SELECTIVE CONTAINMENT MEASUREMENTS ON XENON WITH THE RF CHARGE BREEDER DEVICE BRIC

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Abstract

The Radioactive Ion Beam (RIB) production with ISOL technique should require a charge breeder device to increase the ion acceleration efficiency and reduce greatly the production cost. The "charge breeder" is a device designed to accept RIB with charge state +1 and in order to increase their charge state up to +n. Recently, at the INFN section of Bari first and at LNL (Italy) then, a new charge breeder device, based on an EBIS ion source called BRIC, has been developed. 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 masses and then making a selective more efficient containment of the wanted ions. The RF test measurements for Ar gas confirm, as foreseen by simulation results that the selective containment can be obtained. More measurements on the selective containment of heavier element ions (more close to the radioactive ion produced with ISOL technique) like Xe are needed to study with more details that effect. In this contribution new measurements on the rf selective containement in BRIC for Xe gas will be presented and discussed.

INTRODUCTION

SPES is a project of a new facility for the production of Radioactive Ion Beam accelerated up to several MeV/u [1]. That project is based on the ISOL technique [2] and it is in an advanced phase of study at the Legnaro National Laboratory (LNL) (Padua, Italy). 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. The radioactive elements produced, then, will be ionised for acceleration at the desired energy before of reaching the experimental area. With the aim to obtain sensitive lowering of the accelerator cost a high ion charge state beam must be used. Some charge breeding techniques have been applied [3], before the post-acceleration of RIB, to increase the charge ion state of the radioactive elements. The efficiency of a charge breeder device could be improved by using a device capable o selective containment on the ion produced by the complex of radioactive element production target and ion +1 source which, then, are sent in the ‘charge breeding’. The possibility to get a selective containment in an EBIS where an rf frequency signal is applied in the ion trap region has been explored in these last years [4,5] at LNL in Legnaro (Pd).

The main difference between that device, called BRIC, and a usual EBIS is the adding of an rf quadrupolar field. in the ion trap region of the vacuum chamber. The RF quadrupolar field has been obtained by electrodes of cylindrical shape placed around the symmetry axis of the chamber, where the electron beam of the source is propagated [5]. The RF field, in this way, 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 the ion extraction. Measurements on residual and Argon gas ions have carried out and shown the selective containment effect given by the RF field [6]. The possibility to have the same kind of selective containment also for the Xe gas, more heavy and then more close to the most part of radioactive element produced by the ISOL technique, will be shown in this paper., where, it will be also shown some preliminary measurements.

SIMULATIONS AND MEASUREMENTS FOR XENON

Before to realize and test the charge breeder BRIC a simulation code has been also developed to study the ion behaviour in an EBIS source where an RF quadrupolar field has been applied in the ion trap region [7]. We will use that simulation code to look for the more proper RF parameters that can realize the selective containment also for the Xe.

The RF parameters that define the quadrupolar field are [7]:

$$a = a_x = -a_y = \frac{4eU}{m\varpi^2 r_0^2}$$

$$q = q_x = -q_y = \frac{2eV}{m\varpi^2 r_0^2}$$

where V is the RF amplitude, U the dc component and ω the RF pulsation.

The stability region, in the plane (a,q) is delimited by the red spots, as shown in fig. 1 and it is determined by the numerical solutions of the eq.s shown in ref. [7] and solved by the code. In order to obtain stability conditions for Xe ions, we had to choose a working point in the stable region which had reasonable value of U and V.

