Neutral density measurement of microwave cathode by two-photon absorption LIF

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To investigate the neutral xenon density distribution of electric thrusters such as ion thrusters and Hall thrusters, this paper demonstrates two-photon absorbed laser-induced fluorescence spectroscopy (TALIF) using a microwave cathode. At the first measurement, the background pressure of the vacuum chamber is measured by TALIF, which excites the ground state by 224.29 nm laser and detects the 834.68 nm fluoresce. The first measurement confirms that the fluoresce intensities linearly increase with respect to the ground state number densities. Based on the results, the densities of the ground state of neutral xenon are measured at the exit of the nozzle of the microwave cathode. The transition of the densities is successfully measured at the xenon flow rate of 0.029 mg/s and 0.098 mg/s by changing the microwave power. The measured values vary from 2.3×10^{19} m^3 to 8.4×10^{19} m^3 with an error of ±20% at maximum, which is due to the plasma fluorescence.

I.Introduction

FOR the improvement of the thrust performance and the lifetime endurance, it is highly important for ion thrusters and Hall thrusters to optimize neutral propellant particle distribution in thruster design. Japanese microwave ion thruster "μ10" has been improved 30% of thrust by changing the propellant inlets from the waveguide to the discharge chamber.1-3 The lifetime of its microwave cathode was improved by increasing flow rates.4 It is also important for Hall thrusters to suppress the discharge oscillations.5 In order to understand the neutral distribution of electric thrusters, Direct Simulation Monte Carlo (DSMC) simulations have been performed, however, the method requires the assumptions, such as the reflection at the boundary and a neutral temperature.6-8 In addition, it is taken into consideration that the ionization collisions and neutralization on the wall affect the neutral density distribution.

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Therefore, the experimental validation of neutral particles is necessary to give useful information for numerical simulations. In past, Nakayama measured the neutral density inside a gridded ion thruster by using a pressure gauge.9 Although it was successfully measured the neutrals, the technique cannot be applied to the microwave ion thrusters due to the disturbance between microwaves and the metallic probe. The author measured the excited neutral density inside of the microwave ion thruster by coupling an optical fiber with laser absorption spectroscopy, however, the relationship between the excited state the ground state were not investigated.10 Since the most of neutrals situate on the ground state, this study proposes to use Two-photon Absorbed Laser-Induced Fluorescence spectroscopy.11-13 In our group, Kinefuchi succeeded to detect the signal of fluorescence of xenon using a reference cell by changing the laser power.14 This paper is the successive paper that we will apply TALIF to a microwave cathode. As the first measurement in this study, the back ground pressure of a vacuum chamber will be measured by increasing the neutral xenon. Then, in order to convert the signal strength of the detector into the neutral ground state density, the values of the detector are referred for the second measurement, which measure the density at the exit of the nozzle of the microwave cathode without electron extraction.

II.Experiment

Fig. 1 shows the experimental setup for TALIF measurement. The ND:YAG laser is a pumping laser for the Dye laser, which emits 300 mJ of 10 nanosecond pulse laser. The dye laser converts the wavelength from 532 nm to 224.29 nm at 3 mJ to excite the ground state of the neutral xenon $5P^6\ {}^1S_0$ to $6p'\ [3/2]_2$. The power of the dye laser decreases to 1.2 mJ in the vacuum chamber due to the transmittance of the window. As Fig. 2 shows, the excited neutrals emit the 834.68 nm of fluorescence. In this system, two photo multipliers are used. PMT1 is a detector to measure the ground state density of neutral xenon in vacuum chamber. Collection optics for PMT1 focuses the center point of the orifice at 0 mm from the orifice of the microwave cathode. PMT2 is used to synchronize a pulse laser with the oscilloscope as a function of a trigger.

Eq (1) shows the intensity of the fluorescence S_F is proportional to the number density of the neutral ground state n_0 if the laser power I is constant, where B_{20}, B_{02} and A_{21} are Einstein coefficient shown in Fig. 3.[14]

$$S_F = \frac{B_{02} I^2 A_{21}}{(B_{20}+B_{02}) I^2 + A_{21}} n_0 \qquad (1)$$

To obtain the neutral ground density of xenon n_0, S_F will be measured at first without the microwave cathode. The measurement system is same as Fig. 1 and S_F will be measured by changing the background pressure of the vacuum chamber using xenon. The background pressure is equal to n_0, the experiment reveals the relationship between S_F and n_0. The results will be used for the following measurement of the microwave cathode.

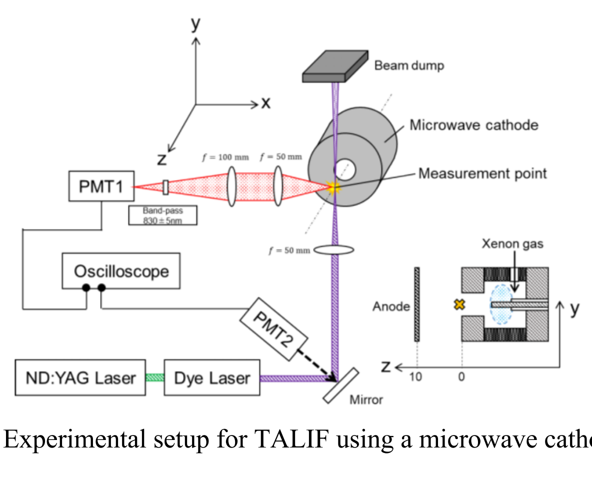

Fig. 1 Experimental setup for TALIF using a microwave cathode.

