A CHARGE STATE BREEDER BASED ON A LOW FREQUENCY RFQ FOR THE ISAC ACCELERATOR COMPLEX

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Abstract

The new ISAC-II facility has just been funded. The main goals of this extension to the ISAC facility are: expanding the mass range from A ≤ 30 to A ≤ 150 and increasing the final energy from 1.5 MeV/nucleon to 6.5 MeV/nucleon. The accepted mass to charge ratio for the actual 36 MHz RFQ is A/q ≤ 30/1. In order to increase the mass range to 150 we have to increase the charge-state to at least 5+. This can be achieved by three different methods: i) using a charge state breeder based on an EBIS as developed at REX-ISOLDE [1], ii) using an ECRIS or ECRIT based on an ECR as developed at Grenoble [2, 3], iii) using a gas charge-state stripper based on a low frequency RFQ [4]. Since intense RIB are difficult to produce it is of primary importance to obtain the highest overall charge-state breeding efficiency and to preserve the beam quality, small emittance and beam purity. In comparing the three above methods, our analysis shows that the combination of a low frequency RFQ and a gas stripper offers the best overall performance.

1 INTRODUCTION

The TRIUMF's ISAC uses the isotope separation on line (ISOL) technique to produce radioactive ion beams (RIB). The ISOL system consists of a primary production beam, a target/ion source, a mass separator, and a separated beam transport system. These systems together act as the source of radioactive ion beams to be provided to the accelerator or the low-energy experimental areas. We use the 500 MeV - 100μA primary proton beam extracted from the H- cyclotron [1]. The accelerator complex comprises an RFQ [4] to accelerate beams of q/A ≥ 1/30 from 2 keV/u to 150 keV/u and a LINAC (DTL) to accelerate ions of q/A ≥ 1/6 to a final energy between 0.15 MeV/u to 1.5 MeV/u. In April 2000 the ISACII proposal was funded. the funding agency. The main goals of this extension to the ISAC facility are: expanding the mass range from A ≤ 30 to A ≤ 150 and increasing the final energy from 1.5 MeV/nucleon to 6.5 MeV/nucleon. The accepted mass to charge ratio for the actual 36 MHz RFQ is A/q ≤ 30/1. In order to increase the mass range to 150 we have to increase the charge-state to at least 5+.

This paper reviewed the different schemes that can allow the production of higher charge-state.

With the PIAFE proposal early 1993-1995 [5,6,7] and, followed with the REX-ISOLDE [8] proposal the idea of the charge state breeder make it way in the accelerator design scheme. Now, every new proposal or upgrade looks seriously into the use of a charge-state breeder. The reason being, the higher the charge-state of an ion, the higher will be the acceleration efficiency. In consequence, a beam accelerated to several MeV/nucleon will require less voltage and reduce considerably the size and the cost of the accelerator.

2 CHARGE-STATE BOOSTER FOR RIB FACILITY

The principle of the 1+ → n+ consists in injecting an ion beam into an other ion source. The charge-state breeding ion source can be either an Electron Beam Ion Source (EBIS) or and Electron Cyclotron Resonance Ion Source (ECRIS). Since it takes some time to obtain the desired high charge-state, the challenge is to be able to capture with high efficiency the mono-charged beam into the breeding ion source.

2.1 TRAP-EBIS combination

In the REX-ISOLDE scheme, the charge breeding will be done by an EBIS. Since the acceptance of this ion source is very small, ≤ 3π mm mrad at 60 kV, they used a Penning trap for accumulation, cooling, and bunching. However, the number of particles that can be trapped in the Penning trap is limited. The maximum ion density for the REX-Penning trap is estimated for A = 140 at 10^6-10^8 ions per accumulation cycle.

The Penning trap is located on a high voltage-platform. The platform is at the same potential as the singly charged ion source at the ISOLDE target. A transfer beam line consists of two electrostatic benders and two electrostatic quadrupole doublets. The confinement time to reach the charge-to-mass ratio larger than 1/4.5 is less than 20 ms. The EBIS magnet has a magnetic field of 2 T with an homogeneity of about 2.5‰ along the confinement length of 0.8 m. The ions ejected from the EBIS are mass analyzed with a magnetic achromat composed of two 90º dipoles.

This scheme is very complex. It requires a lot of beam manipulation and tuning can be very long and difficult. It is not ideal for a facility, which has to serve many users. Furthermore, it is not suitable for high intensity because the Penning trap is space charge limited.

