The characteristics of laser plasma produced in liquid under pressure

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The plasma was produced by focusing YAG laser in liquid under pressure and the plasma property was studied. The YAG laser was used in this experiment. The ultra pure water dissolved with NaCl was used as a test liquid, and the NaCl concentration was changed up to 16 %. The water was pressurized up to 15 atm by nitrogen gas. The electron density was measured by using a laser interferometer. The electron density in ultra pure water was proportional to the about 1/3 powers of pressure. The electron density in NaCl aqueous solution also increased with increasing pressure. The rate of increase was smaller than that in ultra pure water. This implies that dense plasma could be produced using even same laser power. The pressurizing was advantage in production of dense plasma.

1. Introduction

Although a large number of studies have been made on laser-induced plasma on solid surface or in gas, [1, 2] little is known about laser-induced plasma in liquid. One of the applications is to improve the quality of water [3] by resolving environmental materials.

The ultra pure water was dissolved with NaCl and the concentration was changed. The NaCl was used as a substitution of environmental materials. When a YAG laser beam was focused in liquid, dense plasma was produced. In this study, the plasma is produced by focusing YAG laser in liquid under pressure up to 15 atm by nitrogen gas.

2. Experimental arrangement

The experiment arrangement to measure the electron density is shown in Fig. 1. The maximum laser energy of YAG laser is 350mJ with a wavelength of 1064nm and a pulse half width of 15 ns. Moreover, the YAG laser is able to drive the second harmonic oscillation with energy of 180mJ, a wavelength of 532nm and a pulse half width of 15ns. The ultra pure water dissolved with NaCl is used as a test liquid. The NaCl concentration is changed from 0% to 16%. The pressurizing gas is

Nitrogen and the target water is pressurized up to 15atm. The YAG laser light is focused from the outside of the chamber using the lens of the focal length 60mm. The diameter of focal spot is 120µm for 1064nm and it is 80µm for 532nm. The laser power is controlled using the optical filter. The electron density of laser induced plasma is measured by a Mach-Zender interferometer. The Ar-ion laser is used as a probe laser of the interferometer. When the electron density distribution is measured, the experiment is carried out adjusting the position of the focusing lens and the chamber on an X-stage with a micrometer.

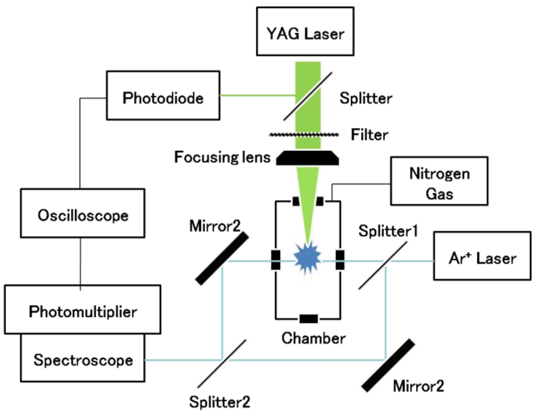


Fig. 1 Experimental arrangement.

3. Electron density

The interferometric signal is shown in Fig. 2. As the electron density is high, it is difficult to find out a turning point in the fringe pattern because the probe laser beam for measurement is almost absorbed or scattered by the plasma. Thus, the peak time of the interferometric signals plots to time and the maximum fringe number is obtained by extrapolating the fringe number until the end of laser pulse from the time that the interferometric signal is not varied. An example of the extrapolation is shown in Fig.3. The maximum electron density is estimated from the following equation by maximum fringe number F_L.

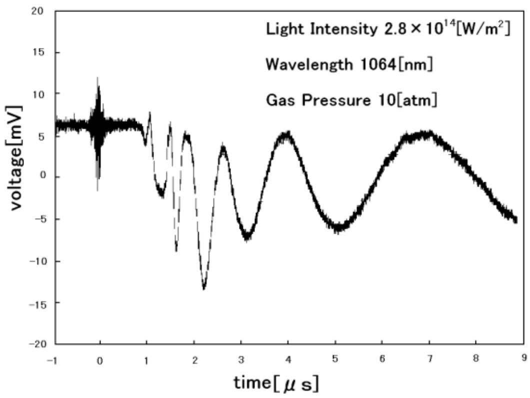


Fig. 2 Interferometric signal

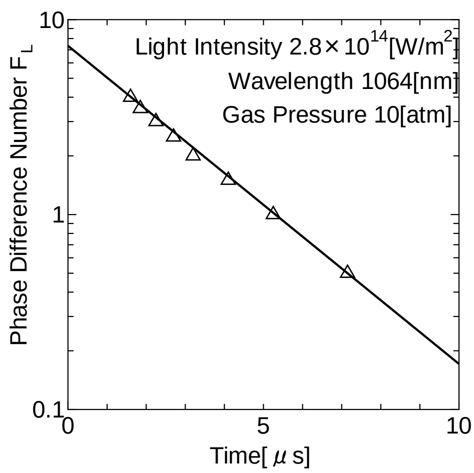


Fig. 3 Example of extrapolation.

The electron density is caluculated by

$$n_e = 2.18 \times 10^{15} \frac{F_L}{L\lambda}, \qquad (1)$$

where n_e is electron density, L is optical length of the probe laser and λ is wavelength of the probe laser. The optical length L necessary to estimate electron density from the fringe number is calculated from theoretical optical path of Gaussian beam of YAG laser.

