25C09

Radial plasma measurements by using multipoint measuring YAG-Thomson scattering system in the tandem mirror GAMMA 10

タンデムミラーGAMMA 10におけるYAG-Thomson散乱計測システムの空間多点計測による径方向プラズマ計測

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A yttrium-aluminum-garnet (YAG) Thomson scattering (TS) system was constructed and applied to the tandem mirror GAMMA 10 device to measure the electron temperature and density. A large solid-angle TS light-collection system was achieved by use of a spherical mirror system and large numerical aperture of bundled optical fiber. We prepared five channel optical fiber bundle and two five-channel polychromators with avalanche silicon photo diodes for multipoint measurements. The electron temperature increases from 0.04 keV to 0.08 keV was observed in the hot ion mode plasma with application of electron cyclotron heating in the plug/barrier cells

1. Introduction

Thomson scattering (TS) is the most important diagnostic to measure the electron temperature and electron density in fusion devices [1-4] and also in GAMMA 10 device [5]. GAMMA 10 is an effectively axisymmetrized minimum-B anchored tandem mirror with thermal barrier at both end-mirrors [5]. The plug/barrier cells are located at both ends of GAMMA 10, where the electron confinement potentials and ion confinement potentials are produced by the application of plug and barrier electron cyclotron resonant heating (B/P-ECH). The plasma is created by plasma guns, and heated and sustained using ion cyclotron range of frequency heating (ICH) systems. The typical electron density, electron and ion temperatures are about 2×10^{18} m^{-3}, 0.1 keV and 5 keV, respectively, during application of P/B-ECH. We planned to install the neodymium-doped yttrium aluminium garnet (Nd:YAG) laser TS system in order to measure electron temperature directly in the central cell of GAMMA 10. The YAG-TS system is normally used in the higher electron density plasmas, over 10^{19} m^{-3}. Then, an efficient TS system is necessary to apply to measure low density plasmas in the region of less than 10^{19} m^{-3}, such as the GAMMA 10 plasma and the peripheral plasma of high density fusion plasmas. In this report, we show the newly installed YAG-TS system and the first results of radial electron temperature measurements in the tandem mirror GAMMA 10.

2. YAG-TS system

The YAG-TS system is constructed with the laser, the incident optics, the light collection optics, the signal detection electronics, and the data recording system. A 10 Hz Nd:YAG laser (Continuum, Powerlite 9010) with an energy per pulse of 2 J and a pulse width of about 10 ns, operating at the fundamental wavelength of 1064 nm is used. The laser beam diameter at the plasma center is about 1 mm with a focusing lens of f = 2 m. For the light collection optics, we used the spherical mirror with Al:SiO2 coated, curvature radius of 1.2 m and diameter of 0.6 m. The scattered light is collected by the spherical mirror, reflected and reaches a bundled optical fiber with cross-section of 2×7 mm. The magnification of the collection optics is 2.2. The length of scattering volume along the laser is 15.4 mm and scattering angle is 90°. A solid angle of 0.078 sr can be realized of the light collection optics. The each channel of 6.67 m long 5-channel bundled optical fiber (Mitsubishi Densen, FS10-43001, NA:0.47) is connected to the 5-channel pohychlomator. The YAG-TS system installed in GAMMA 10 central cell is shown in Fig. 1. The polychromator is composed with five relay

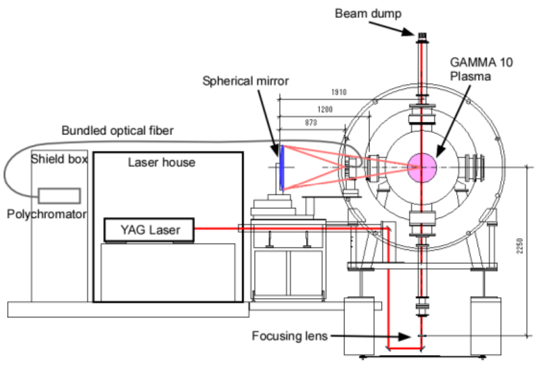

Fig. 1. GAMMA 10 Thomson scattering system.

and collection lenses, five interference filters, and five silicon avalanche photodiodes (APD) (PerkinElmer, C30950E). We prepared a new polychromator with new APD (Hamamatsu, C8890-30) for multi-point measurement. A four-channel high speed oscilloscope (Tektoronix, DPO4034B) was used to measure four wavelength channels simultaneously with bandwidth of 350 MHz and sampling rate of 2.5 GS/s. The measured signals are recorded by the Windows PC with LabVIEW analyzing software.

The Raman and Rayleigh calibration experiments were carried out for setting of optical system and stray light in the evaluation of GAMMA 10 YAG-TS system. The measured scattering signals are proportional to the gas pressure. The stray light in this system is very small.

3. Electron temperature measurement

We applied the YAG-TS system to measure the electron temperature of GAMMA 10 plasma. The plasma is produced from t = 50 to 240 ms with heated by the ICH from t = 51 to t = 240 ms and the confinement potential by applying B-ECH with power of 150 kW from t = 150 to 200 ms and P-ECH with power of 200 kW from t = 151 to 181 ms, respectively. Figure 2 shows the temporal evolutions of diamagnetism (dotted red line) and electron line density (solid blue line). We measure the electron temperatures at t = 140.1 ms and t = 170.1 ms, by changing the YAG laser injection time. The output signal of each channel is integrated in Δt = 40 ns which covers the TS pulse. The background plasma radiation is negligible in GAMMA 10. We used the minimizing the chi-squared value to obtain the electron temperature. The signal to noise ratio is

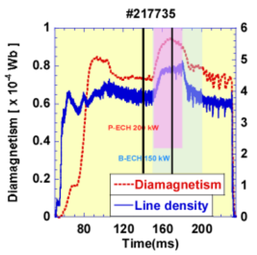

Fig. 2. Diamagnetism and line density.

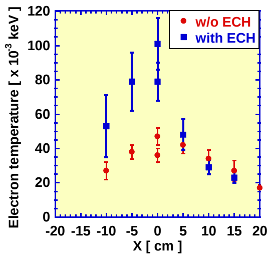

Fig. 3. Electron temperature radial profile.

about 3. We can obtain the electron temperature of about 0.04 keV before applying P/B-ECH. With application of P/B-ECH, the electron temperature increased to about 0.08 keV. We changed the measuring position of electron temperature by changing the bundled optical fiber position shot-by-shot. Figure 3 shows the radial electron temperature in GAMMA 10. In Fig. 3, closed red circles and closed blue squares show the electron temperature radial profiles without P/B-ECH and those with P/B-ECH, respectively. The temperature peeking at the plasma center is observed by applying P/B-ECH. Unfortunately, at this time we could not show the multi-point measurement results. Anyway, we can measure the electron temperature in the very low plasma density region less than 1×10^{18} m^{-3}.

4. Summary

YAG-TS system was newly installed in the tandem mirror GAMMA 10. This system can be operated to measure electron temperature in the very low plasma density region less than 1×10^{18} m^{-3}. We can successfully measure the radial electron temperature in the tandem mirror GAMMA 10 by using YAG-TS system for the first time. The radial electron temperature distribution is obtained at one position and one period during the plasma duration at this time. We have constructed the two-point measuring system. Then we will obtain the multipoint Thomson scattering signals in the next experimental campaign.

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