ACCELERATION OF CHARGE BRED RADIOACTIVE IONS AT TRIUMF

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Abstract

Most ion sources at ISOL (isotope separation on-line) facilities can produce only singly charged ions but efficient post acceleration requires high charge states. For light ions this can be achieved by stripping after a first moderate acceleration, but with heavy ions this is no longer possible and charge state breeding is necessary. The breeder should be able to work at a high efficiency for the required charge state and especially for short-lived radioactive isotopes the process should be fast. For the ISAC facility at TRIUMF an ECRIS charge breeder (14.5 GHz PHOENIX from Pantechnik) has been chosen, as it is well adapted to the continuous mode operation of the accelerator. After off-line optimization on a test bench the source has been moved on-line to the ISAC facility. Mass separated beams of radioactive ions from the on-line ion sources can be directed into the source. During a first test in fall 2008 a beam of $^{80}Rb^{14+}$ was successfully created from $^{80}Rb^{1+}$ and accelerated by the ISAC post accelerator. The paper includes a summary of the results from the test bench and from the on-line commissioning.

INTRODUCTION

At the radioactive ion beam facility ISAC 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 so that products can evaporate into an ion source where singly charged ions can be extracted. The desired isotope is 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 acceptance of the post accelerator requires a maximum A/q value of 30. However, this applies only to the first accelerator stage, a 4 rod 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. At the moment this is achieved by a stripping foil after the RFQ. If additional losses from this stripping process are to be avoided the charge breeding should lead to A/q<7. Charge state breeding is done by injecting singly charged ions produced by the on-line ion source into an ion source for highly charged ions. So far two types of such ion sources have been used in different laboratories around the world. An Electron Beam Ion Source (EBIS) for pulsed beam operation and an Electron Cyclotron Resonance Ion Source (ECRIS) for continuous beam operation. With nearly 8 years operating experience the EBIS type breeder at ISOLDE at CERN routinely reaches breeding efficiencies of 5-10% for almost all available isotopes [1]. It operates in a pulsed mode with a repetition frequency of 5 to 50 Hz. The system can handle up to about 10^8 ions per second. Charge breeding of radioactive ions with an ECRIS has been reported from TRIAC at KEK [2] and ISOLDE [3]. Typical breeding efficiencies reported are about 3% for condensable elements and up to 10% for noble gases. For radioactive charge bred ions in an ECR ion source the achievable beam intensity is limited only by the production process in the target ion source system.

THE ISAC ECR CHARGE BREEDER

At ISAC a 14.5 GHz ECRIS (PHOENIX from PANTECHNIK) has been chosen. Some modifications of the original design especially for the injection and extraction optics have been done followed by extensive testing at an off line test facility. The charge breeder is operated at a high voltage close to the energy of the singly charged ions. This allows an electrostatic deceleration before capturing the ions inside the ECR plasma. While confined in the plasma the ions are undergoing collisions with high energy electrons and are ionized to high charge states. Highly charged ions are extracted opposite to the injection side of the source and accelerated again to ground potential.

Results obtained at the test facility have been already reported elsewhere [4] and will only be summarized here. Stable singly charged ions from ion sources similar to those used at the on-line facility have been injected and their charge breeding optimized. The extracted beam of highly charged ions has been analyzed by a combination of magnetic and electrostatic benders. Efficiencies obtained for a charge state at the maximum of the distribution are around 3% for alkaline elements and 5-6% for noble gases. For elements up to Cs A/q values less than 7 can be reached.

The ISAC RFQ has a velocity acceptance of 2 A keV. This requires the source to operate at different extraction voltages depending on the A/q value. Therefore, a two gap acceleration system has been installed which allows adapting the focusing of the highly charged ions to the extraction voltage. A similar two gap deceleration system allows better control of the incoming beam. Emittance measurements of several charge states of Cesium at extraction voltages between 10 and 18 kV have been performed. The normalized emittance increases from 0.02 π mm mrad at q=12 to 0.04 π mm mrad at q=18. Between 15 an 18 kV it does not depend on the extraction voltage. Only at low voltages near to 10 kV an increase to about 0.05 π mm mrad for high charge states can be found. Space charge effects on the ion beam between the source extraction and the mass separator magnet can explain this.

