J. Plasma Fusion Res. SERIES, Vol. 8 (2009)

Ion Beam Current Characteristics of Bernas-type Ion Source with a Co-axial Cathode

Naoki MIYAMOTO
Shinsuke IMAKITA[1)], Toshiro KASUYA[1)], Satoshi SHIMAMOTO[1)] and Motoi WADA[1)]
Nissin Ion Equipment Co., LTD., Minami-ku, Kyoto, 601-8205 Japan
1) Graduate School of Engineering, Doshisha University, Kyotanabe, Kyoto, 610-0321 Japan

(Received: 1 September 2008 / Accepted: 28 January 2009)

To solve the problem of interaction between a magnetic field due to heating current of a high temperature discharge cathode and the field to shape the produced plasma, we have designed the cathode having a co-axial heater current flow structure, and mounted it in a Bernas-type ion source. Boron and phosphor ion beams were produced at 100 keV beam energy. When the external magnetic flux density was increased from 4 mT to 12 mT at the arc current of 500 mA, B^+ ion beam current produced by the ion source equipped with the co-axial cathode increased by a factor of 15, while that produced by the source with a hair-pin cathode increased by a factor of only 6. The ratios of the beam currents produced by the co-axial cathode to those produced by the hair-pin cathode were 2.6 for B^+ ions at 12 mT of the external magnetic field, and 3.4 for P^+ ions at 8 mT, respectively. Beam currents of multiply charged boron and phosphor ions produced by the co-axial cathode were more than 5 times the beam currents produced by a hair-pin cathode at 12 mT.

Keywords: ion source, ion beam, hot cathode, magnetic field, ionization.

1. Introduction

A long maintenance cycle of an ion source and high current density of an ion beam lead to high production efficiency of a semiconductor production facility. Thus, ion equipment manufactures spend efforts to realize longer life and higher efficiency for plasma production of ion sources. High temperature filaments serve as cathodes in compact ion sources such as a Bernas-type ion source as they produce stable plasma in wide range of arc power. However, these cathodes exhibit relatively short life time. One way to elongate the cathode life is to employ an indirectly heated cathode (IHC) [1] with a thick tungsten plate heated by electron bomberdment. However, the extended cathode life time is achieved only with a complex ion source structure.

The detail of a gas disgarge by a hot filament cathode has been studied by many researchers. Ehlers and Leung had investigated the electron emission from filament cathodes in gas discharge [2], and shown magnetic field produced by the filament heating current caused inhomogeneous emission of electrons and concentration of discharge current at a localized position of a filament. In addition, a small potential drop by filament heating current makes the discharge current concentrated at the most negative part of the filament in the plasma. A pig-tail shape filament commonly used in Bernas-type ion sources has the most negative point located far from an arc plasma, hence the lifetime of a pig-tail filament was longer than a usual hair-pin filament [3]. However, a magnetic field produced by a pig-tail filament interacts with the external magnetic field more severely than a hair-pin filament at a Bernas-type ion source. The ion beam current of a pig-tail filament does not increase in propotion to the arc current adjusted by the filament heating current to the pig-tail filament. The plasma density in the ion source can be affected by the coupling between the external magnetic field and the field produced by the cathode heating current.

In this paper, performance of a high temperature cathode having a co-axial structure which does not produce any magnetic field at the surface of the cathode is discribed. An external magnetic field is un-disturbed by this co-axial heating current path even with running several tens of amperes for the heating current. Thus, the arc plasma is expected focused along a narrow reagion in the external magnetic field. The present research aims at improving the performance of the ion source having a magnetic field, while the work by Tanaka *et al* [4], investigated the LaB_6 cathode performance in a field free plasma with a co-axial current flow structure. The ion beam extracted from a focused plasma produced by a co-axial cathode is expected to be larger than that by a hair-pin cathode. The higher beam extraction efficiency leads to smaller heat load to the hot cathode, which should extend the life time of the cathode. The performance of the Bernas-type ion source with a co-axial cathode are compared with that with a hai-pin cathode by varying the external magnetic field and the source gas flow rate.

