

ELECTRON DENSITY OF HIGH-PRESSURE ARGON PLASMA PRODUCED BY XeCl EXCIMER LASER

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Abstract

When a XeCl excimer laser light was focused in high-pressure Ar gas up to 150 atm, a dense plasma was produced. The interferometer measurement was carried out to study the physical properties of the laser-induced plasma. The electron density was measured by a Mach-Zender laser interferometer. The extremely dense plasma with an electron density of the order of 10^{27} m⁻³ was obtained. The electron density at the focal spot was hardly saturated up to 150 atm when the laser power was 15 MW. The electron density was observed not only at the back but also at the front. The electron density was highest at the focal spot. The forward electron density was higher than the backward one. It was found that the dense plasma could be produced relatively easily when the excimer laser light was focused in high-pressure gas.

1. Introduction

When a laser light is focused in a high-pressure gas, a dense plasma is produced. Various studies about the breakdown threshold of laser-induced plasma [1,2] and the interaction between the laser light and the plasma [3] have been carried out. The high-pressure plasma produced by a visible laser developed backward, toward a focusing lens from the focal spot [4]. The laser-induced plasma may be able to use the laser-induced plasma bridge gap switch [5,6].

With the development of an excimer laser, a high power ultraviolet light is easily utilized. Then, the high-pressure plasma is produced by focusing a XeCl excimer laser. It develops not only backward but also forward [7].

It is important to study the physical properties of dense plasma produced by focusing the ultraviolet laser in high-pressure gases, because the dense plasma can be easily produced. However, the property of the plasma produced by the excimer laser has not been enough studied yet. Then, we carry out an interferometer measurement of the laser-induced plasma.

The extremely dense plasma with an electron density of the order of 10^{27} m⁻³ is produced. The electron density is hardly saturated up to 150 atm when the laser power is 15 MW. The electron density is observed not only at the back but also at the front. The forward electron density is higher than the backward one.

It is found that the dense plasma can be produced relatively easily when the excimer laser light is focused in the high-pressure gas.

2. Experimental arrangement

A schematic of the experimental set up is shown in Fig. 1. The XeCl excimer laser with a wavelength of 308 nm, a maximum power of 17 MW and a full half-width of 30 ns is used.

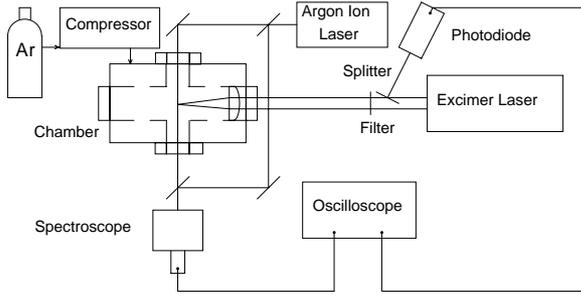


Fig. 1. Schematic view of experimental setup.

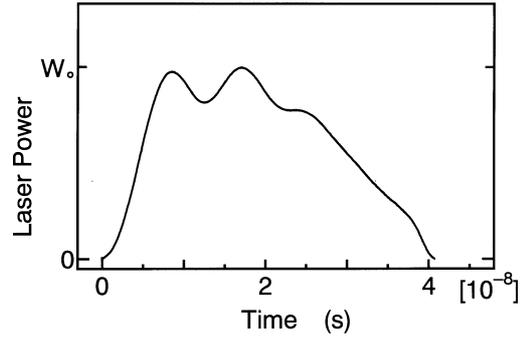


Fig. 2. The waveform of laser pulse.

The output power of the laser radiation is controlled using an optical filter, and the laser light is focused at the center of the high-pressure gas chamber by the lens with a focal length of 40 mm. As the laser light is a rectangle of 11×24 mm, the focused laser light at the focal spot makes an ellipse of 120×80μm. The waveform of laser pulse is shown in Fig. 2. After the gas chamber has been evacuated below 0.1 Pa by a rotary pump, it is filled with high-pressure Ar gas by a compressor. The pressure ranges from 1 to 150 atm.

The electron density of laser-induced plasma is measured by a Mach-Zender interferometer using an Ar-ion laser. The Ar-ion laser is operated with a wavelength of 488 nm and a maximum power of 10 mW. The spatial distribution of electron density is measured by adjusting the position of mirror and a splitter on a stage with a micrometer.

