MEASUREMENT OF FINE PARTICLES USING X-RAY IN A GAS-PUFF Z-PINCH

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Abstract

The x-ray shadowgraph measurement was used for comb over to spatial distribution of fine particles at the besides maximum pinch time in a gas-puff z-pinch. The experiment of Sn fine particles on change to gas density at the discharge starting time was conducted. The fine particles was not observed on condition of high density gas, so it was considered that the generation quantity of fine particles were extremely little. According to the maximum pinch time, the reduce technique to be generated of Sn electrode material include fine particles were discovered on the experiment condition of the gas density gets higher.

1. Introduction

The debris occurred by large current discharge, and debris makes dirty the focusing mirror on development of discharge produced plasma light source. Specially, Sn electrodes for extreme ultraviolet (EUV) light source generate a lot of debris. In the debris of the gas-puff z-pinch, the debris were scattered preference of radially angle direction from between the electrodes in right of the debris by interacting with plasma. The debris are considered to be made of vapor, droplet and fine particles derived from Sn electrodes, specially, the Sn fine particles size is about 1 to 100 μm. The Sn neutral atoms include fine particles radiated characteristic x-ray around the electrode. This x-ray was excited by collision of high energy electrons in a pinch intention. The spatial distributions of characteristic x-ray was cloud like form, and the x-ray form shows distribution of neutral atoms at a maximum pinch time. On the other hand, the mechanism of the generation and scattering process of neutral atoms from electrodes were incompletely understood.

The Sn fine particles of comparatively large size of about 100 μm was focused in this study, the measured spatial distribution and scattering process based on x-ray shadowgraph in gas-puff z-pinch were demonstrated. The x-ray shadowgraph measurement is useful for nondestructive inspection, it was used for examine of fine particles distribution in a plasma. The distribution was measured by change gas density at the discharge starting time in a gas-puff z-pinch, and experiment condition as delay-time and reduce technique of generation quantity of Sn electrode material is discussed.

2. Experiments

Gas-puff z-pinch plasma with generation of fine particles were made by SHOTGUN-1 in the Nihon University. The SHOTGUN-1 is a pulse power device, capacitance and maximum charged voltage were 24 μF and 25 kV and maximum current was about 0.3 MA. The C (graphite) and Sn were used as anode electrode, and aluminum was used as cathode electrode. The distance between anode and cathode electrodes is 30 mm. Helium gas was used as gas-puff. Figure 1 shows set up position of x-ray source, gas-puff electrodes and x-ray detector on the SHOTGUN-1 device.

Fig. 1. Schematic of the vacuum chamber, gas-puff z-pinch plasma position, and the x-ray source and detector for x-ray shadowgraph were used in this study.
The between x-ray source and gas-puff electrodes were divided by miler filter of 50 μm in thickness. This miler filter kept a vacuum in x-ray source chamber. The x-ray source based on a vacuum-arc used as x-ray shadowgraph. The specifications of the vacuum-arc x-ray source device used in this study are as follows: brass needle electron source electrode (size of 4 × 70 mm) and copper target (size of 0.5 mm thick × 20 mm in width, the electron incident angle of 45 degrees), the distance between the electrodes is 1 mm. This x-ray source was connected to pulse power supply by charged condenser with 20 kV, and the x-ray output were characteristic energy of 18 keV and over a 60 ns FWHM. The x-ray energy of 18 keV was absorbed about 90% by Sn thickness about 100 μm. It was already confirmed that to can take a x-ray shadowgraph by Sn wire thickness 150 μm.4 This x-rays source was used to x-ray shadowgraph of Sn particles in this study.

The arrange of x-ray shadowgraph used in this study are as follows: distance between x-ray source and z-pinch plasma L₁ of 470 mm, distance between z-pinch plasma and x-ray detector L₂ of 370 mm. Therefore, the shadowgraph image on x-ray detector was enlarged 1.8 times from effective size. Figure 2 shows schematic illustration of x-ray shadowgraph in a z-pinch plasma. The Tin particles of size about 100 μm in a z-pinch plasma was exposed selectively by x-ray source. A radiant x-ray from z-pinch plasma below the 3 keV was shield by aluminum filter of thickness 15 μm in between a z-pinch plasma and x-ray detector.

