Volumetric recombining plasma in helicon source divertor simulator

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Abstract

A volumetric recombining plasma in a helicon source divertor simulator is investigated. With sufficient gas feeding in the test region, line emissions from highly excited helium atom are observed. Abel inversion reveals that the highly excited states are localized out of the core plasma column. Boltzmann plot method indicates that the plasma is the recombining plasma.

Introduction

Investigation of robustness of volumetric recombinations is important issue for the development of reactor-relevant divertor plasma. Transient increase in a high energy particle flux flowing into the divertor region of magnetic confinement devices[1], which is induced by the edge localized modes (ELMs) or some MHD activities, is concerned to reduce the recombination rate and to destroy the population balance required for the detached plasma[2]. Because the ion temperature of the particle flux is the same order as that just inside of the last closed flux surface, tail component of the transient ion flux is characterized by the energy of several keV to several tens keV. In this energy range, the ion impact collisions can be significant for the population balance in divertor plasma.

Using a beam injector and a linear device is a suitable experiment for basic studies of the recombining processes under the influence of the energetic ion flux, because mono-energy beams simplify the modeling of atomic processes. While a radio-frequency (RF) plasma source has the advantage of the beam penetration and high density plasma production[3], sustaining suitable plasma production was difficult over a wide range of neutral pressures in a recombining test region. In our previous work, stable plasma production in an RF/helicon source and a steady-state high-neutral-pressure environment in a test region have been achieved simultaneously with backflow suppression[4]. In this paper, a volumetric recombining plasma in the helicon source divertor simulator is described.

Experiment

Experiments were performed in a linear plasma device DT-ALPHA[3]. A schematic of the experimental setup is shown in Fig. 1. The vacuum chamber consists of a quartz pipe (36 mm in diameter) coupling an antenna to a plasma, and a downstream chamber (63 mm in diameter) made of stainless steel (SUS). A converging axial magnetic field up to 0.2 T is applied. The working gas (He) for plasma production is injected from a tube adjacent to the aperture. About 1 kW of 13.56MHz RF power is supplied through the antenna for

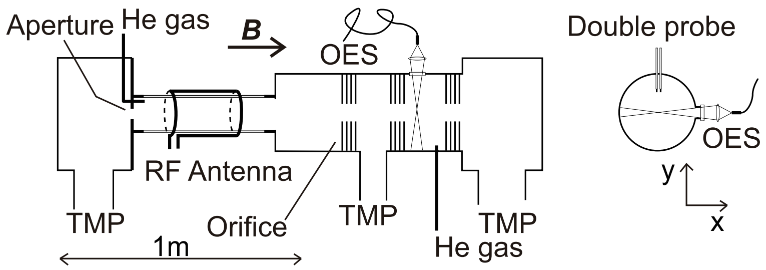

Figure 1: Schematic of DT-ALPHA.

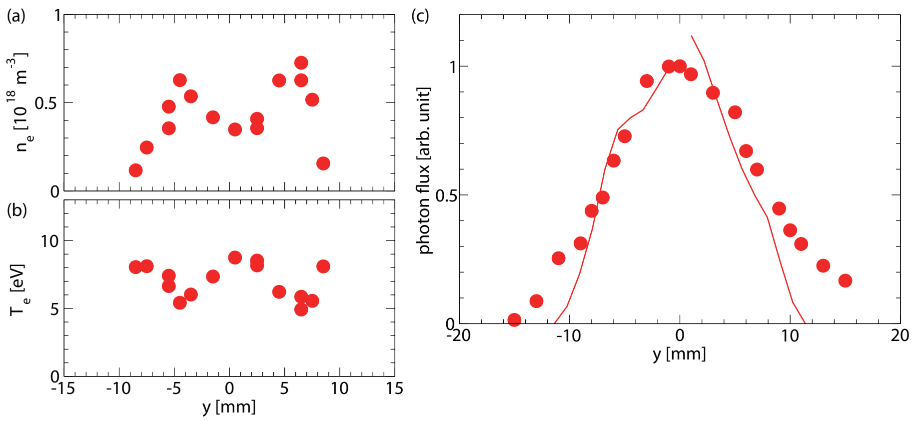

Figure 2: Radial profile of (a) electron density and (b) electron temperature measured using a double probe. (c) Photon flux of He I line at 318.8 nm (2^3S-4^3P) by OES measurement (•) and that reconstructed from n_e and T_e profile.

the plasma production. Three orifice units (20 mm in diameter) are installed in order to suppress backflow of secondary gas fed into the test region.

Measurement is performed in the test region by double probe method and optical emission spectroscopy (OES). For OES, He I emissions in ultraviolet and visible range are collected. A collisional radiative model for helium atom[5, 6] is utilized for an analysis.

Results and discussion

In addition to the source gas-feeding, a small amount of helium is fed in the test region. The neutral pressure at the test region is about 3 Pa. Radial profiles of the electron density and temperature are measured by a double probe as shown in Fig. 2 (a) and (b). Axisymmetrical plasma column is produced. Boundary is about $r = 10$ mm because the plasma column is scraped off by the orifices.

Radial profile of line integrated emission intensities are also measured in the test region. The emission profile of He I line at 318.8 nm (2^3S-4^3P) is shown in Fig. 2 (c). The profile peaks at the center of the plasma column and is axisymmetric. The emission profile extends out of the orifice diameter. The outer wing of the profile implies that there exists lower density plasma than that could be measured by the probe.

