COMMISSIONING OF THE ECRIS CHARGE STATE BREEDER AT TRIUMF

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Abstract

Radioactive isotopes produced at the ISOL facility ISAC at TRIUMF are usually extracted as singly charged ions from the target ion source system. If the mass of these ions exceeds A=30 their acceleration requires breeding to highly charged ions. A modified version of an electron cyclotron ion source (ECRIS) charge state breeder (14.5 GHz PHOENIX from Pantechnik) has been installed and a first on-line test resulting in the successful acceleration of $^{80}Rb^{14+}$ has been performed already in 2008. During the radioactive beam time periods of 2009 and 2010 further measurements with stable and radioactive ions from different target ion source combinations have been performed to further commission the system. Breeding efficiencies of several percent in the maximum of the charge state distribution have been achieved. A major problem for experiments using those beams is the background from residual gas and other ions, which are also produced in the ECR charge state breeder and which result in similar mass to charge ratios than the radioactive isotope.

INTRODUCTION

At the ISAC radioactive ion beam facility at TRIUMF radioactive ions are produced by bombarding solid targets with up to 100 μA of protons from TRIUMF's 500 MeV cyclotron. The target material is operated at high temperature to allow fast diffusion and effusion of the reaction products into an ion source. Mainly singly charged ions are extracted [1]. The desired isotopes are separated with a magnetic mass separator and the ion beam can be transported to low energy experiments at an energy of several 10 keV or injected into a post accelerator for serving high energy experiments. The intensity of the radioactive ion beam covers a broad range from single ions for the most exotic ones up to about 10^9 per second for isotopes close to stability. The acceptance of the post accelerator allows a maximum A/q value of 30. However, this applies only to the first accelerator stage, a 4 rod radio frequency quadrupole (RFQ), which accelerates to 150 A keV. The following drift tube and superconducting cavity sections are able to accelerate ions up to 5 A MeV. They require A/q<7. Up to now this has been achieved by a stripping foil after the RFQ. If additional losses from this stripping process, which becomes less efficient for heavy ions, are to be avoided the charge breeding should directly lead to A/q<7.

Charge state breeding with an ECRIS has been chosen because of its capability to work efficiently in a continuous mode and because of the high charge capacity, which allows the charge state breeding of high intensity ion beams.

SET – UP OF THE SYSTEM

A modified version of a 14.5 GHZ PHOENIX booster from Pantechnik has been installed in a shielded area directly after the mass separation of the radioactive ions. They can be directed to the charge breeder source via a movable electrostatic deflector. The PHOENIX source is operated at a high voltage close to the one of the on – line ion source, so that singly charged ions are decelerated and stopped in the plasma. After extraction of the highly charged ions they are accelerated again to ground potential and separated according to their mass to charge ratio with a combination of a magnetic and electrostatic sector field. This combination assures the separation of scattered and charge exchanged ions out of the beam and thus, guaranties higher beam purity. The mass resolving power ΔM/M of the system is better than 1/100. A small surface ion source for Cs ions in front of the charge breeder source allows for the set-up and tuning of the charge breeder independent from the on-line target ion source system. A more detailed description of the set-up can be found in [2] and [3].

COMMISSIONING RESULTS

The installation has been finished already in 2008 and a first test, cumulating in the first successful acceleration of charge bred radioactive ions ($^{80}Rb^{14+}$) has been performed in November 2008. Results have been already reported in [3]. Final commissioning took place during the beam time periods of 2009 and the beginning of 2010.

With the test ion source a breeding efficiency of 3.5% for Cs^{21+} has been achieved. This is the same as the maximum value, which has been reached before when the source was installed on a test bench [3]. A variety of stable and radioactive ions from different target ion source combinations have been injected and efficiency and charge state distributions have been measured. In order to determine the breeding efficiency for the stable isotopes, current measurements before the charge state breeder and after the A/q selection have been performed. For the radioactive species the beam has been sent first directly to a detection station in the ISAC experimental hall. In this detection station ions can be implanted into a tape, which is surrounded by detectors for α, β and γ radiation. After a measurement the tape can be transported behind a lead shield leaving a fresh spot for a new measurement. After the intensity of the singly

charged ion beam has been determined the ions have been sent into the charge state breeder and the extracted highly charged ions have been sent again to the detector station. The efficiency of the charge state breeding is defined as the ratio of both measurements. Mostly γ measurements have been used, as they allow a clear identification of the isotopes. The implantation times into the tape and the counting times have been chosen to reach a measurement accuracy of about 10%.

