Intense Negative Heavy Ion Source with Cusp Magnetic Field

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abstract.

Performance and the characteristics of the cusp-magnetic-field negative heavy-ion source which has been recently developed at KEK are described. After the first successful experiment to produce intense Cu, Ni, Au an O negative ions with pulsed beams, various species of the negative ions such as Ag, Pt, C, Si, Bi, Fe, Al, Ta, W, P, As, Cr, Ti, Co, Sn, In, V and Pd have been tried to extract from this ion source. Large intensities of the beam current ranging more than mA were obtained for almost all of these species.

1.Introduction

Recently, new type of the negative heavy-ion source which makes it possible to generate 50-100 times more intense negative heavy-ion beams compared with the ordinary negative ion source has been developed at KEK .[1,2] In this ion source, negative heavy- ions are produced at the surface of the material which is placed in a xenon plasma confined by a cusp magnetic field. This type of ion source has been originally developed at LBL(Lawrence Berkley Laboratory) for producing an intense negative hydrogen beam for nuclear fusion and then improved for the accelerator applications at LANL(Los Alamos National Laboratory)[3] and KEK(National Laboratory for High Energy Physics). Therefore, this ion source has a nickname of BLAKE negative ion source. [4]

We have already reported the results of the experiment for copper, gold, nickel and oxyzen negative heavy-ions produced by the BLAKE ion source[1,2] and more than 50-100 times larger beam intenisties compared to the ordinary sputtered negative ion source have been obtained. After the first successful experiment, we have been doing experiments to obtain various other negative heavy ion species such as Ag, Pt, C, Si, Bi, Fe, Al, Ta, W, P, As, Cr, Ti, Co, Sn, In, V and Pd. For these many species, the BLAKE negative ion source shows a large potential to generate intense negative heavy ions.

2.Apparatus and operation

Details of the configuration of the BLAKE negative ion source has already been described in previous papers [1,2]. The schematic layout of the ion source is shown in Fig.1. The ion source consists of a cylindrical plasma chamber made of stainless steel ,a sputter probe,cesium oven and two sets of filaments. The diameter of the plasma chamber is 18cm and the length is about 25cm. There are eighteen pieces of SmCo permanent magnets surrounding the plasma chamber to make the cusp magnetic field and each of them is placed in an aluminum water jacket for cooling. The cross section of each magnet is 10mm wide and 12mm high and the magnetic field strength at the surface of each magnet is about 3.4kG. The diameter of the anode aperture is 18mm. Two sets of small permanent magnets are around the anode aperture to complete the cusp-magnetic-field-line continuity surrounding the plasma chamber and the magnetic field strength in the anode hole is less than 50 gauss. In the previous experiment, the electrons, which were also extracted simultaneously with negative ions, were removed by dipole magnets placed in the beam extraction line. However in the present set-up, the two small permanent magnets making the dipole magnetic field of about 100 gauss were also placed at the exit of the anode hole and used to return the extracted electrons back to the anode. The total drain current of the extraction power supply was substantially reduced with this modification. In this configuration, the anode aperture diameter was reduced to 14mm because of the housing of the magnets as shown in Fig.2.

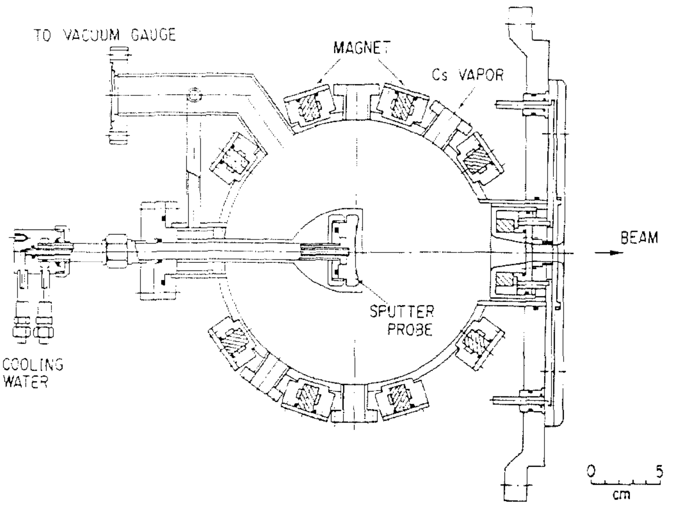

Fig.1 A schematic layout of the cusp negative-heavy ion source.

