HOLLOW CATHODE E-GUN FOR EBIS IN CHARGE BREEDING EXPERIMENT

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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 reacceleration of the radioactive elements produced by a primary beam in a thick target. In some experiments a continuous RIB of 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 paper, an hollow cathode e-gun for an EBIS in charge breeding operation has been presented. Furthermore, a preliminary system design to inject the 1+ ions from the cathode part will be also shown. 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.

INTRODUCTION

SPES (Selective Production of Exotic Species) is a project of a new facility for the production of Radioactive Ion Beams accelerated up to several MeV/u [1]. It is in an advanced phase of study at the Legnaro National Laboratory (LNL) (Padua, Italy). Several proposals were made for the SPES project since 2002, with the aim to fulfil the physics goals and the budget constraints, the main objective being to develop a second generation ISOL facility on the way to EURISOL. Reaccelerated beams of neutron rich nuclei produced by Uranium fission with a fission rate on the order of 10^{13} fission s^{-1} in the production target are expected. The actual proposal represents an effective cost project, which fulfils the original requirement for the production of neutron rich radioactive ion beams able to make a breakthrough in studying nuclei far from stability, and takes advantage of proton drivers accelerators and selected exotic species to open up the possibility for application of nuclear physics in other fields as astrophysics, medicine and material science. Also in its last version, the SPES project foresees a charge breeding device in order to optimize the ion post-acceleration efficiency. The 'charge breeding' is a technique used to increase the ion charge state of the produced radioactive ions that are extracted from the target-ion source system, usually, only with a single charge. After the action of the 'charge breeding' device the produced radioactive ions can increase their charge state up to n+. The increase of the radioactive ion charge state before the post-acceleration can be realised by making use of either an Electron beam Ion Source (EBIS) or an Electron Cyclotron Resonance Ion Source (ECRIS) [2, 3]. During the last past 4 years a large experience has been acquired at ISOLDE facility with both charge breeders. A comparison between those two methods describing advantages and disadvantages in their use can be found in scientific literature [4]. In short, Those systems can handle ion lifetimes down to some 10 ms, with a charge breeding efficiency of around 5%. Each device has its virtues and drawbacks. The clean EBIS is capable of handling low intensity beams, <1 nA, but its setup is relatively complicated. The ECRIS has a large charge capacity, and is the natural choice for beams larger than 1 nA. However, the beam contamination is significantly higher. Neither of the two charge breeders can so far manage very short-lived isotopes. Then, in that case, the technically simpler stripper technique has to be used. Its efficiency is comparable, and very clean high or low current beams can be dealt with, but it requires very big and costly ion pre - post acceleration [4]. The main drawback of a EBIS charge breeder device, which limits the beam intensity of the radioactive ions that can be post-accelerated, is its intrinsic pulsed operation. In a EBIS charge breeder, usually, the 1+ ions are injected in the EBIS ion trap from the e-collector side where there is also placed the n+ ion extraction system. In fact, before the collector ion injection-extraction electrode entrance is located a deflection system that, alternatively, allows the 1+ ion injection from one direction and the n+ ion extraction toward an other direction, in general, transverse to the first direction. That injection system could have a complicate and, further, intrinsically pulsed operation with a relatively low duty cycle. In this paper will be described a charge breeding experiment (TEBREC) with an EBIS having an electron beam generated by a hollow cathode in order to inject the 1+ ions from the e-gun instead that from the e-collector side of the EBIS trap. In that way, at least in principle, the EBIS could be operated in Continuous Way (CW) avoiding the main drawback of an EBIS charge breeder, the intrinsic pulsed operation.

THE TEBREC EXPERIMENT

Recently at LNL 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) with some modifications could be used for

