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Optical emission spectroscopic measurement of Fulcher-α band of microwave discharge H_2/D_2 plasma

マイクロ波放電水素/重水素プラズマのFulcher-α帯の発光分光計測

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We measure Fulcher-α band spectrum and determine rotational and vibrational temperatures of microwave discharge H_2 plasma by spectroscopic observation. We discuss difference in dependence of the temperatures on the distance from the microwave launcher based on non-equilibrium characteristics of vibrational and rotational motions.

1. Introduction

Hydrogen plasma has an important role in a variety of engineerings such as material processing and nuclear fusion. For example, in diamond thin film forming process, the hydrogen atoms in the plasma plays an important role in linking the diamond phase of carbon gas phase. The flow of plasma exerts a great influence on the transport phenomena and recycling of the particles around fusion reactor divertor. In observation of hydrogen molecules in the recycling particles, importance of spectroscopic measurement of Fulcher-α band has been discussed [1 – 2]. In the diagnosis of these non-equilibrium characteristics of various plasma– such as non- equilibrium of electron temperature, vibration temperature and rotational temperature – play an important role. In the field of thermonuclear fusion, atomic and molecular processes of hydrogen and deuterium plasma are considered to be essential. Speculation of energy loss in the boundary area of the plasma is necessary.

In this study, we measured various parameters of the microwave discharge plasma of hydrogen by the emission spectroscopy of Fulcher-α band, to obtain the vibrational and rotational temperatures to examine their dependence on the position of the plasma flow.

2. Experimental method

We show a block diagram of the experimental apparatus in Fig. 1. The microwaves generated by the microwave generator, reach the quartz tube transmitted through the waveguide with the adjustment by the matching device. Microwave frequency is 2.45 GHz, the incident power is 350 W, and discharge pressure is 0.5 – 1.0 Torr.

We take the *z*-axis in the direction of exhaust along the quartz tube from the intersection of the waveguide and the tube. We measured the plasma at z = 6, 10, and 14 cm [3].

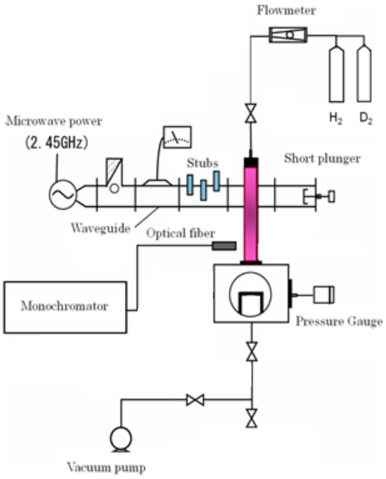

Fig. 1. Block diagram of microwave discharge apparatus and measurement system

3. Optical emission spectroscopic measurement

By performing the spectroscopic measurement of the Fulcher-α band of molecular hydrogen, the rotational-vibrational number density of hydrogen molecules can be obtained. Fulcher-α band is a transition spectrum of $d\,{}^3\Pi_u \rightarrow a\,{}^3\Sigma_g$ of hydrogen molecule and having an emission band at 590 – 640 nm. Vibration and rotational excitation density at Fulcher-α upper level is given by the line intensity Y_λ, the transition probability A, geometric efficiency ε, and the quantum detection efficiency η_λ, determined by the following equation.

$$n_j = \frac{Y_\lambda}{A\varepsilon\eta_\lambda} \qquad (1)$$

We determined quantum detection efficiency and geometric efficiency that appear in the above equation together in the form of a product by using a standard light source [4]. The transition probability values were used literature [5].

The rotational and vibrational temperature of $d^3\Pi u$ state can be defined as Eq. (2) [6].

$$I_{av'J''}^{dv'J'} = \frac{hc}{\lambda_{av''J''}^{dv'J'}} \frac{A_{av'J''}^{dv'J'}}{\sum_{v'',J''} A_{av''J''}^{dv'J'}} \times \exp\left[-\frac{F(J,v)}{kT_{\mathrm{rot}}^{\mathrm{d}}} - \frac{G(v)}{kT_{\mathrm{vib}}^{\mathrm{d}}} \right] \quad (2)$$

4. Results and discussion

We show vibration temperature and rotational temperature of H_2 plasma obtained by Fulcher-α band spectroscopic measurements in Fig. 1 and Table 1. Note that this measurement result is during 1 Torr discharge as an example.

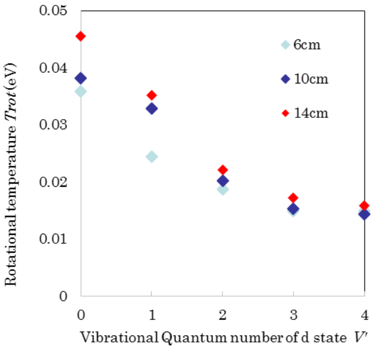

Fig 2. Rotational temperature obtained by Fulcher-α band spectroscopy of H_2

Table 1. Vibrational temperature obtained by Fulcher-α band spectroscopy of H_2

	T_{vib} [eV]
6cm	0.41
10cm	0.40
14cm	0.39

These results show that vibrational temperature is higher by about one order of magnitude than the rotational temperature. This leads that the plasma is in a state of non-equilibrium for the various temperatures [7]. When we compare the rotational temperature at each position, it was found that the rotational temperature increases as the plasma goes to the downstream side. It is considered that, electrons are excited by the energy and relaxation process proceeds along with it to go to the downstram direction. Also, it was found that the rotational temperature becomes smaller for the higher vibrational levels. It is considered that he angular momentum is conserved before and after the electron collision, which results in the lowering of rotational energy with increasing vibratrional quantum number. Dependence on the location was not observed for vibrational temperature. It is considered that electrons cannot reach equilibrium state since the energy level of the excited vibrational state is higher than the rotational excited state.

Concerning vibrational distribution, reduced structure was observed in the vibrational level $v = 4$. It is considered that the dissociation limit exists between the vibrational level $v = 3$ of $v = 4$ on the potential curve of upper state of Fulcher d $^3\Pi_u$.

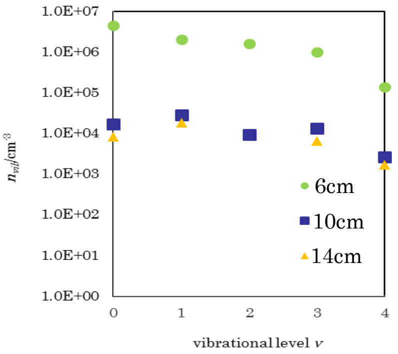

Fig. 3 Measured vibrational population density distribution of H_2 $d^3\Pi u$ state at z = 6 cm with discharge pressure 1 Torr

5. Future prospects

In the field of thermonuclear fusion, to evaluate the characteristics of the hydrogen-deuterium mixed plasma as well as hydrogen plasma and deuterium plasma is also important. We are planning to make a comparison about the emission spectroscopy measurement of Fulcher-α band of plasma of these in the future.

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