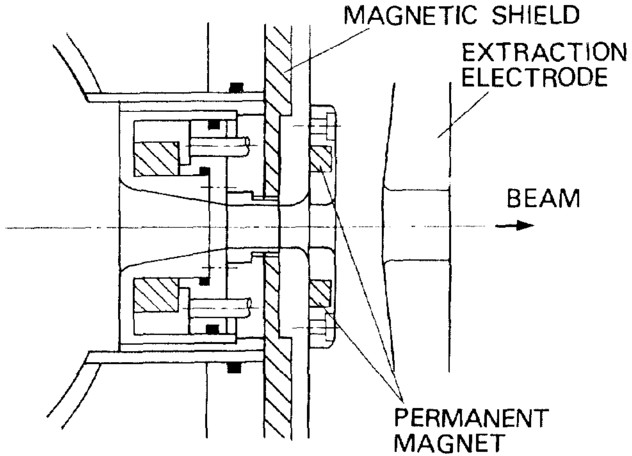

Fig.2 Configuration of the anode apertures with a pair of permanent magnets.

The sputtering probe was placed at the center of the plasma chamber, which was 12cm from the anode aperture, and biased negatively in the plasma by a voltage of up to -970V. A quartz glass covered the probe except the surface to the anode hole and helped to prevent the supporting and cooling channel of the probe from sputtering by xenon ions in plasma. In the previous experiment the sputtering probes were cooled directly by the flowing water. However in this experiment, all of the probes used were cooled indirectly through a backing plate which was made of copper. This was enough for cooling in the pulsed operation.

Two types of probes were used in the experiment for the convenience of preparation. One was a sheet with a thickness of about 0.1mm and the other a thick plate. Probes made of pure metals like Fe,Ti,In,W,Sn were used in the form of thin sheets ,which were made by mechanical pressing to have concave structures. Thick plate probes were used for the compound or mono-crystal materials like silicon,GaAs and Ga, and some of them had to have flat surfaces because of the difficulties of machining to make concave structures.

The cesium oven was made of stainless steel and placed at the outside of the plasma chamber. The cesium metal was charged in the oven by breaking the cesium glass ample in the vacuum to avoid oxidization. The oven and the plasma chamber was connected by a heated stainless steel pipe of 6mm in diameter and the high temperature gas valve was placed between the oven and the ion source to keep the oven in vacuum even when the plasma chamber was opened to atmosphere. The pipe and valves were heated up to about 300°C by a sheath heater. This high temperature valve was also useful to find the optimum condition of the cesium coverage on the sputtered probe surface. If the beam current increases abruptly by closing the high temperature valve, the cesium coverage on the probe surface is considered to be too thick and if there is an opposite trend, the cesium coverage is not enough. For the most of the materials of the sputtering probe, the optimum cesium oven temperature was normally around 220°C and it changed largely by changing the duty factor of the pulsed beam. Even at the condition of the same duty factor, the optimum cesium oven temperature was slightly different for each materials. For the material with high sputtering rate or small thermal conductivity, the optimum cesium oven temperature became higher. The ion source was operated in a pulse mode by making a pulsed arc discharge. The arc voltage and current during the normal operation were 30-40 V and 10-20 A, respectively. A current regulated pulsed power supply was used for making the arc discharge. The duration and the repetition rate of the pulsed arc power supply were 100-200μsec and 1-20 Hz, respectively during the normal operation.

In order to obtain an intense negative ion beam from the ion source, some pre-conditioning was necessary before introducing the cesium vapour. We have seen a lot of small sparking occuring on the probe surface when the voltage was applied to the probe. This sparking was probably caused by the outgasing from the probe surface. After several hours conditioning , the sparking rate was gradually reduced and finally the maximum probe voltage of -970V could be applied without sparking.