e-mail: miyamoto_naoki@nissin.co.jp

2. Experimental setups

2-1. Ion Source

A high temperature cathode having a co-axial electrical current path for the heating is produced with the structure adaptive to the Nissin's BEAR (Bernas-type Electron Active Reflection) ion source [5]. A schematic diagram of the co-axial cathode is shown in Fig.1. The co-axial cathode consists of a tungsten centre wire, a thin-wall tantalum tube, and a tantalum ring connecting the centre wire and the tube at the cathode end. The connecting part of the end ring is welded to ensure the electrical contact. At the other end, the cathode terminals are connected to molybdenum current feed-throughs inserted from the end flange supporting the arc chamber of the ion source. The outer diameter of the cathode tube is 5 mm, and the length of the cathode is about 50 mm. The centre wire is 2.2 mm in diameter.

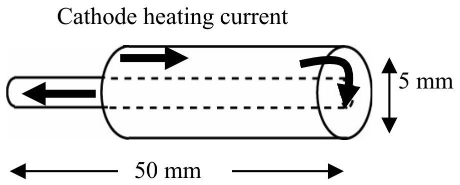

Fig.1 Schematic diagram of a co-axial cathode.

The conventional BEAR ion source uses a hair-pin shaped 2 mm diameter tungsten filament as the cathode. According to previous research, thermionic electron emission is known to localize near the region of the negative end of the filament [2, 6]. The emitted electrons were trapped near the cathode by magnetic field produced by the heating current, and this effect should broaden the energy distribution function of the emitted electrons. A co-axial cathode structure producing small magnetic field at the surface of the external conductor can emit electrons straightly from the tip of the co-axial cathode, forming a high energy electron beam aligned along the magnetic field.

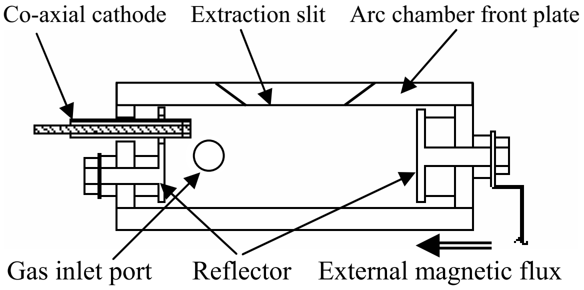

Fig.2 Schematic diagram of an arc chamber for BEAR ion source equipped with a co-axial cathode.

The arc chamber is made of molybdenum with the same dimensions as the BEAR ion source. Figure 2 shows a schematic diagram of the BEAR ion source arc chamber equipped with a co-axial cathode. Two electron reflectors biased at several tens of volts negative with respect to the anode are located at both ends of the arc chamber. These are biased at different potentials to enhance the ionization efficiency of the ion source. The ion beam is extracted from an extraction slit located at the front plate of the arc chamber. The slit size is 3 mm width and 30 mm length. The extraction electric field is controlled by adjusting a gap length between the slit of the arc chamber and the extraction electrode for optimizing the beam optics.

An external magnetic field is applied to the region inside the vacuum chamber where the ion source is inserted. The field is produced by a coil and an iron yoke is set outside of the vacuum chamber. The direction of the external field is perpendicular to the direction of beam extraction.

2-2. EXCEED3000AH Medium Current Ion Implanter

A BEAR ion source with a co-axial cathode is installed to the medium current ion implanter EXCEED3000AH [7]. The beam formation components of the EXCEED3000AH are an ion source, an extraction electrode, a source analyzing magnet for mass separation, an acceleration column, a final energy magnet (FEM), a beam sweep magnet, and a collimator magnet. EXCEED3000AH has a pair of multiple Faraday cup systems in the target chamber. The front Faraday cups and the back Faraday cups are located about 300 mm upstream and 300 mm down stream of the target platen, respectively. The front Faraday cup system has 16 Faraday cups and the back Faraday cup system has 11 Faraday cups. By measuring the beam current signals from the front and the back Faraday cup systems the beam alignment, or the spatial variation of the beam incident angle to the wafer along the beam scanning direction (horizontal direction) is calculated. The beam angle is tuned within an acceptable value by adjusting the beam line parameters. Another Faraday cup is located just downstream from the acceleration column. The position is in the FEM, and so the Faraday cup is called FEM Faraday cup. The FEM Faraday cup is used in case of mass spectrum measurement.