2.2 Charge-state breeder based on ECRIS

Several tests have been done over the past five years to developed the charge breeding using an ECR[9,10,11]. Recently at Grenoble [12], they tested many different elements, noble gases, alkali, and metallic species. The charge-state breeding efficiency is define as

$$\varepsilon_n = \frac{1}{n}\frac{I_{n^+}}{I_{1^+}},$$

charge-state breeding efficiency is define as and the global efficiency is defined as,

$$\varepsilon_G = \sum_{i=1}^{n} \varepsilon_n .$$

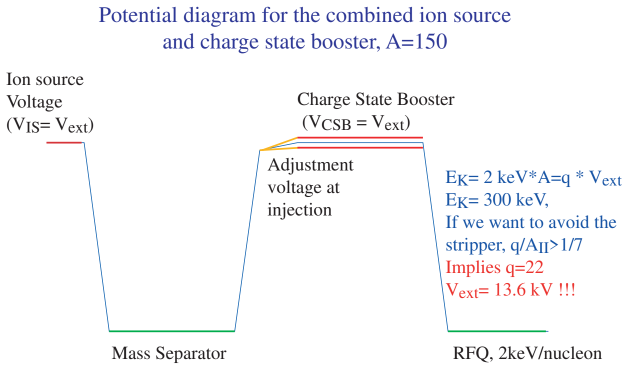

Figure 1: Potential diagram for an ECRIS as charge-state breeder.

For the noble gases, the global ionization efficiency is between 40% to 50%. This efficiency drops significantly for other elements. These results can be explained by the fact that noble gases do not stick to the surface walls of the ECRIS very long. The ions, which are not directly capture by the plasma, are neutralized and the atoms are release after a short period and then be ionized to higher charge-state. The charge breeding efficiency is of the order of 10%.

For species with a large enthalpy potential, the sticking time on the walls can be much longer. In some cases the atoms can react with the surface material and make stable compound. The global efficiency is then much lower and the charge breeding efficiency is between 2 and 3%.

We can see several problems arising from those results. The global efficiency being less than 100% means that radioactive species will stay into the ion source. It will become a major source a radioactivity. We have to be concerned for the services and maintenance of the ECRIS. Furthermore, the decay of the radioactive species will create contamination of the desired beam. This can be a big issue since we are developing a resonant LASER ion source to produce pure radioactive ion beams.

Furthermore, in order to inject at 2 keV/nucleon into our RFQ the extraction voltage of the 1+ RIB has to be adapted accordingly. The for ISACII has to be greater to $q/A \geq 1/7$ in order to avoid any further stripping. This means that we will have to extract the 1+ RIB at very low voltage. It will result a reduction of the transmission by a factor 2 in the mass separator section. Finally, the charge breeding efficiency being very low will somehow reduce the physics opportunities. Experiments will take longer and in some other cases, simply impossible.

3 RFQ-STRIPPER COMBINATION

The other solution we envisage to increase the mass range to A≤150 is to use a gas stripper at low energy. Two different scenarios can be used, a 12 MHz RFQ, gas stripper and a new 36 MHz RFQ or a 12 MHz RFQ, gas stripper and deceleration to 2 keV/nucleon and injection into the actual RFQ. In both cases, the residual intensity will be the same. Figure 2 shows schematic diagram of the two options.

Figure3 shows the relative equilibrium charge-state as a function of the reduced velocity for ions from ^{32}S to ^{181}Ta. In our case, the necessary energy will be between 16 and 20 keV/nucleon.

To preserve beam intensity the RFQ has to operate in CW mode. This design uses an 12 MHz RFQ similar to the one developed at ANL [4]. To maintain an input energy of 2 keV/nucleon at the entrance of the existing ISAC 36 MHz split ring RFQ [13] the new RFQ and the gas stripper would have to be installed on a 300 kV high voltage platform.

The ANL design will not provide the necessary energy. It was shown by the INS-Tokyo group that it is possible to have a split-coaxial RFQ made of several unit [14].

Furthermore, since the stripping is a very fast process no delay is involved and we do not have to fear unnecessary beam losses. Figure 4 shows the residual intensity after stripping in a gas stripper at 0.02 MeV/nucleon and in a carbon foil at 0.4 MeV/nucleon.

One other option we can look at to even increase the intensity is to inject multiple charge-state into the RFQ after the gas stripper. This option is under study at ANL and the preliminary results are promising [15].