X-ray detector were used with Bio-Max MS film detector (made by Kodak company) and intensifying screen (made by FUJIFILM company). The Bio-Max MS film is having sensitivity detector film in EUV or soft x-ray. Consequently, the intensifying screen was used for detect of over 3 keV x-rays. The x-ray film color changes black from translucent when was detected x-ray. Accordingly, x-ray shadowgraph image was observed image of translucent on black film. This x-ray sensitivity of film was showed numerical by photographic density of 0 to 250 in this study. The spatial distribution of Sn fine particles with size of about 100 μm were examined by change gas density at the discharge starting time. The gas density was changed by delay-time of between gas puff timing and discharge start timing. This change of gas density means change of characteristic times in plasma pinch, therefore, change of plasma temperature. This plasma temperature control is big advantage for discharge produced plasma (DPP) light source by gas-puff z-pinch.6

3. Results

![Discharge current graph](image)

Fig.3. The gas-puff z-pinch discharge plasma current and pulse power supply current at delay time of 0.75 ms and x-ray shadowgraph of Sn fine particles at the three timings of (a) +1 μs, (b) +5 μs, (c) +9 μs.
Fig. 4. The spatial distributions of x-ray from Sn neutral atom on between anode and cathode on gas-puff electrodes, and x-ray intensity graph. The x-ray pictures (a), (c), (e) and (g) were examined by x-ray pinhole camera. The (b), (d), (f) and (h) shows the length between gas-puff electrodes vs x-ray intensity.

The spatial distribution between anode and cathode on gas-puff electrodes was examined by x-ray shadowgraph. The x-ray shadowgraph image was measured three different kinds of timing for research of fine particles generate time in discharge. As a result with the experiment of x-ray shadowgraph, shadow of only gas-puff electrodes was observed on x-ray film, and spatial distribution of Sn particles was not observed in experiment condition as delay-time 0.75 ms. As a result with the experiment of x-ray shadowgraph, the generation area of Sn electrode material at the maximum pinch time was reduced as the delay-time gets longer.

4. Discussion

The reason why Sn fine particles with size of about 100 μm were not observed in delay-time 0.75 ms is discussed here. One of the reasons was generation quantity of Sn electrode material include fine particles itself were maybe little in an experiment condition as delay-time 0.75 ms. To change a delay-time gets longer means to make a low temperature plasma in gas-puff z-pinch. Therefore, the scatter of Sn electrode material was not almost occur in low temperature of pinch plasma, and the contact temperature on Sn electrode of plasma maybe was less than temperature of Sn boiling point as 2.88 × 10^3 K and melting point as 5.05 × 10^2 K. Actually, the generation area of Sn at the maximum pinch time was reduced as the plasma temperature gets lower in Fig. 4. In addition, as another reason was generation quantity of fine particles were maybe extremely little, and of fine particles spatial distribution are concealed irregular development of x-ray film. In this case, measurement of fine particles were extremely difficult. Because, if a lot of measurement shot for integration exposure was conducted, the fine particles spatial distribution to be covered black back-ground of x-ray film by substitute exposure. In either case, x-ray shadowgraph measurement was needed to more confirm another delay-time in a gas-puff z-pinch.
5. Conclusion

The x-ray shadowgraph measurement was used for comb over to spatial distribution of fine particles at the besides maximum pinch time in a gas-puff z-pinch.

As per the results of this study, the Tin fine particles were not observed in an experiment condition as delay-time 0.75 ms by x-ray shadowgraph in Fig. 3. According to the maximum pinch time, the generation quantity of Sn electrode material include fine particles was reduced as the delay-time gets longer by x-ray pinhole camera image in Fig. 4.

Therefore, the spatial distribution of fine particles at the besides maximum pinch time was not revealed at this stage, and x-ray shadowgraph measurement needs more a lot of time at other delay-time.

On the other hand, it was revealed in this study that it was considered that the generation of electrode material include fine particles were extremely little on experiment condition of high density gas, and, the generation of electrode material at the maximum pinch time were reduced on the experiment condition of the gas density gets higher.

This reduce technique of fine particles leads to development of the debris less extreme ultraviolet plasma sources based on a gas-puff z-pinch.

References