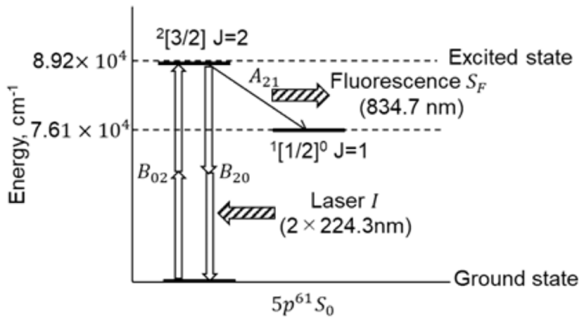

Fig. 2 The grotrian diagram of Xe I.

III.Result

Fig. 3 shows the transition of the signal of the photo multiplier shown as PMT1 in Fig. 1 with respect to the background pressure of the vacuum chamber. The signal of PMT1 linearly increased with respect to the back ground pressure of the neutral xenon. The signal strength will be referred in a following measurement.

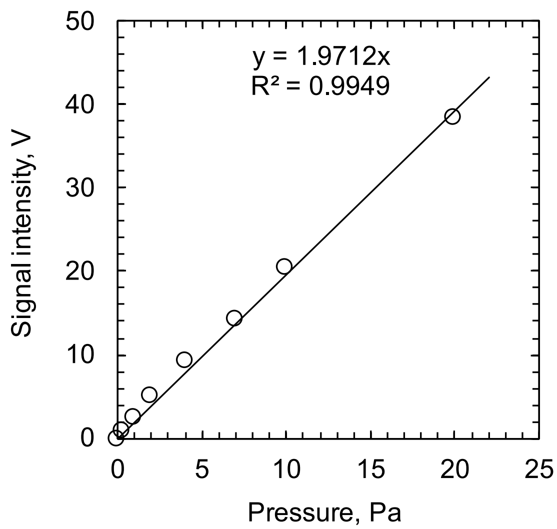

Fig. 3 The signal strength of the photo-multiplier with respect to pressure of Xenon for the of the calibration for TALIF measurement using a vacuum chamber.

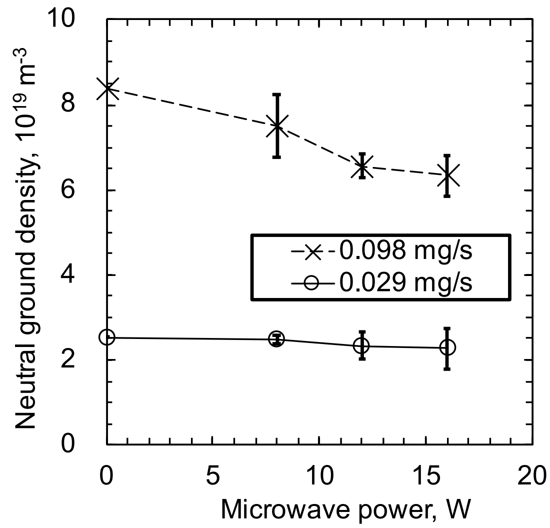

Fig. 4 Neutral grand density at the exit of the nozzle of the microwave cathode without electron extraction by changing microwave power at the mass flow rate of 0.029 mg/s and 0.098 mg/s. There is no plasma at 0 W.

Fig. 4 shows the results of the measurement at mass flow rate of 0.029 mg/s and 0.098 mg/s by changing the input microwave power from 0 W to 16 W. 0.029 mg/s was the minimum flow rate to maintain microwave plasma in the cathode, which is used for comparison with 0.098 mg/s. Each point shows the average of three data sets of measurements, and the error bars show the deviation of the data, which were approximately ±4% to ±20%. It is presumed that the error was caused by the fluoresce from the microwave plasma in the cathode. A bandpass filter, which was set in front of the PMT1 could not completely cut the plasma luminescence. When there was no plasma at 0 W, the deviation was too small and could not be shown in Fig. 4.

Regarding the both flow rates, the neutral ground density decreased with respect to the microwave power. At 0 W and 0.098 mg/s, the densities were recorded at highest, which is 8.4×10^{19} m^3. Then it decreased to 7.5×10^{19} m^3 at 8 W, 6.5×10^{19} m^3 at 12 W, and 6.3×10^{19} m^3 at 16 W, as the ionization rate increased due to the increase of input microwave power. As for the 0.029 mg/s, the density was 2.5×10^{19} m^3 at 0 W, and at 8 W, and it slightly decreased to 2.3×10^{19} m^3 at 12 W, and at 16 W.

The decrease ratio of the neutral ground density from 0 W to 16W at 0.098 mg/s was higher than 0.029 mg/s. Since 0.029 mg/s was the minimum flow rate to maintain the plasma, ionization did not change with respect to microwave power. At 0.098 mg/s, there was plenty amount of neutrals in the cathode, the ionization rate increased as the microwave power increased.

IV.Conclusion

In this study, two-photon absorbed laser-induced fluorescence spectroscopy was applied to the nozzle of the microwave cathode. The following conclusions can be made:

1. The relationship of fluorescence intensities and the ground state density was experimentally investigated. The intensities increased linearly with respect to the number densities.
2. In the measurement of the microwave cathode, 1019 m3 order of the ground state densities were success fully measured at 0.029 mg/s and 0.098 mg/s
3. The measurement error was ±4% to±20%, which is due to the noise of plasma fluoresce.

Acknowledgments

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