Dynamic Behavior of Debris in a Gas-Puff Z-Pinch

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The experiment on understanding of the occurrence of debris was conducted on a z-pinch discharge with tin electrodes. The main scattering source of the debris is not the surface but between the electrodes. The debris was made up of molten droplets of tin with the size ranged from 1 to 100 μm. The droplets could be charged electrically, and they would be splashed by the disruption of the plasma.

Keywords: gas-puff z-pinch, radiation source, EUV lithography, cloud structure, debris, fine particle, dust

1. Introduction

Z-pinch is a useful device for efficient energy injection to the plasma. High-temperature and high-density plasmas can be produced easily in the implosion process by self-magnetic field. Because the radiation from z-pinch plasma lie in various wavelength region, the application to pulsed and intense light source such as Extreme Ultra Violet (EUV) light for the next generation semiconductor lithography is actively investigated. As the plasmas touch the solid as the electrode material, a part of the materials (atoms and fine particles) besides x-rays scatter and sticks to the viewing window and diagnostic instruments. This is called debris. Plasma itself is also recognized as a part of the debris. Elimination of the debris or controlled formations of that are ones of the urgent tasks for the EUV lithography [1.2]. In spite of the importance, the exact origin of the debris and the passes of scattering are still not confirmed experimentally.

In gas-puff z-pinch, cloud structure of x-ray radiations have often been observed around the high temperature areas (hotspot) of plasma column [3]. It can be ascribed to K_α line radiations of electrode materials excited by electron beam generated at the pinch of the plasma [4]. From the reason, the cloud structures would be the major sources of debris.

In order to clarify the source of the debris and to understand its nature, the size and the position of scattering source are identified with a pinhole camera, and the collected debris is observed by scanning electron microscope (SEM), and those of components are specified with energy dispersive x-ray spectroscopy (EDX). And the search for the behavior of emitted debris has been conducted.

2. The SHOTGUN Z-Pinch Device

The experiment was conducted on the SHOTGUN z-pinch device at Nihon University (Fig. 1). The energy storage section of the device consists of 30 kV, 24 μF capacitor bank, and the maximum discharge currents 300 kA. The charged voltage of the bank was 25 kV (7.5kJ) in this research.

The isolated gas distribution can be formed between the electrodes with a high-speed gas valve and an annular Laval nozzle mounted on the anode. Anode was made of graphite, and tin (Sn) sheets were attached on the cathode made of stainless steel. The distance between the electrodes was 30 mm. He gas was used in this research, and plenum pressure of the gas was 5 atm.

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3. Pinhole Measurement of Debris Source

In order to identify the debris source, a pinhole camera was inserted from the azimuthal port. Figure 2 is a schematic view of the pinhole camera for the observation of the debris source. Debris emitted by discharge, passes

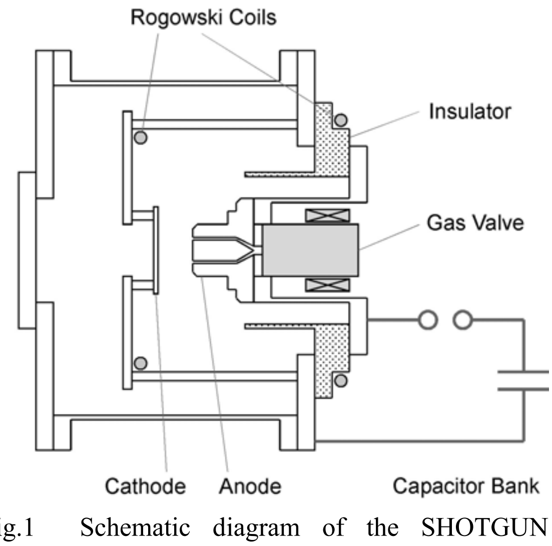

Fig.1 Schematic diagram of the SHOTGUN z-pinch device.