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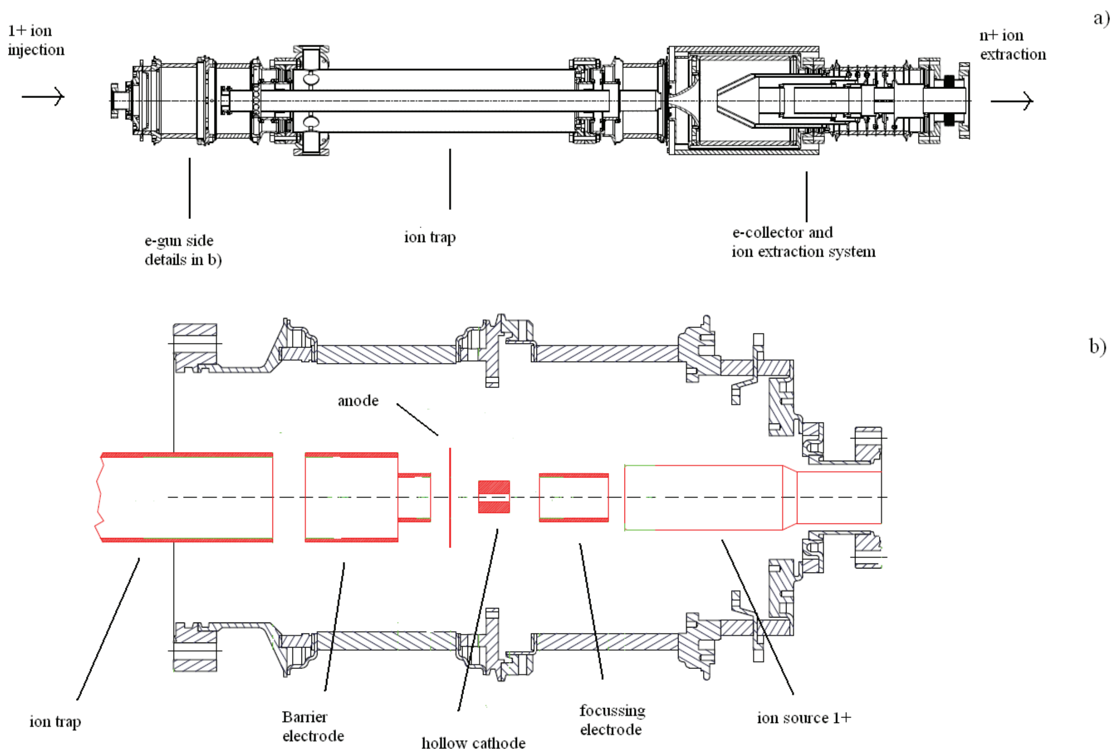

Figure 1: a) EBIS structure, longitudinal mechanical section; b) Details of the e-gun with hollow cathode. The 1+ ion source shown in the figure is a surface ion source.

a further R&D experiment on a EBIS charge breeding in CW operation. Since we have obtained very few funds the same solenoid of the previous experiment will be used and the modifications on the EBIS mechanical structure has been also minimized. The design of the new modified EBIS structure is shown in Fig. 1a) while the details of the new e-gun is shown in Fig. 1b). The main new feature of this charge breeding experiment is that of using an e-gun with hollow cathode in order to allow the 1+ ion injection from the e-gun side and leave in this way the e-collector only for the n+ ion extraction. In this way the duty cycle of the EBIS charge breeding could be sensitively improved and, as we will see, at least in principle the CW operation could be also reached.

In the experiment the 1+ ions that will be injected in the EBIS ion trap through the hollow cathode will be generated by a surface ion source [6].

From Fig. 1b), it can be seen that the surface ion source is very close to the hollow cathode. That solution gives a more compact and cheaper device. A simulation of the ion trajectories from the 1+ ion source up to the EBIS ion trap is shown in Fig. 2. The ion trap and electrode voltages have been chosen to minimize the 1+ ion kinetic energy in the trap. In fact, the 1+ kinetic energy at the end of simulation, that is at the entrance of the ion trap, was about 1 eV. The code used for those simulations has been SIMION.

