CHARGE BREEDING TEST EXPERIMENT WITH A HOLLOW GUN EBIS

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Abstract

The charge breeding technique is used for Radioactive Ion Beam (RIB) production in the Isotope Separation On Line (ISOL) method in order of optimizing the re-acceleration of the radioactive element ions produced by a primary beam in a thick target. That technique is realized by using a device capable of increase the radioactive ion charge state from +1 to a desired value +n. In some experiments a continuous RIB of a certain energy could be required. The EBIS based charge breeding device cannot reach a real CW operation because the high charge state ions produced are extracted by the same part where the 1+ ions are injected, that is, from the electron collector. In this way, the ions extraction system, placed in the electron beam collector, can be left only to extract the n+ ions, and then the CW operation, at least in principle, could be reached. In this paper, a charge breeding test experiment based on a EBIS which has an e-gun with hollow cathode will be described. Furthermore, the status report of the experiment will be presented.

INTRODUCTION

Radioactive ion beams (RIBs) are an important tool for experiments at the foremost frontier of nuclear physics. Recently, the final report of the design study of the European project EURISOL has been published [1]. In that report the design of a European ISOL type facility capable of producing RIBs with intensities several order of magnitude greater than those available today has been presented. An important problem studied in the EURISOL design was how to reach higher efficiency in the RIB post-acceleration. In fact, 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 for the RIB can sensitively lower the accelerator cost. That high ion charge state can be realized by using an appropriate device capable of increasing, before of the post-acceleration, the radioactive ion charge of the elements that have to be accelerated.

The EURISOL design study report has also confirmed that the 'charge breeding' technique used to increase the ion charge state of the produced radioactive ions can be based on two different type of ion sources: the Electron Beam Ion Sources (EBIS) and the Electron Cyclotron Resonance Ion Sources (ECRIS) [1]. The Rex-ISOLDE experiment, in fact, had already shown that the charge breeding of radioactive beams is possible with efficiency, typically, up to *10%* in one charge state and breeding times of *~50 ms* for light beams and *~150 ms* for heavy beams. In order to become comparable in the overall efficiency with the 'classical' more expensive stripper scheme, all the steps of the breeding process have to be optimized. The possibility of optimizing the charge breeding process trough several techniques had been also explored in the European project EURON [2]. Furthermore, also in ref. [2], a comparison between the two types of 'charge breeder', the EBIS and the ECR based has been shown. In that work it has been pointed out the advantages and the drawback of both devices and has been shown as one of the main problem of an EBIS based 'charge breeder', for high RIB intensities, it is the impossibility to be operated in CW. In this paper a new kind of EBIS that at least in principle, could reach the CW operation has been proposed and built for a test experiment [4]. Practically, it consists of a usual EBIS which has an electron gun with hollow cathode. That kind of e-gun, in fact, would allow a continuous injection of 1+ ions from the e-gun side and, as usual, the extraction of the n+ ions from the electron collector side. Furthermore, the status report of that experiment will be presented.

THE EXPERIMENT

Few years ago, at LNL (Padua, Italy), a low cost test EBIS has been designed and built for an experiment on RF selective containment in EBIS [5]. That experiment had the aim to improve the ion charge state breeding efficiency by using a RF quadrupole inside the EBIS trap. The same device (called BRIC) has been modified for a further R&D experiment to test, as above mentioned, an EBIS based 'charge breeder' in CW operation. The modification of BRIC has consisted, essentially, in the redesigning of the electron gun and ion trap which has been reduced in its length. The detailed design of the new e-gun with the hollow cathode and of the ion trap with the related simulations have been already shown in ref. [4]. In this paper we intend, rather, present the mounting and construction problems of the new BRIC and furthermore the ion charge state evolution simulation in an EBIS with a hollow e-beam. For sake of clarity, however, the design of the modified BRIC device with the detail of the modified electron gun side is shown in fig. 1. In that figure it is also shown, as mentioned in the introduction, how the 1+ ions will be injected from the e-gun side and then extracted from the collector side once their charge state has been increased up to n+.

The hollow cathode has been built, tested and, as shown in fig. 2, it has been also mounted in the e-gun part of the BRIC. In that figure, it can be noticed the hole on the centre of the cathode. The mounted cathode is of LaB6 type and has the following sizes: 8 mm, the outer diameter; *3 mm*, hole diameter and *2.5 mm*, the cathode tick length. At the back of the hollow cathode, not shown in the picture, an electrode to focus the 1+ ions inside the

BRIC trap has been placed, as reported in ref.[5], (see fig.1b)).

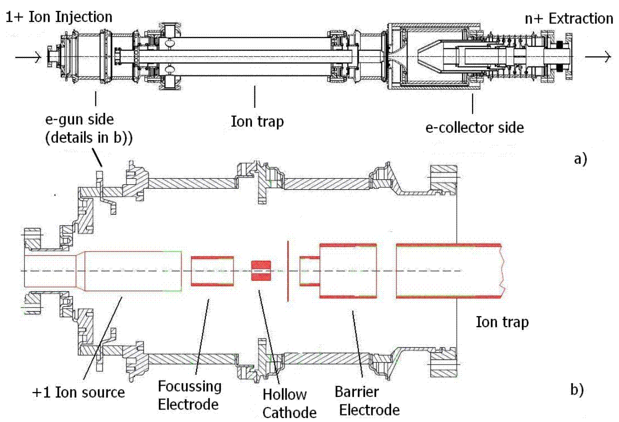

Figure 1: a) The modified BRIC for Hollow cathode insertion; b) e-gun electrode details.

