Evaluation of Bipolar Pulse Generator for 2nd stage acceleration in Bipolar Pulse Accelerator

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ABSTRACT

We have developed a new type of a pulsed ion beam accelerator named “bipolar pulse accelerator (BPA)” for improvement of the purity of the intense pulsed ion beam. The basic BPA system has two magnetically insulated acceleration gaps and is operated with the bipolar pulse. A prototype of the BPA system was developed and we have evaluated the pulsed ion beam accelerated in the 1st stage of the accelerator. The performance of the bipolar pulse generator was evaluated for the experiment on the 2nd stage acceleration of the pulsed ion beam.

Keywords

Pulsed ion beam, Bipolar pulse accelerator, Gas puff plasma gun, Pulse power technology

1. Introduction

The intense pulsed heavy ion beam (PHIB) technology has been developed over the last two decades primarily for nuclear fusion and high energy density physics research [1]. Advances in PHIB technology have led us to a number of potential applications of PHIB to surface modification of materials and a crystallization process of thin films [2-4]. The PHIB technique has also received extensive attention as a new ion implantation technology named “pulsed ion beam implantation” to semiconductor materials for the next generation, since the doping process and the surface annealing process can be completed in the same time.

The PHIB can easily be generated in a conventional pulsed power ion diode using a flashboard ion source. The purity of the PHIB, however, is usually deteriorated by absorbed matter on the anode (flashboard) surface and residual gas molecules in the diode chamber. Thus, the conventional pulsed ion diode is not suitable for the application to the ion implantation. To improve the purity of the intense pulsed ion beam, a new type of pulsed ion beam accelerator named “bipolar pulse accelerator (BPA)” has been proposed and a prototype of the BPA system has been developed [5-7]. The BPA is an electrostatic two-stage accelerator and has two magnetically insulated acceleration gaps. When the bipolar pulse of -114kV, 70 ns (1st pulse) and 85 kV, 62 ns (2nd pulse) was applied to the drift tube, the ions were successfully accelerated from the grounded anode to the drift tube in the 1st gap by the negative pulse of the bipolar pulse. The pulsed ion beam with current density of 60 A/cm^2 and pulse duration of ≈50 ns was obtained at 48 mm downstream from the anode surface [8]. In addition, it was found from the evaluation of ion beam energy by a magnetic energy spectrometer that singly and doubly ionized nitrogen ions with 120~130 keV/Z energy were accelerated with proton impurities.

It is important for the 2nd stage acceleration experiment to generate the bipolar pulse with faster rise time and sharper reversing time. The performance of the bipolar pulse generator was evaluated. In this paper, these experimental results are described.

2. Basic concept of BPA

Figure 1 shows the concept diagram of the bipolar pulse accelerator. As shown in Fig. 1, proposed ion accelerator consists of a grounded ion source, a drift tube and a grounded cathode and is an electrostatic

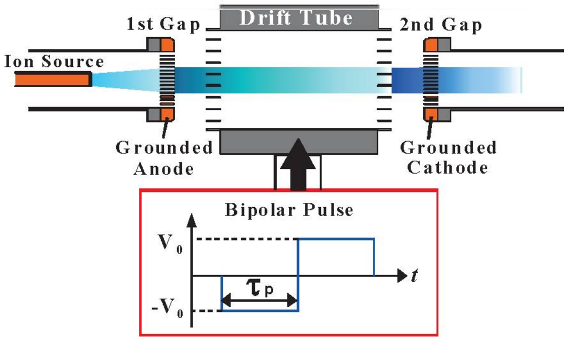

Fig. 1 Conceptual drawing of BPA

two-stage accelerator. In the system, a bipolar pulse of voltage $\pm V_0$, duration τ_p each 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. In the conventional PHIB diode, the ion source is placed on the anode where high voltage pulse is applied, while in the proposed ion diode, the ion source is on the grounded anode, which extremely enhances the accessibility to the anode.

Figure 2 illustrates the principle of the improvement of the purity of the ion beam. Let us now consider the acceleration of ions in the case that the ion beam produced in the ion source consists of N^+ ion and impurity of H^+ ion. In the case, ions of N^+ and H^+ are

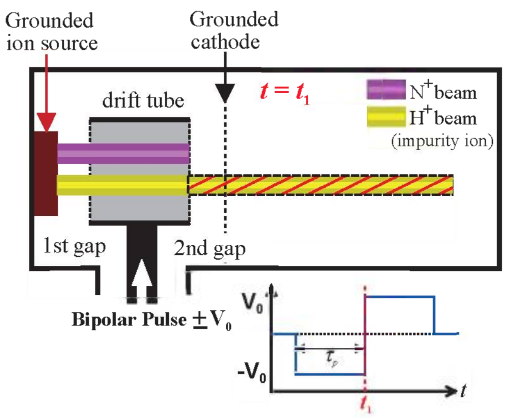

Fig.2 Principle of improvement of the purity of ion beam

accelerated in the 1st gap toward the drift tube when the negative voltage is applied, where N^+ and H^+ ion beams are schematically described in Fig.2.

