Observation of electron temperature anisotropy in high-temperature plasmas by Thomson scattering diagnostics

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Introduction

Thomson scattering systems measure electron temperature and density under the assumption that the motion of electrons is fully thermalized and isotropic. However, recently, electron temperature anisotropy has been observed in LHD experiments by spectroscopic diagnostics [1][2]. Thomson scattering diagnostics is also considered suitable for studying electron temperature anisotropy because it directly observes electron motion along the well-defined scattering vector, which is the difference vector between the incident laser direction and observation direction. We discuss an experimental study of electron temperature anisotropy by Thomson scattering diagnostics in LHD.

Scattering configuration and error estimation

In the original design of the LHD Thomson scattering system, it observes backscattered light at a scattering angle of 167 degrees at the LHD plasma center, and measures electron temperature component nearly perpendicular to the magnetic field line as shown in Fig. 1 a). [3] In addition, electron temperature component nearly parallel to the magnetic field line can be obtained by using a forward scattering configuration as shown in Fig. 1 b). [4-6] For the double scattering configuration measurement, we installed a beam returning system with a 30 m optical delay path and new observation window, and developed a polychromator with nine wavelength channels. The scattering angles are 171.5 degrees and 8.5 degrees, and the angles between the direction of electron motion observed and the magnetic field line are 85.7 degrees and 6.0 degrees for the backscattering and forward scattering configurations, respectively.

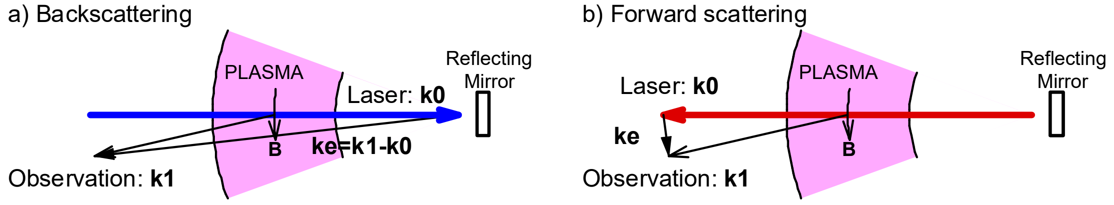

Figure 1: Observed electron motion direction in backscattering configuration, a) and forward scattering configuration, b).

Because the width of the Thomson scattering spectra greatly differs between the backscattering and forward scattering, it is difficult to obtain accurate backscattering and forward scattering temperatures simultaneously when the standard LHD polychromators with five wavelength channels are used. To solve this issue, we developed a polychromator having nine wavelength channels.

Figure 2 shows the schematic diagram and photo of the 9-CH polychromator. Figures 3 a) and b) show the spectral response of the 9-CH polychromator. The wavelength channel set of CHs. 5-9 and channel set of CHs. 1-5 are optimized for backscattering and forward scattering measurements, respectively. Figure 4 a) shows estimated experimental errors as a function of

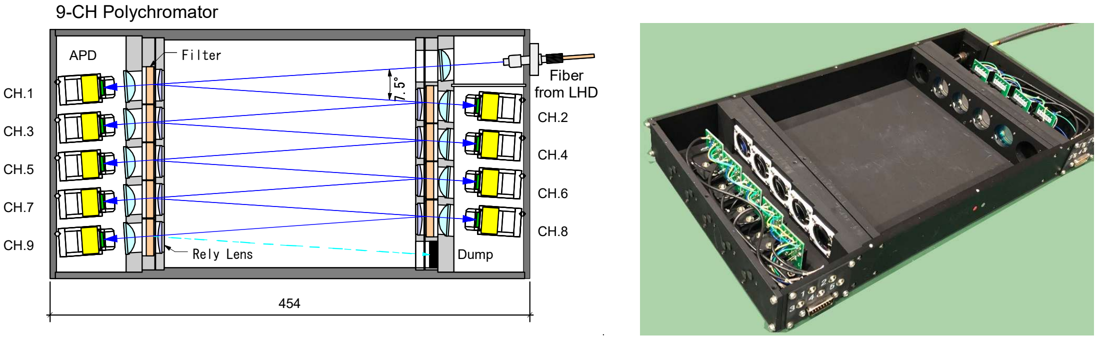

Figure 2: Newly developed 9-CH polychromator. CHs 1-5 and CHs 5-9 are optimized for the forward scattering and backscattering measurements, respectively.

