25C08

Advanced Thomson Scattering Diagnostics in a Burning Plasma

燃焼プラズマにおける先進トムソン散乱計測

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Thermal and nuclear loads from a burning plasma cause many novel issues even in a sufficiently developed diagnostic system such as Thomson scattering system. The degrading of spectral transmissivity due to the neutron and gamma-ray irradiation is one of the most severe problems in obtaining the Thomson scattering spectra. In this paper, two types of *in-situ* calibration method for the relative spectral transmissivity and absolute transmissivity at a wavelength, respectively, of the optical system are discussed. The method to measure anisotropic electron temperature by using Thomson scattering system is also discussed.

1. Introduction

Calibration of spectral transmissivity is one of the most urgent and crucial issues for obtaining a Thomson scattering (TS) spectrum resulting from burning plasmas. An *in-situ* calibration method of electron temperature and relative spectral transmissivity by injecting an additional laser whose wavelength is different from that of the main diagnostic laser is proposed [1].

Two results of electron temperature (T_e) measurements obtained by TS and electron cyclotron emission (ECE) tend to be different under strong NBI [2]. In such a plasma, detecting non-Maxwellian electron velocity distribution function (EVDF) was tried [3]; however, no evidence of the distortion of EVDF from Maxwellian for the specific direction was detected [3]. While, it was suggested anisotropy was important in an equilibrium of plasma when auxiliary heating was high [4].

2. In-situ Calibration of Spectral Transmissivity

We developed a simulation method of the availability of the calibration method proposed in Ref. [1]. It is crucial to sufficiently overlap the spectra of TS resulting from the injection of the main and the additional lasers. For example, as the additional laser for the edge TS system in ITER, a ruby laser is one of the promising lasers from the point views of the wavelength and the pulse energy [5]. Figure 1 shows an example of the accuracy in calibrating the relative spectral transmissivity. From the point view of overlapping the two spectra, the wavelength of an additional laser (λ_C) is required to be located near the main diagnostic laser (λ_0 =1064 nm is assumed in Fig. 1). However, when λ_C is too close to λ_0, short wavelength region cannot be calibrated accurately due to small amount of detected photons in the case for relatively low T_e measurement.

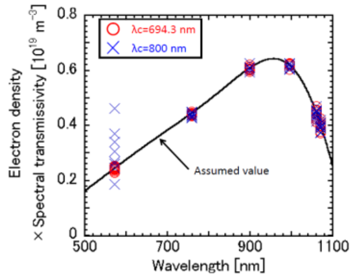

Fig.1. Comparison of the accuracy in the calibration of relative spectral transmissivity as a function of scattered wavelength and wavelength of the additional laser (λ_C). T_e is assumed to be 2 keV.

Since the intensity of the detected signal in TS is proportional to both n_e and the spectral transmissivity, a signal except for spectra of TS is necessary for independent calibration of n_e and the spectral transmissivity. We proposed a novel calibration method of n_e by utilizing a background light at experiments [6]. If we choose an appropriate wavelength band for the background light measurement, the bremsstrahlung is the dominant component of the background light. Note that emission due to the transition of electron in atom and molecule should be avoided. In addition, when the temperature of ion having ionic charge Z is comparable or less than Z^2R_y, where R_y denotes the Rydberg energy, the free-bound emission due to the recombination is significant. When we measure wavelength of more than 834 nm (1.51 eV=13.6 eV/3^2), the spectra due to the recombination to 4th or outer shells only (in the case for recombination of hydrogen atom) are detected, and bremsstrahlung is sufficiently stronger than free-bound emission for such wavelength [7]. On the other hand, thermal radiation from the first wall is not negligible for the near-infrared region in a burning plasma experiment. In order to avoid the thermal radiation from the first wall, measured wavelength should sufficiently be short. As the result, approximately 850-900 nm of wavelength is appropriate for the application of *in-situ* n_e calibration by utilizing bremsstrahlung. Since this calibration method utilize bremsstrahlung, effective ionic charge Z_{eff} can be obtained simultaneously. Moreover, since bremsstrahlung is radiated from whole plasma, data of background light in all spatial channels should be analyzed simultaneously whereas those of TS in each spatial channel are analyzed independently. Figure 2 shows an example of simulated accuracy in this calibration method for an assumed geometry. Both profiles of n_e and Z_{eff} can be re-constructed simultaneously from data of background light.

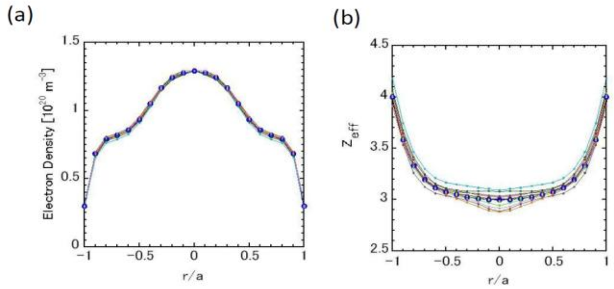

Fig.2. Re-constructed profile of (a) n_e and (b) Z_{eff}. Thick (thin) lines with large (small) closed circles denote assumed (re-constructed) profiles. 10 types of simulated perturbations due to the shot-noise of detector in the intensity of detected photon are shown.

3. Local Measurement of Non-Maxwellian Velocity Distribution Function

Since a TS spectrum reflects an EVDF for the specific pitch angle of the measurement configuration, we can obtain an EVDF for the specific two pitch angles by using two lines of sight. If we have collinear incident beams which are oppositely propagate each other, we can effectively obtain two lines of sight of one collection optics. For applying the anisotropic T_e measurement, the configuration of optical components should have sufficient tolerance about the directions of incident laser propagation, line of sight and the magnetic field. We investigated the tolerance in the configuration of the measurement. Figure 3 shows that a deviation in the direction of the magnetic field rotating parallel to the scattering plane of approximately a few tens degrees from the ideal direction is applicable [8]. Similarly, it is also shown that a deviation in the direction of the magnetic field tilting from the scattering plane of approximately a few tens degrees from the ideal direction is applicable.

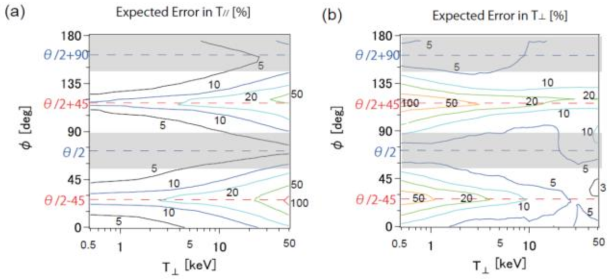

Fig.3. Expected accuracy in (a) $T_{//}$ and (b) $T_{\perp}$ as a function of $T_{\perp}$ and ϕ, where ϕ denotes the angle between the laser beam and magnetic field projected on the scattering plane. $T_{//}$ and the scattering angle of the first pass θ are assumed to be 5 keV and 140 degrees, respectively. Hutched region shows $\phi=\theta/2\pm20$ degrees or $\phi=\theta/2+90\pm20$ degrees.

4. Summary

A Thomson scattering spectrum resulting from an additional laser, whose wavelength is different from the main diagnostic laser, and bremsstrahlung, which is the dominant component of the background light at appropriate wavelength band, are utilized for the calibration of relative spectral transmissivity and absolute transmissivity at a wavelength, respectively. When we have two collinear beams and the configuration of optical system is appropriate, parallel and perpendicular electron temperatures can be independently measured. Those calibration and diagnostic methods will be crucial and significant, respectively, for burning plasma diagnostics.

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**The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.*