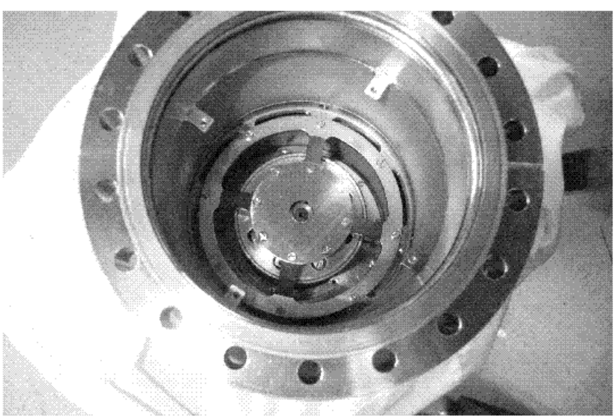

Figure 2: Hollow cathode mounted in the e-gun.

The old BRIC ion trap made of RF quadrupole electrodes, needed in the previous experiment to test the selective ion containment [5], has been substituted by a new one that it is also halved in length as shown in fig. 1a). No modification, instead, have been applied to the electron collector and to the TOF line that analyzed the ions coming from the ion source.

The main problem of the experiment, as already discussed in ref. [5], it is given by the relatively low solenoid magnetic field ($Bmax=1.8$ kG) that we have available to focus our electron beam (*eb*) generated by the hollow cathode. In fact, although that value it is capable of giving to the *eb* a good compression it is not big enough to close completely the hollow formed in it because of the hollow cathode [4]. In fig. 3, it is shown the *eb* trajectories simulation inside the BRIC device from the e-gun to the collector. In that figure, because of the reduced size, it is hardly visible (the green line) the hollow in the cathode that is decreasing toward the ion trap region up to a lower but not null value.

In principle, however, the hollow in the eb could be completely closed as already mentioned in ref. [4], but surely it could be done with a new e-gun design in presence of a higher magnetic field.

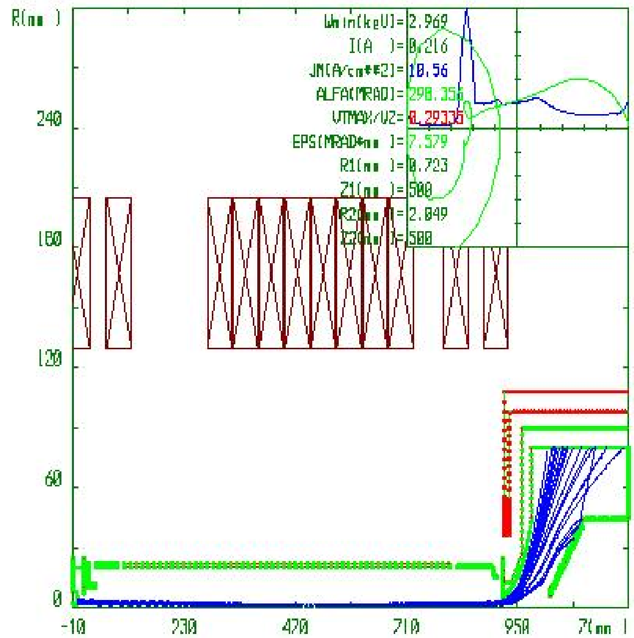

Figure 3: Electron trajectory (blue lines) simulations for hollow cathode in BRIC device from the e-gun to collector.

On the other hand, from the electron trajectories simulation results carried out and shown in ref. [4], it has been concluded that, with the present B_{max}, we could not get rid of the hollow in the *eb*.

For that reason the simulation code BRICTEST [6] has been implemented to include the effect of the ion motion in a hollow eb on the ion charge state increase rate [7].

The ionisation rate is proportional to the overlapping region between the *eb* and the 1+ ion distribution. The maximum rate, then, can be reached only for a complete overlapping. Simulations to evaluating how the hollow in the *eb* could reduce the ionisation rate are, then, needed. In first approximation, the overlapping between *eb* and ion beam cross section has been considered constant for all along the interaction time, τ. With that assumption, the reduction rate resulted, of course, strictly proportional to the overlapping cross section. Actually, however, the 1+ ions injected in the EBIS ion trap oscillate in the *eb* space charge potential well. In the case the ions are injected in the trap with a beam spot of the same size of the *eb* and with zero transverse velocities, v_t, they will continue their oscillating motion inside the *eb* (being the oscillation amplitudes equal to their initial positions). Then, only in this case a continuous complete overlapping between the electrons and ions could be considered true but only for *eb* without hollow. In general, however, since it is practically impossible to inject in the trap ions with $v_t=0$, the ion oscillation amplitudes will increase with respect their initial positions because of their initial v_t. This means, that, since the ion will spent part of their motion time outside the *eb* cross section, the ion charge state breading rate should decrease. In fig. 4, as an example, are shown the initial and final (after *120 μs*) ion beam spots for the cases of two different initial v_t max.