After several hundred hours operation, a small coverage of the material sputtered from the probe was found on the surface of the filaments and electron emission efficiency of the filaments was reduced. For the pulsed mode operation with low duty factor like the present operation, there was almost no problem on this point even after the long period operation of more than a couple of hundred hours. But it might be serious for DC operation.

3. Beam measurement

The beam measurement system is shown schematically in Fig. 3. Beams were extracted at the energy of aboout 30keV from the ion source and focussed by an einzel lens on a Faraday cup which was placed 120 cm away from the extraction electrode. The openeing aperture of the Faraday cup was about 5cm in diameter and at the front of the cup , the negatively biased electron supressor was placed. In order to avoid the contamination of the electrons which were extracted simultaneously from the ion source in measuring the negative ion beam, a small dipole permanent magnet was placed at the entrance of the einzel lens to reflect the electrons away from the ion beam. Moreover, another large permanent dipole magnet which was 5cm wide,4cm high and 15 cm long was placed between the

species	beam current(mA)	converter materials
Cu	10	Cu metal, spherical
Ni	6	Ni metal, spherical
Au	10	Au metal, spherical
C	3.4	graphite,spherical
C_2^-	4.6	graphite, spherical
Fe	1.7	Fe meatl, spherical
Pt	6.4	Pt metal, spherical
Ti	0.8	Ti metal,spherical
Ag	5.4	Ag metal, spherical
BO_2	1.7	LaB_6, spherical
BO	2.8	LaB_6,spherical
Co	2.8	Cometal, spherical
Bi	0.13	Bi metal, sphrical
Ta	1.4	Ta metal, spherical
Si	5.4	Si crystal, spherical
P	0.86	GaP crystal, flat
W	3	W metal, flat
Sn	2.6	Sn metal, spherical
In	0.12	In metal, spherical
Al	1.1	Al metal, spherical
V	0.7	V metal, spherical
Pd	6.8	Pd metal, spherical
Cr	0.2	Cr metal, spherical
As	0.67	GaAs crystal, flat
As_2	2.24	GaAs crystal, flat

TABLE 1. Beam intensities from BLAKE ion source.

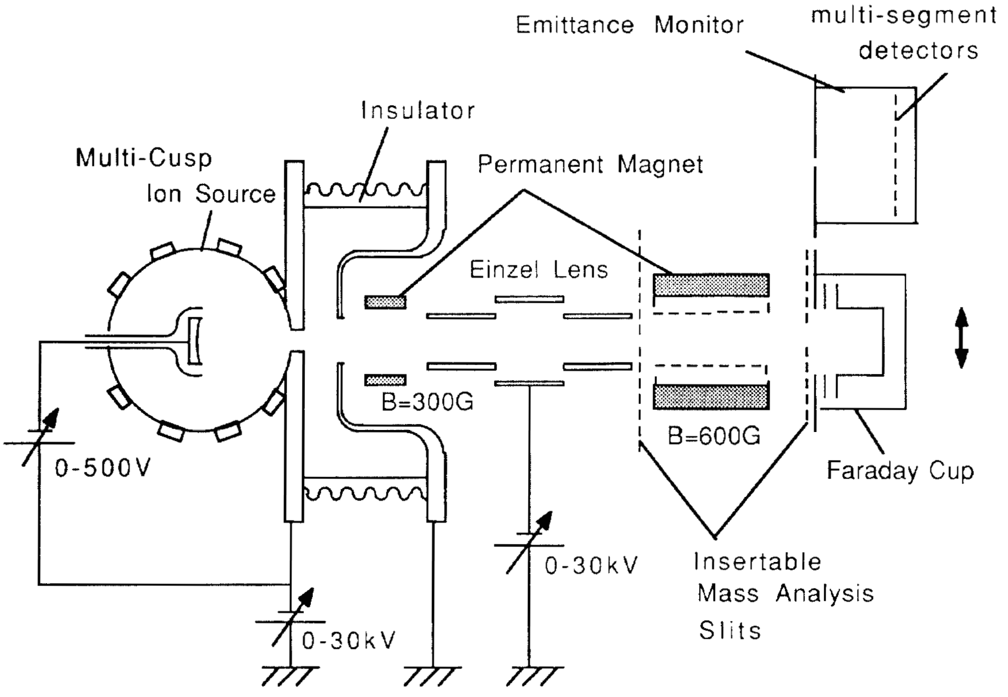

Fig.3 Schematic layout of the measurement system of the negative ion beams.

