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Spectroscopic Measurement of Lithium Plasma Generated by Counter-Facing Plasma Focus System

同軸対向型プラズマフォーカスにより生成されたリチウムプラズマの分光計測

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A plasma focus system with counter facing electrodes was proposed for high energy density plasma creation with long-pulse and/or repetitive high energy density plasma source. We adopted Li as the plasma source which has a narrow and strong spectral line at 13.5nm. In addition, for improvement of the radial uniformity and synchronous operation of the current sheets, a system of laser-assisted discharge was applied. Prior to the facing operation, one of the pair electrodes was energized at positive and negative polarity, to examine the basic operating characteristics. We performed spectroscopic measurement of the focus plasma and emission of the 13.5 nm line was observed at both polarities.

1. Introduction

Recently radiation from high-energy-density plasma is attracting our attention as an Extreme Ultra-Violet (EUV) light source for the next generation semiconductor process. Because they are cost effective and simple, EUV light sources based on high-energy-density discharge plasma have an advantage compared with laser-produced plasma. High average power and conversion efficiency are indispensable for a practical use of extreme-ultraviolet (EUV) light source. However, despite recent efforts in developing a discharge-produced EUV plasma source, an efficient and repetitive light source remains to be realized.

To improve the energy conversion efficiency, we would like to extend the radiative time of source plasma. Then we intend to prolong the lifetime of plasma.[1,2] Previous work achieved the EUV emission of ~10 μs using counter-facing plasma guns.[3] In this study, we apply a counter-facing plasma focus system and adopt Lithium as the plasma source which has a narrow and strong spectral line at 13.5nm. Li plasma is produced by laser-assisted discharge of which laser energy is completely lower than the energy of discharge.

We conducted the spectroscopic measurement of the plasma at EUV region using a grazing-incidence flat field spectrometer in the counter-facing plasma focus system. The purpose of this study is to explore the optimum operating parameters through the spectroscopic measurement, especially the emission of 13.5 nm-line.

2. Experimental Setup

Figure 1 shows an anticipated behavior of the plasma focus system. In this system, gas or/and plasma of Li is produced by laser ablation, which induces trigger of the discharge. Current sheets generated by the discharges were accelerated to the top of center electrodes by the magnetic pressure (J

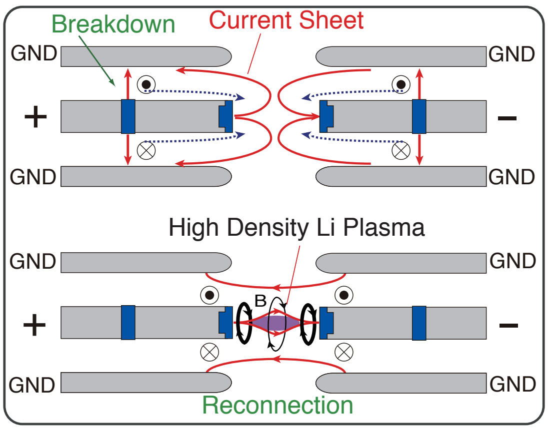

Fig. 1 Schematic diagram of counter–facing coaxial plasma focus system

$\times$B) and collide between the electrodes. Because voltage pulses with opposite polarities can drive a discharge between the center electrodes, the current sheets should be reconstructed and shrunk into an ellipsoidal shape after the collision. Self-magnetic pressure should compress the plasma, while the magnetic pressure gradient should suppress particle loss in the axial direction. Hence the current path should create a stable condition, the plasma becomes dense and high temperature. In order to achieve the stable condition, it is necessary that the uniform current sheets in the radial direction are exhausted at the same timing from both side guns. The laser assisted discharge system is expected to have a potential to produce such condition of the plasma sheets.

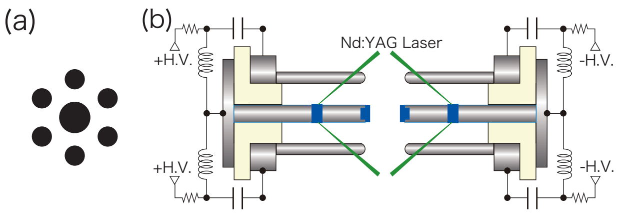

Fig. 2 Schematic of (a) electrodes arrangement and (b)plasma focus and current drive systems

Figure 2 schematically depicts the experimental arrangement. The plasma focus system consists of a pair of plasma guns. The center-electrodes are charged by plus and minus, respectively, which have hollow at the top and groove at the position of 20mm from the top, to implant Li. The outer-electrode is composed of 6 rods arranged cylindrically. 6 capacitors were connected between every outer-electrode and the common center-electrode, hence independent electric discharge circuits are formed. The capacitors charged with high voltage DC power sources are used to drive the discharges.

A Q-switched Nd:YAG laser operating with a single pulse mode, 532 nm wavelength and 15 ns pulse width, was focused on the Li source at middle of the inner-electrode. A grazing-incidence spectrometer, which has a concave grating (No.001-0437, HITACHI) and a Micro Channel Plate (F2223-21P, HAMAMATSU), was used for the observation of plasma.

3. Results

In this study, prior to facing operation, the follow of electrodes was energized at positive and negative polarity. We performed spectroscopic measurement of the plasma to examine the operating characteristics, in particular, polarity effect on the spectrum output. Typical charged voltage of capacitors was 3kV, or 7kV and the laser energy was 8.0×10^8 W/cm^2, or 12.8×10^8 W/cm^2.

Fig. 3 shows the emission spectra measured with this system. As shown, emission of 13.5 nm was observed at each of polarity. This result shows that the system has capability of Li supply to the pinching region. Even the one-sided operation of guns, it was able to produce high temperature plasma enough to radiate the EUV at 13.5 nm. This means that radiation duration of 13.5 nm from Li plasma can be extended to microseconds by using the counter-facing systems.

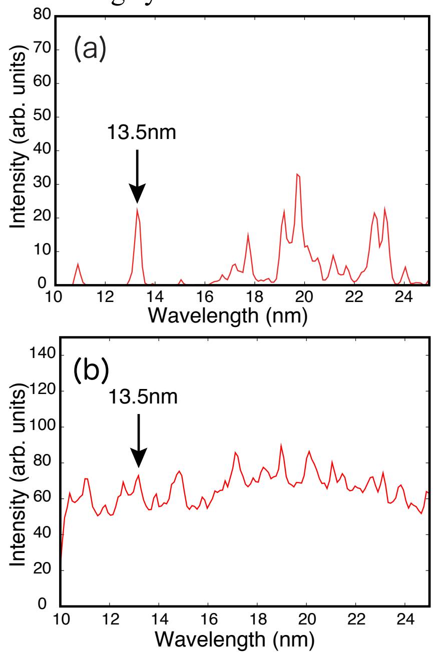

Fig. 3 Emission spectra of 13.5 nm at (a) positive and (b) negative polarity

4. Summary

We proposed a counter-facing plasma focus system, in which Li was adoped as the plasma source. On this system, Li plasma was produced by laser-assisted discharge of which laser energy is completely lower than the energy of discharge. Prior to facing operation, we investigated the emission characteristic of EUV with one-sided operation. With both of polarity, emission of 13.5 nm was confirmed. This indicates that the counter-facing plasma focus system has potential to prolong the radiation of 13.5 nm from Li plasma for more than several microseconds.

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