3. Electron density

The electron density of laser-induced plasma is measured by the Mach-Zender interferometer. The time variation of the interferometer signal is shown in Fig. 3. The upper three signals in this figure are interferometer signals and the lowest signal is the waveform of laser pulse. When the gas chamber is evacuated, the change in interferometer signal is not observed. The number of fringe increases as the pressure increases. But it is difficult to find out a turning point in the fringe pattern at which the electron density reaches a maximum. Therefore, we estimate the peak electron density by extrapolating the observed electron density up to the time when the excimer laser pulse is terminated.

In order to estimate the electron density from the fringe pattern, it is necessary to know the optical length of the probe laser in the plasma, that is, the radial size of the plasma. The plasma radius is observed using a streak camera. It is measured through an upper window of the gas chamber. Observed plasma radius is shown in Fig. 4. The solid line indicates the calculated light channel of the focused laser and the black circle the measured plasma radius. The theoretical

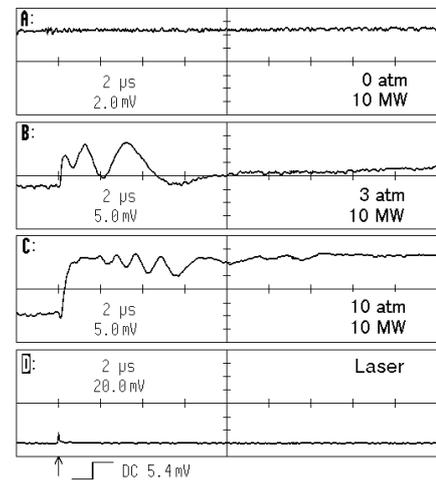


Fig. 3. Time variation of interferometer signals.

radius of the light channel is calculated assuming the laser light to be a Gaussian distribution. The plasma radius at the back is nearly equal to the calculated light channel. However, the plasma radius at the front is much smaller than the light channel, because of the self-focusing effect of the laser light by the plasma. This phenomenon is observed at every pressure. The electron density is calculated using the optical path length obtained experimentally at each position on the optical axis.

The pressure dependence of peak electron density at the focal spot is shown in Fig. 5. The solid line indicates the initial gas atom density. The electron density increases with increasing pressure. The extremely dense plasma with an electron density of the order of 10^{26} - 10^{27} m^{-3} is obtained. However the electron density saturates and decreases when the pressure is above 100 atm and the laser power is lower.

The electron density of plasma produced by the ultraviolet laser is higher than that by the visible laser. Since the frequency of the visible laser was lower than the plasma frequency, the laser light was absorbed only surface of the backward plasma. Therefore, the electron density was saturated above 10 atm. But the ultraviolet laser light can transmit through the plasma because the frequency of the XeCl excimer laser is above 3 times higher than the plasma frequency. Therefore, the electron density is hardly saturated up to 150 atm when the laser power is 15 MW.

The laser power dependence of peak electron density at the focal spot is shown in Fig. 6. The electron density increases with increasing the laser power. After that, the electron density saturates.

The electron density is calculated using the simple rate equation involving the collision

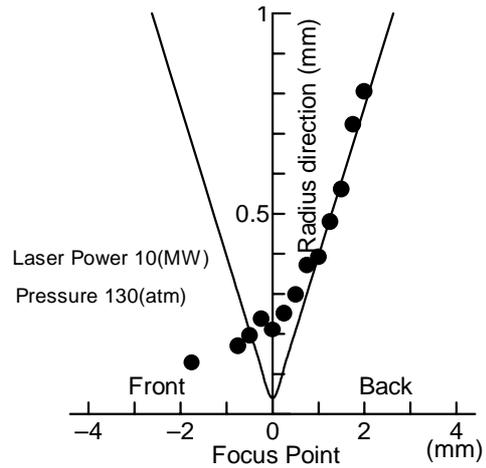


Fig. 4. Observed plasma radius.

