HIGH CURRENT DENSITY ION SOURCES FOR HEAVY ION FUSION ACCELERATORS

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Abstract

Testing of the alumino-silicate ion source and the contact ionizer at high current density was satisfactory. The dispensers embedded in the extraction electrode were capable of providing sufficient cesium vapor coverage to the ionizer thus shows a promising way of constructing an ionizer for long term heavy ion fusion applications.

1 INTRODUCTION

A heavy ion fusion (HIF) driver requires ion sources that can deliver intense heavy ion beams with low emittance. The choice of ion species depends on the range of penetration into the fusion target at the accelerator beam voltage. Typical ions of interest are those of Bi, Pb, Hg, Cs, Xe, Rb, K, Ar, and Ne. Some lighter ions like K, Ar and Ne are included because at the early stages of driver development, they provide the opportunity to do experiments at driver scale ion velocities on a less than full length accelerator facility.

Naturally, not all the ion species of interest can be produced effectively from a single type of ion source. For example, a gas source is suitable for generating Hg, Xe, Ar and Ne ions whereas a metal vapor vacuum arc (MEVVA) source would be more appropriate for ions such as Gd and Bi. In fact the MEVVA source has an additional advantage of generating ions with high charge states, thus reduces the required accelerator beam voltage. Both the gas source and the MEVVA source still need further development in order to meet the driver requirements. So far, the surface ionization sources have been used in most HIF driver designs. The surface ionization type of ion source can efficiently produce singly charged alkali ions such as Cs^+ and K^+. The major advantages of this type of ion source are the absence of gas flow, excellent beam current control and low emittance (due to low ion temperature and a solid emitter boundary). The main concerns here are the source life time, the alkaline vapor delivery system, and the deposition of alkaline vapor onto beam line components.

A typical heavy ion fusion (HIF) driver can have of the order of 100 ESQ injectors at the front-end of an induction linear accelerator [1]. Based on beam transport considerations, a 2-MeV injector should provide a beam with a line charge density of approximately 0.25×10^{-6} C/m. The actual beam current will depend on the ion velocity (or equivalently the square root of the charge/mass ratio). For a potassium ion beam, the corresponding beam current is 0.8 A per ion source. For HIF driver applications, the required pulse length is about 20×10^{-6} s with a rise time preferably not more than 1×10^{-6} s and a repetition rate of 10 Hz.

Previously, an alumino-silicate ion source has been developed for the ILSE project [2]. The ion source has a diameter of 17 cm, thus the potassium current density is approximately 3.5 mA/cm^2. Although this ion source has met the original specifications for the ILSE project, the latest conceptual designs for the next HIF research facility calls for an injector with an ion source that has a current density $\geq$15 mA/cm^2 of K^+ (a factor of 4 increase from the previous case). The major reason for choosing a high current density, compact size injector is to reduce the overall cost of a fusion driver.

In this paper, we present experimental results on testing the ion sources to meet the new specifications. Both the alumino-silicate type and the alkaline vapor contact ionizer have been tested. The results suggest that both types of ion sources will meet the current density requirement and eventually the selection will depend on further experiments relating to the life-time and reliability of the ion sources.

2 EXPERIMENTAL SETUP

2.1 The Ion Extractor and Diagnostics

A schematic diagram of the ion source and the extraction electrodes is shown in Fig. 1. The ion source has a 2-cm diameter concave emission surface (10-cm radius of curvature). The structure, which includes the cylindrical sidewall and the threaded center post, is made of porous tungsten. Heating of the ion source is provided by a molybdenum filament surrounded with ceramic shields. It takes approximately 100 watts to heat the ion source to the operating temperature of about 1000°C. The 3-electrode extractor was designed to extract ion beams uniformly at space-charge-limited flow from the emitter. High voltage is obtained from a pulse forming network feeding into a bi-polar step-up transformer. Typical pulse length is about 1.5×10^{-6} s. The Pierce electrode, which has the same potential as the ion source, receives the positive high voltage output while the last electrode receives the negative high voltage output and the middle electrode is at ground potential. This arrangement allows us to provide the maximum electric field gradient for ion extraction. Although the ions are decelerated in the region between the last electrode and the diagnostic equipment, the beam diameter is kept small enough to avoid collision into the last electrode and to produce a spot size smaller than the opening of the Faraday cup. There is a another advantage of applying negative high voltage to the last electrode because it suppresses electrons from either back streaming into the ion source as well as assists the Faraday cup in capturing its own secondary electrons.

