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# INTENSE NEGATIVE ION SOURCES

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Abstract Negative ion sources based on plasma-surface interactions have been developed at KEK for producing intense negative hydrogen ions and negative heavy ions. A negative hydrogen ion source has been routinely used for the KEK 12 GeV proton synchrotron since 1985 and it provides more than 20mA of H- ion beam to the machine. A negative heavy ion source has been also developed and it generates various species of negative heavy ions with intense beam currents. For example, more than 10mA of Au- ion beam was obtained from the ion source.

## INTRODUCTION

Recently, various new types of the negative ion sources which make it possible to generate various species of intense negative ion beams such as $H^-$,$C^-$,$Si^-$,$Cu^-$,$Ni^-$,$Au^-$ and so on compared with the ordinary negative ion source have been developed at KEK.[1] [2] [3] In these ion sources, negative ions are produced at the surface of the material which is placed in a hydrogen plasma confined by a cusp magnetic field for producing negative hydrogen ions or a xenon plasma for negative heavy-ions. This type of negative ion source has been originally developed at LBL(Lawrence Berkley Laboratory) for producing an intense negative hydrogen beam for nuclear fusion[4] and then improved for accelerator applications at LANL(Los Alamos National Laboratory)[5] and KEK(National

Laboratory for High Energy Physics). Therefore, the ion source has a nickname of BLAKE negative ion source. The BLAKE ion source has produced relatively large beam intensities of more than 10mA compared to the ordinary sputtered negative ion source.

## APPARATUS

Details of the configuration of the BLAKE negative ion source have already been described in previous papers.[1 2 3] 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. There are eighteen pieces of SmCo permanent magnets surrounding the plasma chamber to make the cusp magnetic field. Two small permanent magnets making a 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 these dipole magnets. The sputtering probe was placed at the center of the plasma chamber, which was 12cm from the anode aperture, and biased negatively 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 the plasma.

Two sets of hot filaments made of lanthanum hexa-boride ($LaB_6$)were used for making the arc discharge. The operating temperature of the filaments were about 1400-1500°C, which was almost 1000°C lower to achieve the same plasma condition than that of the tungsten filament The details of the characteristics and performance of the filaments are described in reference.[1]

## PULSED MODE OPERATION

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 1-20Hz, respectively during the normal operation.

The plasma condition was dramatically changed once cesium was introduced into the plasma chamber. The arc voltages dropped abruptly from 60-80V to 30-40V and the electrons extracted from the ion source were also substantially reduced. It is naturally conceivable that cesium atoms introduced into the plasma would be mostly ionized by the energetic electrons in the plasma because cesium has a low ionization potential. Thus the plasma became a cesium-xenon mixed plasma once cesium vapor was introduced. At the very first stage of the operation with cesium vapor, large numbers of impure negative ions such as oxygen were found in the extracted beam. With the present beam duty factor, several hours were needed to reduce these impurities.

The sputtered probe was normally biased at a voltage of -970 V to the anode wall. Thus, a thin plasma sheath was created at the surface of the probe. Many xenon ions in the plasma were accelerated through the plasma sheath, hit the probe surface and sputtered out a large amount of particles from the surface. Some of sputtered particles formed negative ions on the surface because the work function of the surface

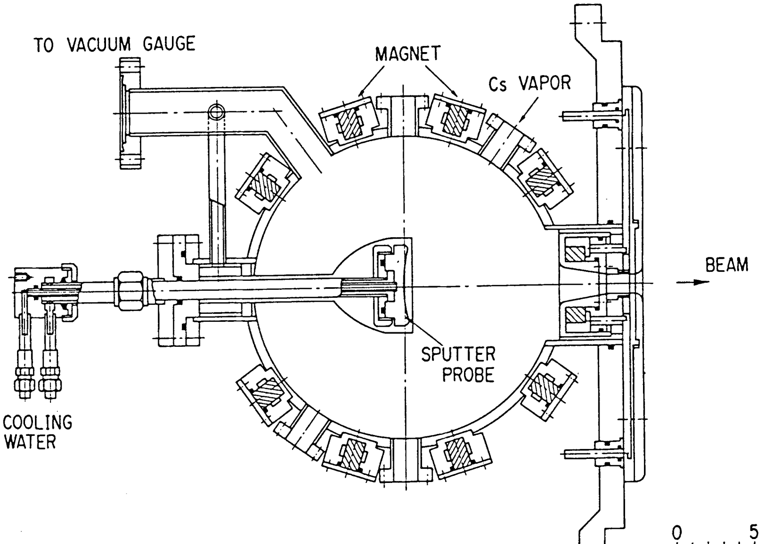

FIGURE 1 Schematic layout of the BLAKE negative ion source.

was reduced by the cesium coating. The drain current of the probe by these accelerated ions was measured and it was about 300mA at an arc current of 15A.

