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DEVELOPMENT OF BIPOLAR PULSE ACCELERATOR FOR INTENSE PULSED ION BEAM ACCELERATION

Y. Fujioka, C. Mitsui, I. Kitamura, T. Takahashi, K. Masugata, H. Tanoue[a], K. Arai[a]

Faculty of Engineering, Toyama University, 3190, Gofuku, Toyama 930-8555, Japan
[a] National Institute of Advanced Industry Science and Technology, 1-1-1, Umezono, Tukuba 305-8568, Japan

ABSTRACT

To improve the purity of an intense pulsed ion beams a new type of pulsed ion beam accelerator named "bipolar pulse accelerator (BPA)" was proposed. In the accelerator purity of the beam is expected. To confirm the principle of the accelerator experimental system was developed. The system utilizes B_y type magnetically insulated acceleration gap and operated with single polar negative pulse. A coaxial gas puff plasma gun placed in the grounded anode was used as an ion source, and source plasma (nitrogen) of current density ≈ 25 A/cm^2, duration ≈ 1.5 μs was injected into the acceleration gap. The ions are successfully accelerated from the grounded anode to the drift tube by applying negative pulse of voltage 180 kV, duration 60 ns to the drift tube. Pulsed ion beam of current density ≈ 40 A/cm^2, duration ≈ 60 ns was obtained at 42 mm downstream from the anode surface.

I. Introduction

Intense pulsed ion beams (PIB) of carbon, nitrogen or aluminum, have a wide area of applications including nuclear fusion, materials science, etc. PIB can easily be generated in a conventional pulsed power ion diode using flashboard ion source. However, since many kinds of ions are produced in the same time, the purity of the beam is usually very poor. For example, in a point pinch ion diode we found that produced PIB contains protons, multiply ionized carbons, organic ions, etc[1]. Hence an application of the PIB has been limited. To improve the purity a new type of pulsed power beam accelerator named "bipolar pulse accelerator (BPA)" was proposed[2-4]. As the first step of the development of the BPA, an experimental system was constructed to confirm the principle of the acceleration. In the paper the preliminary results of the experiment are described.

II. Bipolar Pulse Accelerator

Figure 1 shows the concept of the bipolar pulse accelerator. A conventional PIB diode is also shown for comparison. As shown in Fig.1 (a), proposed ion accelerator consists of a grounded ion source, a drift tube and a grounded cathode. In the diode, bipolar pulse (V_1) is applied to the drift tube. At first the negative voltage pulse of duration τ_p is applied to the drift tube and ions on the grounded ion source are accelerated toward the drift tube. If τ_p is adjusted to the time of flight delay of the ions to pass the drift tube, the pulse is reversed and the positive voltage of duration τ_p is applied to the drift tube when top of the ion beam reaches the 2nd gap. As a result the ions are again accelerated in the 2nd gap toward the grounded cathode.

