21PB-076

Hydrogen and helium spectroscopy of Shinshu RF plasmas
RF プラズマにおける水素・重水素およびヘリウムの発光線解析

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Visible emission line intensity of helium RF plasmas produced using the Nagoya-III type of antenna is analyzed by a collisional-radiative model. Radiation trapping effect in high electron density plasma is investigated. Iterative numerical method to determine the ground state atom from 3^1P- 2^1S and 4^1P- 2^1S emission intensities, which are strongly affected by the radiation trapping, is proposed.

1. Introduction

We are developing collisional-radiative models of hydrogen atom, hydrogen molecule and helium atom, which are included in neutral transport codes for fusion plasmas. RF plasmas in the author's laboratory are used to test these codes [1-4]. We need an RF device which produces high electron density plasmas ($n_e > 10$ cm^{13}) to imitate the fusion edge plasmas. The validity of the electron impact excitation cross sections among the excited state can be investigated using the high electron density plasmas.

We have recently adopted the Nagoya-III type of antenna [5]. In order to determine plasma parameters including n_e, we use emission line intensities of helium atom [2] mixed to hydrogen or deuterium gas. In this study, we produced pure helium plasmas. We will discuss the helium radiation trapping in higher electron density plasmas.

2. Experimental

Figure 1 shows a schematic diagram of the apparatus, which consists of glass tubes. Helium gas was introduced through mass flow controllers. A Nagoya-III type of RF antenna connected to a matching network was supplied with an RF power at 13.56 MHz. We measured the intensities of emission lines of helium atom. The line of sight was scanned along the Z-axis in Fig. 1 by shifting a collecting lens. The collected light was fed via an optical fiber to an echelle spectrometer (BUNKOUKEIKI EMP-200-AS) with a CCD camera (ANDOR DV420), which covers the wavelength range of 376-800 nm. The absolute sensitivity of the optical system was calibrated using a calibrated xenon lamp light source (Hamamatsu L7810).

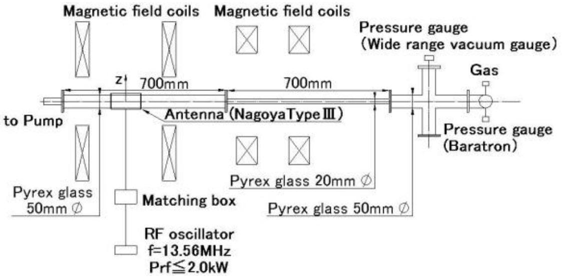

Fig.1 Experimental equipment

3. Model

A method used in determining n_e is as follows: Population of excited state p of helium atom is given in the form [2]

$$
\begin{aligned}
&n(p) \\
&= r_1(p)\, n(1^1\mathrm{S})\, n_e + r_2(p) n(2^1\mathrm{S})\, n_e + r_3(p) n(2^1\mathrm{S})\, n_e \\
&+ R_{2^1\mathrm{p}}(p)\, n(1^1\mathrm{S}) I_{2^1\mathrm{p}} \\
&+ R_{3^1\mathrm{p}}(p)\, n(1^1\mathrm{S}) I_{3^1\mathrm{p}} + R_{4^1\mathrm{p}}(p)\, n(1^1\mathrm{S}) I_{4^1\mathrm{p}} \;\ldots\;,
\end{aligned}
$$

where $r_1(p)$, $r_2(p)$, $r_3(p)$, and $R_{2^1\mathrm{p}}(p)$, $R_{3^1\mathrm{p}}(p)$, $R_{4^1\mathrm{p}}(p)$ are population coefficients calculated by a helium CR model [1,2]. The parameters $I_{2^1\mathrm{p}}$, $I_{3^1\mathrm{p}}$ and $I_{4^1\mathrm{p}}$ are the photo-excitation rates from the ground state 1^1S to 2^1P, 3^1P, and 4^1P states per one atom, respectively. The fitting parameters T_e, n_e, $n(1^1\mathrm{S})$, $n(2^1\mathrm{S})$, $n(2^3\mathrm{S})$, $I_{3^1\mathrm{p}}$, $I_{4^1\mathrm{p}}$ are determined from emission intensities of visible singlet and triplet emission lines including 3^1P - 2^1S and 4^1P - 2^1S which are strongly affected by the radiation trapping.

