Beam Characteristics Using Stable Isotpes from a Multicusp Source for the TRIUMF ISAC Facility

T. Kuo, D. Yuan, K. Jayamanna, M. McDonald, R. Baartman, G. Mackenzie, P. Bricault
M. Dombsky, P. Schmor, G. Dutto, -TRIUMF and
Y. Lee, K-N Leung, D. Williams, R. Gough -LBNL

Abstract

A multicusp source for positive ion beams has been designed and constructed in collaboration with the Ion Beam Technology Department of LBNL for the TRIUMF ISAC project. This type of source has demonstrated a high yield of singly charged ions, a low energy spread, a good emittance and is compact and simple. Several stages of tests and measurements using non-radioactive beams to characterize the source performance are being carried out both at LBNL and at TRIUMF prior to the final phase of radioactive target-source system tests. Results of these non-radioactive tests and certain problems encountered are reported and discussed in this paper.

1 INTRODUCTION

In order to obtain a high RIB to primary beam efficiency for the TRIUMF ISAC project [1], ion sources which are efficient in producing singly charged ions are under study. The criteria for RIB ion sources are more restrictive than those for non-radioactive sources. In addition to having to have a high efficiency, good emittance and small energy spread, a particular source under consideration must be very simple, highly resistant to radiation damage and must have a fast transient time for isotope release. Since surface chemistry is extremely sensitive and critical between the radioactive isotopes and the material along their path to ionization/extraction, the RIB target-sources are nuclear chemistry and high temperature effect dominated.

At TRIUMF, a surface ionization source for alkaline species has been in use successfully for TISOL programs and it will be the first source to be used for ISAC. For gaseous and non-alkaline metallic species production we are exploring other source options such as a compact microwave source and a compact multicusp source.

2 TRIUMF-LBNL MULTICUSP SOURCE

Multicusp volume sources [2] have demonstrated a high yield of singly charged ions, a good emittance and a low energy spread. It was of great interest in 1994 to examine whether such a source can be a candidate for the ISAC project. Since then, a source of this type has been designed and constructed in collaboration with the Ion Beam Technology Department of LBNL. The magnetic structure of this source is modeled after LBNL's RF powered cusp
source[3], using 10 rows of cusp lines on the cylinder, 10 radial lines in the front plate and 4 lines in the back plate for complete magnetic enclosure. All magnet bars are directly water cooled. The plasma chamber is 20 cm in length and 16 cm in diameter. A 48mm circular opening centered in the front plate allows the penetration of the plasma and extraction electrodes to the front surface of the plasma. The plasma electrode is not directly cooled and allowed to go up to near 2000^{o}C. The plasma and extraction apertures are 3mm in diameter and a tungsten filament 18cm long, 2.4mm in diameter powered by 200 amperes is used. A tantalum liner capable of 2000° is designed for on-line use but not installed for these beam tests. Typical arc power used ranges from a few ten of watts to 1.5kW. There is no threshold for plasma ignition, one mW (100V,10μA) will begin to show beams of interest.

3 FIRST TEST AT LBNL

In August 1995 the cusp source was shipped to LBNL for the first phase of tests during which some subsets of source properties such as ion species population, beam intensity and gas efficiency were measured. The source was first mounted on a teststand where a small mass energy-analyser was immediately located after a single stage extraction at 600 volts. Argon and nitrogen were tested for species distribution. Ar^{1+}/Ar^{2+} and N_2^{1+}/N^{1+} ratios as a function of source pressure, gas flow, arc voltage and current were scanned. About 200 scans were taken and some sample results are shown in Fig. 1(a) and 1(b). As can be seen from Fig. 1(a), the ratios of Ar^{1+}/Ar^{2+} are mainly determined by arc voltage. For example, at 3.7x10^{-3} Torr source pressure the ratio is about 40-50 to 1 at 50 volts then falls rapidly to 15 to 1 at 150 volts. Variation of arc current from 5A to 15A does not change the ratio appreciably, but changes the extracted beam intensity. For the case of nitrogen ions, however, the N_2^{1+}/N^{2+} is on the order of 1000 to 1 at 1A and 50 to 1 at 5A, rather insensitive to arc voltage at about 5x10^{-4}sccs gas flow. Similarly, the N_2^{1+}/N^{1+} ratios as seen from Fig.1(b), are more arc current dependent than voltage dependent. At 50 volts and low gas flow (5x10^{-4} sccs), the ratio varied from 20 at 0.5A to 0.6 at 13.5A. These ratios do not change appreciably up to 150 volts.