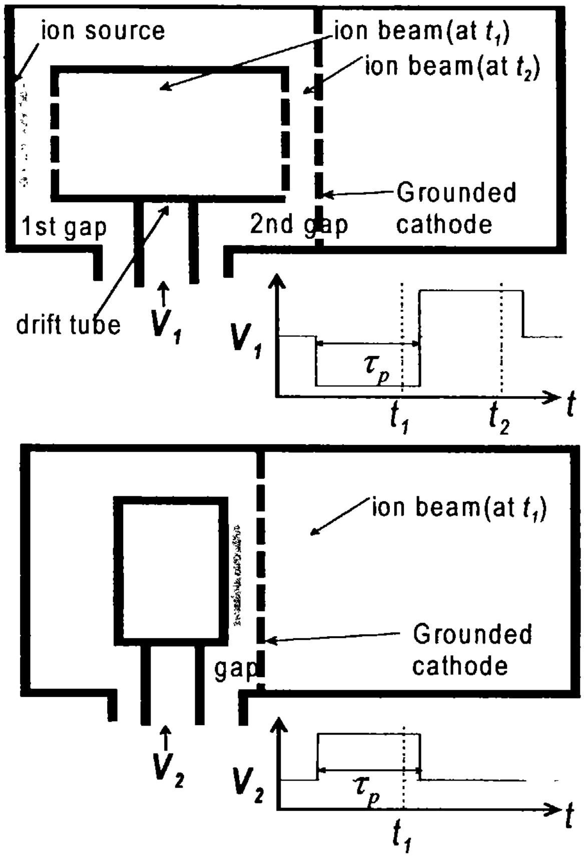

Fig. 1. Conceptual drawing of (a) bipolar pulse accelerator and (b) conventional pulsed ion beam accelerator.

As seen in Fig.1 (b), in the conventional PIB diode, ion source is placed on the anode where high voltage pulse is applied, while in the proposed ion diode, ion source is on the grounded anode. This seems to be favorable for the active ion sources where ion source is powered by an external power supply.

Here, considering the acceleration of ions in the case that ion source contains N^+ and impurity ions of H^+ in the proposed diode (see Fig. 2). In the case, ions of N^+ and H^+ are accelerated in the 1st gap toward the drift tube when negative voltage is applied. In Fig. 2, N^+ and H^+ beams are schematically described and as seen in the figure, due to the deference of the velocity the length of H^+ beam is much longer than

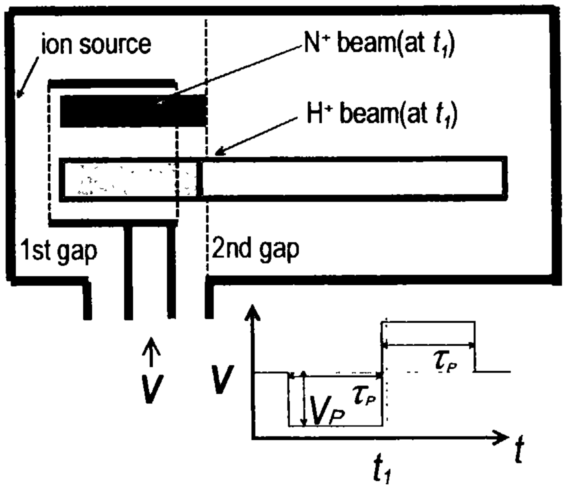

Fig. 2. Principle of the improvement of the purity of the ion beam.

that of N^+. Here assuming that the length of the drift tube is designed to be same as the beam length of N^+ of duration τ_p at acceleration voltage V_p. It is, for example calculated to be 0.19 m when V_p = 1 MV, τ_p = 50 ns. When N^+ beam of length 0.19 m is in the drift tube ($t = t_1$) the voltage is reversed and positive voltage is applied to the drift tube, which accelerate N^+ beam in the 2nd gap. In contrast, since length of H^+ beam at V_p = 1 MV, τ_p = 50 ns is 0.71 m, 73 % of the beam is out of the drift tube at t_1 and it is not accelerated in the 2nd gap. Hence 73 % of H^+ beam is removed in the accelerator.