3. Experimental Results and Discussion

Ion beam extraction tests with various types of cathodes were carried out. Gases of BF_3 and PH_3 were used to produce an arc discharge. Energy of singly charged ion beam extracted from BF_3 or PH_3 gas discharge were 100 keV. A 200 keV of doubly charged and 300 keV of triply charged ion beam were extracted from only PH_3 discharge. The co-axial cathode produced larger ion beam currents than a hair-pin cathode [8].

An effect of the external magnetic field for enhancement of ion beam was measured. Figure 3 shows B^+ ion beam current and an extraction current as functions of the external magnetic flux density. These data were obtained under the 100 keV beam energy, 40 kV extraction potential, 60 V arc voltage, 500 mA arc current, 1.5 cc/min BF_3 gas flow rate. The values of the external magnetic flux density were measured at the centre of the arc chamber without cathode heating current. The ion beam current was measured at the back Faraday cups after the beam sweep width was adjusted for 300 mm wafer.

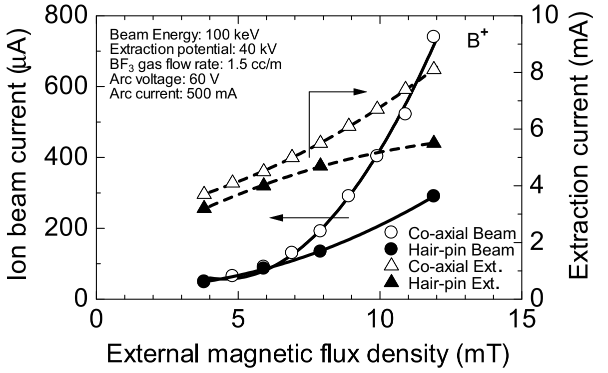

Fig.3 B^+ ion beam current and an extraction current as functions of the external magnetic flux density.

Ion beam increased with increasing strength of the external magnetic field. The co-axial cathode exhibited a dependence more pronounced than that of the hair-pin cathode. Extraction current increased for both cathodes, but that produced by the hair-pin cathode tended to saturate at a larger magnetic flux density. On other hand, the extraction current with the co-axial cathode kept increasing with the magnetic flux density. The ion density in the arc plasma produced by the co-axial cathode seemed increased with increasing magnetic flux density with the dependence stronger than that for the hair-pin cathode. The discharge condition between two types of cathode were the same, therefore the volume of the arc plasma for the co-axial cathode was expected to be smaller than that for the hair-pin cathode. According to the results from a separate experiment, plasma density produced by a co-axial cathode coupled to a linear field was higher than that for a hair-pin cathode by nearly an order of magnitude [9].

Ion production efficiency for each ion species was estimated for both types of cathode. The higher arc plasma density may realize larger ionization efficiency for ions of higher ionization potential. These data were obtained from the result of mass spectrum measured by the FEM Faraday cup. In case of this mass spectrum measurement, the beam optics was optimized to B^+ ion extraction, so the other ion beam currents could have been underestimated due to unoptimized beam optics. Figures 4 and 5 show B^+, BF_2^+ and B^{2+} ion beam current as a function of the external magnetic flux density. The multiply charged ion beam current is defined as the particle flux times the electric charge, thus the B^{2+} ion beam current becomes twice of the particle flux.

Ion beams of B^+ and B^{2+} extracted from the ion source with a hair-pin cathode was increased as shown in Fig. 4.

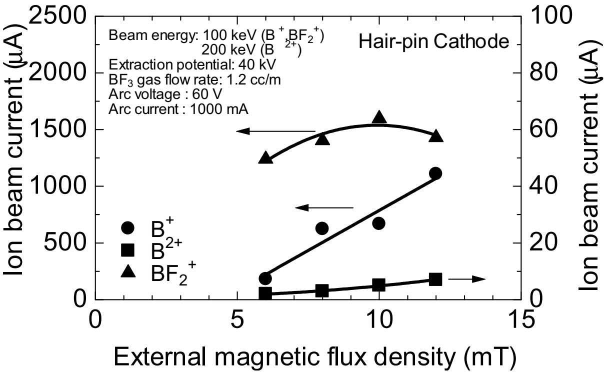

Fig.4 Ion beam currents of different ion species for BF_3 gas discharge as functions of the external magnetic flux density using a hair-pin cathode.

