Characteristics of Bipolar-Pulse Generator for Intense Pulsed Heavy Ion Beam Acceleration

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Abstract

Intense pulsed heavy ion beams are expected to be applied to the implantation technology for semiconductor materials. In the application it is very important to purify the ion beam. In order to improve the purity of an intense pulsed ion beams we have proposed a new type of pulsed ion beam accelerator named "bipolar pulse accelerator (BPA) ". A prototype of the experimental system has been developed to perform proof of principle experiments of the accelerator. A bipolar pulse generator has been designed for the generation of the pulsed ion beam with the high purity via the bipolar pulse acceleration and the electrical characteristics of the generator were evaluated. The production of the bipolar pulse has been confirmed experimentally.

1. Introduction

Intense pulsed heavy ion beams (PHIB) have a wide area of applications including nuclear fusion and materials science, etc. In the past two decades, the PHIB has been used as a tool for surface modification process of materials[1-4] and a crystallization process of thin films[5]. The PHIB is also expected to be applied to a new ion implantation technology i.e. "pulsed ion beam implantation"to semiconductor, since the doping process and annealing process can be completed in the same time.

The PHIB can easily be generated in conventional magnetically insulated ion diodes using a flashboard ion source. However, the purity of the beam is usually very poor since many kinds of ions are produced simultaneously in the flashboard ion source. For example, the PHIB produced in a point pinch ion diode contains much kind of ions including protons, multiply ionized carbons, and organic ions[6]. Hence, the application of the PHIB to the pulsed ion beam implantation has been extremely limited.

A new type of pulsed ion beam accelerator named "bipolar pulse accelerator (BPA) "has been proposed in order to improve the purity of an intense pulsed ion beams[7]. A prototype of the experimental system was constructed to confirm the principle of the BPA[8]. The system utilizes B_y type magnetically insulated ion diode with an ion source of a coaxial gas puff plasma gun and operated with single polar negative pulse. The ions are successfully accelerated from the grounded anode to the drift tube by applying negative pulse of voltage 240 kV with the pulse duration of 100 ns to the drift tube. Pulsed ion beam with the current density 90 A/cm^2 and the pulse duration 50 ns was obtained at 40 mm downstream from the anode surface. It was found from Thomson parabola spectrometer (TPS) measurement that the ion beam consists of N^+ and N^{2+} with the energy 150-300 keV.

As the next step of the development of the BPA, a bipolar pulse generator was developed to carry out the bipolar pulse acceleration experiment. The design parameters of the bipolar pulse generator are negative and positive pulses of voltage ±200 kV and pulse duration 70 ns each. In the developed generator, the multichannel rail gap switch with an enhanced trigger circuit is employed as a main switch of a pulse forming line to generate the bipolar pulse. The characteristic of the switch and the electrical characteristics of the generator were evaluated. In this paper, these experimental results are described.

2. Basic concept of bipolar pulse accelerator

Figure 1(a) shows the conceptual drawing of the bipolar pulse accelerator. For comparison a conventional PHIB diode is also shown in Fig.1(b). The proposed BPA consists of a grounded ion source, a drift tube and a grounded cathode. As seen in Fig.1(a), The BPA is a 2-stage accelerator and operated with a bipolar pulse. When the bipolar pulse (V_1) is applied to the drift tube, ions produced in the grounded ion source are accelerated in the 1st gap toward the drift tube because at first the negative voltage pulse with the pulse duration τ_p is applied. After τ_p the polarity of the pulse is reversed and the positive voltage with the duration τ_p is applied to the drift tube. As a result, the ions are again accelerated in the 2nd gap toward the grounded cathode. The condition for the most effective acceleration is that the pulse duration of the negative voltage is adjusted to the time of flight delay of ions to pass through the drift tube, i.e. $\tau_p = L/v_i$, where v_i is the ion velocity after accelerated in the 1st gap and L is the length of the drift tube. This condition can be satisfied by adjusting the parameter of the bipolar pulse and the drift tube length. In the above condition, when the top of the ion beam reaches the 2nd gap the pulse is reversed and the whole ion beam is accelerated effectively. As seen in Fig.1, the merit of the proposed BPA is that the ion source can be installed on the grounded anode, while in the conventional PIB diode, the ion source is placed on the anode where the high voltage pulse is applied. This seems to be favorable for the active ion sources where ion source is powered by an external power supply.