As seen in Fig.2, the length of H^+ beam is much longer than that of N^+ beam due to the difference of the velocity. We assume that the length of the drift tube is designed to be same as the beam length of N^+ beam with a beam pulse duration τ_p at an acceleration voltage V_0. It is, for example, calculated to be 11.6 cm when V_0=200 kV and τ_p =70 ns. On the other hand, the length of H^+ beam at V_0=200 kV and τ_p =70 ns is 43.3 cm. When the voltage is reversed and the positive voltage is applied to the drift tube at $t = t_1$, N^+ beam of length 11.6 cm in the drift tube is accelerated in the 2nd gap. In contrast, 73 % of the H^+ beam is out of the drift tube and decelerated in the 2nd gap by the first pulse. Hence, 73 % of H^+ beam is not accelerated in the 2nd gap by the positive voltage pulse of the bipolar pulse and is removed in the BPA. As a result, the purity of the ion beam is improved.

3. Experimental Setup

Figure 3 illustrates the cross-sectional view of the bipolar pulse accelerator in the present experiment, which consists of basically a Marx generator, a PFL, a transmission line and a load (accelerator). The designed output of the bipolar pulse generator is the negative and positive pulses of voltage ±200 kV with pulse duration of 70 ns each. In the present system, to generate the bipolar pulse the double coaxial type is employed and has the following features, (i) the length of the line is short, that is, half of the single coaxial type and (ii) the power loss in the switch is reduced, since single switch is used. The PFL consists of three

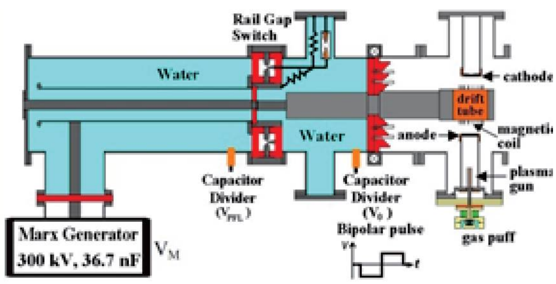

Fig.3 Schematic configuration of bipolar pulse accelerator.

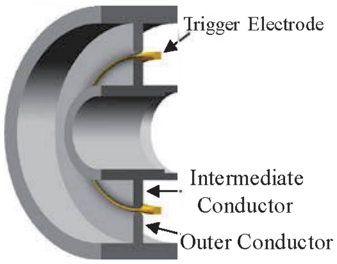

Fig.4 Detail structure of rail gap switch.

coaxial cylinders with a rail gap switch on the end of the line, which is connected between the intermediate and outer conductors and is filled with the deionized water as a dielectric. The characteristic impedance between the inner and intermediate conductors and one between the intermediate and outer conductors are 6.7 Ω and 7.6 Ω, respectively. The line is charged positively by the low inductance Marx generator with maximum output voltage of 300 kV and the stored energy of 1.65 kJ through the intermediate conductor.

The waveform of the bipolar pulse is very sensitive to the performance of the rail gap switch, that is, the rise time and the time to reverse the polarity are dependent on the system's inductance including the inductance of the output switch. In order to realize the bipolar pulse with the fast rising and reversing time, the multichannel rail gap switch is utilized as the output switch of low inductance. The detailed structure of the rail gap switch is shown in Fig.4. It consists of essentially a trigger electrode and a pair of main electrodes (an inner and an outer electrode of 239 mm$^{\phi}$ and 261 mm$^{\phi}$, respectively) separated by a spacing of 11 mm. The main electrodes are made of iron of 20 mm in thickness and have semicircular cross-section of 20 mm in diameter in the end of the electrodes. The knife edged trigger electrode made of copper is placed between the main electrodes and has diameter of 250 mm at top of the edge. These electrodes are carefully aligned and installed in the acrylic vessel. The rail-gap switch is filled with pure SF_6 gas and the pressure is adjusted to control the optimum trigger timing for each experimental condition.