The total beam current extracted from the charge breeder can be as high as several 100 µA but the radioactive ions are produced only in small quantities (single ions up to 10^{10} per second). That means background currents from support gas ions or from residual gas are many orders of magnitude higher than the radioactive ions current. Even with the use of clean Helium as support gas of the ECR plasma, a good mass resolution is essential for the separation of the desired highly charged ions from background peaks. A combination of magnetic and electrostatic sector fields ensures this and separates scattered or charge exchanged ions from the beam.

The charge breeder has been moved to and set-up at the ISAC on-line facility during the first half of 2008. It has been installed in a U shaped beam line in a shielded area directly after the mass separator for the radioactive ions (Fig. 1). The ion beam branches off the existing beam line with a switchable electrostatic bender. After mass separation of the highly charged ions the beam line joins the existing one again in a vertical Y shaped electrostatic bender leading to the experimental hall with the post accelerator. A surface ion source for Cesium ions (HeatWave Labs, Model HWIG-250) is included to allow the tuning of the charge breeder independently from the on-line ion source.

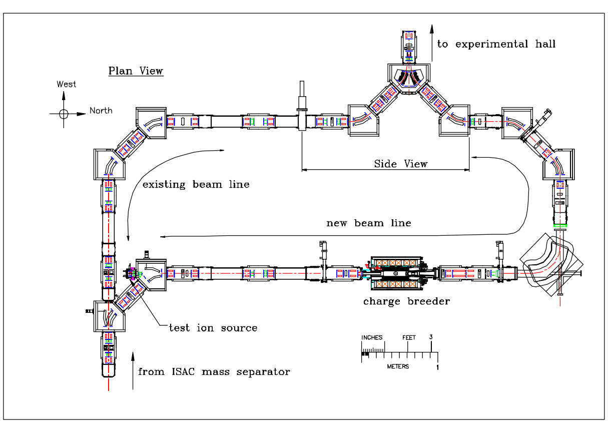

Figure 1: Layout of the charge breeder installation at ISAC.

The charge breeder has been put into operation at its new location first with stable ions both from the test ion source and from on-line ion sources to confirm proper functionality. Unlike to the measurements at the test bench, the on line sources and the charge breeder are operated with separate power supplies for the high voltage. This requires a fine adjustment of the absolute value of both. Figure 2 shows the dependence of the charge breeding efficiency of stable $^{133}Cs^{17+}$ from the test source as function of the voltage difference between the breeder high voltage and the potential of the test source. For optimum performance this voltage difference has to be adjusted with an accuracy of less than 1 V. In order to guaranty this both power supplies are specified to a stability and reproducibility of some 10^{-5}.

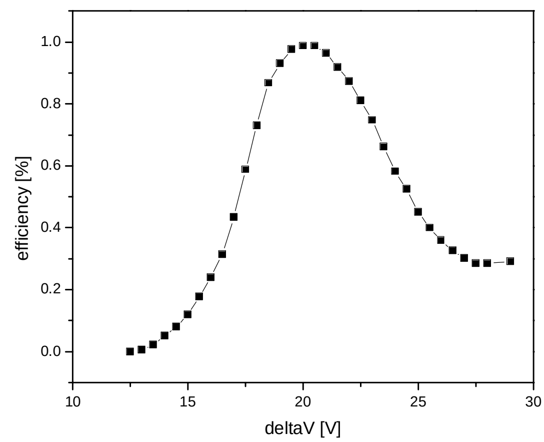

Figure 2: Efficiency for the production of Cs^{17+} as function of the potential difference between the singly charged ion source and the charge breeder.

