A MULTICUSP ION SOURCE FOR RADIOACTIVE ION BEAMS *

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Abstract

In order to produce a radioactive ion beam of $^{14}O^+$, a 10 cm-diameter, 13.56 MHz radio frequency (rf) driven multicusp ion source is now being developed at Lawrence Berkeley National Laboratory. In this paper we describe the ion source performance with respect to its capability as an ion source for radioactive ion beam (RIB) production. using Ar, Xe and a 90% Ar / 10% CO gas mixture. In addition ion optic simulations for the radioactive beam line leading to the design of the ion beam extraction/transport system for the actual experimental setup will be discussed.

1 INTRODUCTION

At LBNL we are presently testing a 10 cm diameter multicusp ion source for the production of radioactive $^{14}O^+$ ions [1]. It will be used as part of an integrated target/ion source system now under development for a radioactive ion beam experiment at the 88” Cyclotron in LBNL. ^{14}O will be produced in the form of CO via the $^{12}C(^3He^+,n)^{14}O$ reaction using a 45 MeV/n ^3He beam from the LBNL 88” cyclotron. Neutral radioactive CO will be transferred via a gas tube into the multicusp source, ionized, accelerated, implanted into a carbon target and analyzed in a beta spectrometer within the 70 sec lifetime of $^{14}O^+$. Since the amount of radioactive CO produced will be very small, the ion source discharge will mainly be argon. In order to design a dedicated extraction and ion beam transport system for the RIB experiment the ion source performance was characterized for Ar and 10% CO in Ar gas mixture for generating the discharge.

2 EXPERIMENTAL SETUP

2.1 Ion Source Design

A schematic view of the multicusp ion source setup and with the accelerator column is shown in Fig. 1. The source chamber is a copper cylinder (10 cm diameter by 9 cm long). The magnetic confinement is achieved with a “closed” cusp configuration. 14 columns of samarium-cobalt magnets form a longitudinal line cusp configuration for the plasma confinement. The magnetic field reaches a maximum of 1.5 kG at the plasma chamber wall. There is a nearly field-free region in the center of the source of approximately 3 cm diameter. This region determines the maximum extraction area, where the plasma density is homogeneous. An additional 14 magnets are mounted radially in the extraction flange. These magnets are imbedded in soft iron in order to keep the extraction area field free. The front magnets together with four rows of magnets mounted on the back flange establish the closed cusp configuration.

Six layers of molybdenum sheets line the inner chamber wall as well as the front and the back plate. This liner provides a hot plasma chamber surface to minimize the gas hold up time and to increase the dissociation rate of molecular gas.

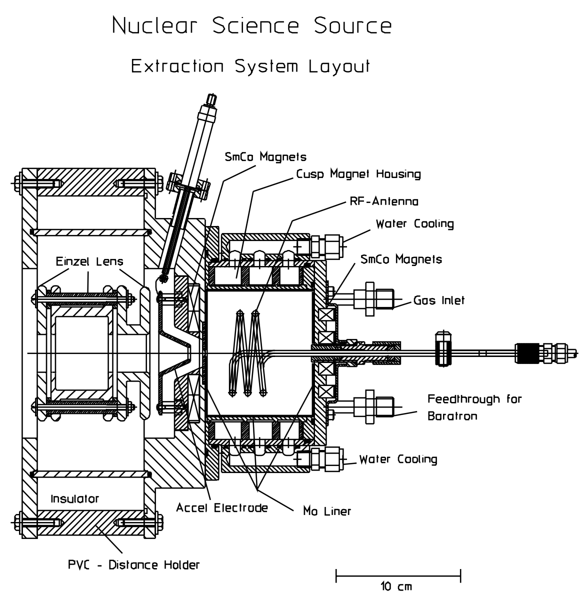

Figure: 1 Design layout of the rf driven multicusp ion source and the accelerator column.

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2.2 RF System

Rf power up to 3 kW at a fixed frequency of 13.56 MHz is inductively coupled into the plasma via a water-cooled, porcelain-coated antenna in the shape of a 2.5 turn induction coil. To ensure maximum rf power transfer, an impedance matching network is used to match with 0º phase the nominal 50 Ω output impedance of the rf amplifier to the plasma-antenna load. (typically a few ohms). In this setup a 4:1 turn-ratio isolation transformer was used to accomplish the impedance matching which also permits isolation of the ion source at high voltage up to 30kV from the instrumentation ground. Additionally, an inductor in series with a variable capacitor forms the secondary circuit accomplishing the fine tuning of the matching network.

