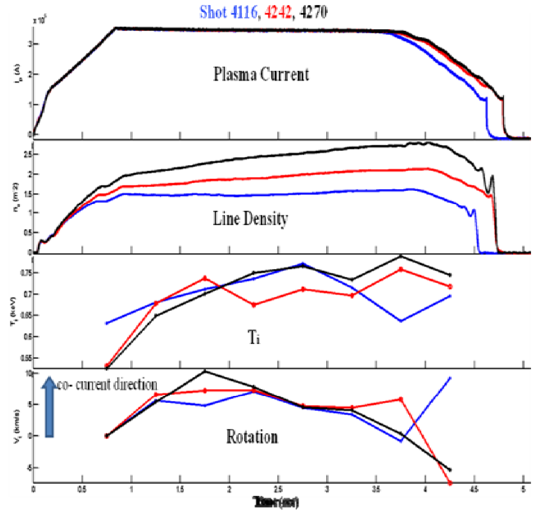


Fig. 1. Experimental arrangement and photo of XICS.

Figure 2 shows the experimental results of three stable Ohmic discharges. The plasma current (I_p) was steady at about 350 kA and the line averaged electron density (n_e) changed from 1 to 2.5 × 10^{19} m^{-2}. The ion temperature (T_i) derived from the XICS is between 0.5 to 0.8 keV. The core Ohmic plasma rotation showed a co-current direction, which indicates in the same direction to the plasma current as shown in Fig. 2. The measured rotation was slightly increased with the plasma line density and it was increased with the plasma current ramp-up rate as shown in Fig. 3. The core toroidal rotation of plasmas with Ohmic heating has been reported in a wide range of velocities in magnitudes and directions [4]. A physics mechanism related with the core Ohmic rotation is not clear so that it is needed to confirm the Ohmic rotation by reversing the plasma current with various plasma current ramp-up rates for the 2011 experimental campaign. It is suggested that the toroidal plasma rotation velocity profile should be measured to investigate the detail physics mechanism for the Ohmic plasma rotation.



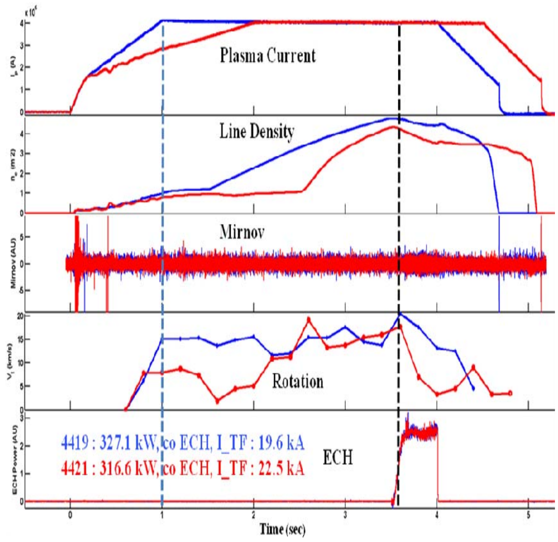
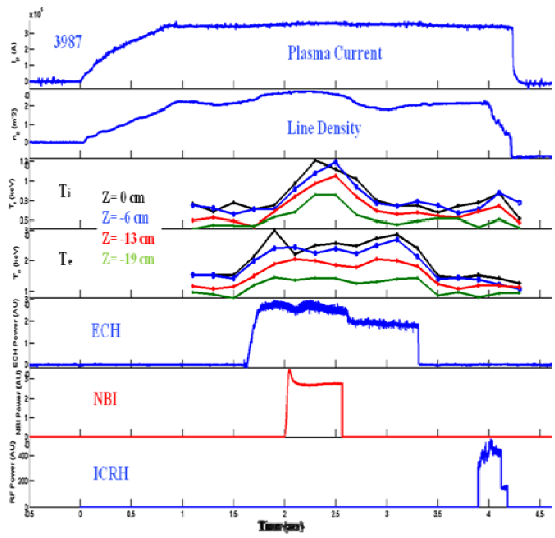


Fig. 2. Core Ohmic rotation.

