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Study of the Plasma Behavior in One-Tesla Magnetic Field
1T 磁場下におけるレーザー生成プラズマの振る舞いに関する研究

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The behavior of the laser-produced plasma in one-tesla magnetic field was investigated by observing the plasma emission and the spatial distribution of the ion current. By comparing the plasma emissions with and without a magnetic field, it was confirmed that the magnetic field changes the momentum of the plasma. Moreover, the existence of the optimum strength of the magnetic field was confirmed.

1. Introduction

The Mars exploration is expected to elucidate the formation processes of the earth. However, it takes long time to Mars by using existing rockets, so that a high-power and low-fuel-consumption rocket is preferable to shorten the mission time. Laser Fusion Rocket (LFR) is expected as the rocket achieving the conditions at the same time. As the design concept, A Vehicle for Interplanetary Space Transport Application Powered by Inertial Confinement Fusion (VISTA) is proposed by Lawrence Livermore National Laboratory (LLNL) [1]. However, in this proposal, the mechanism of the thrust generation system, called magnetic thrust chamber, is not demonstrated. In our previous experiments, the magnetic thrust chamber was demonstrated by directly measuring the impulse bit from the interaction between laser-produced plasma and a magnetic field of a permanent magnet [2]. However, the detail physical phenomenon of the interaction between the plasma and the magnetic field was not measured here. In this paper, we report the observation of the laser-produced plasma behavior in a magnetic field to measure the interaction between the plasma and the magnetic field.

2. The Mechanism of Thrust Generation

Magnetic thrust chamber changes the momentum of plasma by a magnetic field. Figure 1 shows the mechanism of the generation of the thrust. (a) The plasma expands in the magnetic field of an electromagnetic coil. (b) Then the plasma forms the diamagnetic field to cancel out the coil magnetic field. (c) As a result, the coil gains the thrust due to the Lorentz force by the coil current and the diamagnetic field.

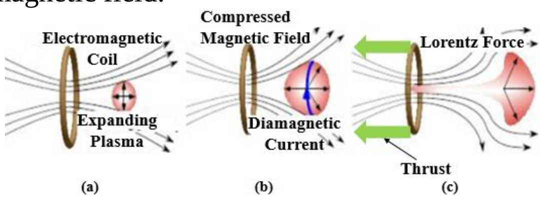

Fig. 1. The mechanism of thrust generation of magnetic thrust chamber

3. Experimental Setup

This experiment was performed at Extreme Ultra-Violet (EUV) database of Institute of Laser Engineering (ILE) in Osaka University. Nd:YAG laser (wavelength of 1064 nm; pulse width of 8.9±1.1 ns; laser energy of 5.7±0.8 J) irradiates the spherical polystyrene target with the diameter of 500 μm. The electromagnetic coil (inner diameter of 26 mm; outer diameter of 50 mm) is set apart from 11 mm from the target. It can generate up to about 1 T at the target position.

To observe the spatial distribution of the ion current, Faraday type charge collectors (CC) are set as shown in Fig. 2 to measure the ion current as a function of time. Because the ion current, I_t, is equal to the increase of the ions colliding with the collector in unit time, *dN/dt*, it can be expressed by Eq (1).

$$I_t = V_i / R = \bar{Z}e\, dN/dt \quad , \qquad (1)$$

where V_i is the output voltage, R is the resistance, $\bar{Z}$ is the average degree of ionization, and e is the elementary charge. The average degree of ionization is set as four from the past experiment using Thomson parabola [3].

In addition, we observed the plasma emission with the wavelength of 660 ± 10 nm 0.3 μs and 1.5 μs after the plasma generation by using Intensified Charge Coupled Device (ICCD) cameras as shown in Fig. 2.

