Observation of fast ion velocity distribution and driven waves by collective Thomson scattering diagnostic in the Large Helical Device

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Introduction

It is essential to understand the behavior of charged fusion products in burning plasmas. For diagnosing them in the plasma core region, one of choices is to employ an electromagnetic wave and their scattering. The collective Thomson scattering (CTS) technique has been developed using a high power and hundred GHz gyrotron in fusion devices such as JET, W7-AS, TEXTOR, and ASDEX Upgrade [1-5]. These results have been reported for understanding fast ion related physics. Moreover, the CTS diagnostic has been designed for ITER [3, 5].

Beam and fusion products driven instabilities are observed in fusion devices. These fast ions not only drive the instabilities, but the driven instabilities, for example Alfven Eigen modes (AEs), fishbone instabilities, ion cyclotron emissions (ICE), lower hybrid wave (LH) turbulence, influence on the fast ion confinement and transport. These nonlinear phenomena are very complex and still need to be studied. The CTS diagnostic is applicable to study these phenomena. These instabilities exist in the various frequency ranges. Although the frequency range would be changed by the plasma parameters and machine parameters, AEs lie below a few ten to sub MHz, ICE in a few ten MHz, and LH turbulence in a few GHz, respectively. The interaction between fast ions and high frequency of more than MHz could be studied by CTS diagnostic. The experimental observation of LH excitation by neutral beam origin fast ions is reported in W7-AS [2]. The LH wave with ICE harmonics is simultaneously observed with the injection of auxilialy neutral beams. The mechanism of LH wave excitation is explained by the double resonance condition between a LH wave frequency and higher ion cyclotron harmonics. In LHD, the excited wave in the frequency range of LH wave is observed with perpendicular neutral beam injection, which has been reported in previous paper [7].

Experimental setup and CTS spectrum measurement

We have developed a CTS apparatus to measure bulk and fast ions in the Large Helical Device (LHD) [8-10]. The CTS broad band receiver of a heterodyne system is shown in Fig.1. The system consists of mainly a notch filter for the rejection of a gyrotron stray light, a mixer with a local oscillator, and intermediate frequency (IF) components. The sensitivity of the CTS receiver is calibrated by using the radiation from liquid nitrogen. The spectra of the scattered radiation from the probing beam are obtained by the broad band receiver resolving the scattered signal into 32 channels.

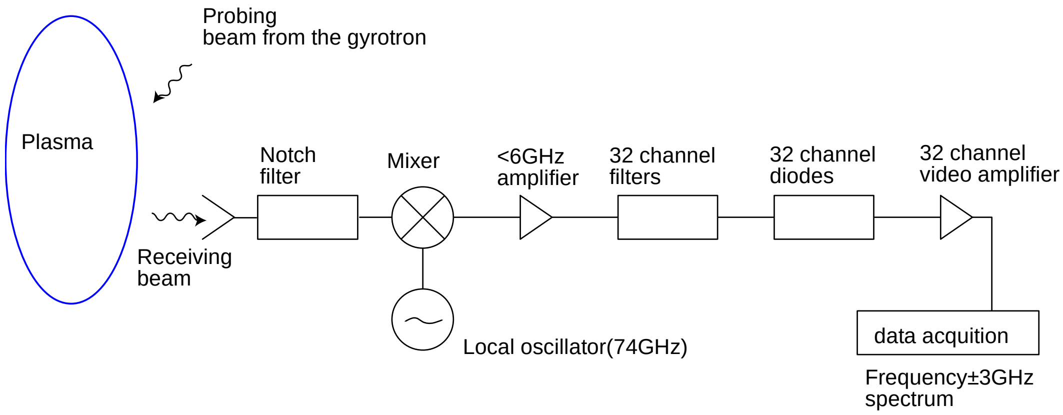

Fig. 1. Schematic diagram of the CTS broad band receiver system. The probing beam of 77GHz gyrotron is used.

The probing beam from a 77 GHz gyrotron is modulated with 50 Hz to subtract the background electron cyclotron emission (ECE) from the detected signals, and it is injected into plasmas. Fig. 2 shows the CTS spectrogram and the CTS spectra at specific times. The angle of $\angle(\boldsymbol{k}^{\delta}, \boldsymbol{B})$=100.4 degrees is sensitive along to $\boldsymbol{k}^{\delta}$. The deviation from the perpendicular direction is about 10 degrees. The response for fast ions with counter- NB2 at t=4.93s is slightly observed in the frequency of more than 1 GHz, although this region includes large errors in CTS signals. GNET code [11] and Newly developed OFMC code [12] show the fast ion density is of the order of $10^{17}m^{-3}$, which is two orders of magnitude lower than the bulk ion density. Measured CTS spectra should be a similar ratio of bulk to fast ion densities. Therefore we have to increase the signal to noise ratio for more accurate fast ion detection.

