MEASUREMENTS OF ION SELECTIVE CONTAINEMENT ON THE RF CHARGE BREEDER DEVICE BRIC*

V. Variale#, A. Boggia, T. Clauser, A. Rainò, V. Valentino, G. Verrone,
INFN-Bari and Physics Department of Bari University (Italy),

P. A. Bak, M.A. Batazova, G. I. Kusnetsov, B. A. Skarbo, S. V. Shiyankov,
BINP, Novosibirsk (Russia)

Abstract

The "charge state breeder" BRIC (BReeding Ion Charge) is based on an EBIS source and it is designed to accept Radioactive Ion Beam (RIB) with charge +1, in a slow injection mode, to increase their charge state up to +n. BRIC has been developed at the INFN section of Bari (Italy) during these last 3 years with very limited funds. Now, it has been assembled at the LNL (Italy) where are in progress the first tests as stand alone source. The new feature of BRIC, with respect to the classical EBIS, is given by the insertion, in the ion drift chamber, of a Radio Frequency (RF) Quadrupole aiming to filtering the unwanted elements and then making a more efficient containment of the wanted ions. In this contribution, the measurements of the selective effect on the ion charge state containement of the RF quadrupole field, applied on the ion chamber, will be reported and discussed. The ion charge state analisys of the ions trapped in BRIC seem confirm, as foreseen by simulation results carried out previously, that the selective containment can be obtained. A modification of the collector part to improve the ion extraction of BRIC will be also presented and shortly discussed.

INTRODUCTION

SPES is a project of new facilities for the production of Radioactive Ion Beam accelerated up to several MeV/u [1]. It is in an advanced phase of study at the Legnaro National Laboratory (LNL) (Padua, Italy) . This kind of project is based on the ISOL technique [1]. With this technique, two beam acceleration stages are used. The primary accelerator is intended to provide a proton, or a light ion, beam incident on a target to induce nuclear reactions. Then radioactive species will be produced inside. These radioactive elements need to be ionised for acceleration and then a secondary stage is intended to accelerate the radioactive ions at the desired energy before they reach the experimental area. Since the cost of an accelerator is roughly related to the inverse of the charge state of the beam to be accelerated, a higher ion charge state beam can allow a sensitive lowering of the accelerator cost. This problem can be solved by using, before the post-acceleration of RIB, an appropriate device capable of increase the charge ion state of the radioactive element that must be accelerated. In the framework of the LNL SPES project, our INFN group, in Bari, has been involved in the development and testing of a "*charge state breeder*" device based on an EBIS source type: BRIC. The BRIC features have been presented in a detailed way in ref. [2]. The main new feature of BRIC is the using of a RF quadrupolar field to obtain a selective containment of the wanted ions to reach, in this way, a more efficient high charge state ion production.

The main purpose of our experiment is to test the BRIC device only as stand alone high charge ion source to verify the idea of the RF selective containment and then study its effect in the ion production. In this paper, the measurement results carried out to test the selective containment of BRIC will be presented and discussed.

Furthermore, the design and construction of a new more efficient ion extraction system developed in order to improve the measurement quality will be shown as conclusion.

THE BRIC DEVICE

As mentioned before, the detailed design of BRIC device has been already presented in ref. [2]. However, for sake of clarity, a shortly description of the device here will be done to recall its main features. As can be seen from fig.1, where the experimental set up is shown, BRIC is practically the same of a classical Electron Beam Ion Source (EBIS). In fact, in that figure, as in an usual EBIS, you can see the electron gun, the ion drift chamber and the typical electron collector with the hole for the ion extraction.

The main difference between BRIC and a usual EBIS can be observed by looking at the inside of the ion drift chamber shown in fig.1. In the chamber, RF electrodes of cylindrical shape, placed around the symmetry axis in such a way to form a quadrupolar RF field, are shown. The RF field, which is added to the electron beam space charge potential, can give the above mentioned transverse selective containment to the wanted ions. The anode and the electrode placed at the end of the cylindrical shaped RF electrodes are used to create the longitudinal trap for the ions, needed for the ion charge state breeding, before that they could be extracted.