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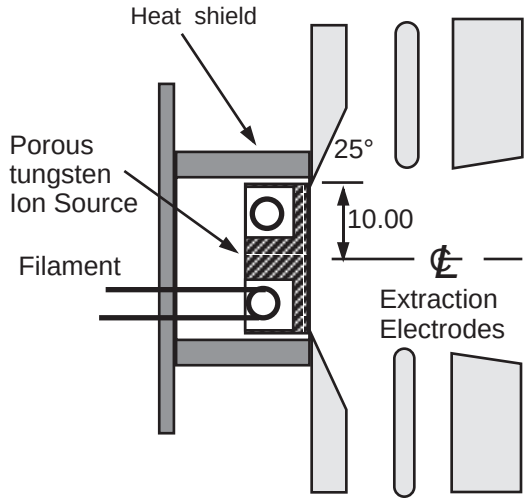

Figure: 1 Schematic diagram of the ion source and extraction electrodes.

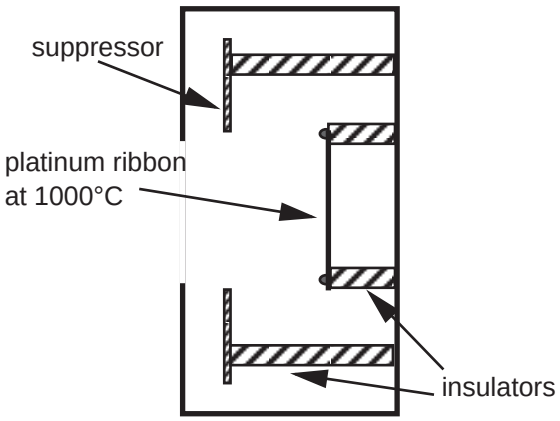

Figure: 2 Schematic diagram of the neutral detector

The ion beam current density profile was measured by moving a 2-mm diameter pinhole across the Faraday cup entrance. A pair of permanent magnets was mounted behind the pinhole to produce a transverse magnetic field for stopping secondary electrons that were generated at the pinhole from entering the Faraday cup. The pinhole plate and the Faraday cup aperture are located at 1 cm and 3 cm downstream of the last electrode respectively.

A platinum-ribbon contact ionization detector was used to measure the alkaline neutrals flowing out of the ion source, see Fig. 2. Platinum has a high work function which offers excellent ionization efficiency. In steady state, the amount of adsorbed alkaline atoms on the hot platinum surface (approx. 1 cm^2) will reach equilibrium in such a way that the flux of incoming alkaline atoms equals to the ion current emitted by the surface. Here, we assume that the ionization probability is near 100%. The emission is measured by monitoring the drain current on the 2 kV bias power supply (after subtracting the leakage background current). Good agreement was obtained by calibrating our measurement against the flow rate specified by the manufacturer of an alkaline vapor dispenser.

2.2 Two Types of Surface Ion Sources

For the alumino-silicate ion sources, a thin layer (approx. 0.3 mm) of alumino-silicate was melted on top of the porous tungsten curved surface. Some recently developed techniques have improved the coating quality to reliably achieve surface uniformity. In testing the contact ionizer scheme, the bare porous tungsten surface was loaded with a fraction of a monolayer of cesium (or potassium) by either doping the source with a solution of alkaline carbonates or by using alkaline dispensers.