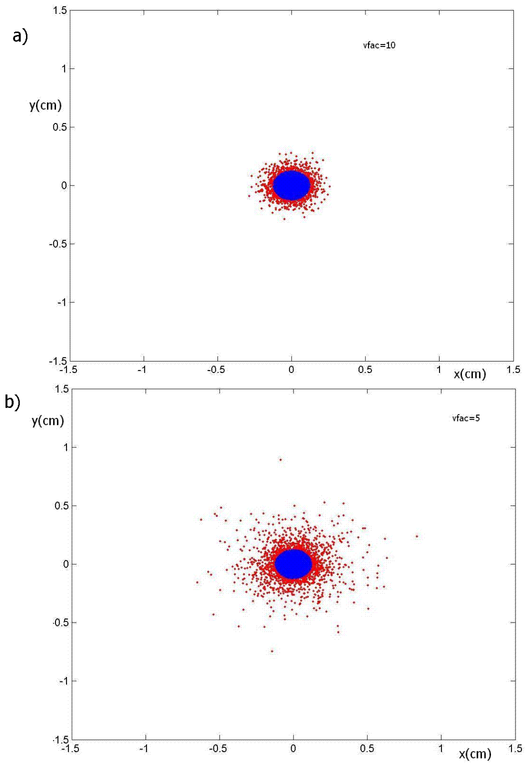

Figure 4: *xy* ion beam spot for different initial v_t max.: a) $v_{fac}=10$, corresponding to $v_t= v_l /10$; b) $v_{fac}=5$ corresponding to a $v_t=v_l /5$ (v_l=longitudinal vel.). The initial beam spot is represented by blue points (the same of *eb* transverse size); after *120 μs*, by red points.

In presence of conservative forces the ion oscillation amplitudes will not change and will remain higher than eb transverse size for a initial v_t value enough high. In the case a hollow *eb* is used, the ionisation rate is expected be more serious. In that case, in fact, the space charge potential well will be less depth and then the ionisation rate reduction will be higher with respect to the case without hollow. Further more the ions will not be intercepted by the electrons also at oscillation amplitudes lower than r_h (the hollow radius). This means, that in the case of hollow *eb*, the ion charge state increase rate, in the ion trap, will be still slower than the *eb* case without hollow. The ion charge state simulations that take into account the ion motion inside the *eb* potential well are shown in fig. 5. In that figure, in fact, the ion charge state increase for the case in which the hollow is taken into account as a lack of complete overlapping between the electron and the ion beam is shown in the black line, there a constant overlapping value of *96%* is considered.

That value corresponds to an hollow having $r_h=0.024cm$ (since the *eb* radius was $r_b=0.12cm$). From those simulations it can be seen that the case without hollow (cyan line) presents an ion charge state evolution very close to that one of the case with the *96%* of constant overlapping. When the ion motion, instead, it is taken into account (red line) a big difference cane be noticed in the simulation results.

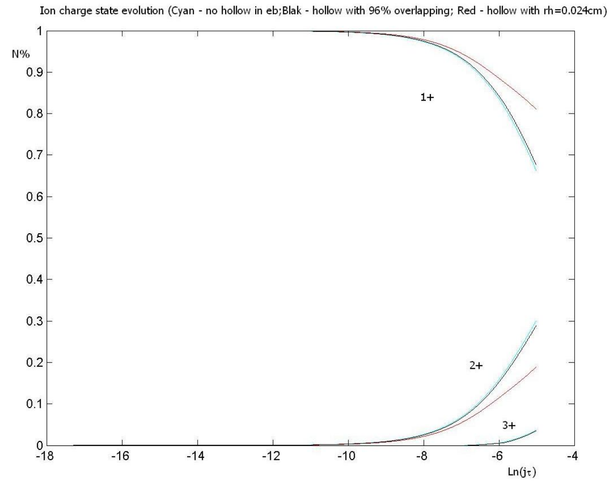

Figure 5: Ion charge state increase in the BRIC ion trap.

Then, in order to obtain a good evaluation of the ion charge state increase rate the simulations must include the ion motion in the *eb* potential well. Further simulations have shown that the ion charge state increase rate is very sensitive to r_h. However, since, in general, the r_h can be reduced, in principle, up to zero by using higher solenoid magnetic field this drawback could be overcome and the test experiment remains valid.

CONCLUSION

The simulation results carried out with the implemented TESTBREC code has show that the ion charge state rate is very sensitive to the *eb* hollow radius value r_h.

The new parts of the experimental apparatus have been built and tested. The mounting of that apparatus which had already started the end of the last year at LNL has been stopped because no further funds for mission to LNL could be assigned for this year. For that reason, the possibility of transferring the experiment in a smaller laboratory available in the Physics Department of Bari University has been studied. Next June will start the re-mounting of the experimental apparatus in Bari

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