To find out whether the RF quadrupolar field could be used to obtain a selective ion containment also in the presence of the electron beam space charge force and of the axial magnetic field, needed for the electron beam

*Work supported by INFN (Italy)
#vincenzo.variale@ba.infn.it

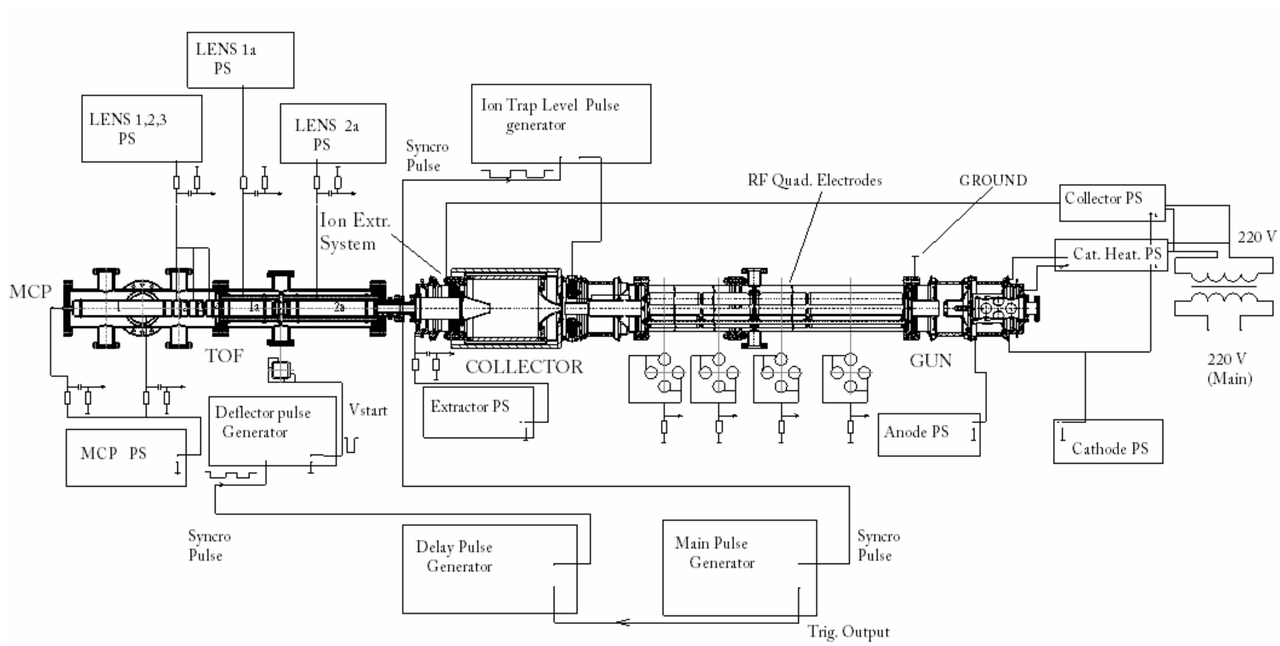

Figure 1: BRIC Experimental set-up with mechanical scheme. MCP indicates Micro Channel Plates detector.

focusing, a simulation code package called BRICTEST has been developed [3]. The simulation results obtained by using BRICTEST code have shown both that the electron beam is not significantly perturbed by the RF and that the selective ion containment could be possible also when to the RF quadrupolar field is added also the axial magnetic field and the electron beam space charge force [3]. However, since many approximations are used to simplify the calculations of the ion motion in the BRIC device a test experiment is required to confirm the simulation results. The goal of our experiment, then, as mentioned in the introduction, is essentially of testing the RF selective containment. The main BRIC design parameters have been: a current density, J_e, of about 10 A/cm^2 and an electron beam energy of about 5 keV [2]. For that current density (following the SPES project requirements), if an ion mass of about 100 a.m.u. and a charge state of 10 (charge over mass ratio = 1/10) is considered, a "breeding parameter" [6]: $J_e \bullet \tau_c \approx 3 \div 4$ [$A \bullet sec/cm^2$] can be obtained by using the Lotz formula [4] as ionization cross section. Then, to reach, for example, a ion charge state of 10, confinement times of about 300 ms had to be required. In the actual test experimental conditions, however, an electron density current of about 2 A/cm2 with an energy of about 2 keV could be reached.