Table 1 summarizes results for the charge state breeding of radioactive ions so far. Some variations in the breeding efficiencies for the different isotopes also reflect the different amount of time spent on tuning. A general trend to higher efficiency, when going to higher mass ions can be seen. The efficiency for the metallic elements is lower than for the gaseous elements Kr and Br. This effect has been seen before at the test bench and has been reported by other groups as well [4]. The difference can be explained by the possibility of recycling atoms from the plasma chamber walls for the non condensable elements. This leads to an efficiency of more than 6% for ^{74}Kr.

In the case of Br also singly charged molecular ions have been injected. Within the accuracy of about 10% the efficiency for the charge state breeding from the injection of singly charged molecules or atoms can be considered the same. The injection of some species as molecular ions can be beneficial if the release from the target is preferable in the molecular state. In the case of AlBr the method can be used to purify the beam from the isobaric rubidium isotopes, which are normally released and ionized at a much higher rate. Rubidium doesn't form this molecule. $^{78}Br^{14+}$ charge bred in this way has been injected into the accelerator and accelerated to 5 A MeV. The radioactive isotopes were then detected at the TIGRESS experimental station and identified by their decay scheme. For a more detailed description of this detector facility see for example [5] and references therein.

Table 1: charge breeding efficiencies from different radioactive ions

isotope	$T_{1/2}$ [s]	q	A/q	efficiency [%]	I(in) [pps]	injected ion	background [pA]
^{46}K	115	9	5.11	0.5	$4.0 \cdot 10^4$	K^+	340
^{64}Ga	157	13	4.92	0.75	$4.9 \cdot 10^6$	Ga^+	7
^{64}Ga	157	14	4.57	0.7	$4.9 \cdot 10^6$	Ga^+	44
^{74}Br	1524	14	5.28	3.1	$3.2 \cdot 10^7$	Br^+	10000
^{74}Br	1524	15	4.93	2.1	$3.2 \cdot 10^7$	Br^+	25
^{78}Br	388	14	5.57	4.5	$2.8 \cdot 10^7$	$^{27}Al^{78}Br^+$	20
^{74}Kr	690	15	4.93	6.2	$2.1 \cdot 10^6$	Kr^+	25
^{76}Rb	37	15	5.07	1.68	$3.8 \cdot 10^6$	Rb^+	15
^{80}Rb	30	13	6.15	1.17	$5.7 \cdot 10^7$	Rb^+	35
^{80}Rb	30	14	5.71	1.1	$5.7 \cdot 10^7$	Rb^+	70000
^{122}Cs	21	19	6.42	1.1	$3.1 \cdot 10^5$	Cs^+	6
^{124}Cs	31	20	6.2	1.37	$2.75 \cdot 10^7$	Cs^+	50

The last column of the table shows the background from stable elements extracted at the same A/q value from the charge breeder. Those are mainly isotopes of oxygen, carbon and nitrogen from the residual gas, but also helium and other noble gases from the support gas of the source. Additionally there are contributions from sputtered ions from the stainless steel plasma chamber. Although, their beam intensity is only in the range of pico Amperes, for most cases this is several orders of magnitude higher than the intensity of the radioactive beam. Furthermore, the beam may contain more than one contaminant and the composition and intensity may change with time and source condition.

Figure 1 shows a mass spectrum of ions extracted from the charge state breeder in the range between A/q = 5 to 6. In total 18 peaks with intensities above 5 pA can be found, the most intense being charge states from oxygen, carbon and argon. The spectrum represents the source condition after about 1 week of running and after being optimized for the breeding of radioactive rubidium isotopes. The cesium ions, which are normally not present, occur in this spectrum as the initial set-up with

the test ion source has been done before. Table 2 gives a summary with the most probable constituents in the mass peaks.

