Doppler and Stark Broadenings of He II Emission in NAGDIS-PG

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(Received 20 December 2020 / Accepted 5 January 2021)

Time evolutions of the emission from helium (He) ion at 468.6 nm were observed in the magnetized co-axial plasma gun device NAGDIS-PG, and the broadening of the spectrum was analyzed in terms of Doppler and Stark broadenings to deduce the ion temperature and the electron density. A significant broadening of the He II spectrum was identified around a dip in the discharge current, suggesting that increases in the temperature and density occurred.

Keywords: plasma gun, spectroscopy, Doppler broadening, Stark broadening

DOI: 10.1585/pfr.16.1202013

One of the most serious issues for plasma facing components will be the impact of transients accompanied by edge localized modes (ELMs) and disruptions [1]. Plasma devices that can produce pulses have been used to investigate the impact of transients including the formation of clacks [2], the effect of vapor shielding [3], and formation of arcing [4]. Characterization of the plasma is important to discuss the effect in a quantitative manner. In Magnum-PSI, laser Thomson scattering was used to measure the temporal evolutions of the electron density, n_e, and temperature, T_e, in response to pulses [5] by scanning the trigger time of the measurement. A triple probe and an interferometer have been used in magnetized co-axial plasma gun devices [6–8]. Also, the broadening and peak shift of a He II line were used to measure the ion temperature and flow velocity, respectively [3]. In terms of its simplicity, it is of interest to further explore the application of spectroscopy for the characterization. In this study, we will investigate temporal evolutions of the spectral broadening of He II line at 486.6 nm in a magnetized co-axial plasma gun device.

Figure 1 (a) shows a schematic of the experimental setup in the plasma gun device NAGDIS-PG [9]. The emission was observed from the bottom of a target that terminated the plasmoid. In this study, the discharge voltage was 2.8 kV and the feeding gas for discharges was helium (He). The strength of the magnetic field produced by the pulsed plasma was typically 0.2 T [3]. The Zeeman effect due to the magnetic field is much smaller than the broadening observed in this study and negligible. An optical fiber array collected the emission via a lens and transfered to a Czerny-Turner type spectrometer, which has a focal length of 0.5 m and a grating with 1200 g/mm. A fast-framing camera (Photron Limited, FASTCAM MAX-II) that has an image intensifier was used as a detector to observe the temporal evolution of the emission. The frame rate was 100000 frame per second (fps), i.e., the time resolution of 10 µs. The image size shrinks with increasing the frame

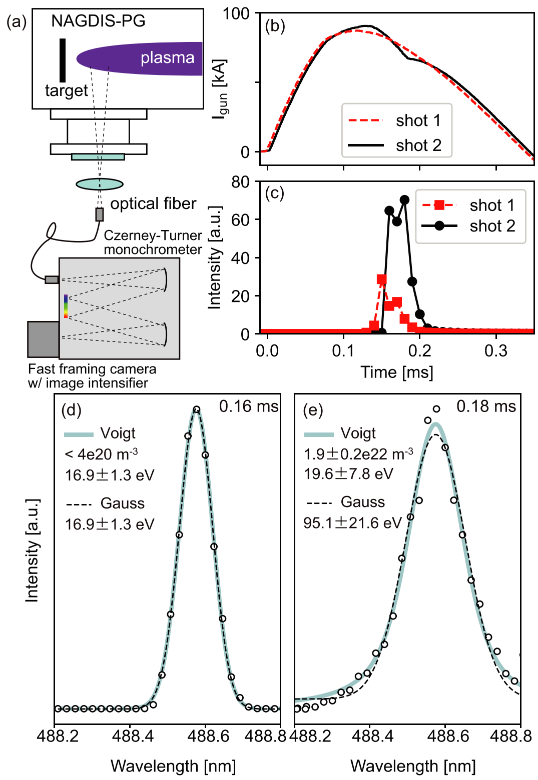

Fig. 1 (a) A schematic of the experimental setup in NAGDIS-PG, (b,c) temporal evolutions of the discharge currents and emission of He II at 486.6 nm in shots 1 and 2, and two typical He II spectra in shot 2 at (d) 0.16 and (e) 0.18 ms.

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rate and is 128×32 pixels at the frame rate of 100000 fps. Although we used a bundle optical fiber and an imaging detector, we summed up the intensities of all the fibers, because the intensity was not strong enough.

