Development of Exploding Wire Ion Source for Intense Pulsed Heavy Ion Beam Accelerator

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ABSTRACT

A Novel exploding wire type ion source device is proposed as a metallic ion source of intense pulsed heavy ion beam (PHIB) accelerator. In the device multiple shot operations is realized without breaking the vacuum. The basic characteristics of the device are evaluated experimentally with an aluminum wire of diameter 0.2 mm, length 25 mm. Capacitor bank of capacitance 3 μF, charging voltage 30 kV was used and the wire was successfully exploded by a discharge current of 15 kA, rise time 5.3 μs. Plasma flux of ion current density around 70 A/cm^2 was obtained at 150 mm downstream from the device. The drift velocity of ions evaluated by a time-of-flight method was 2.7x10^4 m/sec, which corresponds to the kinetic energy of 100 eV for aluminum ions. From the measurement of ion current density distribution ion flow is found to be concentrated to the direction where ion acceleration gap is placed. From the experiment the device is found to be acceptable for applying PHIB accelerator.

Key word; pulse power, intense pulsed ion beam, pulsed heavy ion beam, exploding wire, metallic ion source, aluminum ion source

1. Introduction

Intense pulsed heavy ion beam (PHIB) technology [1] is expected to be applied to materials processing including pulsed ion beam implantation, surface modification, and thin film deposition [1-5]. For those applications, it is very important to develop the accelerator technology to generate ion beams with various ion species. For the purpose we have developed various types of intense pulsed ion sources for the generation of PHIB [1, 6, 7]. Gas puff plasma gun [6], vacuum arc ion source [7] and wire explosion ion sources. In those sources, wire explosion ion source [8] is very useful since the system is very simple and various ion species can be produced only by changing the wire. In our experiment, sufficiently high current density is obtained with good reproducibility. However, conventional wire plasma ion source can produce only one shot without braking the vacuum since the wire is evaporated in each shot.

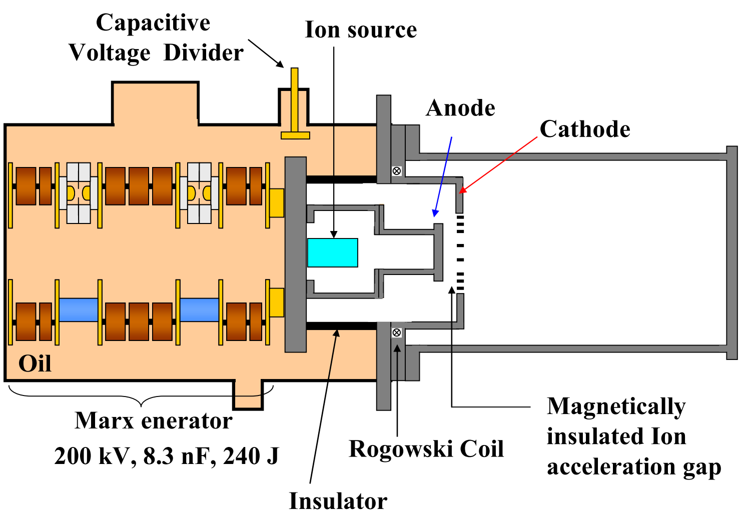

Fig.1. Schematic of the PHIB accelerator.

In the paper we have proposed a new type of wire plasma ion source to realize the multi-shot operation without breaking the vacuum. The detail of the proposed ion source system is introduced with the results of preliminary experimental results of the characteristics of the ion source.

2. PHIB accelerator

Figure 1 shows the cross sectional view of the PHIB accelerator system used in our laboratory. [1, 6, 7] It consists of a high voltage pulsed power generator, an ion source of pulsed plasma gun, and a $\mathbf{B}_y$ type magnetically insulated acceleration gap (ion diode). The diode consists of a cylindrical anode of 60 mm$^{\phi}$ and a cathode of grid structure. The gap length ($d_{A\text{-}K}$) is adjusted to 10 mm. Inside the anode active ion source is installed to supply source plasma to the acceleration gap. The top of the anode has a punching board structure and the source plasma can penetrate to the A-K gap. The cathode acts a multi-turn magnetic field coil. The coil is powered by a capacitor bank of 250 μF, 5 kV and uniform, transverse magnetic field of 0.7 T is produced in the A-K gap, which insulate the electron flow.