The spatial distributions on optical axis of the electron density are shown in Fig. 4 a), b), c). When the pressure is 15 atm, the electron density of the order of 10^{26} m^{-3} is obtained in Fig4 a. Since the laser intensity is highest at the focal spot, the electron density is highest there. The electron density is increased with increasing the pressure.

3-1. Wavelength dependency

The wavelength dependence of electron density shows in Fig. 4 a), b). The ratio of decrease of electron density at 532 nm is bigger than that at 1064 nm. This is caused from the deference of the beam sectional area, because the sectional area of laser beam of 532 nm is large, and the spot size of this is small.

3-2. Pressure dependency

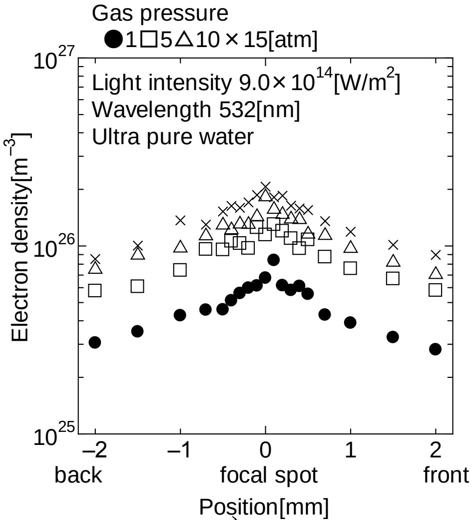
The pressure dependence of electron density shows in Fig. 4 b), c). The laser induced plasma in water is produced easily by pressurizing. The electron density is increased with increasing the pressure. The electron density of laser induced plasma in NaCl dissolved solution is lower than that in ultra pure water, because the collisions cross section of Na atom is large and the energy loss is increased.

The gas pressure dependence of electron density at the focal spot is shown in Fig. 5. The electron density in NaCl aqueous solution also increased with increasing pressure, although the ratio of increase was smaller than that in ultra pure water. The electron density does not saturate in this experimental condition.

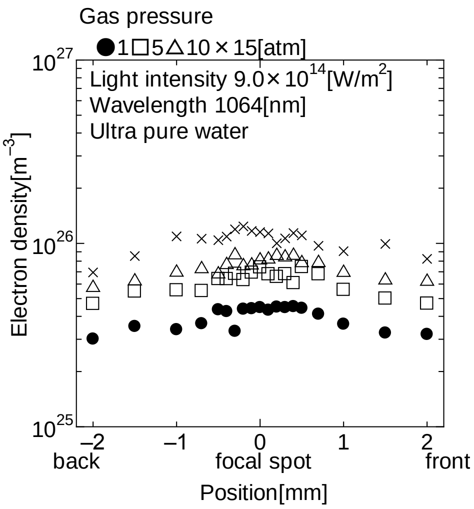
The electron density in ultra pure water is proportional to the about 1/3 powers of pressure, because the speed of the state change from water to plasma is fast, and the change is transitional as the pressure in plasma and the pressure from outside does not come to equilibrium.

4. Conclusion

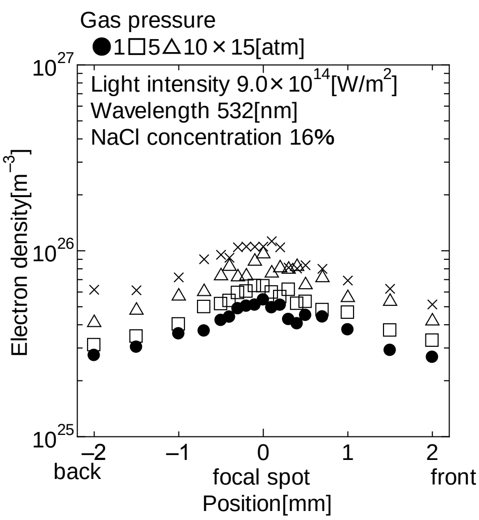
When YAG laser beam is focused in liquid under pressure, the physical properties of the plasma in liquid is studied. The interferometric measurement is carried out to estimate the electron density distributions of plasma in liquid. The electron density of the order of 10^{26} m^{-3} is obtained at the focal spot. The electron density in ultra pure water is proportional to the about 1/3 powers of pressure. When the Nitrogen pressure is 15 atm, the electron density reaches about 3 times higher than the electron density of laser induced plasma under the atmospheric pressure.



a)



b)



c)

Fig. 4 Spatial distribution of electron density.

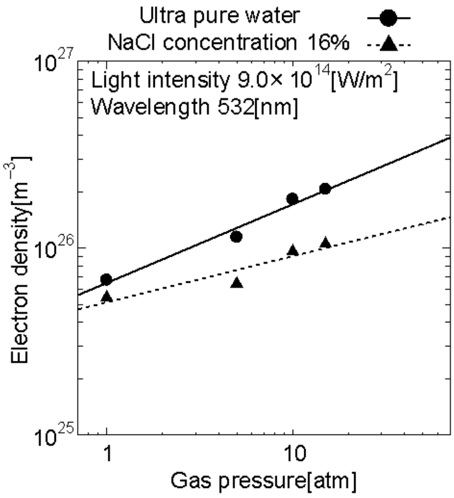


Fig. 5 Gas pressure dependence of electron density at the focal spot.

5. References

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