Thomson Scattering Measurement of Two Electron Temperature Components in Transition to Detached Plasmas

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We have performed laser Thomson scattering (LTS) measurements during the transition between attached and detached helium plasmas in the linear divertor simulator NAGDIS-II. In the detached plasma, the LTS spectrum shows a discrepancy with a single Gaussian function. The discrepancy is resolved by the spectrum fitting with a sum of two Gaussian functions, indicating that the electron energy distribution contains two different temperature components.

Keywords: electron energy distribution, detached plasma, plasma diagnostic, Thomson scattering, NAGDIS-II

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Detached plasma plays an essential role for magnetically confined fusion devices to prevent divertor plates from being seriously damaged. In the detached plasmas, volume plasma recombination is one of the most important processes, strongly depending on electron temperature T_e and density n_e. In order to design DEMO and future devices, reliable plasma simulations should be established to predict the particle and heat loads on the divertor plate. A recent SOLPS modeling of DIII-D detached plasmas indicated that atomic and molecular processes and kinetic effects were important for reliable modeling particularly in low-temperature recombining plasmas [1]. Therefore, the precise measurements of T_e and n_e in the detached plasmas are an essential issue.

Laser Thomson scattering (LTS) is known as a reliable technique for the measurements of T_e and n_e. LTS measurements of detached plasmas have been conducted in linear devices. In the MAP-II device, T_e below 0.1 eV was acquired and compared with T_e measured with Boltzmann plot and collisional-radiative (CR) model [2]. In the Magnum-PSI device, single-laser-pulse LTS measurements were performed with low observational errors [3]. LTS techniques for measurements of detached plasmas have also been used in the DIII-D device. A 2D divertor characterization was performed using the divertor Thomson scattering system through the transition from attached to detached plasmas [4].

In this study, we applied LTS techniques to helium (He) plasma in the linear plasma device NAGIDIS-II (NAGoya DIvertor Simulator) and measured T_e and n_e in between attached and detached plasma states.

In this LTS system, the second harmonics (wavelength 532 nm) of an Nd:YAG laser (Continuum: Surelite II-10: pulse width 5 - 6 ns, pulse energy −0.3 J, repetition rate 10 Hz) was used. The collected light is transferred through the optical fiber (23 channels for observation) to the spectrometer, in which a volume phase holographic grating (2600 l/mm) was used. The signals were measured with the Gen-III ICCD camera (Andor: iStar) and accumulated for 300 s (3000 laser pulses). In order to reduce the stray light, baffles are equipped on the laser path, and a viewing dump is placed at the end of the field of view (detailed setup was described in Ref. [5]). Detachment was induced by controlling the neutral gas pressure, P, via the amount of injected gas near the end target.

A typical LTS spectrum and fitting curve in attached He plasma (P = 5 mTorr) are shown in Fig. 1. The spec-

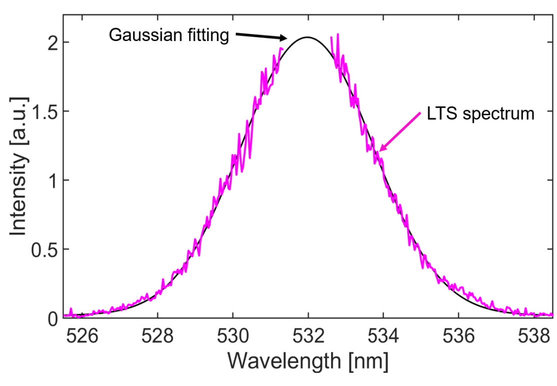

Fig. 1 Typical LTS spectrum and fitting curve in attached plasma (P = 5.1 mTorr).

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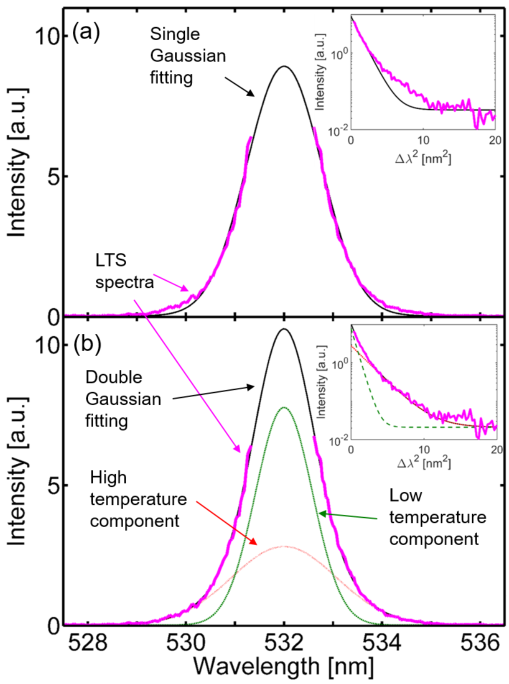