A Marx generator of 200 kV, 240 J is used to apply the acceleration voltage. Typical diode voltage, diode current and pulse duration are 200 kV, 15 kA, 100 ns (FWHM), respectively.

Two types of pulsed plasma guns have been used to generate ion beams of nitrogen and aluminum. For nitrogen ion beam gas puff plasma gun is used, whereas for aluminum ions a vacuum arc discharge plasma gun is used, both of the guns we have successfully produced a PHIB of current density around 100 A/cm^2. [6, 7]

Wire explosion ion source have also developed in our laboratory as the aluminum ion source. In the experiment more than 100 A/cm^2 of ion flux has been observed with good reproducibility. However, since repetitive operation is not realized, the ion source has not been installed in the accelerator.

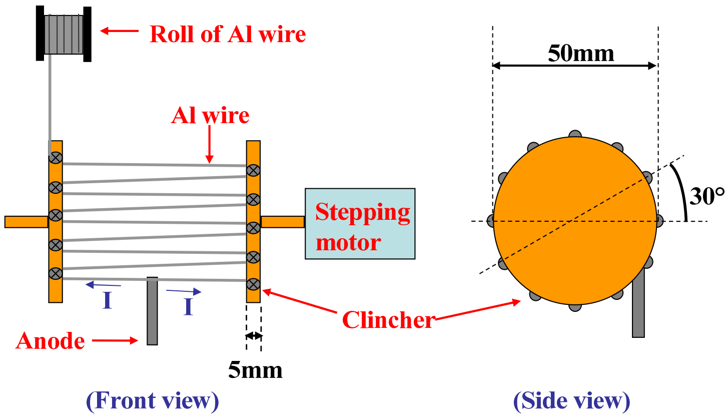

Fig.2 Schematic of wire explosion ion source proposed to realize multi-shot operation.

3. Proposed ion source.

Figure 2 shows the proposed metallic wire plasma ion source to realize the multi-shot operation of plasma generation without breaking the vacuum. A Pair of 50 mm diameter metallic disk is used as a cathode whereas a rod electrode is used as an anode. The anode is placed in the center of the gap of cathode wheels. Between the cathode wheels thin wire of aluminum is strained in zigzag. Capacitor bank is connected between the cathode discs and the rod anode, which provide the discharge current.

The procedure of the plasma production is as follows; By rotating the cathode wheels, the anode rod contacts with the aluminum wire. Capacitor bank is discharged and the discharge current flows from the anode to the cathode wheels through the aluminum wire and both side of the wire is exploded and produces aluminum vapor. The vapor is beaked down and produces aluminum plasma. After the shot one pass of the wire disappears, however, by rotating the wheels, the cathode will contact to the next span of the wire. The wire will be automatically strained in the upstream of the wheels, which make possible the multiple shot operations without breaking the vacuum.

To develop the proposed plasma source we have evacuated the characteristics of the wire explosion ion source.

4. Experiment

A) Basic characteristics of wire explosion

To evaluate the basic exploding process of the wire explosion, single wire system is used. Capacitor bank of 1.0 μF 30 kV is used to explode the pure aluminum wire of 0.1 mm diameter, 30 mm in length.

Fig.3 shows the rise phase of the discharge current waveform. By the kilo-ampere of current flow, the wire is ohmic heated, melted and vaporized. After the vaporization the resistance between the electrode increases and the discharge current dips steeply. By the steep decrease of the current, inductive voltage is generated across the electrodes, providing the discharge ni the aluminum vapor and the current again increases.

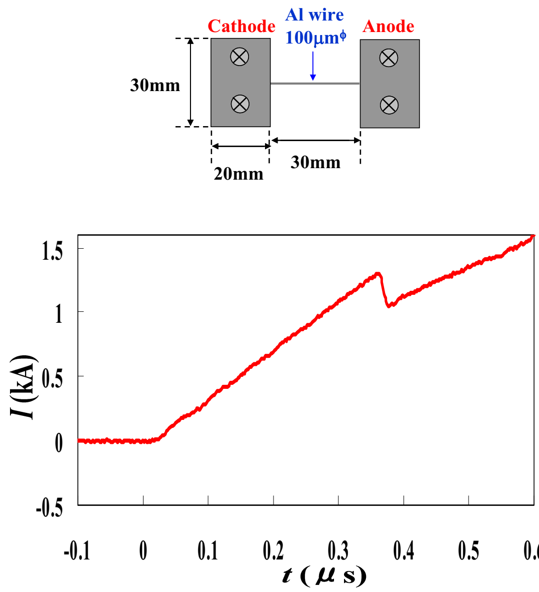

Fig.3(a). Experimental arrangement. (b) Discharge current waveform (the rising phase)