4. Results and Discussion

In order to evaluate the performance of the bipolar pulse generator, the $CuSO_4$ water solution is used as a dummy load instead of the accelerator. Figure 5 shows the typical waveforms of the charging voltage of the PFL (V_{PFL}) and bipolar pulse output (V_{OUT}) at the charging voltage of 30 kV for the Marx generator. The bipolar pulse voltage (V_{OUT}) and charging voltage of the PFL (V_{PFL}) are measured by the resistive voltage divider and capacitive voltage divider placed near the rail gap switch, respectively. Here the filling pressure of the rail gap switch is 0.26 MPa and the impedance of the dummy load is set at Z_L=7.3 Ω, which is almost same as the characteristic impedance of the line between the inner and intermediate conductors. As seen in Fig. 5, the bipolar pulse with voltage of about −110 kV and +74 kV and pulse duration of about 70 ns (FWHM) each is successfully obtained after the charging voltage of the PFL reaches the peak of 240 kV and the rail gap switch is self-broken at t≈225 ns. The peak voltage of the first pulse is almost equal to the half of the maximum charging voltage of the PFL. In contrast, the voltage of the second pulse is smaller. The reduction of the voltage in the second pulse seems to be due to the resistance of the rail gap switch.

It turns out from Fig. 5 that the rise time (10-90 % rise time) and reversing time (90-90 % reverse time) of the bipolar pulse are 26 ns and 38 ns, respectively. The performance of the rail gap switch has an influence on the waveform of the bipolar pulse. Especially, the rise time and reversing time is dependent on the switching inductance. The switching inductance can be estimated from the falling time (90-10 % fall time) of the PFL's charging voltage (V_{PFL}). It is found from Fig. 5 that the falling time of V_{PFL} is 29

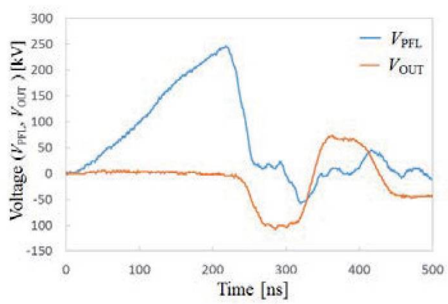

Fig.5 Typical waveforms of the charging voltage of the PFL (V_{PFL}) and bipolar pulse output (V_{OUT}).

ns. Considering that the characteristic impedance of the line between the outer and intermediate conductors is 6.7 Ω, the switching inductance is estimated to be 62 nH. Figure 6 shows the charging voltage (V_{PFL}) of the PFL and the switching inductance as a function of the SF_6 gas pressure in the rail gap switch, where the charging voltage of the Marx generator is 30 kV. The charging voltage increases proportionally with the gas pressure and has the peak at P=0.3 MPa because the switch cannot break down at more than 0.3 MPa. The switching inductance decreases with the increase of the gas pressure and has the minimum value of 62 nH. We need the bipolar pulse with faster rise time and sharper reversing time in order to carry out the 2-stage acceleration experiment. According to Ref.[9], it is reported that the switching inductance of the multichannel rail gap switch can be reduced to less than 10 nH when using the mixture of SF_6 with N_2. There is a need for making improvements in the performance of the rail gap switch. Thus, there seems to be some room for making improvements in the performance of the rail gap switch such as switch inductance.

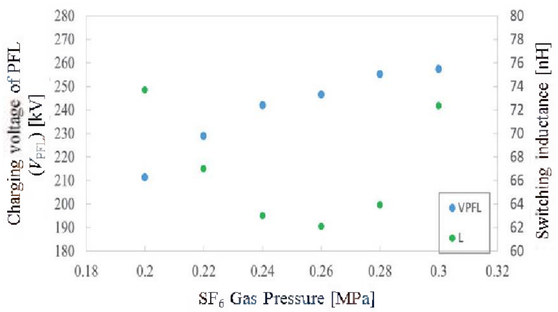

Fig.6 Charging voltage (V_{PFL}) of PFL and switching inductance as a function of SF_6 gas pressure.

5. Conclusions

The performance of the bipolar pulse generator was evaluated for the experiment on the 2nd stage acceleration of the pulsed ion beam. When the charging voltage of the Marx generator was set to 30 kV, the bipolar pulse with the rise time of 26 ns and reversing time of 38 ns was obtained at the filling SF_6 pressure of the rail gap switch of 0.26 MPa. The switching inductance of the rail gap switch was evaluated to 62 nH. There is need for making improvements including the performance of the rail gap switch to produce the bipolar pulse with faster rise time and sharper reversing time.

Acknowledgement

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