22P093-P

Spectroscopic study of hydrogen and helium plasmas
水素・ヘリウム衝突輻射モデルによる発光線解析

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For LHD plasmas, using atomic helium collisional-radiative model which includes radiation trapping effect, the electron temperature and density have been determined from emission intensity of helium atoms. The population of 3^1P is dominantly produced by the photo-excitation from the ground state. The contribution of the electron impact transition from the photo-excited 3^1P to 3^1D is nearly the same as the direct electron impact excitation from the ground state to 3^1D. The influence of the photo-excitation on the other excited states is small. For RF hydrogen plasmas at Shinshu University, using molecular hydrogen collisional-radiative model, molecular emission lines have been analyzed.

1. Introduction

Understanding of the reactions of atomic and molecular hydrogen in fusion edge plasmas is essential to improve the performance of the main plasmas and to reduce the heat flux to the divtertor wall. In order to investigate the reactions, we have been developing collisional-radiative (CR) models and neutral transport code for hydrogen and helium species. In the models, the electron temperature T_e and density n_e are input parameters. In this study, we are developing spectroscopic methods to determine them. First, we will discuss an analysis of helium atom emission intensity of LHD plasmas with a helium CR model, in which radiation trapping is considered. Second, we are constructing a CR model of molecular hydrogen, which will be used to determine T_e and n_e as well as helium model. We will discuss an application of the model to RF plasmas at shinshu University.

2. Helium atom spectroscopy for LHD plasmas

Determining T_e and n_e from visible emission line intensities of helium atoms with a CR model is one of widely used methods [1]. However, the radiation trapping effect is neglected in many cases. We have recently proposed a simple and precise method to include the radiation trapping effect in the CR model [2], where the photo-excitation rate from the ground state is included as fitting parameter in addition to T_e and n_e to reproduce measured line intensities. The method was applied to RF plasmas (n_e ~10^{16} m^{-3}) at Shinshu University. Measured intensities of the helium emission lines were well reproduced by the model, and T_e, n_e and the photo-excitation rate were successfully determined. However, because of the low n_e, the contribution of the photo-excitation to the population density except for the singlet p states was small.

In order to test the method for high n_e, we have applied the method to LHD plasmas where the contribution of the radiation trapping to the population density distribution is expected to be not negligible. We have analyzed visible helium line intensities emitted from gas puffed helium atoms in hydrogen plasmas. Figure 1(a) shows measured spectra (Shot No. 98898). Figure 1(b) shows the population densities of the excited states derived from the intensities.

We have estimated the relaxation times of the metastable states 2^1S and 2^3S, and have adopted the quasi-steady-state approximation to 2^1S and 2^3S. Then the population density of the excited state p, n(p) is given by,

$$n(\mathrm{p})=r_1(\mathrm{p})n_{\mathrm{He}}n_e+r_{2\mathrm{p}}(\mathrm{p})n_{\mathrm{He}}I_{2\mathrm{p}}+r_{3\mathrm{p}}(\mathrm{p})n_{\mathrm{He}}I_{3\mathrm{p}}+\cdots \quad (1)$$

where n_{He} is the ground state atom density. The first term on the right side of eq.(1) is the conventional ionizing plasma component. The second and third terms denote the photo-excitation from the ground state to 2^1P and 3^1P, respectively. I_{2p} and I_{3p} denote the excitation rates to 2^1P and 3^1P from the ground state by the photo-excitation per atom.

Figure 1(b) shows the result of the fitting by eq.(1). The experimental population densities are well reproduced. Obtained T_e and n_e are 12.7 eV and $5\text{x}10^{18}\text{m}^{-3}$, respectively. We can understand that these values reflect T_e and n_e at a position where emission intensity is maximum along the line of sight. The population of 3^1P is dominantly produced by the photo-excitation from the ground state. For the population of 3^1D, the contribution of the electron impact transition from the photo-excited 3^1P to 3^1D is nearly the same as the direct electron impact excitation from the ground state. For the other excited states, the contribution of the photo-excitation is small. We could not determine I_{4p} in eq.(1) due to the low intensity of 4^1P-2^1S emission line. However, transitions from 4^1P to other states by electron impact are expected to be small because the population densities of 4^1S and 4^1D are well reproduced by the model. The excitation from the photo-excited 2^1P to other states is negligible for n_e in this plasma.