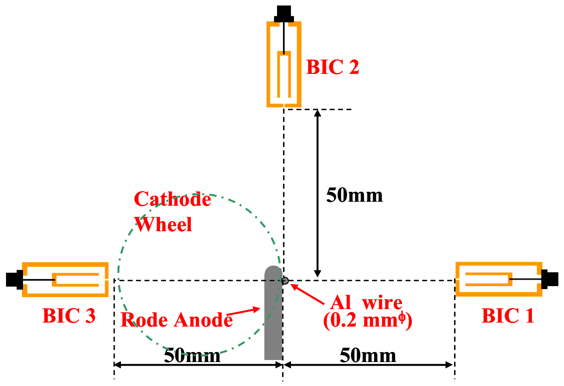

Fig.4. Experimental setup to evaluate the ion current density distribution

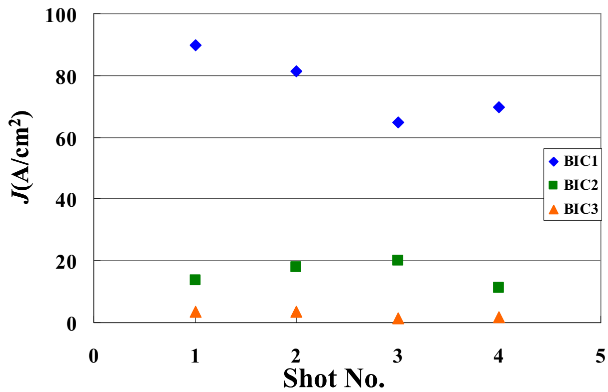

Fig. 6. History of the peak values of J_i measured by the three BICs. For four of continuous shot was evaluated.

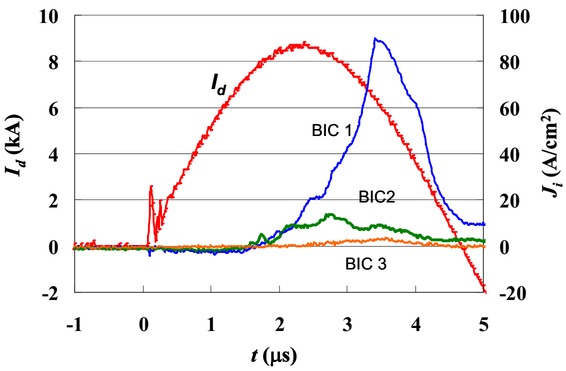

Fig.5. Typical waveforms of discharge current and ion current density

The discharge current will heat the plasma and produces dense aluminum plasma.

B) Characteristics of the ion source

By using the ion source system described in section 2 we have evaluated the characteristics of produced plasma, as well as the discharge characteristics in repetitive operation. Capacitor bank of 1.0 μF, 30 kV is used with aluminum wire of 0.2 mm diameter. The separation between the cathode wheels was 20 mm; hence the wire length between the wheels is around 45 mm.

Figure 4 shows the experimental setup to evaluate the ion current density distribution of expanding plasma. Three Biased ion collectors (BIC1, BIC2, BIC3) are installed as shown in the figure to evaluate the ion current density distribution. The charging voltage of the capacitor bank was 30 kV in the experiment.

Figure 5 shows the typical waveform of discharge current (I_d) and ion current densities (J_i) observed by each BICs. As seen in the figure I_d rises in 2.3 μs and reaches the peak value of 8.8 kA. About 1.5 μs after the rise of I_d, J_i begin to be observed. Assuming that the plasma begins to expand at t = 0, the expansion velocity of the plasma is estimated to be 3.3×10^4 m/s. If assuming the aluminum plasma the kinetic energy of the ions is estimated to be 150 eV.

For BIC1, J_i rises in 2 μs and obtained a peak value of 90 A/cm^2, whereas in BIC2 and BIC3, the peak values were 13.6 A/cm^2 and 3.6A/cm^2, respectively. The result suggests that the plasma is mainly expands to the front side of the ion source. This un-isotropic expansion is considered to be caused by the magnetic pressure produced by the discharge current.