Figure 1 (b) shows two typical discharge current evolutions (shots 1 and 2) used in this study. While the experimental condition that we set was the same, it is noted that a small dip appeared in shot 2 at 0.18 ms. Figure 1 (c) shows time evolutions of the emission intensity of He II around 486.6 nm. The plasmoid is observed at 0.15 - 0.2 ms, and the intensity in shot 2 is stronger than that in shot 1. In Figs. 1 (d, e), two typical He II spectra in shot 2 at 0.16 and 0.18 ms, respectively, are shown. The width of the spectra at 0.18 ms is wider than that at 0.16 ms. Assuming that the broadening is determined only by the Doppler effect, the deduced ion temperatures, T_i, at 0.16 and 0.18 ms are 16.9±1.3 and 95.1±21.6 eV, respectively. We took into account 13 line components in the fine structure multiplet for fitting [10]. In addition to Doppler broadening, Stark broadening would be effective if n_e is high enough, typically $>10^{21}\ \mathrm{m}^{-3}$. To assess the effect, a Voigt function is used to analyze the spectra, and n_e is assessed from the Lorentzian component. Reference [11] is used for the relation between n_e and Stark broadening of He II at 468.6 nm. Almost no Stark effect is identified in the spectrum at 0.16 ms, while the spectrum at 0.18 ms is better fitted with a Voigt profile and the density is assessed to be $1.9\pm0.2\times10^{22}\ \mathrm{m}^{-3}$.

Figures 2 (a, b) show time evolutions of T_i and n_e, respectively, for shots 1 and 2. In Fig. 2 (a), T_i without considering the Stark effect is also plotted. From T_i obtained from Gaussian fitting (no Stark effect), it is seen that the spectrum broadens significantly in shot 2. In Fig. 2 (b), in addition to the case where both of T_i and n_e are free parameters for fitting, n_e under the assumption of T_i = 50 eV is also plotted. In shot 1, T_i < 10 eV and n_e ~$2\times10^{21}\ \mathrm{m}^{-3}$ at maximum; the parameters are consistent with previous reports [9]. On the other hand, in shot 2, T_i is higher and increases significantly at 0.18 ms, when the dip appears in the discharge current. Also, n_e is deduced to be an order of magnitude higher than that in shot 1 at maximum.

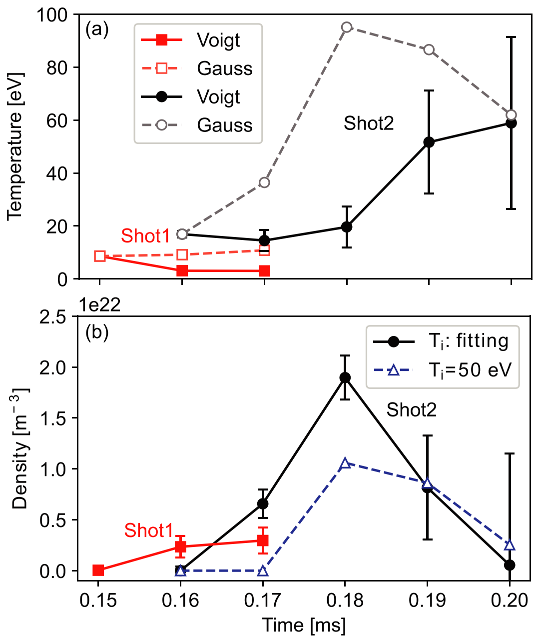

Fig. 2 Time evolutions of (a) T_i and (b) n_e for shots 1 and 2 deduced from the spectrum broadening using the Voigt function fitting procedure. In (a) T_i deduced from Gaussian fitting is also shown.

We must admit that Gaussian and Lorentzian components might not be well separated by the fitting procedure. However, the observation clearly showed that a significant broadening occurred around the time when the dip of the discharge current was identified. And the broadening was likely caused by increases of both of the plasma density and temperature. In general, in magnetized co-axial plasma gun devices, the waveform of discharge current is disturbed when the gas injection is not enough, magnetic field flux is low, or the discharge electrode is damaged. Since magnetic reconnection and the formation of spheromaks are related to the formation of magnetized co-axial plasma gun [12], the dip is likely caused by a rapid change in the configuration of magnetic field due to an occurrence of magnetohydrodynamic (MHD) instabilities. Detailed measurement of magnetic field will be helpful to confirm the physics behind the dip of the discharge current. Although the reasons to cause the increases in the temperature and densities in response to the dip have not yet been understood, it is attractive to produce such high density (> $10^{22}\ \mathrm{m}^{-3}$) plasmas. We might be able to change the waveform of the discharge current by controlling, e.g., the amount and timing of gas injection.

In this study, we summed up the signal of all the fibers to increase the signal level. As introducing a detector with a higher sensitivity such as the one with Gen 3 image intensifiers, spatio-temporal resolved observation is of interest. For future work, with the support of further advanced measurements, it is expected to understand the mechanism and to control the production of the high-density plasmoid.

This work was supported in part by a Grant-in-Aid for Scientific Research (B) 19H01874 and (A) 20H00138 from the Japan Society for the Promotion of Science (JSPS) and NINS program of Promoting Research by Networking among Institutions (01411702).

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