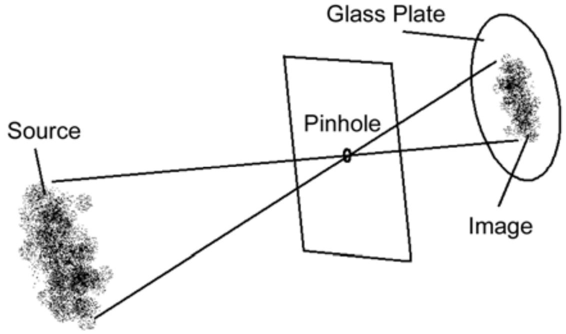

Fig.2 Schematic arrangement of the pinhole camera for the observation of debris source.

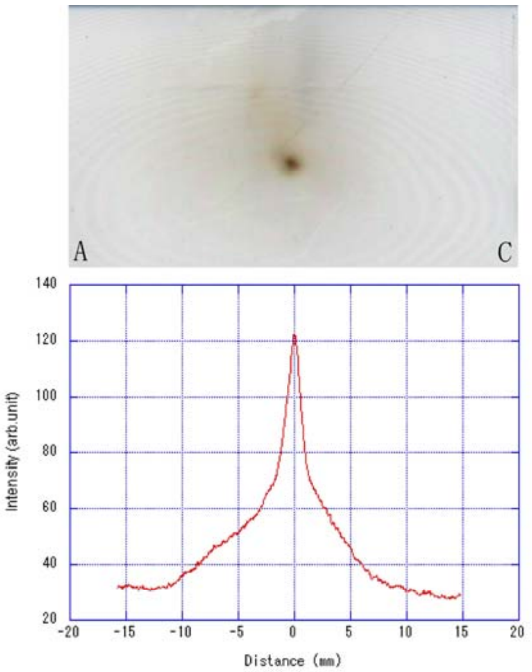

Fig.3 Collected debris on the glass plate and its density trace. The distribution has two components.

the pinhole and collected on the glass plate (26 mm × 38 mm). Materials of debris are projected on the plate through the pinhole. Distances from the center of device to the pinhole, and from the pinhole to the plate are 207 mm and 20 mm, respectively. Diameter of the pinhole is 3 mm.

Figure 3 shows the images of the plate exposed over 50 shots. It is understood that projected debris has double structure, i.e. darker part in the center and lighter one in the edge.

The diameter of the center area is approximately 7 mm. If debris particles assumed to be scattered straight from the center of device, the size of debris source would be about 30mm. Because the distance corresponds to the one between the electrodes, it is thought that debris was mostly derived from between the electrodes. As the diameter of edge area is about 21mm, it corresponds to the

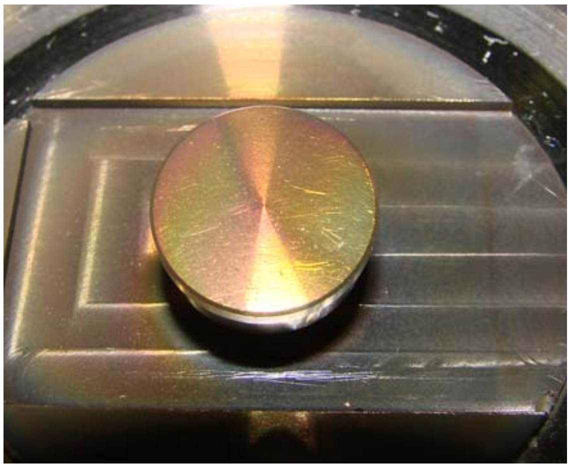

Fig.4 The debris collected by the aluminum SEM stand. The surface color was changed to yellow.

