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Study on Suppression of Liquid Metal Flow by Supersonic Free Jet toward X-ray Source
高輝度短波長光源に向けた超音速フリージェットによる液体金属流の膨張抑制

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X-pinch plasma is expected to generate a point high intense X-ray source. However, conventional X-pinch system should reload thin wires per discharge. To demonstrate repetitive-intense X-ray source by using X-pinch system, we proposed an innovative X-pinch method using liquid metal injection. To suppress the expansion of liquid metal in a vacuum chamber, we have demonstrated the liquid metal injection with coaxial supersonic free jet generated by an aerospike nozzle. The results indicate that the droplet formation and the expansion of liquid metal is suppressed by the coaxial supersonic free jet.

1. Introduction

X-rays or EUV source [1-5] is applied to an observation of hydrodynamic behavior in dense plasma, an observation of the bio-tissue, and lithography. A plasma light source, which is small source size with intense emission, is expected to apply these applications. Laser produced plasma (LPP) [1] and discharge produced plasma (DPP) [2] have been developed as a plasma light source. Compared with the feature of LPP, DPP has high conversion efficiency from input power to emission intensity. However, DPP has the large source size with low energy density.

To solve the above problems, we focus on an X-pinch [3-4], in which load consists of two or more fine wires which cross and touch at one point. When high pulsed current flows into the load, the point grows up to the high temperature and dense plasma by pinch effect. However, the conventional X-pinch load should reload the thin wires for each shot. Hybrid X-pinch [5], in which load consists of one thin wire and two cone electrodes, has been developed. The plasma size and emission intensity from the hybrid X-pinch are similar to the conventional X-pinch. However, it is difficult to generate high repetitive-intense X-ray source due to reloading thin wire.

To find a solution to the load problem, we have proposed an innovative X-pinch load using a liquid metal and a nozzle corn electrode. However, X-pinch plasma should compress and heat by self-magnetic pressure. Thus, the liquid metal radius is key parameter to obtain the X-pinch. In this study, reducing pressure gradient between the liquid metal flow and a vacuum, we examined a suppression of liquid metal flow by supersonic free jet.

2. Suppression of expanding liquid metal flow using supersonic free jet

Experimental and observing setups for a liquid metal injection device are shown in Fig. 1. Figure 1 (a) shows a schematic diagram of liquid metal injection. The used liquid metal is Galinstan (Ga: 68.5 %, In: 21.5 %, Sn: 10%), which is liquid state at room temperature. The dispenser nozzle with the diameter of 8 μm injected the liquid metal. An aerospike nozzle [6] with the diameter of 2 mm introduces a coaxial supersonic free jet to the surface of the liquid metal flow. The coaxial supersonic free jet suppresses the expansion of the liquid metal by reducing pressure gradient on the surface of the liquid metal flow. Helium gas is used for optically thin in short wavelength regime. It provides the magnetic valve to prevent pressure increase in the chamber. The experimental setup of observing liquid metal behaviors is shown in Fig. 1(b). The liquid metal injection device is placed in the vacuum chamber. The image of the liquid metal flow was taken after the supersonic free jet had reached the chamber. The image was exposed by camera using a single focus lens for 20 μs that the high pressure Xe flash ramp had emitted. In the experiment, the pressure in the chamber was 10^2 Pa. The air in atmospheric pressure injected liquid metal from the dispenser nozzle into the chamber.

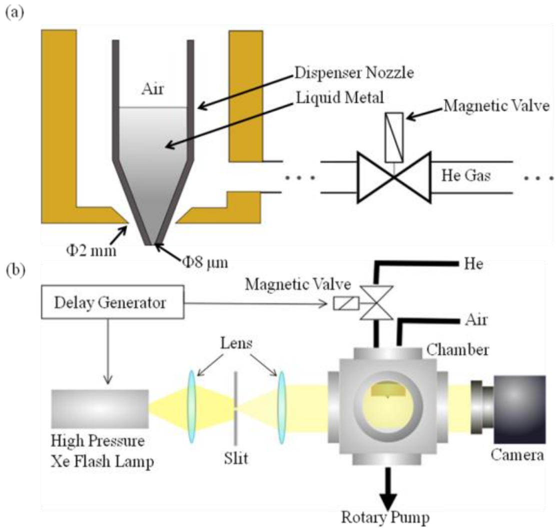
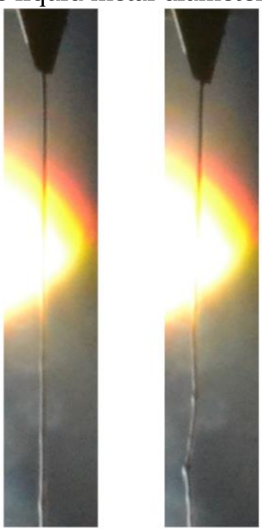