For the contact ionizers, six 12 mm long commercially available dispensers (by SAES GETTERS) are embedded around the center opening in the middle electrode, so that the dispensers output release slits are facing the source emitter surface. Fig. 3 shows the dispenser layout schematics. Since this electrode is facing an hot ion source, there is indirect heating from radiation. Additional electrical heating of the dispensers can be done to control the vapor release. In order to avoid overheating, the middle electrode is cooled by a waterline at the edge.

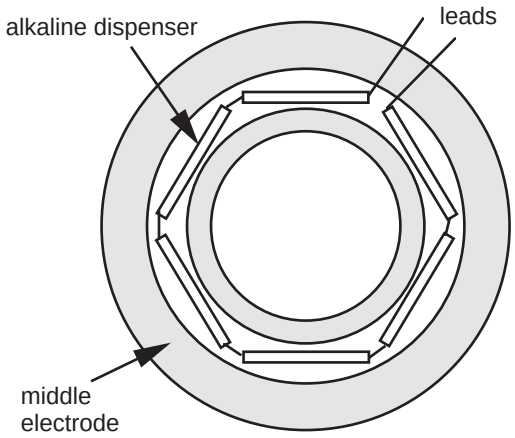

Figure: 3 Front fed vapor source dispenser layout.

3 EXPERIMENTAL RESULTS

The beam current extracted from the ion source depended on the ion source temperature and the applied extraction voltage. The I-V characteristics are shown in Fig. 4 (the extraction voltage is defined as the total potential difference between the positive Pierce electrode and the negative last electrode). In the space-charge-limited flow regime, the beam current increased according to the "$V^{3/2}$ law". This relationship sustained until the ion source reached the emission limit mode. The emission limit increased with the ion source temperature. At 44.5 kV and at an ion source temperature of 1050°C, we have obtained 43.2 mA of K^+ ions. This corresponded to an average current density of 13.75 mA/cm^2.

As shown in Fig. 5, the current density profile of the ion beam was uniform to within ±5%. There was a data uncertainty of a few percent due to signal noise and digitization.

Also shown in Fig. 4 and 5 are the performance of an ionizer doped with potassium carbonate. As the source

was heated to operating temperature, the carbonate decomposed and subsequently reached an equilibrium coverage of potassium atoms adsorbed to the emitter surface. This is an easy way of "delivering" alkaline atoms to an ionizer. The doped source usually lasted only for a few days of operation before completely depleting the alkaline storage, thus it is mainly used for calibration purposes and is not considered a long term solution for HIF applications.

A long life ionizer must have some way of continuously feeding the alkaline vapor, either from the front side or via diffusion through the porous tungsten from the back side. In our experiment, we have tested the effectiveness of delivering cesium vapor from dispensers embedded inside the extraction electrode. It was found that the radiation from the ion source produced sufficient heat to the dispenser, without requiring any additional electric heating, to release Cs vapor. During initial operation, there was enough cesium coverage to produce a beam current density as high as 15.4 mA/cm^2 (space-charge equivalent to 29.4 mA/cm^2 of K^+). The I-V characteristics are shown in Fig. 6. As time went on, additional electric current could be used to drive the remaining cesium content out of the dispenser.

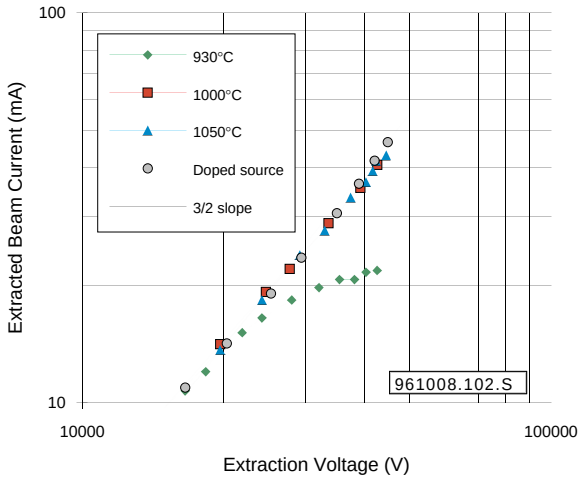

Figure: 4 I-V characteristics for the alumino-silicate K^+ ion source and the doped source.