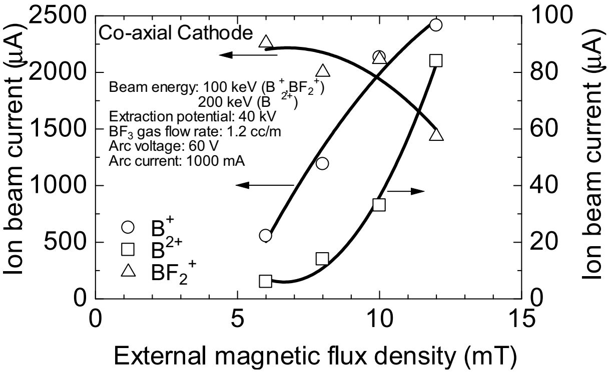

Fig.5 Ion beam currents of different ion species for BF_3 gas discharge as functions of the external magnetic flux density using a co-axial cathode.

Increasing tendency due to employing the hair-pin cathode for B^{2+} ion beam current was smaller than that for B^+ ion beam current. Furthermore, BF_2^+ ion beam current saturated above 10 mT of the external magnetic flux density. An ionization efficiency of the hair-pin cathode ion source is not strongly influenced by the external magnetic field.

Contrary to the case of hair-pin cathode, increasing tendency of B^+ and that of B^{2+} ion beam current by increasing the external field were higher for the co-axial cathode than those for the hair-pin cathode. In particular, the B^{2+} ion beam from co-axial cathode ion source was about 10 times that from the hair-pin cathode ion source at 12 mT. In addition, BF_2^+ ion beam current did not saturate but decreased with increasing external magnetic flux density. The reduction in BF_2^+ ion beam current was possibly resulted from higher ionization/dissociation efficiency at large magnetic flux density. Hence the ionization efficiency of a co-axial cathode ion source was more strongly enhanced than a hair-pin cathode ion source by the increase in external magnetic flux density.

Various kinds of phosphor ion beam current were compared between a hair-pin and a co-axial cathodes adopted to a BEAR ion source for PH_3 gas against the external magnetic flux density. These ion beam currents were measured by the back Faraday cups. The beam optics were individually adjusted for each charge species in ion beam measurement. These data were obtained under the condition; 100 kV acceleration voltage, 40 kV extraction potential, 75 V arc voltage, 550 mA arc current and 1.0 cc/m PH_3 gas flow rate.

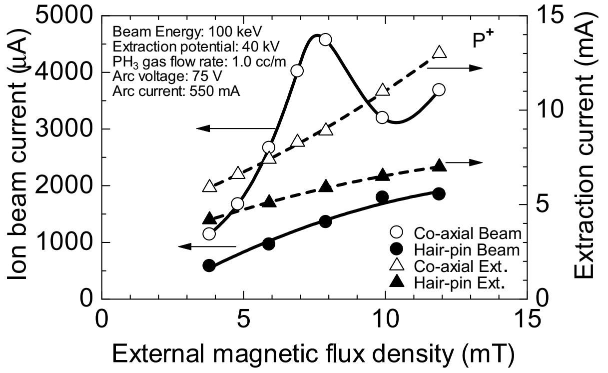

Fig.6 P^+ ion beam current and extraction current as functions of the external magnetic flux density.

Ion beam current of P^+ and an extraction current for two types of cathodes as functions of the external magnetic flux density are shown in Fig. 6. Ion beam current of P^+ extracted from the ion source of both types of cathode increased with increasing external magnetic flux density. Meanwhile the ion beam current extracted from the ion source with the co-axial cathode increased more rapidly for increase of the external magnetic flux density than the ion source with the hair-pin cathode. In particular, P^+ ion beam current from the ion source with a co-axial cathode was 3.4 times the ion source with a hair-pin cathode at 8 mT of the external magnetic flux density. The P^+ ion beam current for the co-axial cathode above 8 mT of the external magnetic flux density became smaller, while the extraction current kept increasing against the increasing external magnetic flux density. Judging from the tendency of the extraction current, the reason for observing this reduction in ion beam current seems caused by unoptimized source extraction optics.