Fig. 1. Experimental setup of liquid metal injection, (a) schematic diagram of liquid metal injection, (b) experimental setup of observing liquid metal behaviors.

The behavior of the liquid metal flow with the supersonic free jet generated by the aerospike nozzle is shown in Fig. 2(a) and that without the supersonic free jet is shown in Fig. 2(b). In these results, the droplet formation of the liquid metal was observed in the direction of the liquid metal flow without the supersonic free jet. On the other hand, the droplet formation is suppressed with the supersonic free jet. It indicates that the supersonic free jet could suppress the droplet formation of the liquid metal. The pinch effect may inhibit the droplet formation of the liquid metal.

The liquid metal diameter as a function of the direction of the liquid metal flow is shown in Fig. 3. In this result, the liquid metal diameter without the



(a) (b)

Fig. 2. Photographs of liquid metal behaviors, (a) with supersonic free jet and (b) without supersonic free jet.

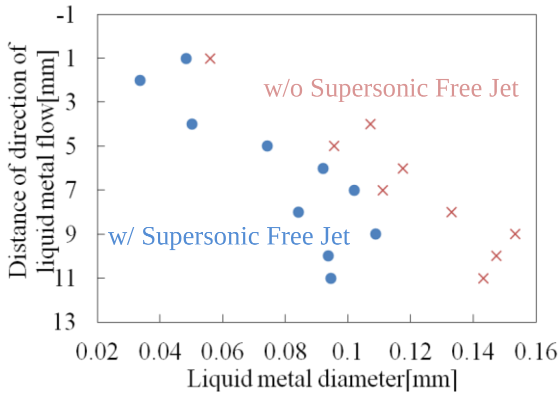


Fig. 3. Liquid metal diameter dependence on supersonic free jet.

supersonic free jet is 55 μm in the liquid metal injection distance of 1 mm. On the other hands, the liquid metal diameter with the supersonic free jet is 48 μm in the liquid metal injection distance of 1 mm. These results indicate that the liquid metal expansion could be suppressed by the supersonic free jet.

3. Summary

We have demonstrated the X-pinch load using the liquid metal and the aerospike nozzle. In the case of the supersonic free jet provided by the aerospike nozzle, the droplet formation and the expansion of the liquid metal were suppressed. It reveals that the liquid metal flow by supersonic free jet is possible to approach for the X-pinch load.

References

[1] T. Higashiguchi, M. Hamada and S. Kubodera: J. Appl. Phys. **96** (2004) 6147.

[2] M.A. Klosner and W.T. Silfvast: Appl. Optics **40** (2001) 4849.

[3] T. A. Shelkovenko, D. B. Sinars, S. A. Pikuz, and D. A. Hammer: Phys. Plasmas **8** (2001) 1305.

[4] F. Tachinami, N. Anzai, T. Sasaki, T Kikuchi and N. Harada: Nuclear Instruments and Methods in Physics Research Section A **733** (2014) 25.

[5] T. A. Shelkovenko, S. A. Pikuz, A. D. Cahill, P. F. Knapp, D. A. Hammer, D. B. Sinars, I. N. Tilikin and S. N. Mishin: Phys. Plasmas **17** (2010) 112707.

[6] T. T. Bui and J. E. Murray: *41st AIAA/ ASME/ SAE/ ASEE Joint Propulsion Conference & Exhibit*, AIAA-2005-3797 (2005).