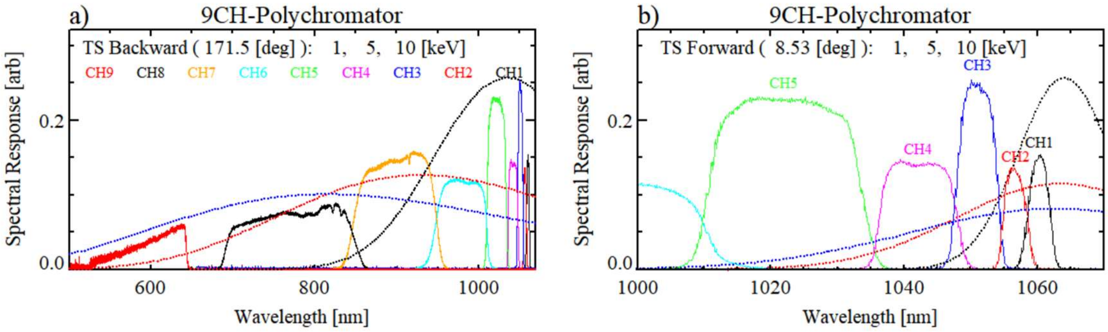

Figure 3: Spectral response of the new 9-CH polychromator. Thomson scattering spectrum at T_e = 1, 5, and 10 keV, for backscattering and forward scattering are also plotted in a) and b), respectively. The sets of CHs 1-5 and CHs 5-9 are optimized for the forward scattering and backscattering measurements, respectively.

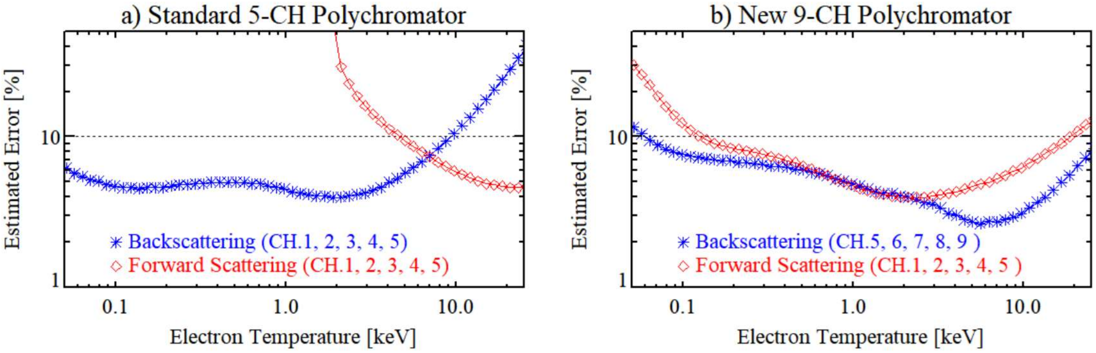

Figure 4: Observed electron motion direction in backscattering configuration, a) and forward scattering configuration, b).

electron temperature for a standard 5-CH polychromator. The standard polychromators are optimized for the backscattering measurement, and the experimental error is estimated to be less than 10 % in the range of T_e = 20 eV – 10 keV for the backscattering measurements. However, the temperature range where experimental error is less than 10 % is $T_e \geq 5$ keV for the forward scattering measurements. So, the temperature range where both experimental errors in backscattering and forward scattering measurements are less than 10 % is narrow, T_e = 5 – 10 keV. The temperature range where the both errors in backscattering and forward scattering configurations are less than 10 % is successfully expanded when the new 9-CH polychromator is used. Figure 3 b) shows the error estimated for the 9-CH polychromator. Both the errors are expected to be less than 10 % in the temperature range of T_e = 140 eV – 19 keV.