Fig. 2 Thomson scattering spectra and fitting curves with (a) single Gaussian function and (b) double Gaussian function and its individual components (P = 15.8 mTorr). Insets are logarithmic plots of the intensity as a function of squared shifted wavelength from the spectral peak ($\Delta\lambda^2$). Residual sum of squares in 528 - 536 nm decreased to 25%.

trum at around 532 nm (the width is ~2 nm) is not used for the fitting in order to remove the stray light. In this figure, fitting curve with a single Gaussian function shows good agreement with the LTS spectrum. Evaluated T_e and n_e were 2.8 eV and 8.9×10^{18} m^{-3}, respectively.

Figure 2 (a) shows the LTS spectrum in detached plasma (P = 15.8 mTorr) and fitting curve with single Gaussian distribution. It is found that fitting curve differs from the spectrum in the tail region, indicating that a high energy component in electron energy distribution exists. The fitting curve with two Gaussian components and their individual curves are shown in Fig. 2 (b). The spectrum agrees with the fitting curve well even in the tail region.

The dependences of T_e and n_e evaluated with single Gaussian fitting (closed circle) and individual components of double Gaussian fitting on P are plotted in Fig. 3. The high temperature component of double Gaussian evaluation are plotted as open triangles, and the low temperature one are plotted as open squares. As shown in this figure, from the single Gaussian evaluation, T_e decreased and n_e rolled over with increasing pressure. From the double Gaussian evaluations, the high temperature component is dominant at 5 mTorr, indicating that the spectrum obeys the single Gaussian function in the attached plasma. At $P > \sim 7$ mTorr, the low temperature component becomes non-negligible and becomes dominant at 9 mTorr, where

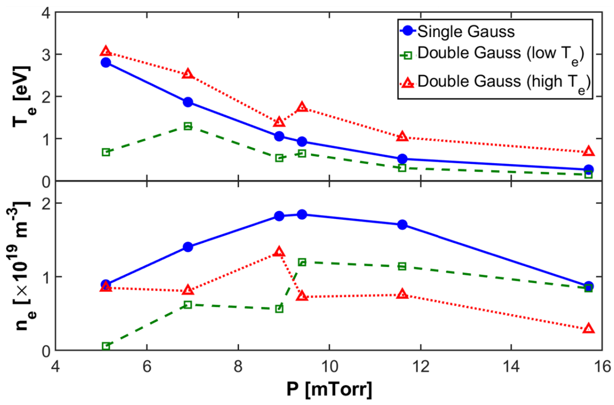

Fig. 3 Pressure dependences of (a) T_e and (b) n_e. Closed markers are evaluated with single Gaussian fitting, open markers are evaluated with double Gaussian fitting.

the rollover of n_e appears.

Non-Gaussian electron energy distribution functions (EEDFs) in the divertor have been identified with Langmuir probes on tokamak divertors [6, 7]. Kinetic effects are considered to be the cause of these non-Gaussian EEDFs, as shown in earlier modeling [8]. Non-local electron transport can only occur when high-energy electrons pass to different regions, e.g., from near the last closed flux surface to the divertor region. In NAGDIS-II case, however, due to the high neutral pressure (~1 Torr) in the source region and low electron temperature compared to tokamak devices [9], such a non-local electron transport can be neglected.

A possible reason for the non-Gaussian EEDF in NAGDIS-II is fluctuations of plasma parameters. In this experiment, scattered signals were time-integrated for 300 seconds. The two different temperature components may not exist simultaneously but independently in time. Because localized fluctuations near the recombination front was observed in Ref. [10], the high energy component probably flows in intermittently. For LTS measurements of intermittent events, the conditional averaging (CA) technique can be used, as reported in Ref. [11]. We are planning to conduct the CA combining with the Langmuir probe measurement.

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