Beams were extracted at an energy of about 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. A large permanent dipole magnet which was 5cm wide, 4cm high and 15 cm long was placed between the einzel lens and Faraday cup to analyze the mass spectrum of the beam extracted form the ion source.

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. The measured mass-spectrum for Au ion beam is shown in Fig.2.

The beam emittance was measured by the emittance monitor which was developed for the 750keV H- beam of the 12GeV synchrotron. Figure 3 shows the measured normalized emittance for Ni- ion beam for 2.5 and 6mA respectively. A typical value of the 90% normalized emittance of the beam was about 37 $\pi$ 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 inten-

TABLE 1 Negative heavy ion beam intensities from the ion source.

| Ion Species | Beam Current(mA) | Ion Species | Beam Current(mA) |
|---|---|---|---|
| Ag | 5.4 | Ni | 6 |
| Al | 1.1 | P | 0.86 |
| Au | 10 | Pd | 6.8 |
| As(As$_2$) | 0.67(2.24) | Pt | 6.4 |
| Bi | 0.13 | Si | 5.4 |
| C(C$_2$) | 3.4(4.6) | Sn | 2.6 |
| Co | 2.8 | Ta | 1.4 |
| Cu | 10 | Ti | 0.8 |
| Cr | 0.2 | V | 0.7 |
| Fe | 1.7 | W | 3 |

sity is 50-100 times larger.

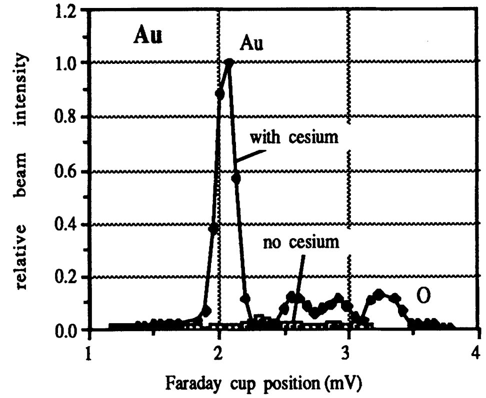

FIGURE 2 Mass-spectrum of Au ion beam.

## DC-MODE OPERATION

Compared with pulsed-mode operation, dc-mode operation requires substantially higher cesium flow rates because the cesium coverage on the sputtering. Therefore, a new cesium oven, cesium valve and cesium transport line for feeding more cesium vapor into the ion source were designed. The diameter of the feed line was increased from 6 to 10cm. The distance between the oven and ion source was decreased from 50 to 15cm. The optimum temperature of the new cesium oven for pulsed-mode operation was decreased by about 50$^{0}$C compared with the previous oven.

The dc arc current was limited to less than 5A because of the lack of cooling in the ion source chamber and the maximum current capability of the beam extraction power supply(50kV-10mA).

In the preliminary experiment of dc-mode operation, a spherical geometry copper sputter probe was used. At a sputter probe voltage of -610V, the total drain current to the sputter probe was typically 90mA at an arc current of 2A.

The cesium vapor density for an oven temperature of 258°C was estimated to be ~30 times higher than that for pulsed-mode operation (~160°C). Measured total beam intensity as a function of sputter probe

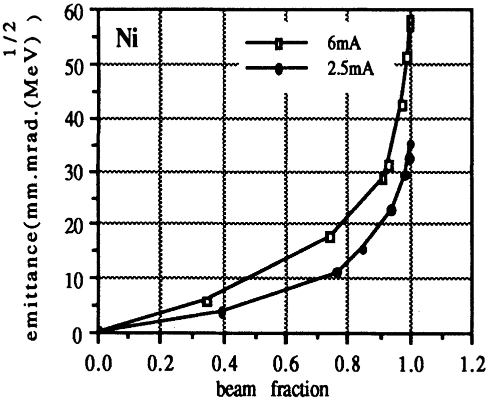

FIGURE 3 Beam emittance of $\text{Ni}^-$ ion beam.

current is displayed in Fig.5. The beam intensity is estimated to increase almost linearly with sputter probe current. By linear extrapolation of this data, the beam intensity would reach the same level observed during pulsed-mode operation provided that the arc current could be increased to 15-20A.

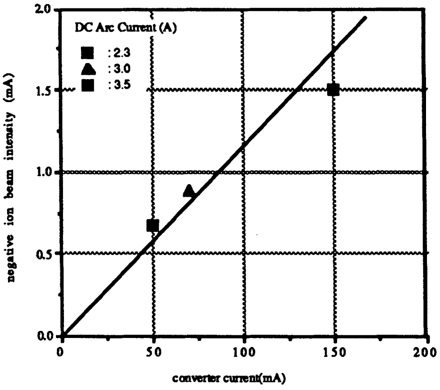

FIGURE 4 Negative beam current as a function of sputter probe current.

## CONCLUSION

Characteristics and performance of the newly developed negative ion sources 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 37π mm.mrad.$(\mathrm{MeV})^{1/2}$.

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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