In first approximation, the initial ion distribution used in carrying out the simulation of Fig. 2 has been not Maxwellian but had a constant distribution in the range of ± a fraction of eV with initial transverse positions in the range ± 1.5 mm around zero and with the vector velocities having a maximum angle of 90° around the symmetry axis. The main problem in our experiment is the electron gun design with a hollow cathode that could generate a beam without hollow in the ion trap region. An e-gun of this type has been proposed studied and tested few years ago for electron cooling application [7, 8, 9]. In Fig. 3d), it is shown the proposed e-gun design with the electron trajectory simulation that close completely the hollow on the e-beam axis. Unfortunately, in designing the hollow e-gun for our experiment we had some constrain that prevented us to get an e-beam with the hollow completely closed as in Fig. 3d). The main constrain was given by the relatively low magnetic field that we could use for the e-beam focussing (about 1.8 kG). In fact, the electron beam compression depends on the square root ratio between the magnetic field on the trap region (B_{max}) and the magnetic field on the cathode (B_c) [10]. In Fig. 3a) the value of that ratio is 4 while in 3c) it is 8. From those figures, it can be seen that for the higher ratio value a greater beam compression can be obtained. However, on the other hand, if the maximum magnetic field value is not enough big to keep the electron beam scallop amplitude low, a high magnetic field ratio could generate scallop with very high amplitude as shown in Fig. 3b). A trade off between these two effect must be found to get a relatively high compression with a minimum electron beam scallop (Fig. 3a). In Fig. 3c) is also shown the simulation of the electron trajectories that starting from the hollow cathode go through the ion trap up to the collector. In the top of that ure is also shown the position of the coils forming the focussing solenoid capable to give a B_{max} of 1.75 kG [5].

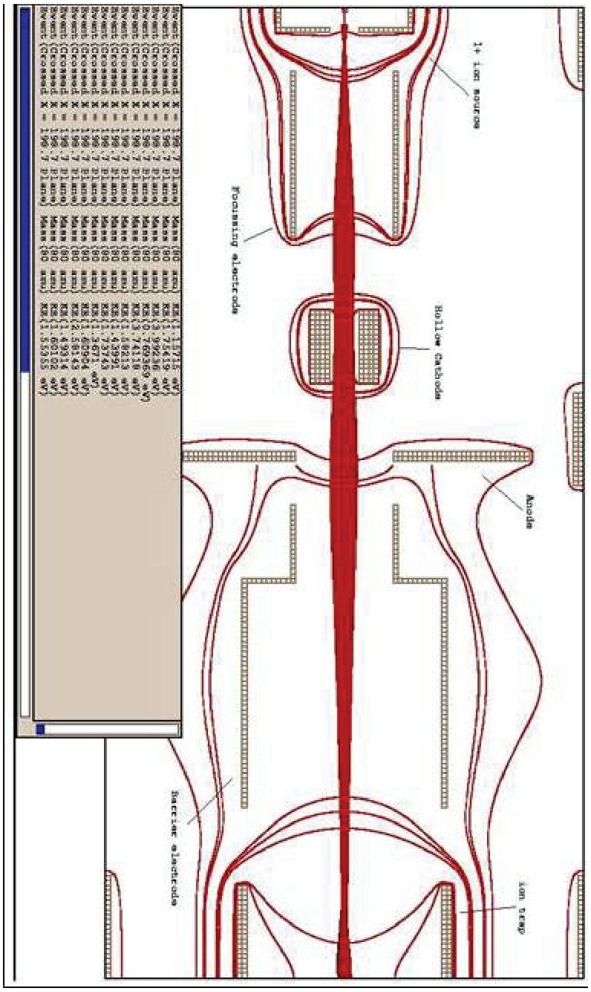

Figure 2: The 1+ ion trajectory simulation at the trap injection. The 1+ ion source is put at V = +3 kV; The hollow cathode at -0.5 V and the anode to +2.2 kV. On the left box are written the 1+ ion kinetic energy at the trap entrance after the hollow cathode.

From the Fig. 3c) however, it can be seen that with our e-gun the electron beam cannot get a compression high enough to close completely the hollow on the beam axis. This problem, of course, will reduce the ionisation efficiency of our electron beam. In fact, the ionisation rate will depend, also, on the overlapping region from the electron beam a 1+ ion distribution. That is, the maximum of ionization can be obtained when there is a complete overlapping. Just to give an idea on how this problem could worsen our ionization efficiency, in Fig. 4 it is shown a simulation of the ion charge state time evolution for an e-beam with a hollow having a radius of 30% respect to rb (the electron beam radius). The code used for that simulation has been BRICTEST code [11].

