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Generation processes of Ca atoms via interaction between Ca^{2+} containing droplets and laser-produced plasma in atmosphere

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1. Introduction

We have studied the interaction between plasma and liquid using atmospheric-pressure dc glow discharge with a liquid electrode [1-3]. In the discharge with a liquid electrolyte solution, the optical emission of metal atoms originated from the liquid is observed in the gas phase. It is known from previous studies that droplets are induced from the liquid surface by the discharge, and the generation of droplets strongly correlates with the optical emission of metal atoms. However, the detailed mechanism for generation and the optical emission of metal atoms are still unclear. It is difficult to carry out experiments which focus only on reactions between plasma and droplets by using the discharge apparatus, since the formation of steam from heated water and the influence of electric field are unavoidable. In this work we investigated the interaction between a laser-produced plasma and droplets containing Ca^{2+} which is generated using ultrasonic nebulizer to avoid these factors. By using the plasma which produced by a pulsed laser, we can follow the spatiotemporal evolution of the interaction process. We investigate the temporal evolution of the droplet density and Ca, Ca^{+} density produced from droplets of $CaCl_2$ solution to find out the generation process of metal atoms from droplet.

2. Experimental Procedure

All of experiments were carried out in atmospheric air. The plasma was generated by irradiating a focused Nd:YAG laser pulse (532 nm, 10 Hz) onto the cloud of droplets. Droplets are generated from $CaCl_2$ with a weight concentration of 1% using an ultrasonic nebulizer. Droplets are sprayed using a gas compressor at a flow rate of 1.5 L/min. The diameter of a droplet was 5 – 10 μm. Ca atom at the ground state (^1S) was excited to the $^1P^0$ state and Ca^{+} at the ground state (^2S) was excited to the $^2D^0$ state using a tunable optical parametric
Laser, 239.86nm, 393.37 nm 10 Hz). The excited state emitted the fluorescence at 504.16 nm and 849.80 nm respectively. We captured the image of the laser-induced fluorescence using an ICCD camera (Princeton Instruments, PI-MAX4). Interference filters , which had the transmission at 500 ± 12nm and 852 ± 5nm, were placed in front of the ICCD camera. The temporal evolution of Ca, Ca^{+} and droplets density were obtained by changing the delay time ⊿T between the oscillations of the YAG and OPO lasers.

3. Results and discussion

Figure.1 (a), (b) show the temporal evolution of the LIF and the scattered light intensity. These are Integral value at area indicated by Figure.2. In area 'a', Ca , Ca^{+} density increased synchronously with the decrease of the droplet density. When the decrease of droplets was stopped, Ca density increased synchronously with the decrease of Ca^{+} density. In area 'b', Ca^{+} density is less than detection limit and only Ca density increased synchronously with the decrease of droplet density. It should be noted that the optical emission of the plasma is less than detection limit at ⊿T = 3 μs [4].

As has been described above, in area 'a', Ca atoms are generated dominantly by recombination of Ca^{+} which generated by ionization and dissociation with electron, however in area 'b', Ca atoms are generated directly from droplet. We estimate that these differences are due to the distribution of electron temperature has a peak at center and low outside. In general, the plasma by using dc glow discharge with $CaCl_2$ solution does not reach the electron temperature at which ionization and dissociation occurs. From these result, we estimate that the direct production process of Ca atoms from droplet is similar to the case of dc glow discharge.

References

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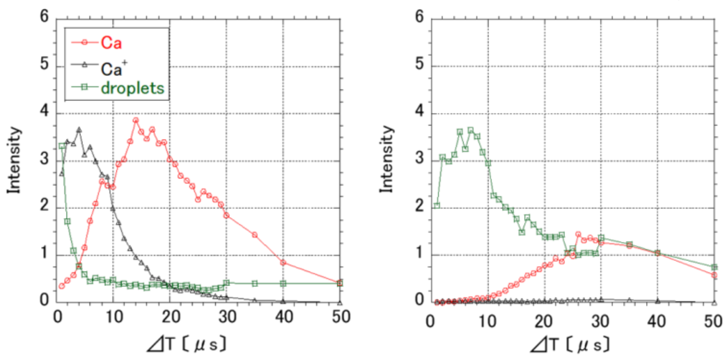

(a) (b)

Fig.1 Temporal variation of the LIF intensity and the scattered light intensity of droplets (⊿T is the delay time after the irradiation of the YAG laser pulse)

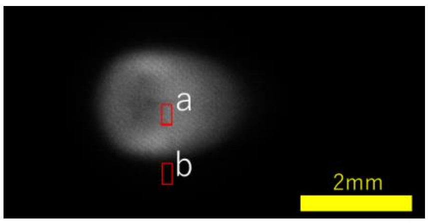

Fig.2 Snap shot LIF image of Ca atoms at ⊿T is 10 μs.