For high power operation and with the molybdenum liner installed, the lifetime of the porcelain-antenna is limited. Therefore experimental investigations, where the porcelain-coated copper antenna is replaced by a glass antenna, are in progress. Preliminary results indicate an improved lifetime with the new glass antenna arrangement.

2.3 Ion Source Test Stand

A dedicated new ion source test stand is currently under construction to examine the transport system. The ion source test stand consists of the following components: a multicusp ion source, an accelerator column, a diagnostic spool with a Wien (ExB) filter and a Faraday cup for analyzing the ion beam species and currents. The diagnostic spool provides a drift length of 1 m between the Wien filter and the Faraday cup. The Wien filter has a homogenous field of 0.4 T over its length of 30 cm and in a gap of 1 cm by 1 cm. The extraction system incorporates an electrostatic lens, that allows one to focus the ion beam through the homogenous region of the Wien filter gap (see section 4). With this new test stand, measurements are planned for the efficiency of the transport and mass separation system as well as the gas hold up time for oxygen in the source.

3 ION SOURCE PERFORMANCE

The ion source performance has been reported in detail elsewhere [1]. In this paper we only summarize the ion source characteristics with respect to its capability as a prospective ion source for the production of radioactive ion beam. The ion source shows promising features: a gas efficiency of up to 60% for argon and up to 80% for xenon has been obtained, a relatively low axial energy spread of 2 to 3 eV for the filament driven source and 4 to 7 eV were observed for the case of the rf driven source. The molybdenum liner provides a hot plasma chamber surface where temperatures up to 1100°C can be achieved [1].

A two-grid extraction system was used to determine the total extracted current and current densities for an argon discharge with plasma conditions similar for the planned $^{14}O^+$ experiment. The current densities for these operating conditions vary from 30 to 60 mA/ cm^2. These values correspond to a total extracted current of 1 to 2 mA out of our 2 mm extraction hole and determine the range of current the ion beam transport system has to handle.

In order to explore the ion source performance at operation conditions similar to the planned experiment a 90% Ar with 10% $^{12}C^{16}O$ gas mixture was used for the discharge. Ion species measurements were conducted by

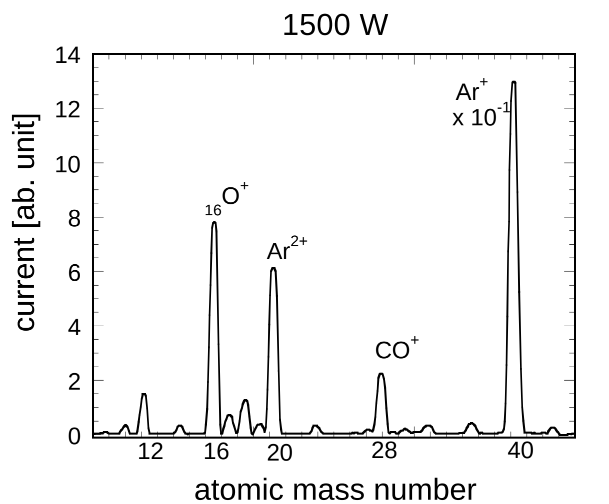

Fig. 2 Ion species distribution for a Ar/CO discharge at 1500 W rf input power. The Ar^+ current was reduced by a factor of 10 to fit it on the graph.

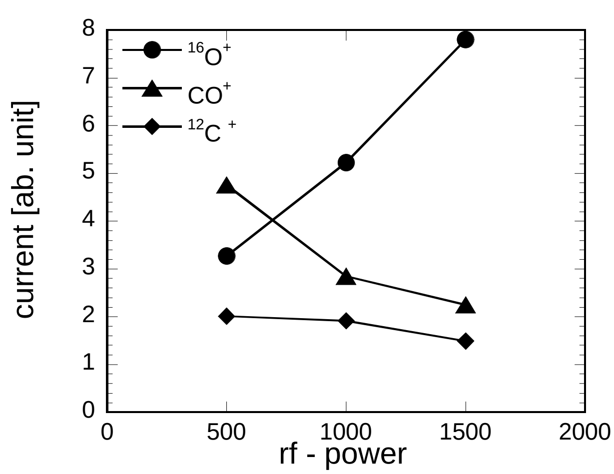

Fig. 3 Relative current change for O^+, C^+, CO^+ versus rf input power for a fixed discharge pressure of 1.1 mTorr.

using a 90° spectrometer magnet.