4. Results and Discussions

Figure 2 shows the measured line-of-sight spectra of an pure helium plasma at Z=0 cm. The helium gas pressure was 0.38 Torr. RF power was 1200 W. Figure 3 shows population density at *R*=0 cm obtained from the emission intensities with the Abel inversion. Electron density derived from the population distribution was 1.12×10^{13} cm^{-3}. The population of 3^1D is produced from 3^1P which is strongly affected by the radiation trapping. In this electron density, for the production of 4^1P atoms, the photo-excitation from 1^1S to 4^1P is less important than the electron impact transition among the excited states after the electron impact excitation from the ground state. The contribution of the photo-excitation from 1^1S to 4^1P is not evaluated precisely because it is negligible. For comparison, Fig. 4 shows population density of a plasma with lower electron density 1.26×10^{11} cm^{-3}.

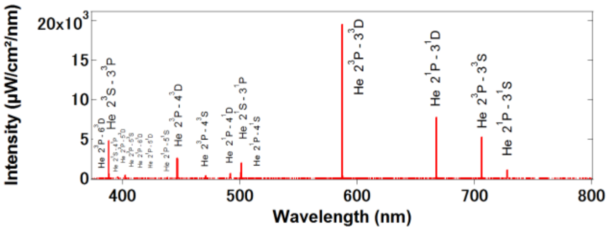

Fig.2 Spectra of an pure helium plasma. Gas pressure was 0.38 Torr. RF power was 1200 W.

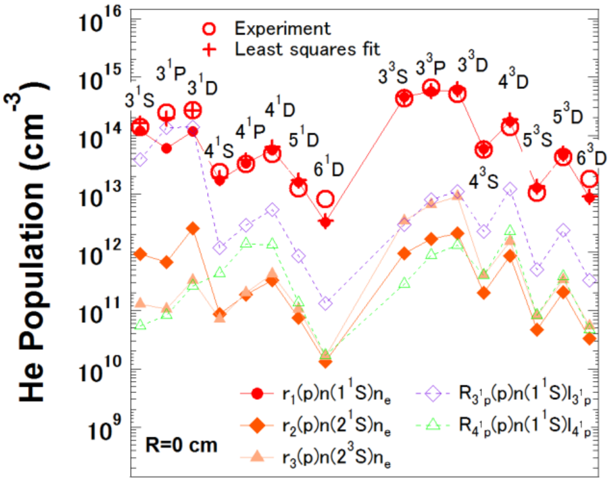

Fig.3 Population distribution of helium excited states. Gas pressure was 0.38 Torr. RF power was 1200 W.

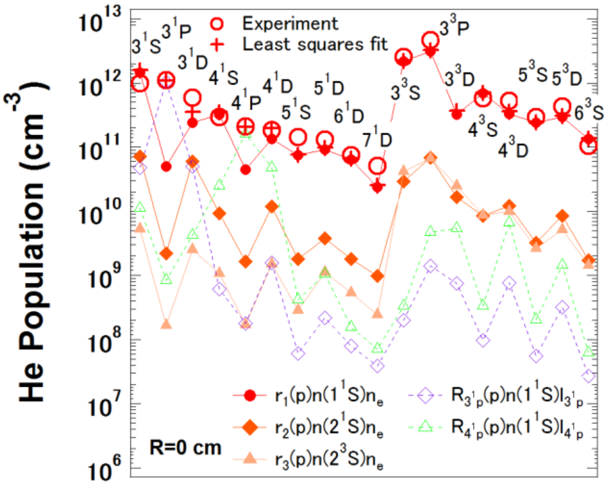

Fig.4 Population distribution of helium excited states. Gas pressure was 0.38 Torr. RF power was 150 W.

In the present low temperature case ($T_e < 10$ eV) , T_e dependence to the excited state relative population distribution is small. Giving the ground state atom density evaluated from gas pressure, we determined T_e from the absolute intensity of the emission lines. However, it is not clear that $n(1^1S)$ evaluated from the gas pressure is equivalent to $n(1^1S)$ at the spectroscopic measurement position. We are developing an iterative numerical code for the radiation trapping[6] in order to determine $n(1^1S)$ from intensities of 3^1P - 2^1S and 4^1P - 2^1S whose upper state populations are strongly affected by the radiation trapping.

References

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