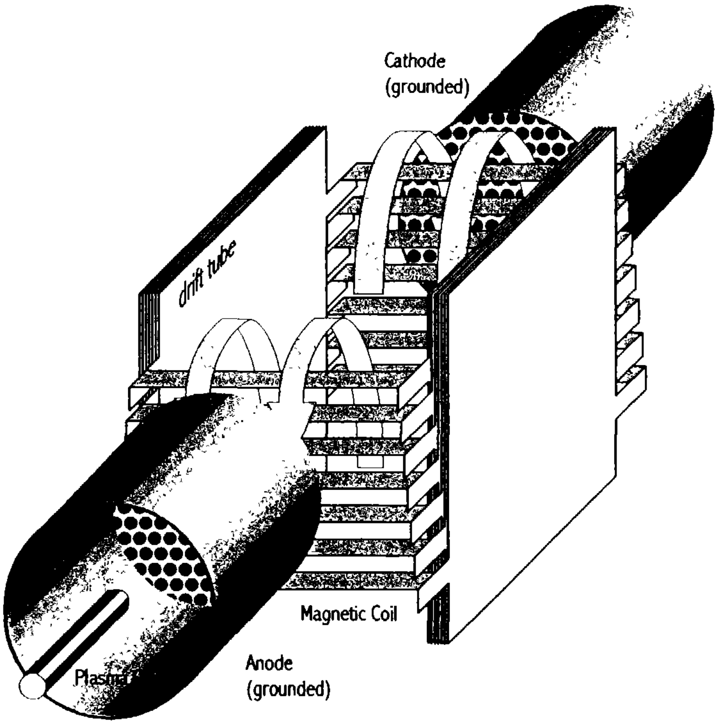

Fig. 3. Conceptual drawing of B_y type magnetically insulated gap for the BPA.

Figure 3 shows the conceptual design of the BPA. The accelerator consists of a grounded anode, drift tube and a grounded cathode. To produce insulating magnetic fields in two acceleration gaps, a magnetic field coil of grating structure is used to produce uniform magnetic field in vertical direction (y-direction).

III. Experiment

Figure 4 shows the cross-sectional view of the experimental system. The system consists of a grounded anode (copper), a drift tube (stainless steel) and a magnetically insulated acceleration gap (MIG). The drift tube is connected to a high voltage terminal of Blumlein type PFL (designed output, 300 kV, 48 kA, 60 ns). By applying negative pulse, ions on the anode are accelerated toward the drift tube. The magnetic coil of the MIG is installed on the rectangular drift tube where acceleration voltage is applied and produces magnetic field of vertical direction (y-direction). To obtain higher transmission efficiency of the ion beam, right and left sides of the coil (facing the anode or cathode) consist of 8 blades each and have a grating structure. Each of the blade (10 mm^W x 118 mm^L x 1 mm^T) are connected in series and constructs an 8-turn coil. Since high voltage pulse is applied to the drift tube, pulsed current produced in the capacitor bank (500 μF, 5 kV) is applied to the coil through an inductively isolated current feeder (IC). The IC is a helically winded coaxial cable and the

