Hard X-Ray Radiation from a Z-Pinch with a Divergent Gas-Puff

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An experiment on a new type of z-pinch with divergent gas-puff was conducted for the realization of a point radiation source with high efficiency. X-ray radiation of energy 150 - 200 keV that far exceeded the power-supply voltage was observed. The x-rays were radiated from the center of the anode surface, and the point radiation source was achieved.

Keywords: gas-puff z-pinch, plasma focus, x-ray radiation, point radiation source, hot spot

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Since the energy transfer to a gas-puff z-pinch is efficient [1, 2], and high temperature and high density plasma is easily achieved, it can be used as a soft x-ray and EUV light source. The high temperature plasma points (hot spots) produced are distributed on the center axis between the electrodes.

On the other hand, the plasma converges to a single point in the plasma focus, and the point radiation source is formed. As the plasma flows axially after the conversion, dispersial to surrounding areas like the z-pinch is limited. However, previous plasma focus has the disadvantage of not obtaining a strong pinch easily. Since the device is filled with operating gas and initiated using the surface discharge from the insulator, the energy input is limited by the insulating material [3].

The essence of the plasma focus is that the structure of the electrodes is coaxial, and not in plane symmetry. So the plasma produced is not axially uniform. The experiment using the z-pinch with the divergent gas-puff was conducted in order to realize the point radiation source with good efficiency using the advantage of both devices. It was understood during the process of the experiment that not only soft x-rays but also high energy x-rays would be radiated from the plasma, and the energy, the intensity, and the source of the x-rays were examined.

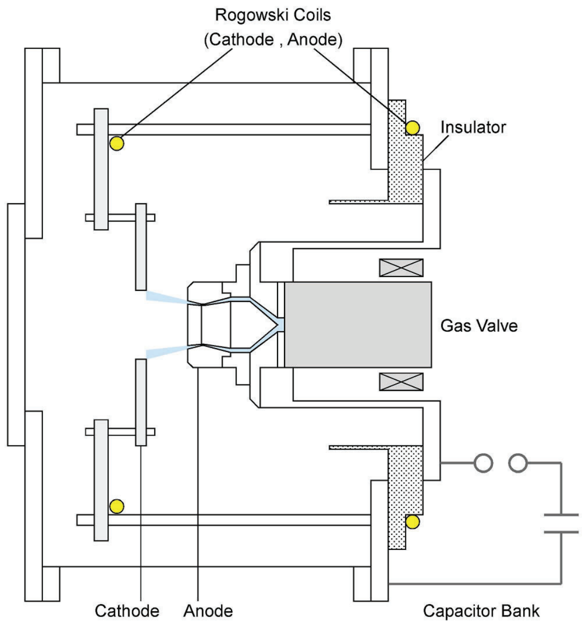

Fig. 1 Schematic diagram of the z-pinch device with divergent gas-puff. The ejection angle of the gas is 10° outward.

The experiment was conducted using the SHOTGUN gas-puff z-pinch device at Nihon University (Fig. 1). The energy storage section of the device consists of a 30 kV 24 μF capacitor bank, and the maximum discharge current is 300 kA. The charged voltage of the bank was 25 kV in this experiment.

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 [4]. The gas was ejected parallel to the axis in the usual z-pinch experiment. Here the ejection angle of the gas was 10° outward, and the radially divergent gas distribution was formed from the anode to the cathode. The distance between the electrodes was 3 cm. Ar gas was used in this experiment, and the plenum pressure of the gas valve was 5 atm.

Discharge currents were measured using Rogowski coils located both outside (anode) and inside (cathode) the chamber. Soft x-rays were measured using x-ray diodes (XRDs) with Au, Ni and Al photocathodes. The XRDs are more sensitive to high energy photons of this order. The x-rays were measured using a scintillation probe (SCI) with a 10 μm Be filter. An x-ray pinhole camera was used for taking an x-ray image of the pinch plasma. Moreover, in order to detect high energy x-rays around the device, an

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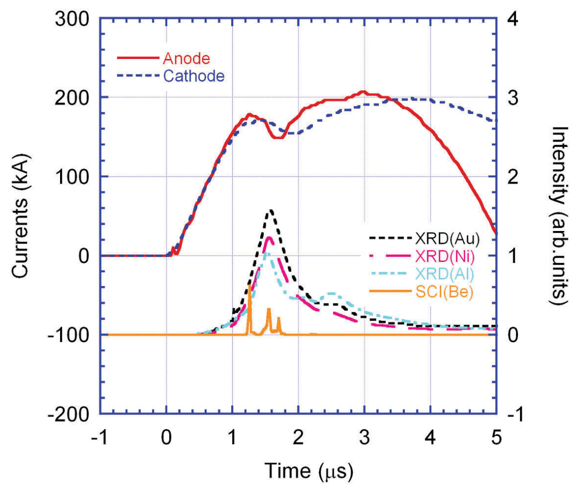

Fig. 2 Discharge currents, XRD and SCI signals of the divergent gas-puff z-pinch discharge.