When the NB4 with the energy of ~ 40 keV is injected, the spectrogram of the scattered radiation presents the transient changes in the ion velocity distribution function with auxiliary neutral beam heated plasmas. Especially in low temperature plasmas (T_e, T_i < 1 keV), a wave excitation is also observed in a narrow frequency band between 0.5 and 1.0 GHz, and at both upper and lower frequency sides asymmetrically. These peaks are considered to be due to an excitation of perpendicular-fast-ion driven waves such as lower hybrid waves and their parametric interaction with the injected probe wave. The wave frequencies are slightly lower than those of the lower hybrid waves. A similar phenomenon has been observed at W7-AS [2].

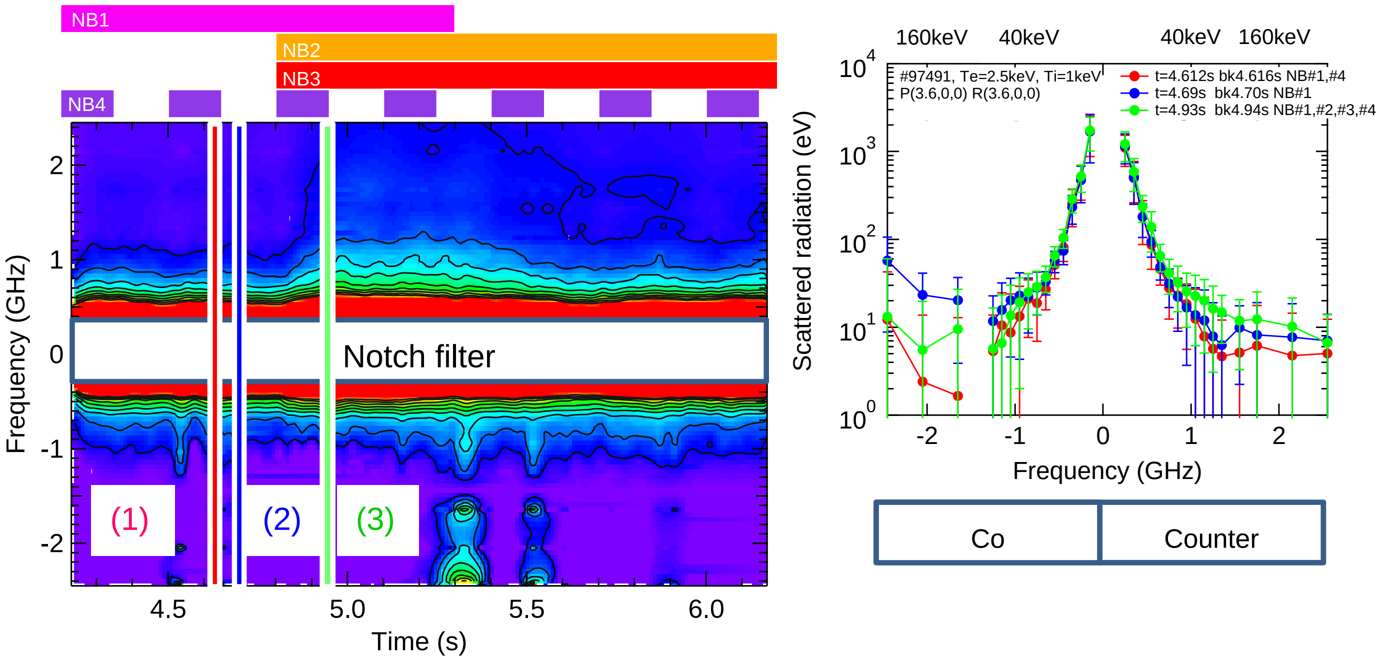

Fig. 2. Measured CTS spectrogram with neutral beam injections. The NBs in LHD is directed to co-NB1, counter-NB2, co-NB3, and perpendicular-NB4. The CTS spectra at different NB injection timing for (1) t=4.612s, (2) t=4.69s, and (3) t=4.93s. The beam energies are ~170keV for NB1 to 3, and ~40 keV for NB4.