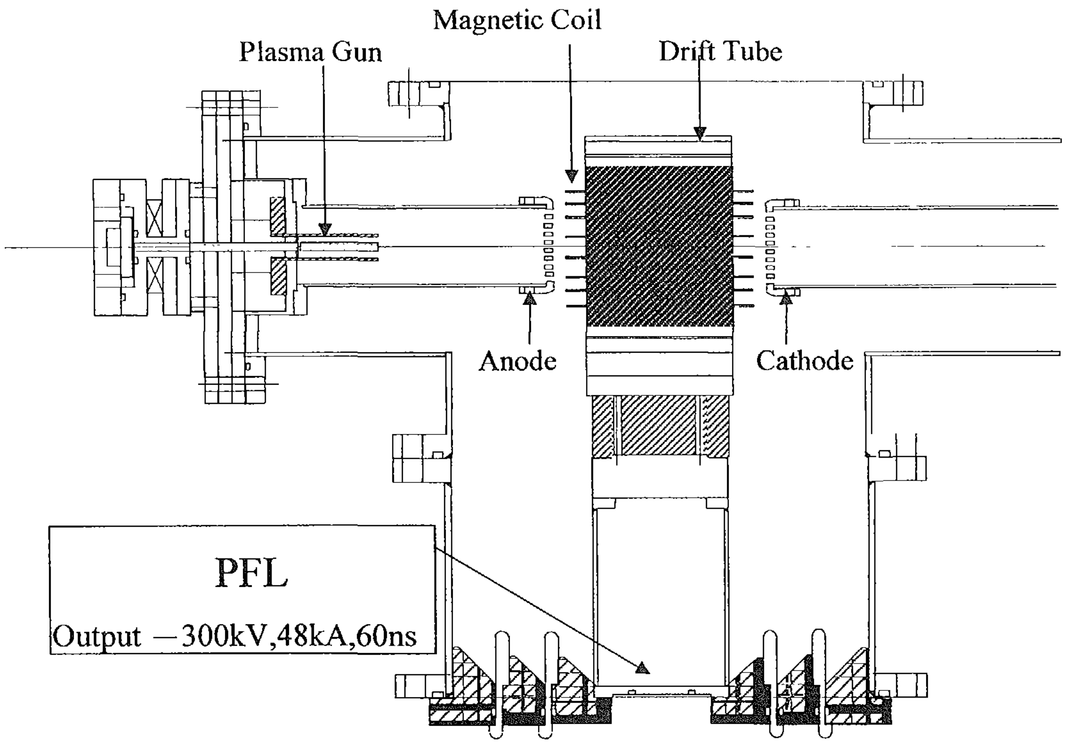

Fig. 4. Cross sectional view of the experimental system.

outer conductor of the IC is connecting the grounded vacuum chamber and the drift tube with inductance of 4.6 μH.

Anode and cathode are circuler blass electrode of diameter 78 mm, thickness 5mm. The electrodes are uniformly drilled with apertures of diameter 4 mm, giving beam transmission efficiency of 50 %. To produce anode plasma (source plasma of the ion beam) gas puff plasma gun was used, which was placed inside the anode.

Figure 5 shows the magnetic filed distribution in the gap. As seen in the figure uniform B_y field of strength 0.4-0.5 T is produced in the acceleration gap of $d_{A\text{-}K}$ = 10 mm.

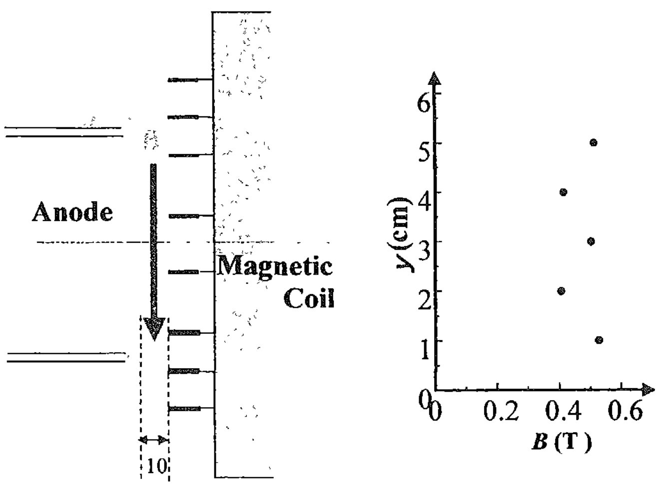

Fig. 5. Magnetic field (B_y) distribution in the acceleration gap when charging voltage of the bank is 4.0 kV.

Figure 6 shows the cross-sectional view of the gas puff plasma gun used in the experiment. The plasma gun consists of a high-speed gas puff valve and a coaxial plasma gun. The gas puff valve consists of a nylon vessel, an aluminum valve and a drive coil and the vessel is pre-filled with N_2 gas. By applying pulse current to the coil magnetic stress presses the aluminum valve to open. The gas expands with a supersonic velocity and reaches the gas nozzles on the inner electrode of the plasma gun.