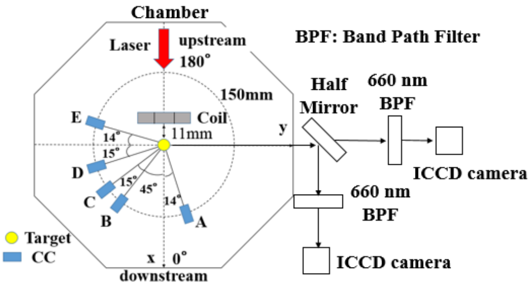

Fig. 2. The experimental setup for the measurement of the ions and the observation of the plasma emission.

4. Result and Discussion

Figures 3 and 4 show the plasma emission with the magnetic field of 0 T and 0.99 T at 0.3 μs and 1.5 μs after the plasma generation, respectively. Without the magnetic field, Fig. 3 shows that most plasma collides with the coil at 0.3 μs and diverges with large divergence angle to the right at 1.5 μs. On the other hand, with the magnetic field, the plasmas colliding with the coil decrease and the plasma layer, apart from the coil by 8.58 mm, where the expansion of the plasma stops is observed at 0.3 μs (See Fig. 4). The distance between the layer and the coil saturates around 0.8 T as shown in Fig. 5 (dash line). Furthermore, Fig. 4 shows that the plasma flows to the right with small divergence angle at 1.5 μs.

It is preferable that a lot of ions diverge downward with small divergence angle to increase the thrust efficiency. Therefore, we next observe the change of the number of the ions downward (at B in Fig. 2) with respect to magnetic field as shown in Fig. 5 (solid line). It shows that the increase of the number of the ions saturates around 0.5 T.

The remarkable point is the existence of the optimum strength of the magnetic field for the thrust efficiency. The plasma layer between the coil and expanding plasma indicates that the magnetic pressure is balanced with the plasma pressure. The distance between the plasma layer and the coil saturates around 0.8 T, which the total number of the ions at B saturates near there. It indicates that the optimum strength of the magnetic field for maximizing the thrust efficiency is about 0.5 - 0.8 T.

For further research, the plasma parameters, the temperature and the density, is measured to investigate how the optimum strength of the magnetic field changes with the plasma parameters.

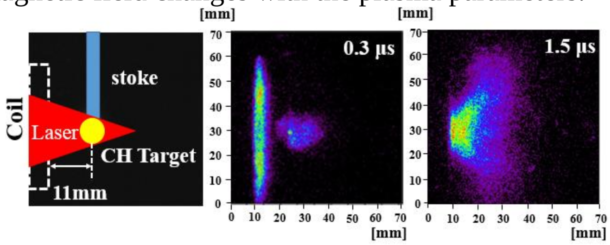

Fig. 3. Plasma emission without magnetic field.

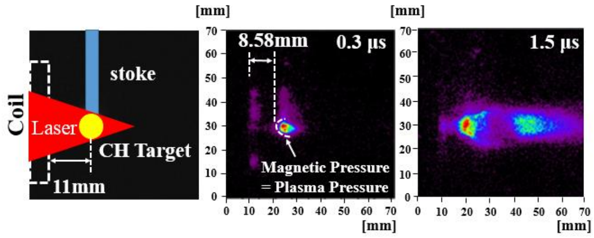

Fig. 4. Plasma emission with magnetic field of 0.99 T.

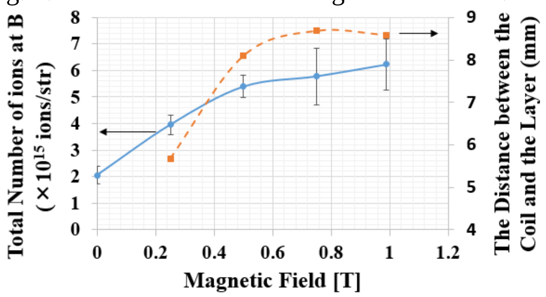

Fig. 5. The total number of the ions at B in Fig. 2 (solid line) and the distance between the surface of the coil and the plasma layer (dash line) with respect to magnetic field.

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