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Development of laser absorption spectroscopy system for velocity distribution measurement in Ar arcjet plasma

アルゴンアークジェットプラズマの速度分布計測のためのレーザー吸収分光システムの開発

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We developed a laser absorption spectroscopy system for measuring the flow velocity of the argon arcjet plasma. The wavelength employed for absorption measurement was 794.8-nm transition, and the spectral profile were readily scanned by a laser diode. We also constructed a handmade Fabry–Pérot interferometer to obtain calibration signals for spectral line-width measurement of the arcjet plasma. The free spectral range of the Fabry–Pérot interferometer was determined by Doppler-free saturated absorption signal of rubidium atoms.

1. Introduction

Arcjet plasmas have been studied for fundamental hydrodynamics, space thrusters, and disposal treatments. Shock wave in arcjet plasma is an interesting target for studying shock-wave formation dynamics because it is in a macroscopic steady state. Recently, we observed the shock cell formation in a helium arcjet plasma expanding through a supersonic conical nozzle [1]. Furthermore, we have observed a helical shock wave without any magnetic field in the arcjet [2]. To investigate the dynamics of the helical shock wave, measurement of a spatially-resolved velocity distribution of atoms in the plasma is indispensable.

In the present study, we developed an optical system for flow velocity measurement of atoms in the arcjet plasma by means of a laser absorption spectroscopy. The absorption wavelength is set to 794.82 nm, which is one of the 4s-4p transitions of metastable argon atoms. This wavelength can be easily obtained by the commercial laser diode. For the velocity measurement, the wavelength calibration should be performed carefully. To this end, we constructed a handmade Fabry-Pérot interferometer. In this paper, we report a characterization of the interferometer by performing saturated absorption spectroscopy of D1 line (794.76 nm) of atomic rubidium.

2. Experiment

Schematic of the experimental setup is shown in Fig. 1. A single-mode laser diode (90 mW, 785 nm, Thorlabs, L785P090) was attached on an optical mount (Thorlabs, TCLDM9) and controlled by temperature and current controller (Thorlabs, TED200C and LDC205C). To generate 795-nm emission, the temperature of the laser mount was set to 41.0 °C. The laser wavelength was scanned by 10-Hz ramp-wave current modulation using a function generator. An optical isolator was inserted to prevent return light into the laser diode.

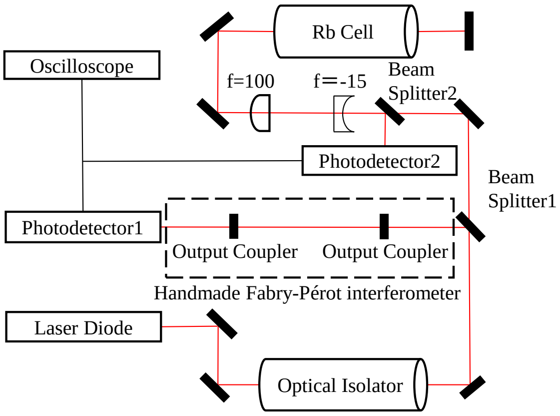

Fig.1. Schematic for performing FSR calibration of the Fabry–Pérot interferometer by saturated absorption spectroscopy of rubidium.

Thirty percent of output after passing through the optical isolator was fed into the handmade Fabry-Pérot interferometer that was composed of two output couplers (90% reflection, Layertec, 100447). The distance between the couplers was about 30 cm, which corresponds to 0.5-GHz free spectral range (FSR). Output signal from the interferometer was detected by photodetector-1. Angles of output couplers were carefully adjusted to obtain clear interference signals.

For a precise calibration of the FSR of the interferometer, we performed saturated absorption spectroscopy of rubidium atoms. Rubidium gas cell was heated to 70 °C to vaporize atoms. The laser light expanded its diameter by a pair of spherical lenses was introduced to the gas cell. Subsequently, the output laser beam was returned to the same path to obtain the Doppler-free saturated absorption signals, again. Finally, the laser was separated by the beam splitter, and detected by photodetector-2. The signals of photodetector-1 and -2 were simultaneously recorded by a digital oscilloscope.

3. Results and Discussion

Signals measured around rubidium D1 line are shown in Fig. 2. Some sharp dips were observed at peak positions of the absorption signal. Each dip can be assigned to a hyperfine transition or its crossover signal of D1 lines [3,4]. Here, the crossover signal is known to appear at the central position between two-neighboring transitions in the same isotope. The transitions assigned are also shown in Fig. 2.

The horizontal axis of obtained signal was converted from time into frequency by using the transitions on the saturated absorption signal. We performed linear fitting using all the observed transitions and crossover signals. The linearity of unit conversion was sufficient in the observed wavelength region.

The FSR of the Fabry-Pérot interferometer was evaluated by the frequency difference between neighboring interference peaks. The averaged value of FSR was determined to 0.501 ± 0.015 GHz. Assuming the temperature of argon arcjet plasma is 1000 K, we expect the Doppler-width of 1.35 GHz. This width will be sufficiently calibrated with the interferometer constructed here.

4. Conclusion

We developed a laser absorption spectroscopy system for flow velocity measurement of argon arcjet plasma. For calibration of laser wavelength, we constructed a handmade Fabry-Pérot interferometer and determined precise free spectral range by performing saturated absorption spectroscopy of rubidium D1 lines. As a result, the optical system developed will be applicable to the velocity measurement for the arcjet plasmas.

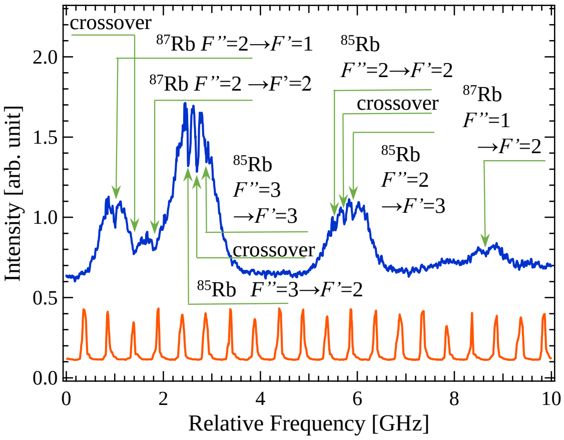

Fig.2. Saturated absorption signal of rubidium atoms (upper curve) and interference signal from the Fabry–Pérot interferometer (lower curve).

References

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