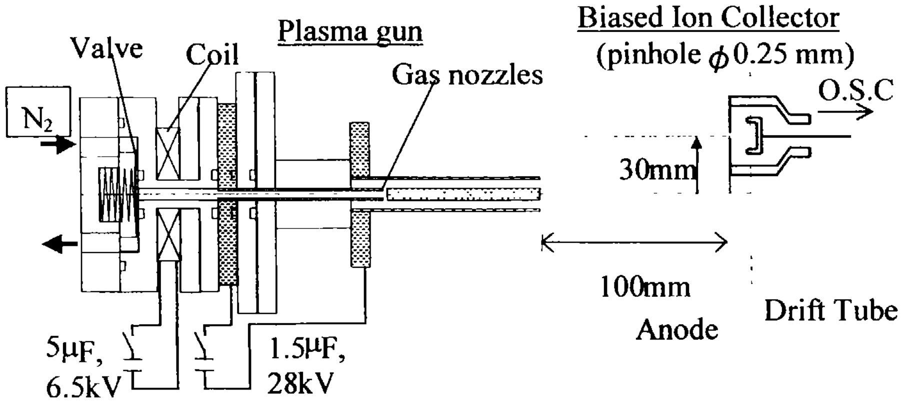

Fig. 6. Cross-sectional view of the gas puff plasma gun.

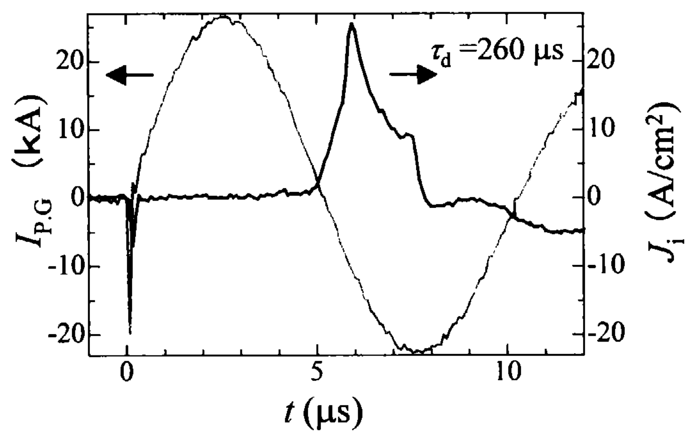

Fig. 7. Typical waveforms of $I_{P.G}$ and J_i.

The plasma gun has a pair of coaxial electrodes, i.e. an inner electrode of outer diameter 4 mm, length 100 mm, and an outer electrode of inner diameter 10 mm. Since it takes about a hundred μs to open the valve and several tens μs for N_2 gas to drift to reach the gas nozzle of the plasma gun, the capacitor bank of the plasma gun is discharged with a delay time of τ_d around 200-320. To apply pulsed current to the gas puff coil and the plasma gun capacitor banks of 5 μF and 1.5 μF were used, respectively. Both of the capacitors were usually charged to 6.5 kV, and 28 kV, respectively.

Figure 7 shows the waveforms of the discharge current of the plasma gun (I_{PG}) and the ion current density (J_i) obtained by a biased ion collector

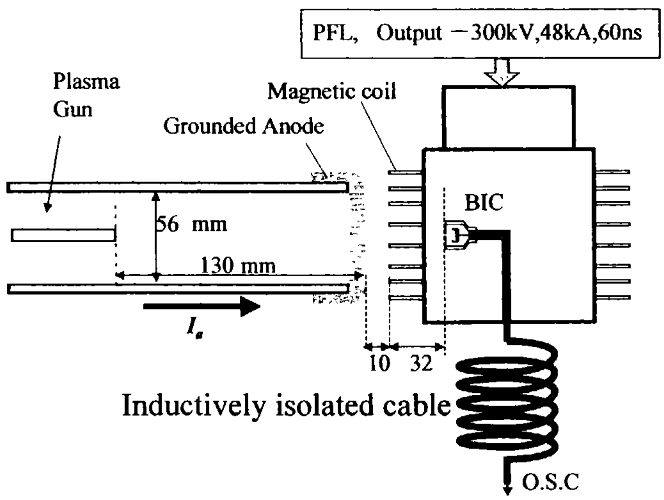

Fig. 8. Experimental setup.