It has been shown that CO can be efficiently dissociated in the ion source at rf input power levels above 1500 W. Fig. 2 shows a typical ion species spectrum with 1500 W discharge power for the Ar/CO gas mixture. Fig. 3 shows the relative current change for O^+, C^+, CO^+. The discharge pressure was maintained at 1.1 mTorr to achieve the maximum gas efficiency.

4 DESIGN OF THE EXTRACTION SYSTEM

4.1 Layout of the electrostatic LEBT

The ion source insulation allows a maximum extraction voltage of 30 kV. An all electrostatic LEBT design was chosen, because the construction is compact and cost effective. The system consists of three electrodes (accel-decel type), followed by an einzel lens that focuses the beam through the Wien filter. This arrangement will keep the beam envelope from expanding in the mass separator due to space charge. The LEBT has a total length of 15 cm and is incorporated in the ion source insulator (Fig.1). The design of the extraction system was optimized by using the 2D ion optics code IGUN [2]. Fig. 4 shows the layout for the extraction system in the IGUN simulation. For the actual design the extraction and the einzel lens were simulated in different runs with higher resolution (see Section 4.2).

4.2 Plasma Extraction Region

A careful study of the plasma region is essential for the design of the extraction system, since the plasma surface provides the starting condition for all the following lenses. In order to achieve an accurate plasma simulation the region has to be resolved in a much higher resolution grid.

To adjust the electric field at the plasma/extraction boundary, the accel electrode potential can be varied up to -5 kV. This electrode allows an optimal match of the different plasma conditions to the focusing lens. The measured current densities of 30 to 60 mA/ cm^2 require an minimum electric field strength of 3 kV/mm for the low and 4 kV/mm for the high densities in the first gap to transport the beam into the Faraday Cup. These experimental values were used as a guidance for the design of the first gap.

Beside the geometry, IGUN requires the input of the plasma electron temperature in order to self consistently compute the plasma potential. The electron temperature also determines the plasma densities required to extract a given ion current. In our simulation we measured the total extracted ion currents used in the calculation. In order to get an estimate for the plasma potential, we used the axial energy spread distribution of the extracted ion beam from the rf driven multicusp ion source and we compared these values with the ones IGUN calculated. It was found, that setting the electron temperature in IGUN to 1-2 eV leads to plasma parameters, which are in good agreement with measured values for multicusp ion sources [3].

5 ACKNOWLEDGEMENTS

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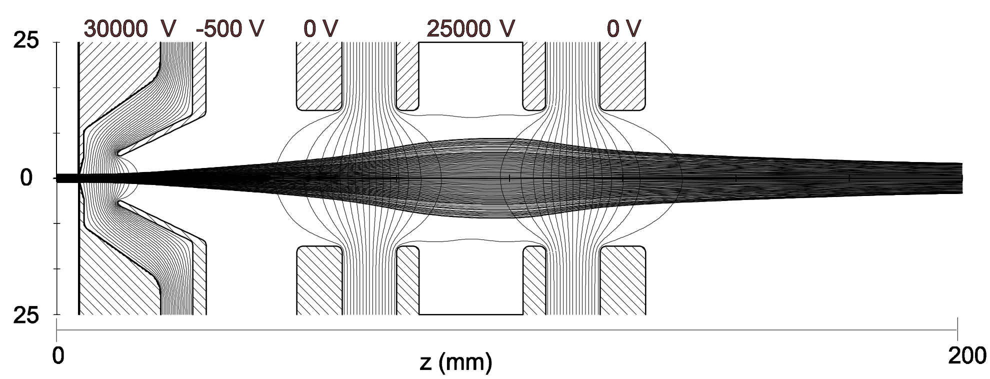

Fig. 4 Typical IGUN simulation run for an Argon beam showing an overview of the extraction system including the einzel lens. The dimensions are shown in mm.