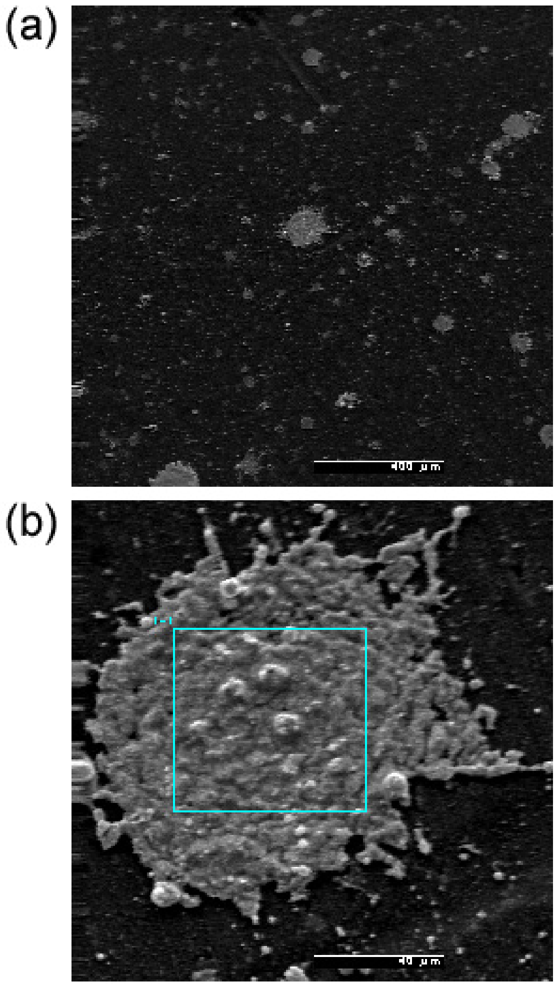

Fig.5 Debris particles observed using the SEM. The scales shown in the photographs are (a) 400 μm and (b) 40 μm.

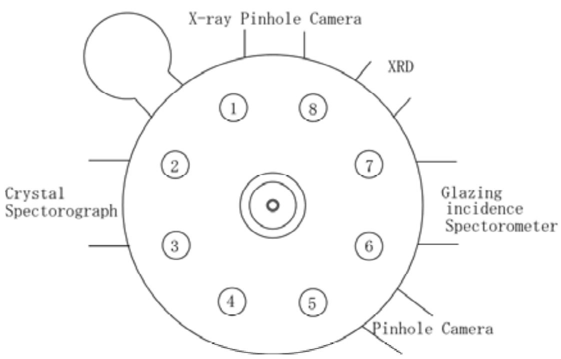

Fig.6 Location of glass plates for the measurement of the debris distribution. They were numbered from 1 to 8.

distance of 180 mm. It is thought that the second component of the debris was scattered from the wall of the device.

4. Observation of Debris by SEM

After the discharge of 150 shots, the debris deposited on the metal stage (Al, ϕ15 mm × 6 mm) placed for SEM measurements near the return rod 5. Figure 4 shows the resultant image of the deposited stage. Thin filmy deposits were observed macroscopically with some fine distributions.

Secondary electron images (SEI) were observed using SEM (HITACHI S-2150). Figure 5 shows SEI of spatial distribution of debris on the metal stage. The scale of (a) is 400 μm, and (b) expanse (a) to ten times. In Fig. 5, many droplet-shaped debris particles were observed in the whole area. The size distribution of debris droplets is not homogeneous in the ranged from 1 to 100 μm.

The compositional analysis of the squared area in Fig. 5(b) was performed by EDX (HORIBA EMAX7000). From the results, debris droplets were consisted of mostly Sn, and a small amount of Fe and C.

These observations show consequently that scattered molten droplets of debris (mostly Sn) would have collided with the metal stage, and then solidified to the many splashes of different sizes.

5. Measurement of Debris with Glass Plates

Glass plates, which would not be damaged significantly by the ultraviolet radiation and x-rays from plasmas, were equipped as the photochemically-inactive plates in order to measure the spatial distribution of the debris. Size of the glass plate is 26 mm × 76 mm. Eight glass plates were put on each inner face of the return rods, which were used for fixing the device center (Fig.6). Each return rod and glass plate were numbered from 1 to 8 in Fig. 6, respectively.