(BIC) when τ_d = 260 μs. As seen in the figure $I_{P.G}$ rises in 2.5 μs and have a peak value of 27 kA. The peak value of J_i of 25 A/cm^2 was obtained at 100 mm downstream from the plasma gun at t = 5 μs after the rise of $I_{P.G}$.

The dependence of J_i on τ_d was evaluated experimentally and found that J_i rises at $\tau_d \approx$ 210 μs and have a peak around 220 μs, and after that gradually decreased. The results suggest that it takes 210 μs after the election of gas puff coil for the gas to reach the nozzles.

Figure 8 shows the experimental setup to measure the accelerated ion beam. BIC was installed inside the drift tube to observe the ion current density (J_i) in the drift tube. Since high voltage pulse is applied to the drift tube, inductively isolated cable was used to transport the BIC signal.

IV. Experimental Results

To confirm the acceleration of ions in the 1st gap negative pulse was applied to the drift tube. The test system was operated at 60 % of the full charge condition of the PFL. Insulating magnetic field of 0.3-0.4 T was applied to the acceleration gap of gap length $d_{A\text{-}K}$ = 10 mm. The plasma gun was operated at $\tau_d \approx$ 260 μs. PFL was fired to apply negative pulse tu the drift tube at and high voltage negative pulse was applied to the drift tube at $\tau_{pp} \approx$ 6.2 μs after the rise of the $I_{P.G}$.

Figure 9 shows typical waveforms of the output voltage (V_g), anode current (I_a) ion current density (J_i). I_a is equivalent to the current flowing in the 1st gap. As seen in the figure, V_g rises at t = 200 ns and peak voltage of -180 kV is obtained. I_a rises with V_g and has a peak of 9 kV. J_i rises at t = 270 ns and have a peak of 30 A/cm^2.

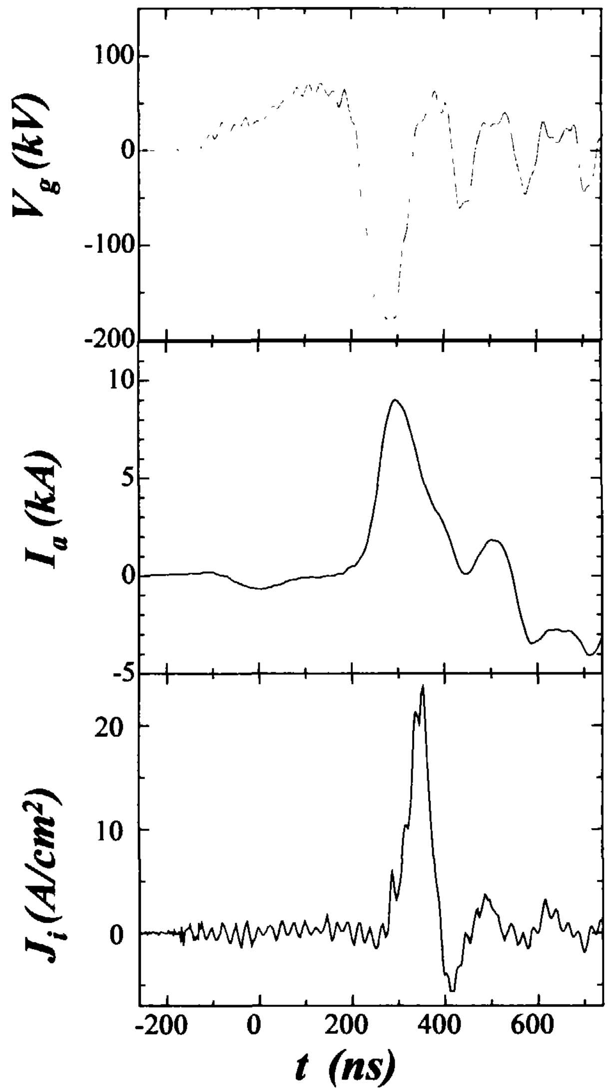

Fig. 9. Typical waveforms of V_g, I_a and J_i.