For the electron beam focusing system are used two short solenoids made of special coils suitable to be mounted together in such a way to form a solenoid [2].

The solenoid coils have a water cooling system that allows to supply a current of 150 A without any increase of the copper temperature. In our measurements, a maximum magnetic field of 1.4 kG has been reached on the axis of the solenoid.

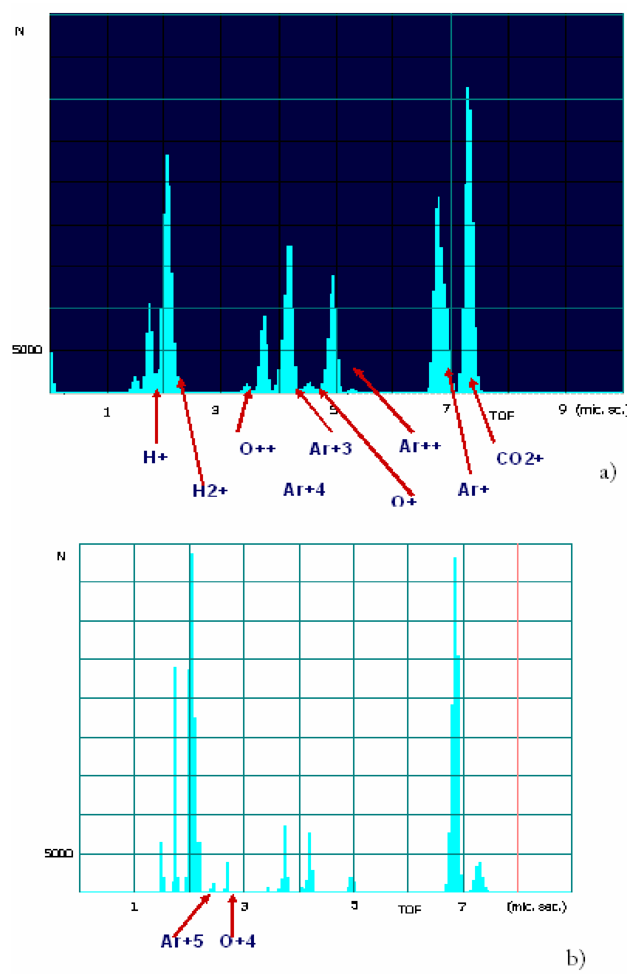

Figure 2: Ion charge states measurements. *N* (ion counting) *vs* ion TOF (μs): a) case without the application of RF field, b) case with RF field.