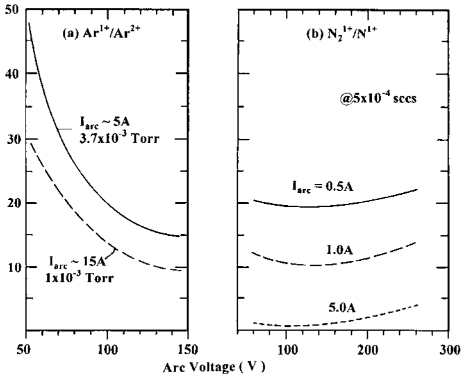

Fig. 1. Argon and nitrogen gaseous species as a function of arc voltage and current.

The beam currents of argon and nitrogen ions were measured on a second teststand which is equipped with a Faraday cup and secondary electron recapture mechanism. Current intensities as a function of extraction voltage (Child-Langmuir curve) at different arc currents were measured. Fig. 2 shows some samples for Argon beams.

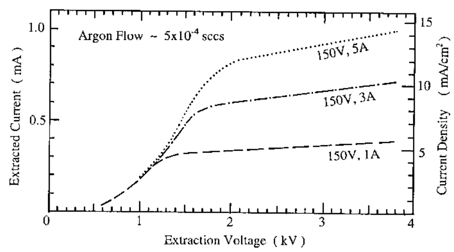

Fig. 2. Child-Langmuir curves for Argon beam at 3 power levels.

4 TESTS at ISAC TESTSTAND

A non-radioactive source/matching section/separator test-stand for ISAC has been constructed for source study and optics verification[4]. It is also used as a testbed for the ISAC EPICS control system as well as various diagnostics devices. The cusp source was used to provide beams for the initial commissioning. A prototype ISAC surface ionization source [5] was later used for the optics verification for the matching section and the separator. Very good agreement has been obtained between the computed and measured emittance ellipses based on a given set of optics tunes.

4.1 Extraction and Emiitnace

The initial extraction system designed for the cusp source used a three electrode arrangement. The extractor was designed to be set at 3 kV negative to the plasma electrode while the third was put at ground potential. When this extraction system was tested at the teststand with 30 keV beam energy, 1.3 kV must be set for extraction voltage to achieve the best beam transmission. This resulted in low current intensity and loss of benefit from higher arc power and gas flow as can be seen from Fig. 2. The "system gas efficiency" appeared to be very low. A new five-electrode system including an einzel lens has been designed using IGUN simulation code and was tested briefly at LBNL with a 15 keV nitrogen beam. A factor of 4 in beam intensity was obtained with the einzel lens powered. This was mainly because the einzel lens permitted operation at a higher extraction voltage. The new system has also been tested at TRIUMF with 30 kV Argon beams. Extraction voltage greater than 2.5 kV can now be used to optimize the beam current through a 2 mm object slit. As a result, a gain of 3 in beam intensity at high arc power was obtained with the einzel lens on compared to off. At low arc power the gain was about 1.5.

An Allison type scanner [6] was constructed for heavy ion emittance measurement. However, the position of the scanner had to be located about 1.5 meter from the point of extraction. The divergence resolution of the device was found to be 3 mrad. These two limitations made it necessary to use a focused beam for measurement. Using a 3-electrode extraction system, the measured 4RMS emittance for a 30 µA argon beam was 7.5 and 15 π-mm-mrad respectively for 1mm and 3mm extraction apertures. When the 5-elecrode system and a 3mm extraction aperture were used, the corresponding emittance measured to be about 25 π-mm-mrad for an Argon beam at 50 µA.

4.2 Source Gas Efficiency

The source gas efficiency was obtained with a single extraction gap using extraction voltage above saturation and a Faraday cup immediately after the extractor electrode. This set up avoids any optics requirement. Since the dominating ion species is singly charged, the gas efficiency is approximately represented by the ratio of the extracted beam currents to a calculated currents assuming all the inflow gas atoms were singly ionized. For the source under test we observed that the efficiency increases as arc power increases and as gas flow decreases. The dependence on gas flow at 500 watts arc power is shown in Fig. 3. The ionization of Ar is quite efficient, up to 80% at a small flow ($0.4x10^{-3}$ sccs) but falls to 25% at a higher flow ($3x10^{-3}$ sccs). For N_2 gas the overall nitrogen beam has less gradient dependence on gas flow, from 20% at $0.3x10^{-3}$ sccs to 15% at $2.2x10^{-3}$ sccs.