A doubly charged phosphor ion beam current and an extraction current as functions of the external magnetic flux density are shown in Fig. 7, and a triply charged phosphor ion beam current and an extraction current as functions of the external magnetic flux density are shown in Fig. 8. Magnitudes of charged phosphor ion beams were about the same at small external magnetic flux for both types of cathodes. However, the multiply charged ion beam from the ion source with a co-axial cathode showed a large enhancement at a higher external field. The both doubly and triply charged ion beams from the ion source with a co-axial cathode were more than 5 times the ion beams from a hair-pin cathode ion source at 12 mT of the external magnetic flux.

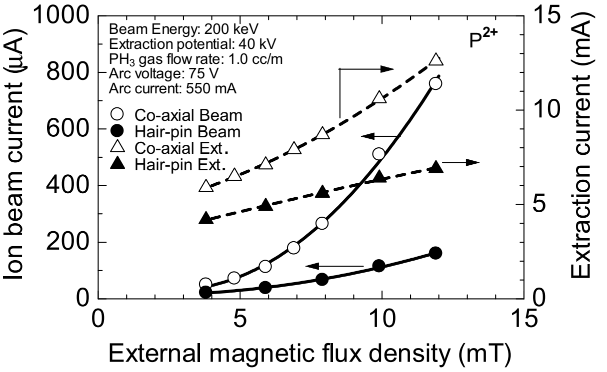

Fig.7 P^{2+} ion beam current and extraction current as functions of the external magnetic flux density.

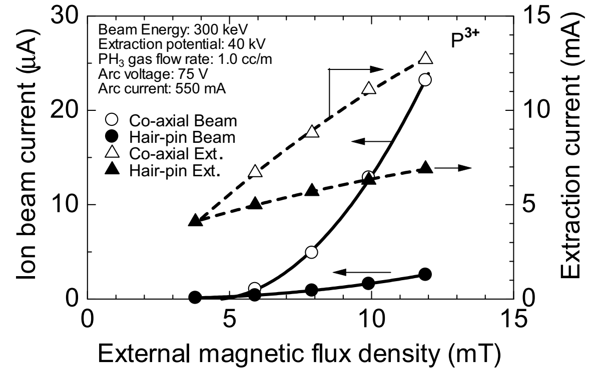

Fig.8 P^{3+} ion beam current and extraction current as functions of the external magnetic flux density.

Ion extraction characteristics against source gas flow rates were measured using BF_3 and PH_3 gases. Each source gases were supplied by a mass-flow-controller (MKS type1640). Figure 9 shows B^+ ion beam current as a function of BF_3 gas flow rate. These data were obtained under the discharge condition; 60 V arc voltage, 1000 mA arc current and 8 mT external magnetic flux density. The B^+ ion beam was extracted by 40 kV of extraction voltage and 100 keV of beam energy. These ion beams were measured at the back Faraday cups. Both beam currents for a co-axial cathode and that for a hair-pin cathode increased with increasing gas flow rate until 1.4 cc/m. The beam current produced by a co-axial cathode was 3 times that of the hair-pin cathode. The ion beam produced by a co-axial cathode saturated above 1.5 cc/m of BF_3 gas flow rate. In contrast, the hair-pin cathode maintained a slowly increasing tendency. These characteristics against gas pressure were attributable to higher ionization efficiency of the co-axial cathode.

Figure 10 shows P^+ ion beam current as a function of PH_3 gas flow rate. The PH_3 gas flow rate characteristic was also similar to that of the BF_3 gas flow rate characteristics. These results show that the ionization efficiency does not depend on the gas kind but depends on the magnetic field structure decided by the cathode shape and the surrounding magnetic field geometry.