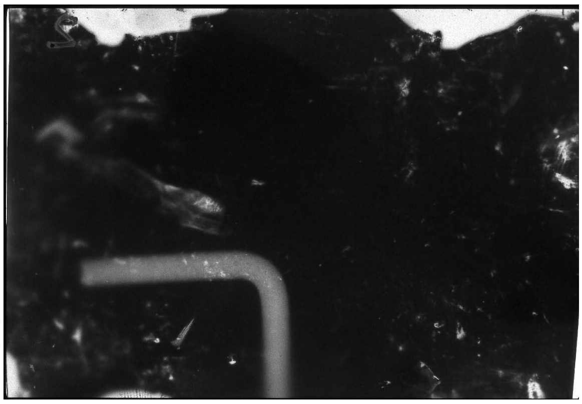

Fig. 3 X-ray radiograph located axially removed from the device center. The x-rays penetrated a 4 mm hex-head steel wrench.

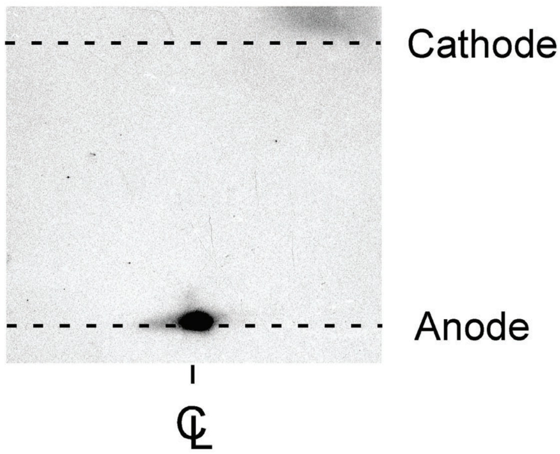

Fig. 4 X-ray pinhole photograph of the plasma exposed over 10 shots. The x-rays are generated at the center of the anode surface. The distance between the electrodes is 3 cm.

x-ray film cassette was prepared. Kodak BioMax MS film with a Fuji GRENEX G-8 intensifying screen was used for recording the x-rays. A surveymeter of the ionization chamber type was used for the measurement of the dose of the x-ray radiation.

The discharge currents, and the XRD and SCI signals of a typical discharge of the divergent gas-puff experiment are shown in Fig. 2. The peak current is about 200 kA, which is almost identical to the usual z-pinch in the same device. The difference between the two currents shows the current leakage between two Rogowski coils [4]. The current begins to decrease at time 1.2 μs and forms a dip. The circuit inductance briefly increases with the shrinkage of the plasma. The current dip is deeper than that observed in a usual z-pinch experiment. The analysis of the current waveform shows that the input energy increases with the divergent gas-puff. The delay in the dip of the cathode current indicates the transmission of the pinch from anode to cathode. Three XRD signals increase at the current dip, indicating the increment of the bulk plasma temperature. X-ray emission is seen pulsing, which is accompanied by local MHD instability. Soft x-ray radiation from hot spots has been observed in the usual z-pinch [5], but x-rays exceeding 10 keV have not been observed [2]. Since it had been understood that high energy x-rays would be radiated from the device during the process of the experiment, x-ray radiation outside the device was measured for safety.

Figure 3 is an x-ray radiograph taken by the cassette located 60 cm axially removed from the device center. The film is exposed over 20 shots to take the picture. Evidently, hard x-rays are radiated from the z-pinch device. It was known that the x-rays passed through both a 2 cm aluminum flange and a 0.2 mm stainless steel shading plate, because the film was pitch-black. The top white section of the film shows where an intensifying screen is lacking. The x-rays also penetrated a hex-head steel wrench of 4 mm corner placed on the cassette. The energy of the x-ray is estimated as 150 - 200 keV from the transmission of the materials. A lead plate of 1 mm thickness is necessary for protection from the x-rays. The dose of the x-rays was about 1 μSv on the shot average according to the surveymeter placed at the same position.

The pinhole camera was used to specify the location of the x-ray source. In order to remove soft x-rays, the cassette was covered with a 0.2 mm stainless steel shading plate. Figure 4 shows the x-ray pinhole photograph of the plasma exposed over 10 shots. X-rays are generated at the center of the anode surface, where the plasma focuses. The reproduction is good, and x-rays are not generated from other places.

In summary, a new type of z-pinch experiment was conducted using a z-pinch with a 10° divergent gas-puff. X-rays were radiated from the center of the anode surface, and a point radiation source was formed. It was understood that x-rays of an energy of 150 - 200 keV were emitted from the discharge of 25 kV and 200 kA. The dose of the x-rays at a position 60 cm away from the device was about 1 μSv for each shot.

The observation of high energy x-rays may be due to high energy electrons hitting the anode. The generation of high energy particles that exceed the power-supply voltage has been reported in a conventional plasma focus device [6], and this observation is thought to be the appearance of a similar phenomenon.

[1] J. Shiloh, A. Fisher and N. Rostoker, Phys. Rev. Lett. **40**, 515 (1978).
[2] K. Takasugi, H. Suzuki, K. Moriyama and T. Miyamoto, Jpn. J. Appl. Phys. **35**, 4051 (1996).
[3] W. Kies, Plasma Phys. Control. Fusion **28**, 1645 (1986).
[4] K. Takasugi, A. Takeuchi, H. Takada and T. Miyamoto, Jpn. J. Appl. Phys. **31**, 1874 (1992).
[5] P.G. Burkhalter, J. Shiloh, A. Fisher and R.D. Cowan, J. Appl. Phys. **50**, 4532 (1979).
[6] T. Yamamoto, K. Shimoda, K. Kobayashi and K. Hirano, Jpn. J. Appl. Phys. **23**, 242 (1984).