Fig. 3. Experimental results from ECH.

In KSTAR plasmas, ECH usually drives a counter-rotation torque both with on and off-axis injection in the core region as shown in Fig. 3. Both the behavior and mechanism determining the intrinsic rotation with ECH will be investigated further in detail in 2011 experimental campaign.

Figure 4 shows the measured T_i and T_e profiles measured from the XICS with the main heating sources include ECRH, NBI, and ICRH. The experimental results from the ICRH showed a clear ion heating because the T_i and its profiles were increased during the ICRH injection period as shown in Fig. 4.



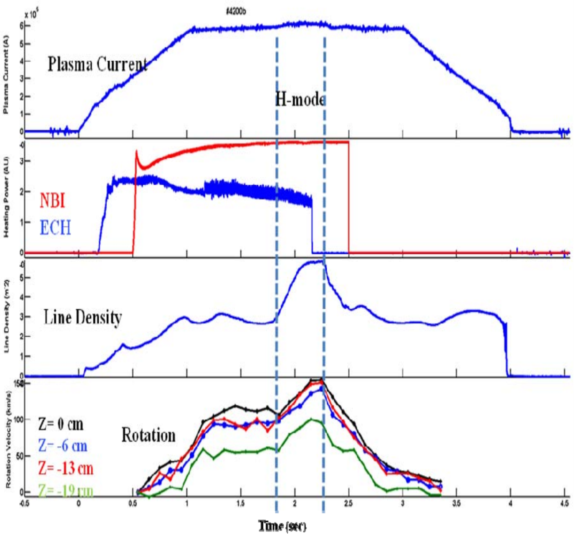


Fig. 4. Experimental results from various heating sources. Fig. 5. H-mode results.

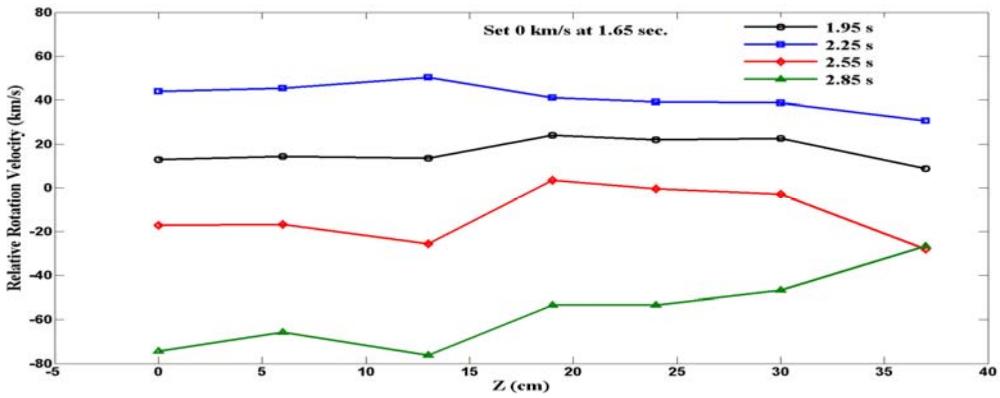


Fig. 6. Toroidal rotation velocity profiles for shot 4200.

The first H-mode experimental results are shown in Fig. 5. The line density and toroidal rotation velocity were clearly increased during the H-mode periods. Figure 6 shows the relative toroidal rotation velocity profiles during four different time periods for shot 4200, which was shown in Fig. 5. An abrupt change between z = 15 to 20 cm may be due to the q = 1 surface.

In summary, the X-ray imaging crystal spectrometer for the KSTAR device was successfully operated with pure Ohmic plasmas as well as plasmas with ECRH, ICRH, and NBI heating sources. It is expected that the XICS will play an important role to provide many important plasma parameters for the next KSTAR experimental campaign.

ACKNOWLEDGEMENTS

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