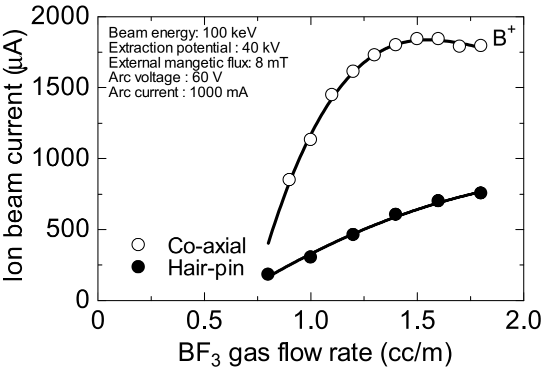

Fig. 9 B^+ ion beam current as a function of the BF_3 gas flow rate.

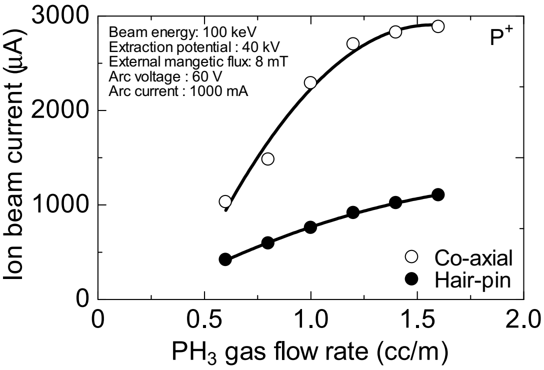

Fig. 10 P^+ ion beam current as a function of the PH_3 gas flow rate.

4. Summary

A co-axial cathode adaptive to a Bernas type ion source for ion implanter was developed. Boron and phosphor ion beam extraction experiments were carried out at an actual medium current ion implanter. Boron and phosphor ion beams were produced by using a co-axial cathode and a hair-pin cathode. Extracted ion beams from an ion source with a co-axial cathode showed a strong influence upon the external magnetic field than those from an ion source with a hair-pin cathode. Furthermore, multiply charged ion beams showed even stronger dependence upon the external magnetic flux density.

Characteristics of singly charged boron and phosphor ion beam currents against source gas flow rates were measured. The dependence of the ion beam current upon the source gas flow rate for the co-axial cathode tended to saturate at lower gas pressure than that for the hair-pin cathode. A co-axial cathode can realize localized higher ionization efficiency in the arc plasma.

Acknowledgments

The authors thank K. Miyabayashi, N. Hamamoto and the colleagues of the system development group of Nissin Ion Equipment Co., LTD. for their technical advices and discussions on the experiment. Valuable assistance for realizing the co-axial cathode production from Y. Minosaki and H. Sasaoka of Creative Technology Corporation are greatly acknowledged. The authors thank Dr. T. Kenmotsu and Dr. Y. Kimura at Doshisha University for their beneficial comments.

[1] K. Tanaka, S. Umisedo, K. Miyabayashi, H. Fujita, T. Kinoyama, N. Hamamoto, T. Yamashita and M. Tanjyo, Proceedings of 16th International Conference on Ion Implantation Technology, 421 (2006).

[2] K. W. Ehlers and K. N. Leung, Rev. Sci. Instrum. **50**, 356 (1979).

[3] S. R. Walther, Rev. Sci. Instrum. **65**, 1307 (1994).

[4] S. Tanaka, K. N. Leung, P. Purgalis and M. D. Williams, Rev. Sci. Instrum. **59**, 120 (1988).

[5] N. Miyamoto, K. Miyabayashi, T. Yamashita and H. Fujisawa, Rev. Sci. Instrum. **73**, 819 (2003).

[6] M. E. Arciaga, T. Kasuya, A. G. Mendenilla, H. J. Ramos and M. Wada, The Science and Engineering Review of Doshisha University, **44**, 185 (2003).

[7] S. Sakai, M. Tanjyo, N. Hamamoto, S Umisedo, T. Kobayashi, T. Yamashita, T. Matsumoto, T. Ikejiri, K. Tanaka, Y. Koga, S. Yuasa, M. Naito and N. Nagai, Proceedings of 16th International Conference on Ion Implantation Technology, 605 (2006).

[8] N. Miyamoto, N. Hamamoto, S. Imakita, A. G. Mendenilla and M. Wada, Proceedings of 17th International Conference on Ion Implantation Technology, 304 (2008).

[9] S. Imakita, T. Kasuya, N. Miyamoto, S. Shimamoto and M. Wada, These proceedings.