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Charge state breeding of radioactive isotopes for ISAC

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Abstract For the acceleration of radioactive isotopes with a mass greater than 30 amu charge breeding with an electron cyclotron resonance ion source (ECRIS) is being used at ISAC. Singly charged ions from the target ion source combination are injected into a 14.5 GHz ECRIS from PANTECHNIK and charge bred to highly charged ions with a mass to charge ratio around 6. Efficiencies from 1 to 8 % could be reached for different isotopes. The article describes the set- up of the system and reports on results obtained for efficiency as well as purity of the beam. Methods to improve the purity are discussed.

Keywords Radioactive isotopes · Charge state breeding · Electron cyclotron resonance ion source

1 Introduction

At the ISAC facility at TRIUMF radioactive nuclides are produced by bombarding solid target materials with high energy protons from the TRIUMF cyclotron. The targets are operated at high temperature to allow the products to be released into an on line ion source (see contribution by P. Bricault et al.). Mainly singly charged ions are produced. They can be extracted and accelerated up to an energy of 60 keV, separated by their mass and injected into a post accelerator. The accelerator consist of a room temperature radio frequency quadrupole accelerator (RFQ), a room temperature drift tube section and a superconducting linac, which allow final

ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program.

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energies up to about 10 MeV/u. The RFQ section can accept ions with a mass to charge ratio up to 30 amu/e. The following drift tube and superconducting cavities require mass to charge ratios less than 7 amu/e. Therefore the ions have to pass a stripper foil after the first acceleration at an energy of 150 keV/u to increase the charge state. If ions with a mass greater than 30 amu are to be accelerated their charge state has to be increased already before entering the accelerator. In order to avoid further losses from the stripping process, which becomes less efficient for high masses, it is preferable to start with mass to charge ratios less than 7 amu/e.

The charge state of low energy ions can be increased by injecting them into an ion source for highly charged ions. Two types of ion sources are used for this purpose at different facilities: an electron beam ion source (EBIS) or an electron cyclotron resonance ion source (ECRIS). In both sources the ions are stopped and confined while more electrons are removed in collisions with high energy electrons. An overview describing the different techniques and compiling results from different facilities is given for example in [1]. At TRIUMF an ECRIS (PHOENIX booster from PANTECHNIK) has been chosen as it allows a continuous mode of operation and can handle high current throughput. Thus, it is well adapted to the accelerators and the target ion sources. An rf-field at a frequency of 14.5 GHz heats up the electrons in the source to several 100 keV, sufficient to reach high charge states even for heavy isotopes. Charge state breeding with an ECRIS has been described in more detail for example in [2].

The velocity acceptance of the RFQ requires an energy of 2.04 keV/u for the injected ions. That means with a desired charge to mass ratio below 7 amu/e both the ion source for the singly charged ions and the charge state breeder have to operate at a voltage of less than 14 kV.

2 Set-up

The charge state breeder (CSB) source is installed in a shielded room just following the mass separator for the singly charged ions. If ions with a mass higher than 30 amu are to be accelerated, an electrostatic bender can be inserted into the beam path to direct the ions into the charge breeder. The plasma chamber of the source is floated at an electrical potential close to the one of the target ion source. This allows the ions to be decelerated before they are finally stopped in the plasma. The highly charged ions are extracted at the opposite side of the source and accelerated again to ground potential. Both the injection and extraction electrodes have been changed from the original PHOENIX design to a two step configuration. This allows an easier adaptation to different operating voltages. The following combination of a magnetic dipole and two electrostatic benders acts as a Nier type spectrometer and allows the selection of the desired mass to charge ratio. The highly charged ions are then injected into the transport beam line to the accelerator. Details of the ion optics design can be found in the contribution by R. Baartman. Figure 1 shows the layout of the beam lines after the ISAC mass separator before the ions are send to the experimental hall and the accelerator.

A small surface ion source for Cs ions is located in front of the charge breeder to allow set up and commissioning independent from the operation of the ISAC target ion sources.