Experimental result

Figure 5 shows a comparison of the electron temperatures which are nearly perpendicular, parallel and 64 degrees to the magnetic field line, T_e^{perp}, T_e^{para} and T_e^{64}, respectively. Another perpendicular temperature measured with another standard five channel polychromator that observes near the measurement point is also plotted for comparison, T_e^{perp2}. In addition, electron density is plotted (green curve). In this plasma discharge, base electron cyclotron heating (ECH) power of 2 MW was injected during *t* = 3.0 – 6.0 sec. Furthermore, an additional 2.5 MW of ECH power was injected during *t* = 4.0 – 5.0 sec. After *t* = 6.5 sec, 4 MW ECH and 12 MW neutral beams (NBs) were injected. In the figure, the averaged values for the four periods, *t* = 3.4 – 4.0, 4.1 – 5.0, 5.1 – 6.0, and 6.8 – 7.9 sec are also plotted as straight lines. During the only ECH phase of *t* = 3.0 – 6.0 sec, T_e^{perp} is more effectively heated than T_e^{para} as expected from the principal of ECH mechanism, showing electron temperature is anisotropic. After *t* = 6.5 sec

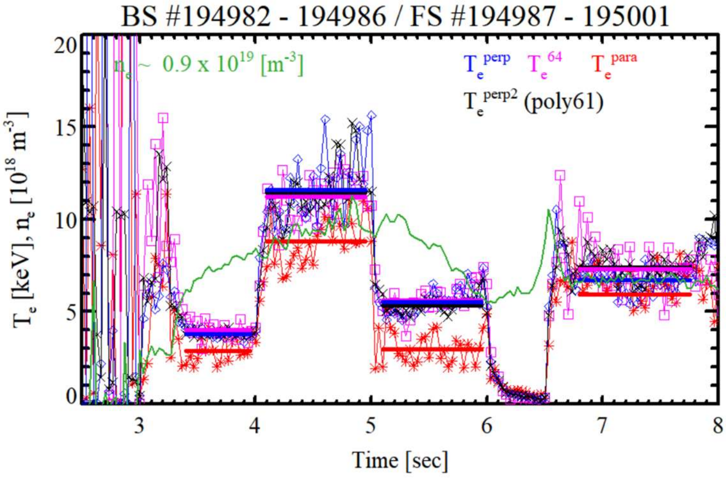

Figure 5: Electron temperatures measured by the 9-CH polychromator. T_e^{perp}, T_e^{64} and T_e^{para} show electron temperature for which the angle between the magnetic field line and measured directions are almost perpendicular, 64 degrees, and almost parallel. T_e^{perp2} shows another perpendicular temperature measured by another polychromator at a near potion.

when ECH and NBs were injected, T_e^{perp} was slightly higher than T_e^{para}, however the degree of the temperature anisotropy becomes smaller. The electron temperature anisotropy appears clearly in pure ECH phase, whereas it seems to be dismissed due to additional injections of NBs.

Conclusions

In LHD, electron temperatures that are almost perpendicular, parallel and 64 degrees to the magnetic field have been measured by the backscattering and forward scattering configurations, respectively. We obtained experimental results showing the formation of electron temperature anisotropy in pure ECH plasmas. However, when additional NBs were injected, the electron temperature anisotropy disappeared. This suggests that electron temperature anisotropy may appear in pure ECH plasmas and NBI has the effect to dismiss the electron temperature anisotropy. The experimental results of electron temperature anisotropy will be useful for further research in plasma transport and plasma heating physics.

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References

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