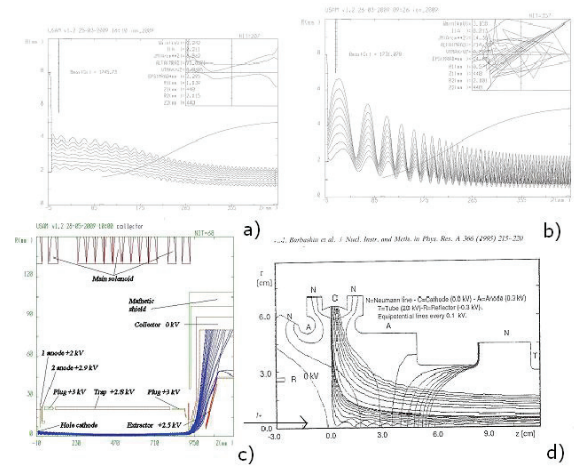

Figure 3: E-gun design with electron trajectory simulation: a) case with B_{max}/B_c= 4; b) case with B_{max}/B_c= 8.3; c) electron trajectory simulation from the hollow cathode to the collector; d) e-gun design proposed for electron cooling applications where the hollow beam is completely closed.

From the simulation results shown in Fig. 4 it can be noticed that between the cases of electron beams with and without hollow there should be a very slight difference. In those simulations, however, the overlapping between the hollow e-beam and the ion distribution has been considered, in first approximation, unchanged along all the ionisation time as in a fixed target. A better approximation in the ion charge state evolution simulation can be obtained if the ion motion inside the electron beam potential well could be considered in the calculation of the new ion charge state distribution after each time integration step. Then, the BRICTEST code has been implemented of that possibility and further simulations are under way in order to obtain more precise results [12].

However, since the ions oscillating in the e-beam potential well slow down at the edge of the oscillation (since they invert their direction) they should stay more time in the beam edges respect to the time out of the beam (in the hollow) on the symmetry axis. Then, we could expect that the next better approximated simulation results should have still slighter difference than that noticed in the curves of Fig. 4.

The n+ ions produced in the EBIS ion trap will be extracted, as usually, from the collector and then analysed in a TOF line that practically will be the same line already used in the previous experiment [13]. At the end of the TOF line a fast MCP device will be used to detect the extracted ions.

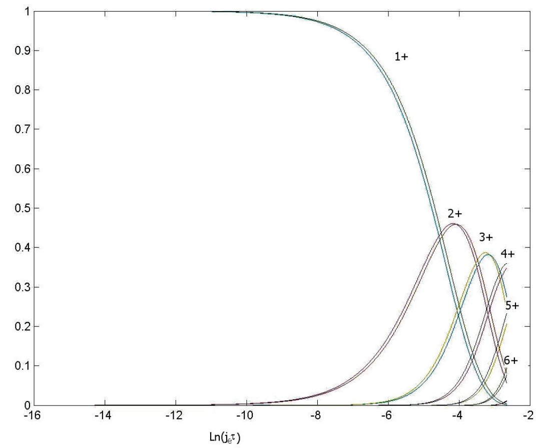

Figure 4: Ion charge state time evolution for Xe. The lower curves refer to an electron beam with hollow radius of 30% with respect to e-beam radius (upper curves).

CONCLUSION

The TEBREC experiment should finish in 2 years. The 1+ ion injection system, the new e-gun with hollow cathode and the EBIS trap has been already designed and the new electrodes are in construction. Meanwhile the surface 1+ ion source has been ordered and soon will be installed and tested. The first high charge state distribution measurement, in which should be used alkali ions as Cs and/or Rb, can be foreseen for the beginning of the next year.

In this experimental scheme a continuous 1+ ion injection should sensitively increase the device 'duty cycle' and, at least in principle, could give the CW operation. The 1+ ions, in fact, can be injected continuously in the ion trap with a kinetic energy just greater than of the trap barrier electrode voltage. The charge breeding time needed to reach the desired ion charge state of the injected ion, essentially, depends on the breeder parameter [14] $j_e\tau_c$, with τ_c indicating the confinement time. For example, the ion charge state foreseen for SPES for Sn should be 18+ then for a j_e of about 300A/cm^2 a τ_c of about 10 ms should be needed [15]. This means that the ions should stay in the trap for a time of about 10 ms before to be extracted. Usually, that ion trapping time is realized by confining the longitudinal ion motion with an electrostatic longitudinal trap that at the same time can prevent the continuous n+ ion extraction. However, alternatively, a kind of magnetic longitudinal confinement has been also proposed in ref. [16] where, to allow a continuous ion extraction and then a really CW operation, the ions bombarded by the e-beam are slowed down in such a way they could reach the extraction electrode at the time needed to get the desired ion charge state.

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