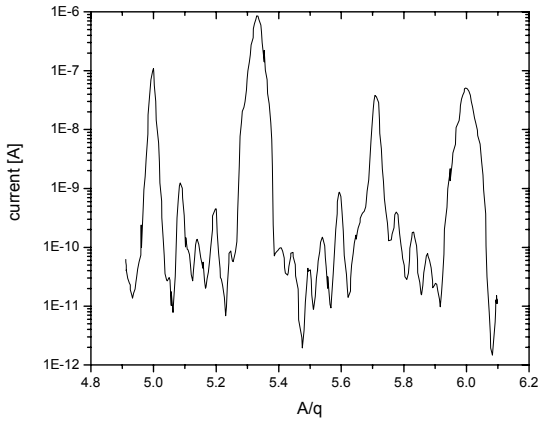

Figure 1: Mass spectrum of ions extracted from the charge state breeder in the range between A/q=5 to 6.

CONCLUSION AND OUTLOOK

Commissioning of the ECRIS charge state breeder at TRIUMF has shown that the system can be used to efficiently produce beams of highly charged radioactive ions suitable for the acceleration with the ISAC accelerators. The desired mass to charge ratio A/q < 7 can be reached for isotopes with masses up to about 150 amu with efficiencies up to about 2% for metallic and 6% for non condensable elements. Further increases in efficiency can be expected with improved understanding, mainly of the injection into the charge state breeder. The injection of molecules into the charge state breeder can be used as a method for beam purification from unwanted isobaric contaminations. Up to now only relatively long lived isotopes have been used. If their half-life approaches the breeding time, which is in the range of several 100 ms [2] a reduction in efficiency can be expected.

Beam purity after the charge state breeder has been found to be the main problem for experiments. The low signal to background ratio makes it difficult to identify reactions from the radioactive isotopes. Although research grade helium with impurity levels in the ppm range has been used as a support gas, further purification from the other noble gases may be necessary. Two cryogenic pumps, one on either side of the charge state breeder are already in place to keep the residual gas pressure at about $5 \cdot 10^{-8}$ T. The amount of background originating from the stainless steel plasma chamber may be reduced by exchanging it to aluminium. A similar approached has been chosen for example at TRIAC [6].

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Table 2: Most likely constituents of peaks in the A/q spectrum of figure 1. An accuracy of 0.005 amu/e for the determination of the peak centre has been assumed

A/q	isotopes
5	$^{40}Ar^{8+}$, $^{20}Ne^{4+}$,…
5.11	$^{133}Cs^{26+}$
5.14	$^{36}Ar^{7+}$
5.2	$^{52}Cr^{10+}$, $^{78}Kr^{15+}$, $^{130}Xe^{25+}$
5.24	$^{84}Kr^{16+}$, $^{131}Xe^{25+}$
5.33	$^{16}O^{3+}$
5.41	$^{54}Cr^{10+}$, $^{54}Fe^{10+}$, $^{130}Xe^{24+}$
5.44	$^{136}Xe^{25+}$
5.5	$^{22}Ne^{4+}$, $^{132}Xe^{24+}$
5.54	$^{61}Ni^{11+}$, $^{133}Cs^{24+}$
5.6	$^{28}Si^{5+}$, $^{56}Fe^{10+}$
5.66	$^{17}O^{3+}$, $^{136}Xe^{24+}$
5.71	$^{40}Ar^{7+}$
5.78	$^{52}Cr^{9+}$, $^{133}Cs^{23+}$
5.83	$^{134}Xe^{23+}$
5.88	$^{129}Xe^{22+}$
5.90	$^{53}Cr^{9+}$, $^{124}Xe^{21+}$
6	$^{12}C^{2+}$, $^{18}O^{3+}$, $^{54}Cr^{9+}$, $^{54}Fe^{9+}$, $^{60}Ni^{10+}$,…

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