RADIOACTIVE ION CHARGE BREEDING AND ACCELERATION

The first test with ions from the on-line ion source was performed in October/November 2008 with Rb and Cs ions produced from a Tantalum target equipped with a surface ion source. The injection into the charge breeder has been set up with a beam of about 180 pA of stable ^{87}Rb from the on-line source. Beams of radioactive ions have been first sent directly into the experimental hall to a tape station in order to identify the isotopes and determine their intensity from gamma or beta radiation. After this, they have been directed into the charge breeder. The extracted highly charged ions have been sent to the tape station again to determine the efficiency for the different charge states. Figure 3 shows a typical result for the dependence of the efficiency on the extracted charge states of ^{80}Rb; only charge states from 10 to 16 around the maximum in the distribution have been measured. Similar measurements have been performed for the two radioactive isotopes ^{120}Cs and ^{124}Cs. The maximum in the charge state distribution for the cesium isotopes was at q=19+ leading to A/q values of 6.31 and 6.52

respectively. Breeding efficiencies for both elements were about 1% in the maximum of the distribution, which is lower than the values obtained at the test bench, but further optimization especially of the ingoing beam should improve this value.

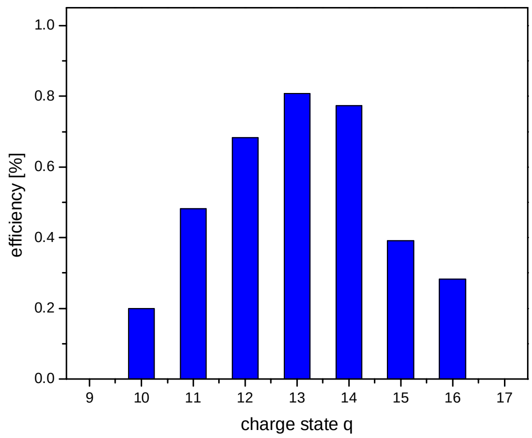

Figure 3: Efficiency for the production of high charge states of ^{80}Rb.

In order to test the beam transport to the accelerator and the acceleration of highly charged ions, a beam of $1.1 \cdot 10^5$ ions/s $^{80}Rb^{14+}$ has been injected into the RFQ. This isotope and charge state has been chosen as it is accompanied by a strong beam (~100 nA) of $^{40}Ar^{7+}$ at the same A/q value coming from the charge breeder. This allows an easy tuning of the beam line optics and the accelerator. The Argon originates from impurities in the Helium support gas of the ECR plasma. Most physics experiments with radioactive ions will not be able to accept such high background of stable ions. In such a case a different charge state has to be chosen and the accelerator has to be optimized with beam from an off-line source delivering stable ions with the same A/q value. After acceleration the beam has been sent through a bending magnet for energy analysis and implanted into a Faraday cup. A Ge detector was placed beside this cup and the gamma radiation from the ^{80}Rb has been measured. The gamma detection efficiency has been determined with calibrated ^{60}Co and ^{152}Eu sources placed inside the cup and on a slit in front of it. $3.5 \cdot 10^4$ ^{80}Rb ions/s have been measured. Comparing this to the value measured at the tape station after the charge breeder it leads to an efficiency of 32%. Simultaneously the current measurement of the $^{40}Ar^{7+}$ leads to a transmission from the charge breeder to the analyzing Faraday cup of 33%. The transmission has not been fully optimized at this time but the result shows, that there are no further losses associated with the radioactive ion or the higher charge state. Further matching of the beam from the charge breeder into the accelerator will be necessary and should improve the transmission.

SUMMARY AND OUTLOOK

For the first time radioactive ions charge bred in an ECR ion source have been accelerated at the radioactive beam facility ISAC at TRIUMF. This has extended the range of available accelerated beams of radioactive ions towards heavier masses beyond A=30 and will open up a new era of experiments with those ion beams at TRIUMF. Although, the efficiency for the charge breeding of ^{80}Rb was only 1% in this first test run based on results obtained at a test bench higher values should be possible. It will need further optimization of the system by better matching the incoming beam of singly charged ions to the charge breeder. Further tests with different on line target ion source combinations are scheduled within this years running period for a final commissioning of the charge breeder. Besides the condensable elements beams from gaseous ions will be used as well as molecular species. In some cases the break up of the latter ones may allow isobaric purification of the extracted radioactive ion beam. This has been demonstrated at ISOLDE [5].

ACKNOWLEDGEMENT

TRIUMF receives federal funding via a contribution agreement through the National Research Council of Canada

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