After 36 shots, debris was collected on the glass, shown in Fig. 7. Glass plates 1 and 7 are little, and on 2

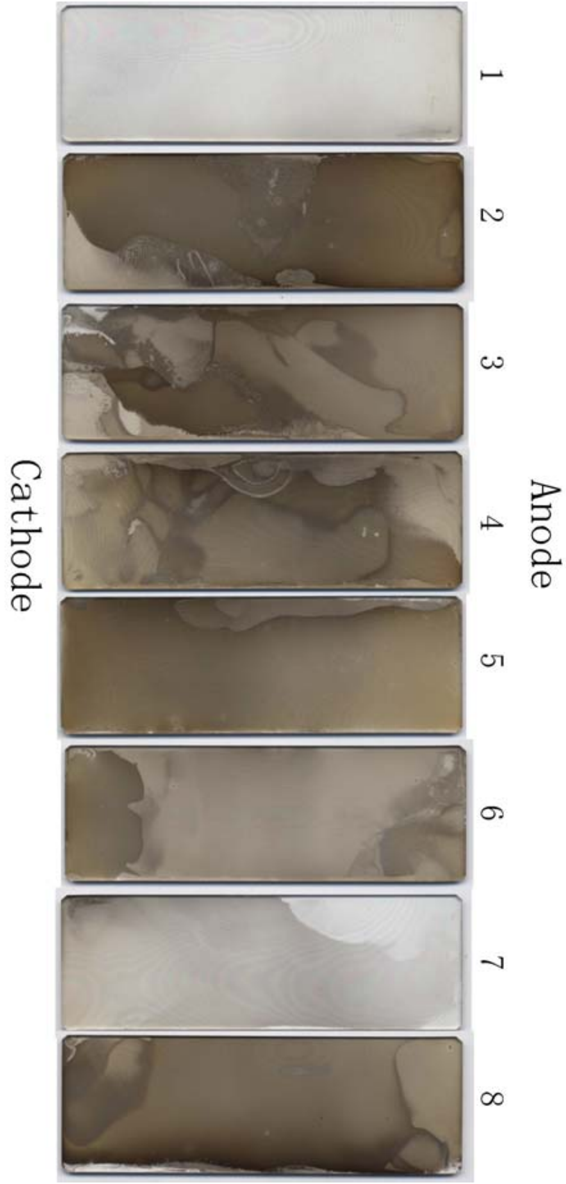

Fig.7 Spatial distribution of debris collected by the eight glass plates.

and 8 are relatively more. And the plate 3 and 4 are shown, one glass plate was also observed detailed pattern.

If the debris scattered straight from its source, the debris is sure to attach on the glass plates uniformly. The result shows that the scattering of the debris is not uniform and has some spatial structure. Consequently, it is thought that the scattering of debris has some relation to the motion of the plasma, and that the debris is scattered in accordance with disruption of the plasma.

6. Summary and Discussion

The experiment on understanding of the occurrence of debris was conducted on a z-pinch discharge with tin electrodes.

In the experiment using pinhole, the collected debris had double structure, and it was confirmed that the size of the main source of debris was about 30mm. That is to say, the main scattering source is not the surface of electrode but between electrodes. And the debris was also scattered from the wall of device.

The observation using SEM showed that the debris was made up of molten droplets (dust) of tin with the size ranged from 1 to 100 μm.

From the measurements of debris using the glass plates, the scattered of debris was not isotropic and might be affected by the motion of the plasma.

The observed droplet-shaped debris particles could be charged electrically by the contact with plasma. If charged, they would be affected be electromagnetic fields around the plasma, and they would move with the plasma. Because the z-pinch plasmas disrupts by MHD instability, the debris would also be splashed by it. Therefore, the spatial distribution of debris should reflect that of the instability of the plasma.

If the pinhole camera had a good precision, an asymmetric structure of the debris source could be observed. Some precise dynamic measurements are necessary for the understanding of the debris.

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