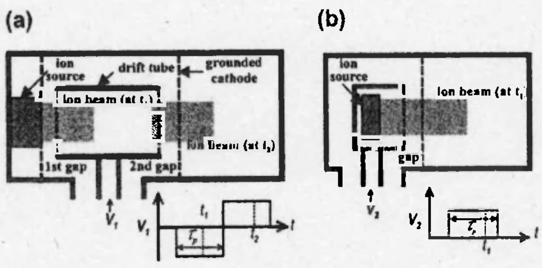

Fig.1 Conceptual drawing of (a) bipolar pulse accelerator and (b) conventional pulsed ion beam accelerator.

As above mentioned the bipolar pulse accelerator has the advantage of the improvement of the purity of the ion beam. As shown in Fig.2, assuming that ion source contains N^+ and impurity ions of H^+ in the proposed diode, let us consider the acceleration of the ions. In the case, ions of N^+ and H^+ are 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 this figure, the length of H^+ beam is much longer than that of N^+ due to the difference of the velocity. 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 11.6 cm when V_p = 200 kV and τ_p = 70 ns. 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, since length of H^+ beam at V_p = 200 kV and τ_p = 70 ns is 43.3 cm, 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.

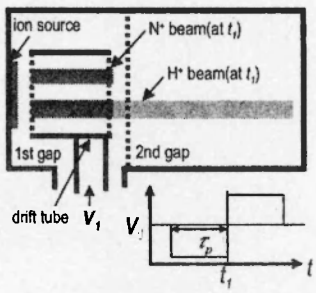

Fig.2 Principle of the improvement of the purity of the ion beam.

3. Experimental Setup

Figure 3 shows the cross-sectional view of the bipolar pulse generator developed in the present experiment. The output parameters of the designed generator are (-200 kV, 7 Ω, 70 ns) + (+200 kV, 7 Ω, 70 ns). The generator consists of a Marx generator and a water coaxial type pulse forming line (PFL). As shown in Fig.1(a), the line consists of three coaxial cylinders with a rail gap switch connected between the intermediate and the outer conductors on the end of the line and is charged by a low inductance Marx generator with the output voltage 300 kV and the stored energy 1.6 kJ at a charging voltage(V_G) of 50 kV. The waveform of the bipolar pulse is very sensitive to the performance of the rail gap switch, that is, the time to reverse the pulse is dependent on the inductance of the switch. In order to realize the bipolar pulse with the fast reversing time and the fast rise time, the multichannel rail gap switch with an enhanced trigger circuit is utilized as the main switch of low inductance. The rail gap switch is operated with pure SF_6 and a mixture of SF_6 with N_2. The detailed structure of the rail gap switch is shown in Fig.3(b). The rail gap switch is constructed of a pair of main electrodes and a trigger electrode. The knife edged trigger electrode is placed between the main electrodes. These electrodes are carefully aligned and installed in the acrylic vessel.

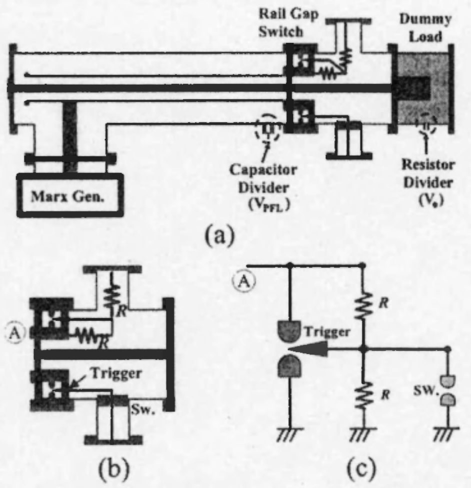

Fig.3 (a) Cross sectional view of the bipolar pulse generator utilized in experiment. (b) Detailed structure of rail gap switch. (c) Trigger circuit of rail gap switch.