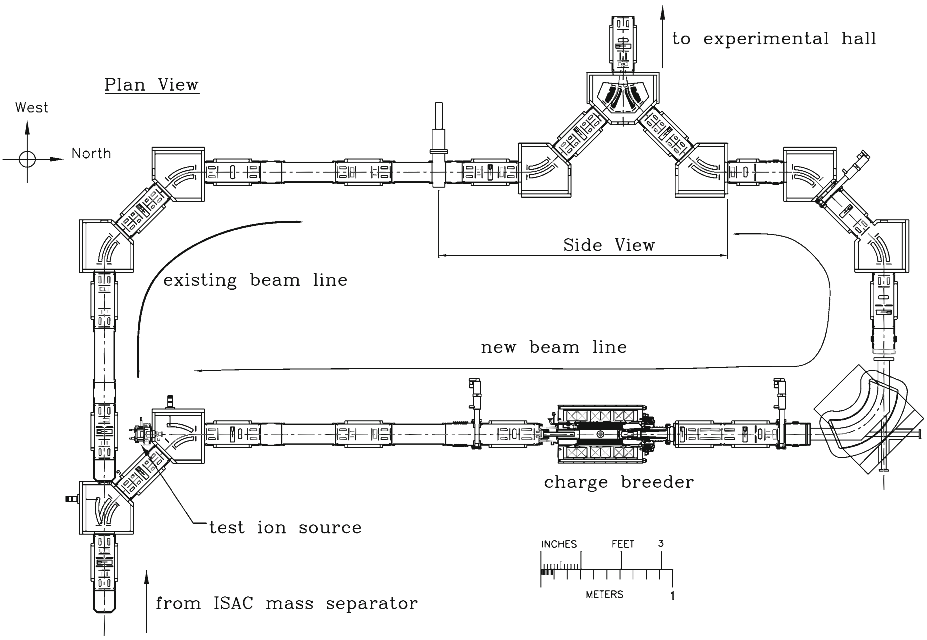

Fig. 1 Layout of the CSB beam lines in the ISAC mass separator room

3 Results

3.1 Charge breeding efficiency

During the commissioning phase, several stable and radioactive ions have been injected into the charge breeder and the charge state distribution of the highly charged ions and the breeding efficiency has been determined. Table 1 shows a list of the radioactive ions, which have been charge bred so far together with the maximum efficiency obtained. In general the charge state breeding efficiency is higher for gaseous elements than for condensible ones. If an ion hits the wall of the plasma chamber in case of a gaseous element it can be released and ionized again, whereas for condensible elements it will stick and is lost. In some cases it is beneficial to inject ions not in the atomic state but in a molecular form. This may reduce background from isobars, which do not form this specific molecule or increase the extraction efficiency out of the on line target. The method has been used for the charge breeding of ^{78}Br which has been injected as AlBr. The main isobaric contaminant ^{78}Rb does not form this molecular ion. Most of those results have been published before [3].

3.2 Beam purity

The major problem encountered while operating the charge breeder source is the background of ions from the residual gas or from sputtered material from the plasma chamber wall or the surrounding electrodes. The intensity of those ions can be several orders of magnitude higher than the intensity of the charge bred

Table 1 Charge state breeding efficiency and background levels for radioactive isotopes

Isotope	q	A/q	Efficiency [%]	I (in) [1/s]	Background [pA]
^{46}K	9	5.11	0.5	4.0E4	340
^{64}Ga	13	4.92	0.7	8.4E4	150
^{64}Ga	14	4.57	0.75	8.4E4	210
^{74}Br	14	5.28	3.1	3.2E7	10,000
^{74}Br	15	4.93	2.1	3.2E7	25
^{78}Br	14	5.57	4.5	2.8E7 AlBr	20
^{74}Kr	15	4.93	6.2	2.1E6	25
^{76}Rb	15	5.07	1.68	3.8E6	15
^{80}Rb	13	6.15	1.17	5.7E7	35
^{80}Rb	14	5.71	1.1	5.7E7	70,000
^{122}Cs	19	6.42	1.1	3.1E5	6
^{124}Cs	20	6.2	1.37	2.75E7	50

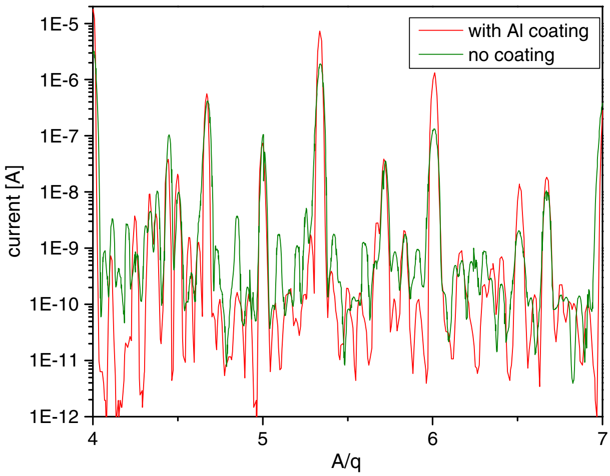

Fig. 2 Ion current extracted from the CSB as function of mass to charge ratio for an aluminum plasma chamber and with additional pure aluminum coating

radioactive ions. This presents a big challenge for the experiments performed after the post acceleration. In most cases additional filtration and cleaning techniques in the acceleration chain have to be applied. In general this is accompanied with a loss in the efficiency for the desired ions as well. In order to reduce this background from the source the original stainless steel plasma chamber of the PHOENIX source and all electrode surrounding the plasma chamber have been replaced by aluminum. Additionally, the plasma chamber has been coated with ultra clean aluminum. In Table 1 background levels from the original stainless steel chamber are given as well. In some cases charge states with a smaller breeding efficiency beside the optimal one have to be chosen to keep the total intensity below acceptable limits.

First results with the aluminum coated plasma chamber have been obtained. Figure 2 shows a comparison of mass spectra with and without the aluminum coating in the relevant mass to carge ratio range between 4 and 7. Although, the intensities of ion beams from multicharge components of the residual gas like C,O and N are still the same or higher, those from other components in between are reduced. More detailed measurements will be performed in the next few months.

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