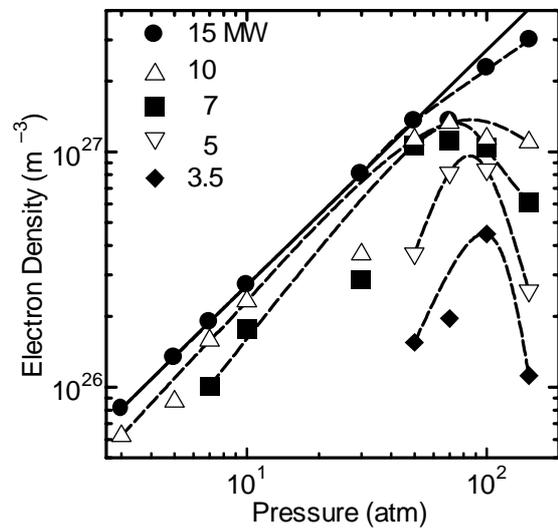


Fig. 5. Pressure dependence of peak electron density at the focal spot.

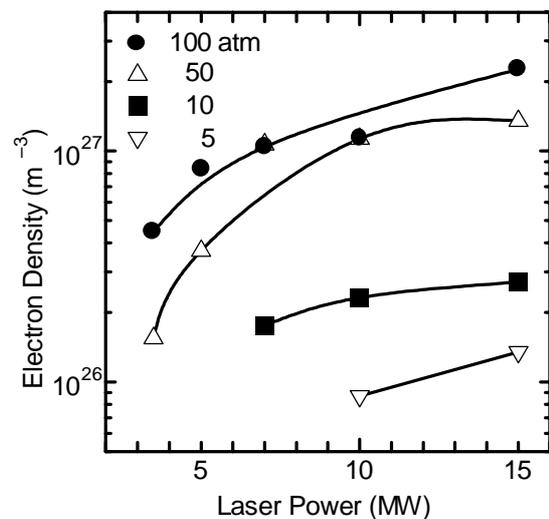


Fig. 6. Laser power dependence of peak electron density at the focal spot.

ionization and the two-electron, three-body recombination processes in order to know why the degree of ionization is saturated and decreased at the higher pressure. The time variation of calculated electron density is similar to the waveform of laser pulse. The calculated electron density increases with increasing pressure, after that it is saturated same as the experimental result, but the electron density is not decreased in this calculation. The saturation of the electron density causes by increasing the number of recombination process.

The electron density is observed not only at the back but also at the front. The spatial distribution of the electron density is depicted in Fig. 7. The laser intensity is highest at the focal spot, so the electron density is highest there. The forward electron density is higher than the backward one.

4. Conclusion

When a XeCl excimer laser light was focused in high-pressure Ar gas, a dense plasma was produced. The interferometer measurement was carried out to study the physical properties of the plasma produced by the excimer laser.

When the laser power was 15 MW, the extremely dense plasma with an electron density of the order of 10^{27} m^{-3} was obtained. The electron density at the focal spot was hardly saturated up to 150 atm when the laser power was 15 MW. However the electron density saturated and decreased when the laser power decreased and the pressure increased above 100 atm.

The electron density produced by the ultraviolet laser was observed not only at the back but also at the front. The electron density was highest at the focal spot. The forward electron density was higher than the backward one.

It was found that the dense plasma could be produced relatively easily when the excimer laser light was focused in the high-pressure gas.

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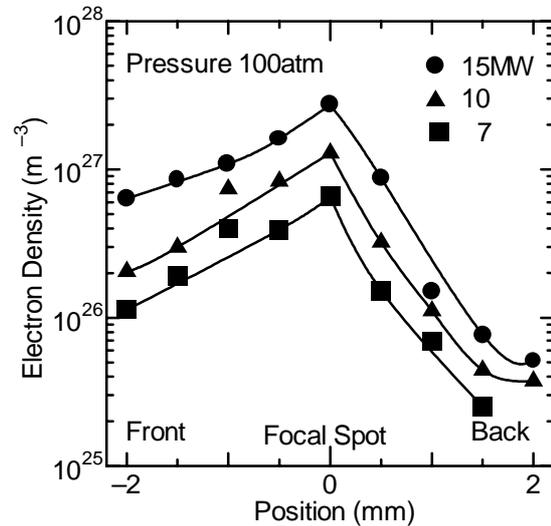


Fig. 7. Spatial distribution of electron density.