einzel lens and Faraday cup to remove these electrons completely. This large permanent dipole magnet was also used to separate the ion species in the beam and analyze the mass spectrum of the beam extracted form the ion source. In the measurement of the mass spectrum of the beam, a small slit of 0.2mm width was mounted on the entrance of this large permanent dipole magnet and the beam current analysed by the magnet was measured by a movable Faraday cup.

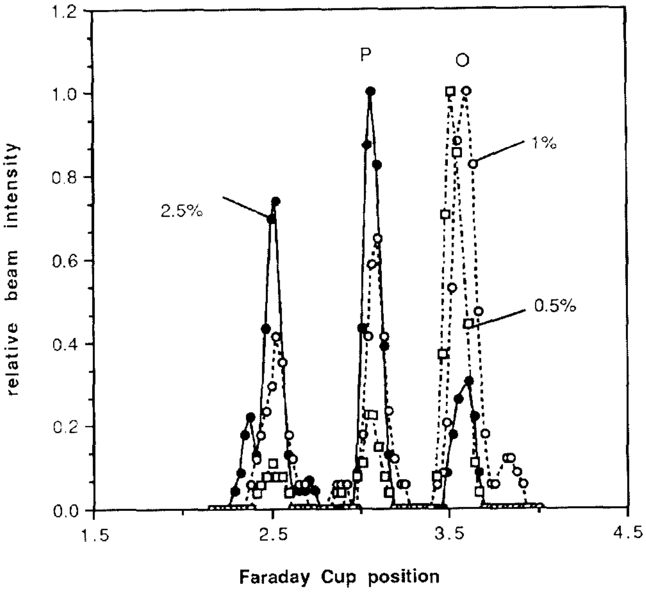

Fig.4 Mass spectrum of negatiuve P ion beam for various duty factors of pulsed beam operation.

More than 20 species of the negative-heavy ions have been tested and the results of the obtained beam intensities are summarized in Table 1 with the sputtered target configurations for each species. As can be seen from this table, the beam intensities for most of species are almost 50-100 times larger than those obtained from the ordinary cesium sputtered negative-heavy ion source. Beams from the ion source were very stable and reproducible. In Fig. 4, the changes of the mass spectrum of the negative P ions for three different duty factors, 0.5%,1% and 2.5% are shown. As is obviuos from this figure, portions of the impurity ions were reduced by increasing the duty factor of the beam. And these ions were increased right after the duty factor of the beam decreased. This shows that the most of the impurities come from the outside ,not from the inside of the probe, for example, from the filaments.

Beam emittance is measured by the emittance monitor which was developed for the 750keV H^- beam of the 12GeV synchrotron. The emittance monitor consists of a single slit and 32 segments of beam current detectors. Data are taken by a CAMAC waveform transient memory system and analyzed by a minicomputer(micro-VAX). In fig. 30, the measured beam emittance contour of the negative nickel beam is shown. As is clearly seen from this figure, some aberation was found in the beam. This might be due to two reasons; one was the abberation of the einzel lens and the other is the space charge effect in the beam. A typical value of the normalized emittance occupied in 90% fraction of the total beam was about 37 p mm.mrad.$(MeV)^{1/2}$. This value is about 3-4 times larger than the ordinary sputtered negative ion source. However, the brightness of the beam is relatively large because the beam intensity is 50-100 times bigger than that.

4 Conclusion

Characteristics and performance of the newly developed cusp magnetic field negative ion source have been described. More than 20 species of negative heavy-ion beams have been obtained so far at the ion source test stand and the beam intensities from the ion source were found to be almost 50-100 times larger than those from the ordinary cesium sputtered negative ion source. Beam emittance was also measured for Ni beam and the 90% normalized emittance was about 37p mm.mrad.$(MeV)^{1/2}$.

This ion source might be useful not only for nuclear experiment with a tandem accelerator but also for ion beam applications such as ion implantation.

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