4 CONCLUSION AND DISCUSSION

The low frequency CW RFQ combined with a gas stripper offer the best overall residual intensity for RIB facility. The RIB intensity with this method is more than one order of magnitude compare with ion source charge-state breeding.

This solution eliminates the contamination problem that arises using the charge-state breeder based on ion source.

In the next six months we will collaborate in order to obtain the best answers to our concern and have the best estimate of the charge-state breeding efficiency for several refractory elements. We will try to determine what are the crucial parameters and try to increase the efficiency. For example, the injected beam phase has a crucial role to play in the capture efficiency for other elements than noble gases. One option we can envisage is to reduce the beam emittance before injection into the ECRIS. We would prefer to use a cooler based on an RFQ instead of a Penning trap for it larger acceptance at reasonable cost.

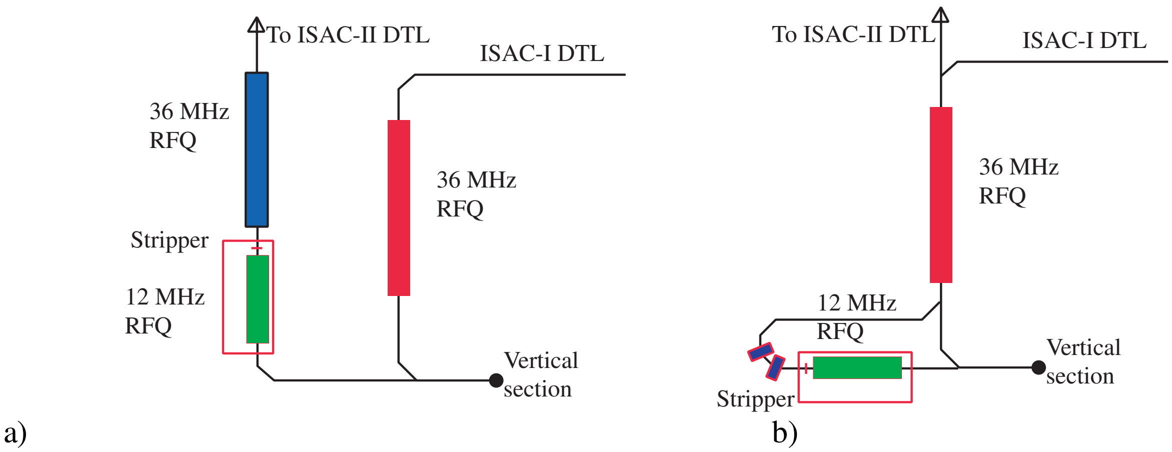

Figure 2: Two schemes using a low frequency RFQ and a gas stripper combination. Figure a represents a

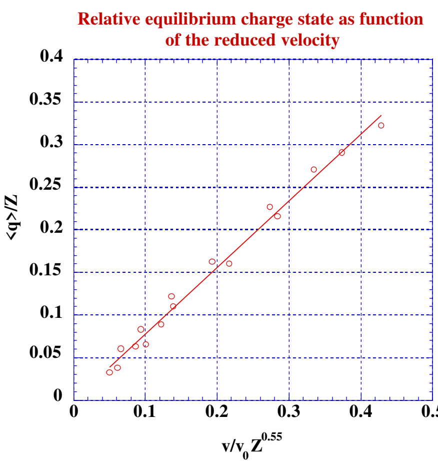

Figure 3: Relative equilibrium charge-state as a function of the reduced velocity.

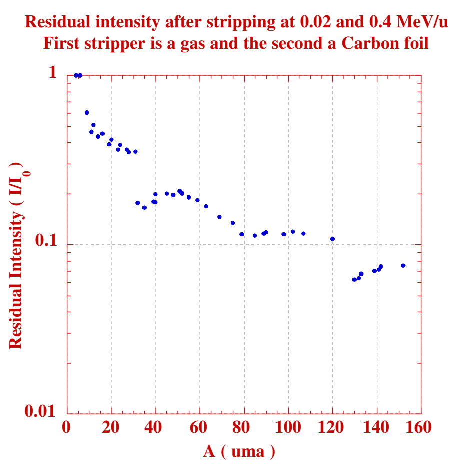

Figure 4: Residual intensity after to strippers. The first stripper is a gas stripper at 0.02 MeV/nucleon and the second striper is a carbon foil at 0.4 MeV/nucleon.

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