A line integrated emission profile is reconstructed using the radial profile of n_e and T_e in

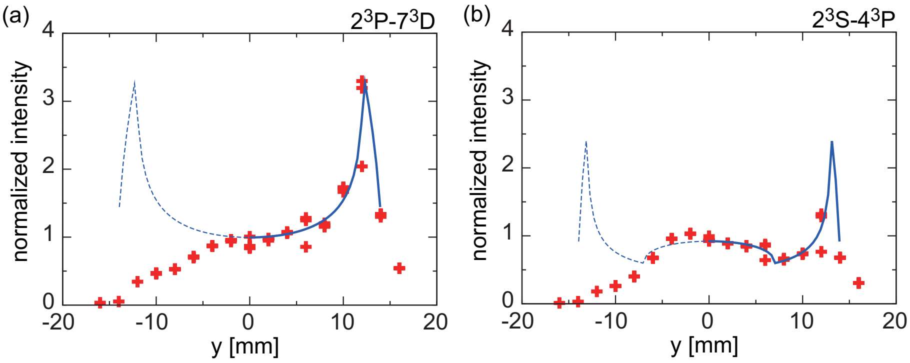

Figure 3: (a) Radial profile of He I line emission intensity at 370.5 nm (2^3P-7^3D) and (b) that at 318.8 nm (2^3S-4^3P). Equation (1) is shown by solid curves.

Fig. 2 (a) and (b). At first, local emission intensity is calculated using the CR model. Then, integration along a viewing chord is performed. The local emission out of the probe measurement range is linearly extrapolated. The reconstructed profile, shown by solid curves in Fig. 2 (c), agrees with the measurement profile in core region. Adequate extrapolation will reconstruct the outer wing of the emission profile. These results indicate that the plasma is in ionizing phase. In fact, recombining component in the CR model calculation is negligibly small.

After the target plasma is characterized, larger amount of helium is fed in the test region. The neutral pressure in the test region increases to about 6 Pa. Then line spectra from highly excited helium atom are observed. Radial profiles of line integrated emission are plotted in Fig. 3 (a) and (b). Although asymmetry is observed, strong emission is localized at the boundary of the plasma column, especially the emission from higher principal quantum number such as He I line at 370.5 nm (2^3P-7^3D) [Fig. 3 (a)]. The emissions from moderate states, plotted in Fig. 3 (b) for example, rather show the center peaked profile.

In order to obtain local emission profile, Abel inversion with a step function distribution is adopted. Local emission profile $\varepsilon(r)$ assumed to consist of a homogeneous core and a homogeneous edge ring, $\varepsilon(r)=\varepsilon_c(|r|<r_1), \varepsilon_e(r_2<|r|<r_3), 0(\text{otherwise})$. Abel transform of $\varepsilon(r)$ is

$$I(y)=\int_{-\infty}^{\infty}\varepsilon(r)\mathrm{d}x, \quad (1)$$

which is easily expressed by analytical formulae. Then fitting of the line integrated emission profile directly returns the five parameters for the local emission profile. In the present experiment, fitting is performed in $r\geq 0$ region. For example, $\varepsilon_c=0.06(r<7.0)$ and $\varepsilon_e=0.5(13.0<r<14.1)$ are obtained for the 318.8 nm (2^3S-4^3P) emission, while $\varepsilon_c=0$ and $\varepsilon_e=0.5(12.1<r<14.3)$ for 370.5 nm (2^3P-7^3D). This means that the plasma column consists of the core and edge region, and that highly excited states are only exist in the edge region.

In the edge region, emissions from transition of 2^3P-n^3D, where principal quantum

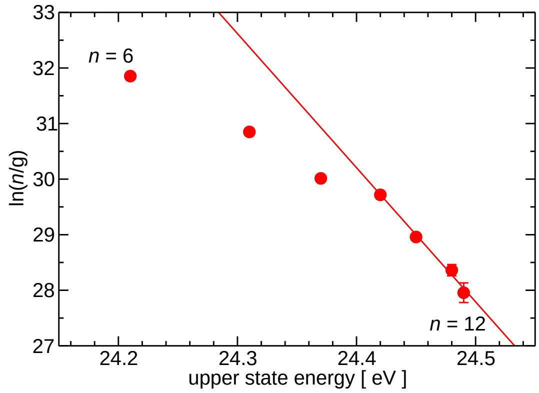

Figure 4: Boltzmann plot of He I n^3D spectra obtained at $y = 14$mm. A solid line indicates a slope of $T_e = 0.04$ eV.

number n reaches up to $n \geq 12$, are observed. In helium recombining plasma, it is well known that line spectra from highly excited levels are observed so the result implies existence of the recombining plasma in the edge region. The electron temperature of recombining plasma can be estimated using Boltzmann plot method. Figure 4 shows the natural logarithm of the population density divided by the statistical weight as a function of energy level above the ground state. Excitation states $n \geq 9$ are in the local thermal equilibrium with 0.04 eV. The temperature is small enough to induce the volumetric recombination.

Summary

Characterization of a plasma column produced by an RF source is performed. With sufficient gas feeding in the test region, line emissions from highly excited helium atom are observed. Abel inversion reveals that the highly excited states are localized out of the core plasma column. Boltzmann plot method indicates that the plasma localized in the edge region is the recombining plasma. Operation with volumetric recombination in the core has been developing.

Acknowledgements

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