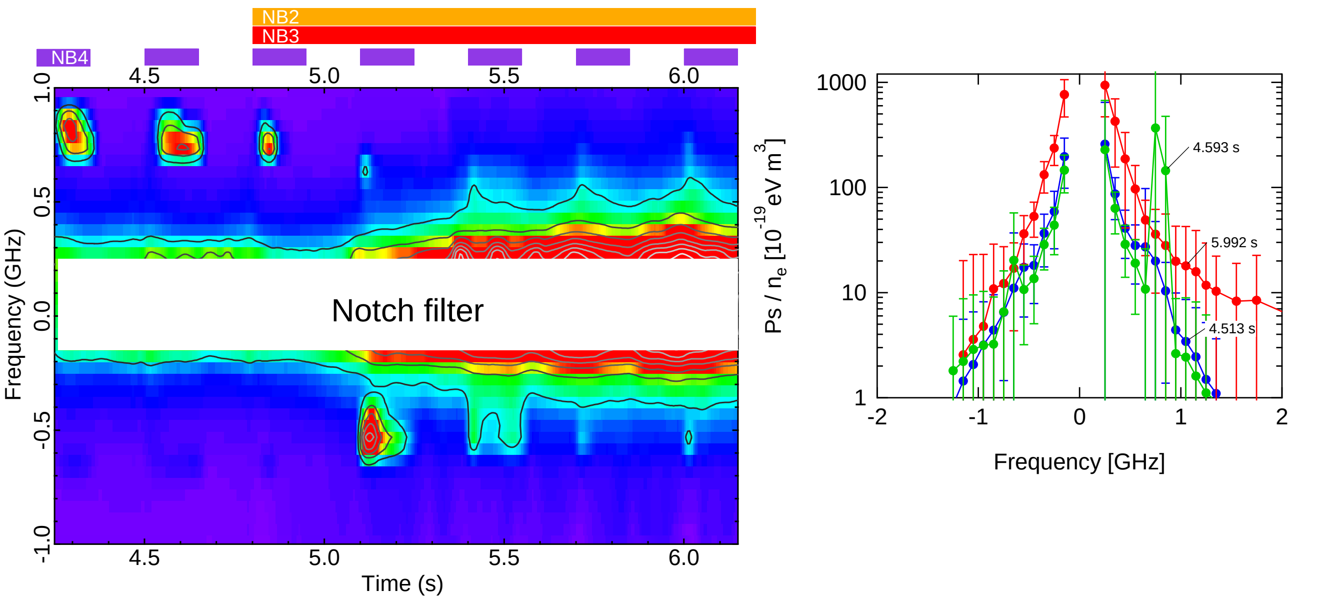

Fig. 3. Measured CTS spectrogram with neutral beam injections. The direction of NBs in LHD is described in Fig.2. The CTS spectra at different NB injection timing for (1) t=4.513s, (2) t=4.593s, and (3) t=5.992s. The

beam energies are ~170keV for NB1 to 3, and ~40 keV for NB4.

Summary

We have developed a collective Thomson scattering diagnostic system in LHD. The CTS spectrum has been measured, and then the CTS spectrum spread is observed during NB injection. For better SN ratio, the improvement of the CTS receiver should be carried out. During periodic perpendicular NB injections, high peaks in LH wave range appeared in CTS spectrum. However, these peaks disappeared with parallel NB injection. This feature is similar to the observation of LH turbulence at W7-AS.

Acknowledgment

This work is supported by Grant-in-Aid for Scientific Research(B)#21360455 and by a research granted from The Murata Science Foundation.

References

[1] H. Bindslev, J. A. Hoekzema, J. Egedal *et al.*, Phys. Rev. Lett. **83**, 3206(1999).
[2] E. V. Suvorov, V. Erckmann, E. Holzhauer *et al.*, Plasma Phys. Control Fusion **37**, 1207(1995).
[3] S. B. Korsholm, H. Bindslev, F. Meo *et al.*, Rev. Sci. Instrum. **77**, 10E514(2006).
[4] M. Salewski, F. Meo, M. Stejner *et al.*, Nucl. Fusion **50**, 035012(2010).
[5] F. Meo, H. Bindslev, S. B. Korsholm *et al.*, Rev. Sci. Instrum. **75**, 3585(2004).
[7] M. Nishiura, S. Kubo, K. Tanaka, published in Plasma and Fusion Res. (2011).
[8] M. Nishiura, K. Tanaka, S. Kubo, T. Saito, Y. Tatematsu, T. Notake, K. Kawahata, T. Shimozuma, T. Mutoh, Rev. Sci. Instrum. 79, 10E731(2008).
[9] S. Kubo, M. Nishiura, K. Tanaka, T. Shimozuma, Y. Yoshimura, H. Igami, H. Takahashi, T. Mutoh, N. Tamura, Y. Tatematsu, T. Saito, T. Notake, S. B. Korsholm, F. Meo, S. K. Nielsen, M. Salewski, M. Stejner, Rev. Sci. Instrum. 81, 10D535(2010).
[10] Y. Tatematsu, S. Kubo, M. Nishiura *et al.*, 23rd IAEA Fusion Energy Conference 2010, FTP/P6-31.
[11] S. Murakami *et al.*, Fusion Sci. Technol. 46 (2004) 241.
[12] Ryosuke Seki, Yutaka Matsumoto, Yasuhiro Suzuki, Kiyomasa Watanabe, Kiyotaka Hamamatsu, Masafumi Itagaki, Plasma and Fusion Research, Vol. 5, 027(2010).