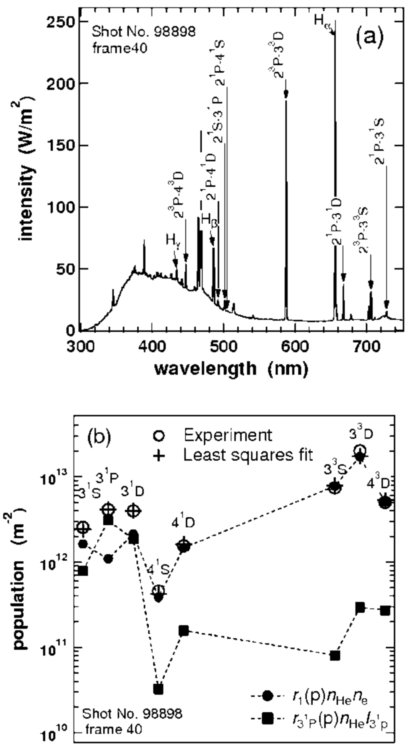

Fig.1 (a) Spectra observed in LHD plasma (Shot No. 98898). (b) Population distribution. Open circles: spectroscopic measurement; plus signs: result of the least-squares fit calculated using eq. (1) with optimized values n_e, T_e, I_{3P}, and n_{He}.

3. Molecular hydrogen spectroscopy for RF plasmas at Shinshu University

Hydrogen RF plasmas were produced by a device at Shinshu University as shown in Figure 2. Figure 3(a) shows emission lines measured by echelle spectrometer. We have identified the wavelength of molecular hydrogen emission lines using data in Ref. [3]. Figure 3(b) shows emission lines calculated by the CR model of molecular hydrogen. The model reproduced the Fulcher band intensity in the experiment well. We are investigating other molecular line intensities using the model.

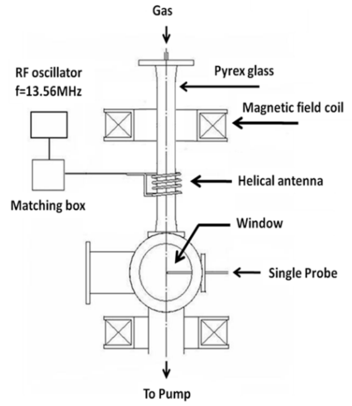

Fig.2 RF Device at Shinshu University

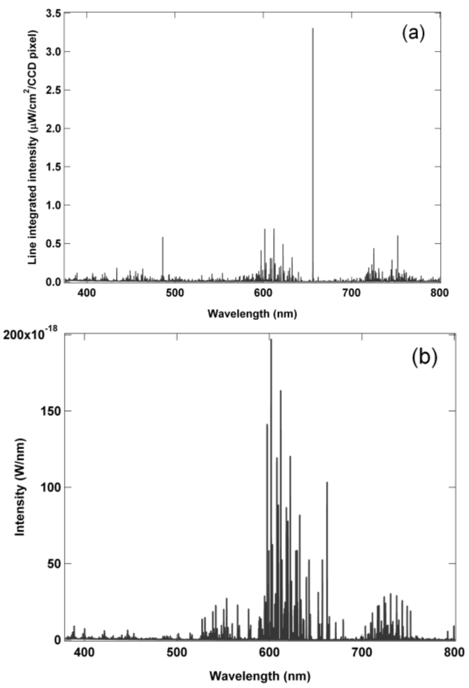

Fig.3 (a) Emission lines of an RF hydrogen plasma at Shinshu University. (b) Calculated emission lines.

References
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