Figure 3(c) shows the circuit of the rail gap switch with the enhanced trigger circuit. The trigger circuit consists of resistors of divider(R) and a self-breakdown spark gap switch, where ceramic resistors of 100 Ω are utilized as R. In the circuit, point A is connected to the intermediate conductor of the line and the trigger electrode is kept at the half of the charging voltage of the line in the charging phase. When the discharge gap switch is self-broken the potential of the trigger electrode is dropped to the ground level. As a result, breakdown of the rail gap switch is initiated and the bipolar pulse is transmitted to the load.

4. Experimental Results

Figure 4 shows the typical waveforms of the charging voltage of the PFL (V_{PFL}) and bipolar pulse output (V_0) and the photograph of the rail gap switch, where the rail gap switch is filled with the mixture of SF_6 with N_2 (SF_6 : N_2=1 : 1, total pressure 4.8 atm) and the pressure of the spark gap switch (SW) is optimized to produce a trigger pulse. The capacitive voltage divider and the resistor divider are applied to measure V_{PFL} and V_0, respectively (see Fig.3(a)). The production of the bipolar pulse has been confirmed by the experimental result in which the bipolar pulse of the first pulse (-115 kV, 65 ns) and the second pulse (+80 kV, 60 ns) can be seen just after the charging voltage of PFL reaches the peak 240 kV at $t \approx$ 185 ns and the rail gap switch is triggered. The peak voltage of negative pulse is almost equal to the half of the PFL charging voltage as be expected. In contrast the voltage of positive pulse is smaller. The reduction of the voltage in the 2nd pulse seems to be due to the resistance of the rail gap switch. The bipolar pulse seems to be dull waveform with the rise time of 30 ns and the reversing time of 40 ns. This is considered to be due to the impedance mismatch between the PFL and the transmission line and to switching inductance of the rail gap switch.

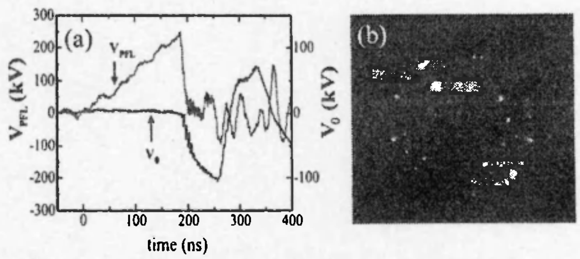

Fig.4 (a) Typical waveforms of PFL charging voltage (V_{PFL}) and bipolar pulse(V_0). (b) Photograph of rail gap switch at the shot.

It is found from Fig.4 that the number of conducting channels in the rail gap is around 15 and that the falling time (90-10 % fall time) of V_{PFL} is 10 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 22 nH.

For comparison, Fig.5 shows the waveforms of the PFL charging voltage in the case of (a) the rail gap switch is operated in triggered mode and (b) in self-breakdown mode when the rail gap switch was filled with pure SF_6. The fall time of V_{PFL} in the case with trigger and without trigger are 13 ns and 19 ns, respectively. Estimating the switching inductance from the fall time in the same manner, the corresponding inductances are 29 nH and 42 nH, respectively. This estimation indicates that the switching inductance is reduced by using enhanced trigger circuit and the mixed gas. In 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. Although the bipolar pulse can be produced by the developed generator, there seems to be need for making improvements including the performance of the rail gap switch.

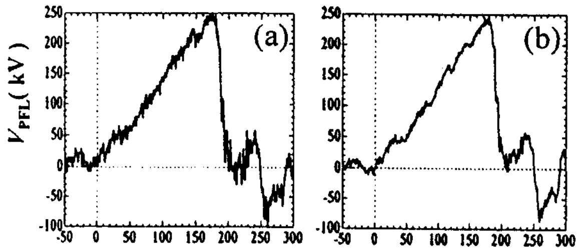

Fig.5 Waveforms of the PFL charging voltage for the case (a) with trigger and (b) without trigger.

5. Summary

We have developed the bipolar pulse generator to carry out proof of principle experiments of the bipolar pulse accelerator. The production of the bipolar pulse has been confirmed experimentally We have found that the performance of the rail gap switch is improved by using enhanced trigger circuit and the mixture of SF_6 with N_2. Further improvements of the bipolar pulse generator are now undertaken in order to produce the bipolar pulse with sharp rise time and reversing time.

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