4.3 System Gas Efficiency

The system gas efficiency was obtained from the beam current achievable after the image slit (2 mm in width) of

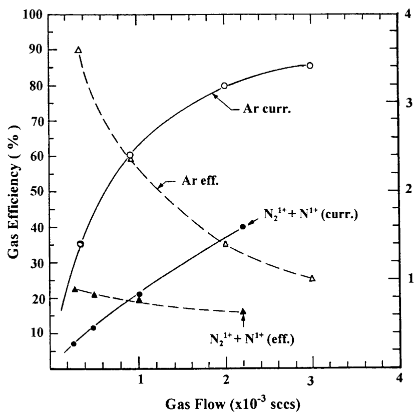

Fig. 3. Source gas efficiency as a fuction of flow at 0.5 kW.

the separator. The optics quality of the extraction system becomes very critical. Results from the new 5-electrode extraction system showed that about 15% of the source efficiency can be translated to the system efficiency for both Ar^{1+} and N_2^{1+} at 28 keV beam energy. The system efficiency dependence on gas flow was very similar to that of the source efficiency except for a scaling factor of 0.15. A 0.8 mm image slit will drop the system efficiency further to about 10% of the source efficiency. In other words, only 2% system efficiency for N_2^{1+} at high arc power with a small gas flow.

A Neon leak gas of 2×10^{-6} sccs was sent to the source with N_2 or He as support gas. A total of 300 nA of Ne^{1+} was recorded after a 2 mm image slit (3% system eff.) when a minimal N_2 support gas (1×10^{-4} sccs) was used. As the N_2 support gas was increased the Ne^{1+} beam current fell off very rapidly, to 0.15% when N_2 gas flow reached 2.2×10^{-3} sccs. The use of He as support gas improves the Ne^{1+} efficiency to 3.5% and the falloff was not as steep.

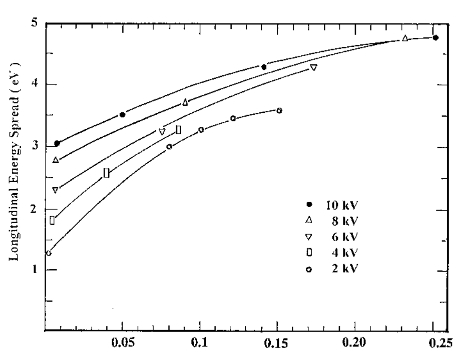

Fig. 4. Energy spread as a function of beam energy and I_i.

5 ENERGY SPREAD MEASUREMENT

The longitudinal energy spreads of the cusp source were measured at LBNL, in April 1997, using an axial retarding field energy analyzer designed by IMS [7] and optimized by LBNL. The details of the instrument and method of measurement is described by Y. Lee [8]. A very low energy spread of 1.25 eV was obtained with a 2 keV Argon beam.

The ion current I_i through the 3 mm entrance aperture of the analyzer was used as an independent parameter. We observed a strong dependence of measured energy spread on the ion beam current I_i, while the beam energy is fixed. As shown in Fig. 4, Beams at 2, 4, 6, 8 and 10 keV are plotted as a function of I_i . There is a common trend that energy spread increases as I_i increases rather independent of beam species, arc power and beam optics. This ion current dependence is tentatively attributed to the severe space charge effect as the beam energy approaches zero. On the other hand, the energy dependence trend might come from a deeper field penetration to the plasma and from the gas ionization effect inside the analyzer. During May-July, 1997, the source intrinsic energy spread was measured at TRIUMF at 1.2 keV beam energy using a parallel-plate 45^{o} entrance/exit energy analyzer [9]. At very low arc power the spread can be as low as 0.8 eV and at higher arc power it reaches 1.8 eV.

6 SUMMARY

The TRIUMF/LBNL cusp source under tests indeed shows its merit in generating copious singly charged gaseous ions. The *source gas efficiency* for argon beam can be up to 80% while the *system gas efficiency* is between 0.1 to 0.15 of the source efficiency depending on the width of the image slit. Emittance scans show a figure less than 10 π -mm-mrad using a focused beam tune. At 2 keV beam energy the longitudinal energy spread can be as low as 1.25 eV. Due to the concerns of radiation damage on the permanent magnets and of the filament lifetime, this source has not yet been incorporated into the target-source module design.

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