Figure 10 shows the dependence

of V_g and J_i on the delay time (τ_{pp}) for the fixed condition of insulating magnetic field = 0.3-0.4 T and 60 % of full charging voltage of the PFL. As seen in the figure J_i increases monotonically with increasing τ_{pp} This seems to be due to that quantity of the plasma on the anode or in the first gap increases with increasing τ_{pp}. Due to the increase of J_i, output current of the PFL incrases and as the results V_T decreases with increasing τ_{pp}.

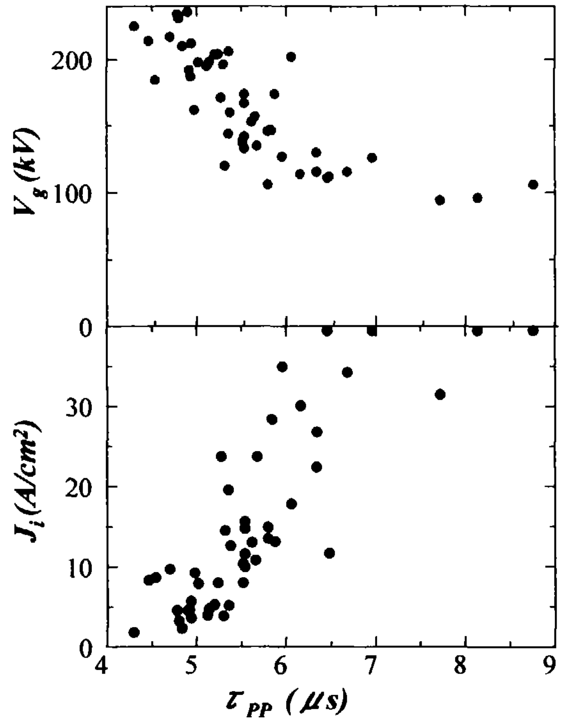

Fig. 10. Dependence of the peak values of V_g and J_i on the delay time (τ_{pp})

V. Conclusion

To confirm the principle of the BPA accelerator experimental system was developed. The system utilizes B_y type magnetically insulated acceleration gap and operated with single polar negative pulse. A coaxial gas puff plasma gun placed in the grounded anode was used as an ion source, and source plasma (nitrogen) of current density ≈ 25 A/cm^2, duration ≈ 1.5 μs was injected into the acceleration gap. The ions are successfully accelerated from the grounded anode to the drift tube by applying negative pulse of voltage 180 kV, duration 60 ns to the drift tube. Pulse Ion beam of current density ≈ 40 A/cm^2, duration ≈ 60 ns was obtained at 42 mm downstream from the anode surface.

References

1) K. Masugata, H. Okuda, K. Yatsui and T. Tazima, J. Appl. Phys. **80** pp. 4813-4818, 1996

2) K. Masugata, "High current pulsed ion beam accelerators using bi-directional pulses" Nuclear Instrum. & Methods in Phys. Res., A 411, pp.205-209, 1998

3) K. Masugata, K. Kinbara, T. Atsumura, Y. Kawahara, T. Takao, I. Kitamura, and T. Takahashi, Proc. 12th Symp. on High Current Electronics (1st Int'l Congress on Radiation Physics, High Current Electronics, and Modification of Materials, Tomsk, Russia, 24-29 September 2000), pp.111-114 (2000)

4) K. Masugata, I. Kitamura, T. Takahashi, Y. Tanaka, H. Tanoue, K. Arai, Proc. 28th IEEE Int'l Conf. on Plasma Science and 13th IEEE Int'l Pulsed Power Conf., Las Vegas, Nevada, June 17-22 2001, pp.1366-1369 (2001)