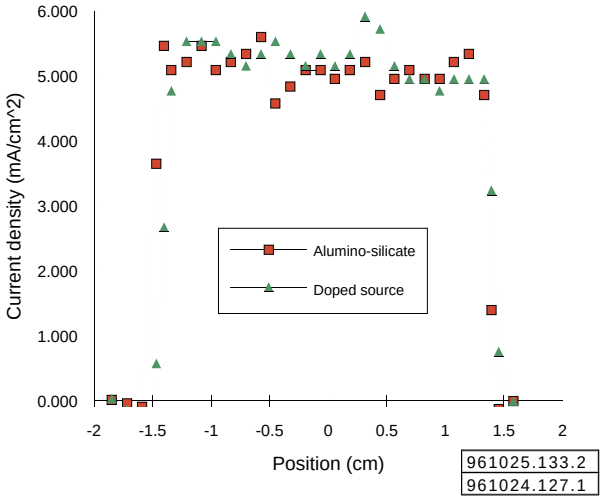

Figure: 5 Beam profiles for the alumino-silicate ion source and the doped source.

In measuring the alkaline neutrals at 15 cm downstream of the extractor, we compared the signals for 2 detector positions, at beamline center and away from center without line of sight. The background pressure was about 5x10^{-7} Torr. The cesium neutral flow rate arriving at the platinum foil was determined to be 7.5x10^{11} /cm^2/s while the ion source was kept at 1100°C. This corresponds to an atomic emission rate of 1.7x10^{14} /cm^2/s (0.14 mg/cm^2/hr) from the ion source.

4 DISCUSSION

We have shown that both types of ion sources can produce the required current density. The current denstiy uniformity is good. The method of using alkaline dispensers embedded inside the extraction electrode was proven to be adequate for even the highest current density cesium beam that we have achieved. Further investigation of this concept can lead to the successful development of a long life front-fed contact ionizer.

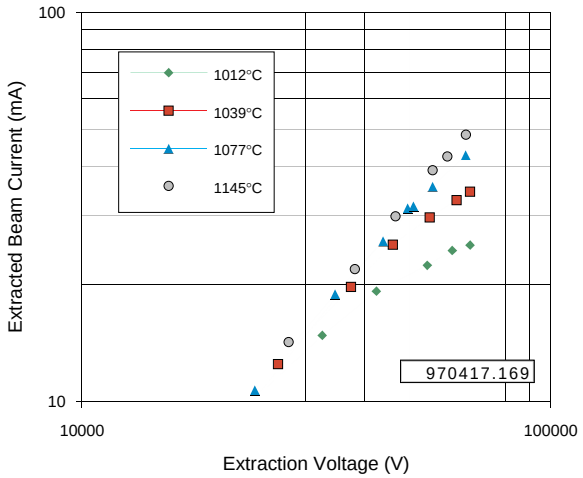

Figure: 6 I-V characteristics for the cesium vapor ionizer.

5 ACKNOWLEDGEMENTS

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REFERENCES

[1] R.O. Bangerter, Proc. of Inter. Symp. on Heavy Ion Inertial Fusion, Frascati, Italy, May 25-28, 1993, Nuovo Cimento 1445 (1993).

[2] S. Eylon, E. Henestroza, W.W. Chupp, and S. Yu, Proc. of Inter. Symp. on Heavy Ion Inertial Fusion, Frascati, Italy, May 25-28, 1993, Nuovo Cimento 1509 (1993).