ION CHARGE STATE MEASUREMENTS

The parameter used in our test measurements are shortly described in the following. The power supply connected to the collector, which recovers the electron beam extracted from the cathode, is insulated from the ground (see experimental set-up in fig.1) and it was set to, V_{coll}=1.25 kV. Since the cathode potential was, V_k=-1.8kV the collector was placed to -530 V with respect to the ground. The electron extraction electrode potential was, V=+1.8kV and the anode potential was placed to the ground. The electron current recovered on the collector has been about 200 mA with an efficiency of 99.7% and the ion extraction electrode placed in the collector had a voltage of about –2 kV. The ion trap emptying pulses (see also fig. 1) are given with a frequency of 70 Hz allowing a τ_c of about 14 ms. The TOF start pulse given by the deflector pulse generator (the ions are deflected when it is off) had an amplitude of –1.3 kVand pulse width of 500 ns. The ions with different charge state have been detected by a very fast Micro Channel Plate (MCP) detector which signals have been analysed by a MultiChannel Scaler (MCS)[5]. The measurements obtained with the above parameter values when Ar gas was injected inside the ion chamber up to a total pressure of about 1 x 10^{-7} Torr are presented in fig.s 2. In both those figures are shown the ion counting number *N vs* ion TOF for the case without the addition of the RF quadrupolar field, in a), and the case with a quadrupolar field of ν_{rf}=0.8 MHz and V_{pp}=10 V in b). From the comparison of a) and b) it can be seen how the adding of the RF field to the ion chamber produced a amplitude reduction of some ion charge state peaks and the increase of others. Furthermore, on the case b), it can be seen the appearance of 2 further small peaks that refer to ions Ar^{5+} and Ar^{4+}. Further measurements have been carried out for different RF frequencies and they all have shown that the frequency which gave major effect on selective containment, for the used parameters, was about 1.2 MHz. More sensitive effects on selective containment should be expected for higher values of RF amplitudes (see simulations on ref. [3]). However, since we had our RF amplifier broken, RF amplitude values greater than 10 V pp could not be applied in the measurements carried out up to now. New measurements with higher RF amplitude values are under way to verify the foreseen results of the simulations of ref. [3].

Recently, the vacuum system of the ion chamber has been implemented to improve the device vacuum level as required by the EBIS source to reach high charge states [6]. The vacuum level in the BRIC ion chamber has improved about of a factor 10 (10^{-9} mb). A higher vacuum level means a lower quantity of trapped ions and then that requires a more efficient ion extraction. In fig. 3 is shown the design and the simulations of the new ion extraction system that will be used in the next measurements. The adding of more electrostatic lenses (see comparison in fig.1) and the moving of the extraction electrode closer to the collector hole has produced a very efficient extraction as shown by the simulations.

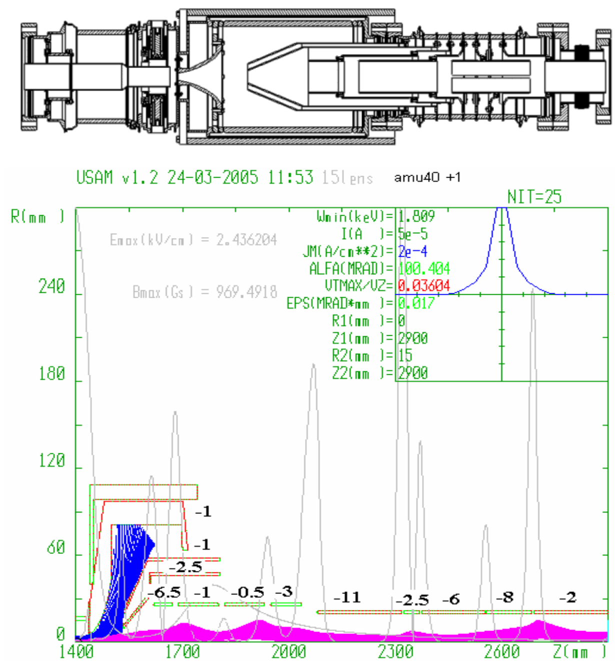

Figure 3. Mechanical drawing of the new ion extraction system and the ray tracking simulations. The bleu trajectories are electrons and the magenta ones are ions. The numbers on the electrodes indicate the voltage values in kV (The simulation code is SAM developed at BINP of Novosibirsk) .

CONCLUSION

The first experiment results have shown that ions in BRIC trap can be selectively contained when an appropriate RF field is applied to the quadrupole electrodes. More extensive measurements with RF field to better characterize the selective containment effect and to better understand if this effect could be used to improve the ion production efficiency of a wanted ion with proper charge state have been planned. The implementation of the vacuum system has allow to reach 10-9 mb and that requires a more efficient ion extraction system (fig.3) that will be employed on BRIC before the end of this year.

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