Figure 6 shows the history of the peak values of J_i in each shot. From the figure we confirmed the reproducibility of the ion source.

Figure 7 shows the experimental arrangement to evaluate the transport of the plasma to the acceleration gap of the PHIB diode. Three BICs are used to evaluate the ion current density at 150 mm downstream from the ion source. The arrangement of the ion source was same as that shown in Fig. 4, however, to enhance the ion flux to the downstream, capacitor bank of 3.3 μF was used, which was charged to 30 kV

Figure 8 shows the results of the experiment. As seen in the figure, discharge current (I_d) rises in 5 μs and the peak current of 15 kA is obtained. The ion current

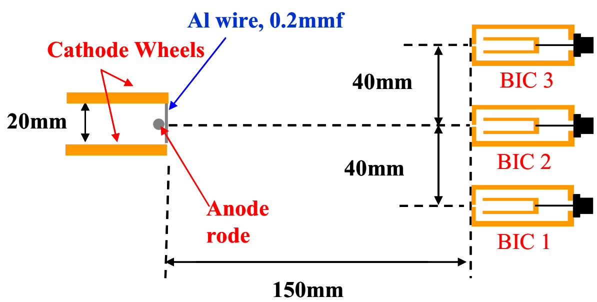

Fig. 7. Experimental arrangement.

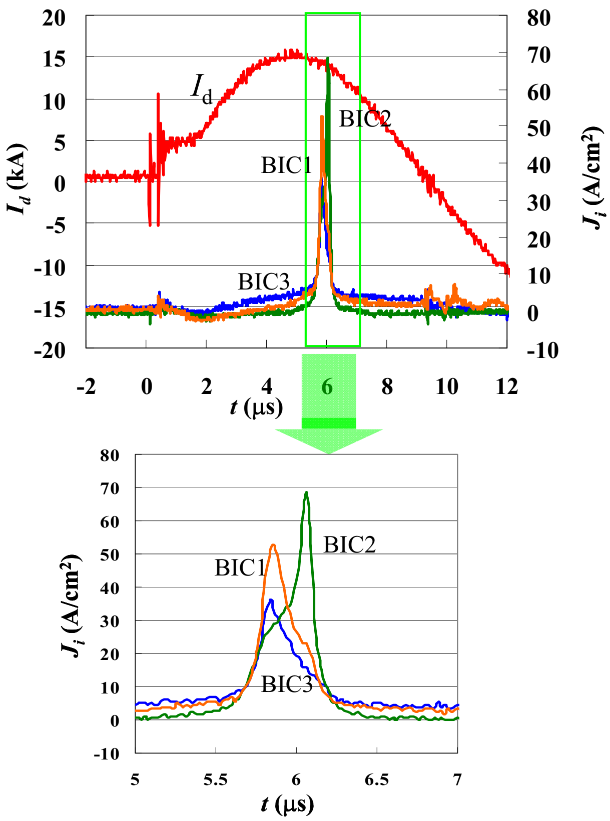

Fig.8. Typical waveforms of discharge current and ion current density

densities (J_i) observed in 3 BICs rise at t = 5.5 μs and have a peak at t around 6 μs. From the time of flight delay the drift velocity of the plasma is estimated to be $2.7x10^4$ m/s, which corresponds to the kinetic energy of 100 eV for aluminum atoms. The peak values of J_i are 36 A/cm^2, 69 A/cm^2 and 53 A/cm^2 for BIC1, BIC2 and BIC3, respectively.

5. Conclusion

An exploding wire type of intense pulsed metallic ion source device is proposed as the ion source of HPIB accelerator. In the device multiple shots operation is realized without breaking the vacuum. Characteristics are evaluated experimentally using thin aluminum wire. The device is successfully operated with acceptable reproducibility. Plasma flux of ion current density around 70 A/cm^2 was obtained at 150 mm downstream from the device. The drift velocity of ions evaluated by a time-of-flight method was $2.7x10^4$ m/sec, which corresponds to the kinetic energy of 100 eV if assuming aluminum ion beam. From the measurement of ion current density distribution ion flow is found to be concentrated to the direction where ion acceleration gap is placed.

Acknowledgments

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