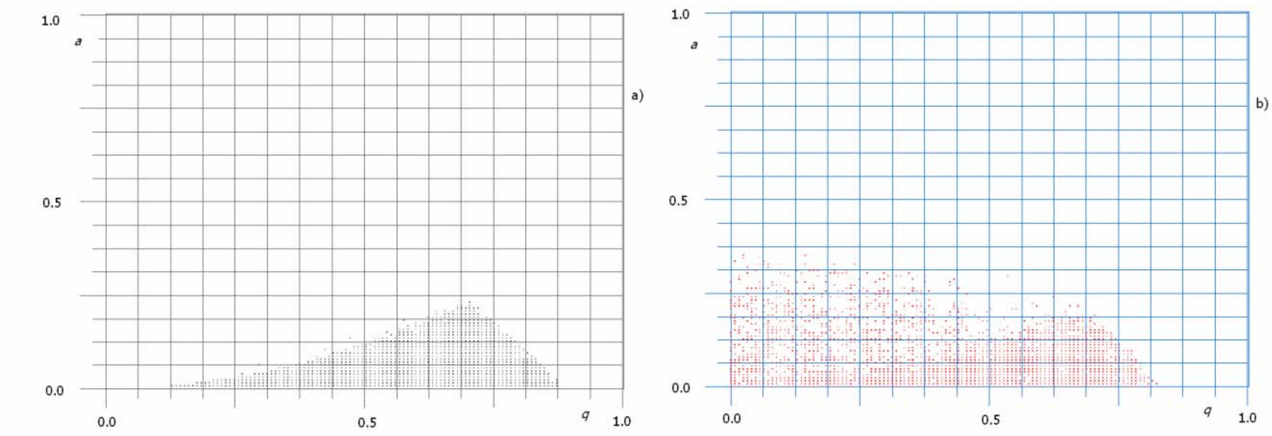

Figure 1. Simulation results in the plane (*a*,*q*): a) stability region (black dots) of Xe^+ ions for f_{RF}= *2.5 MHz*; b) stability region (red dots) of Xe^+ for f_{RF}= *0.5 MHz*. In a), for low values of *a* and *q*, there is no stability.

Stability regions for different RF frequencies have been explored for the ion $^{131}Xe^+$ and from the results it can be seen that for frequencies higher of about 2.0 MHz the confining effect of the space charge reduces for low value of *a* and *q* [7]. As an example, the case of frequency *2.5 MHz* is shown in fig. 1a). In the figure, it can be seen that the part of the region identified by low value of *a* and *q* (that is for low values of *U* and *V*) the stability region seems disappear. However, Once a lower RF frequency has been fixed, we can use *U* and *V* to choose a stable working point in the stable region of the plane (*a*, *q*). .If we consider, for example, a f_{RF} = *1 MHz*, and *a = 0.02* and *q = 0.1* we obtain *V = 4.27 kV* and *U = 420 V* (very high values). For a lower frequency, *0.5 MHz*, we get *V =1.0 kV* and *U = 81.7 V* (still high values). Then, to get more reasonable values for *V* and *U* we choose a *q* of about one order of magnitude lower than the above value. In that case, *V = 100 V.* That is an acceptable value, as matter of fac it is enough lower than the electron beam energy (2.5 keV).

The parameters found are then used in the simulation of a propagation of a bunch of Xe ions in the BRIC trap, where ion charge state evolution and electron beam space charge compensation is taken in account [7] to verify the stability property of the chosen parameters.

As mentioned before, selective containment in BRIC of residual and Ar gas has been already shown in measurements carried out last year and in 2005 [6]. These measurements for Xe gas would demonstrate that this effect of selective containment is confirmed also for heavy elements.

The experimental set-up used for the measurements has been already described, shortly, in the introduction and it can be found in details in ref. [4,5].

Unfortunately, although last year a new, more efficient, ion extraction system has been implemented [8], the measurement results of Xe ion charge states, on BRIC device, have been very difficult to obtain because of some problems occurring during the experiment.

The main problem to face has been the ion chamber vacuum that had a limit of about $3x10^{-8}$ mbar and cannot be improved.

In the past, for Ar gas measurements we reached a vacuum level of *$3÷4x10^{-9}$mbar*, not so good as the other usual EBIS (better than 10^{-10} mbar) but largely enough for our test measurements on selective containment. Unfortunately, recently, we have found light leakages on 2 electrical high vacuum feedthroughs placed just before the collector for electron beam diagnostic. This problem has been fixed by using TORR-SEAL, which, however, could not be heated more than about *100°C*. For this reason we could not heat, as usual, the ion chamber to reach ultra high vacuum. In those conditions we could reach just below *10^{-7} mbar*. In order to improve further the vacuum level, the BRIC eb (without ion trapping) has been used as pump. However to reach the limit vacuum level (about *$3x10^{-8}$*) few days of continuous pump were needed.

The vacuum problem has been a very big trouble for our measurements. In fact , with that vacuum level the neutralization time of the trap should be very low. This means also that low ion charge states could be reached and furthermore a very small quantity of the injected gas (the Xe in our case) could be trapped in BRIC. In fact, the neutralization time can be given by [8]:

$$\tau_N \approx \frac{1.51\times10^{-10}}{P_0}\cdot\frac{\sqrt{V_e}}{\log_{10} 3.076V_e}$$

Where V_e is the electron energy (in our case about 2.5 *keV*) and P_0 the ion chamber pressure. With our parameters, we got *a* τ_N of about *20 ms*. Furthermore, we had to inject, in the ion chamber, also a certain quantity of Xe gas. That operation, of course, produced a further increase of the already high pressure (about *3x10-8 mbar*). Then we had to inject a very tiny quantity of Xe otherwise the ion chamber pressure could become too high to allow ion charge state measurement of Xe. In fact, at that level of vacuum the most part of the residual gas was H_2 (*60 ÷ 70%*) and then, also the ion trap will be filled in most part by H_2. The other residual gas and the injected Xe, then, could give very small peak signals on the Mass spectrum.

Although we had some problem on the leakage valve through which we realized the Xe injection, at the end, we succeeded in putting in the ion chamber a very tiny quantity of Xe.

The measurements results showing the ion charge states of the BRIC trap in presence of Xe are in fig.2.

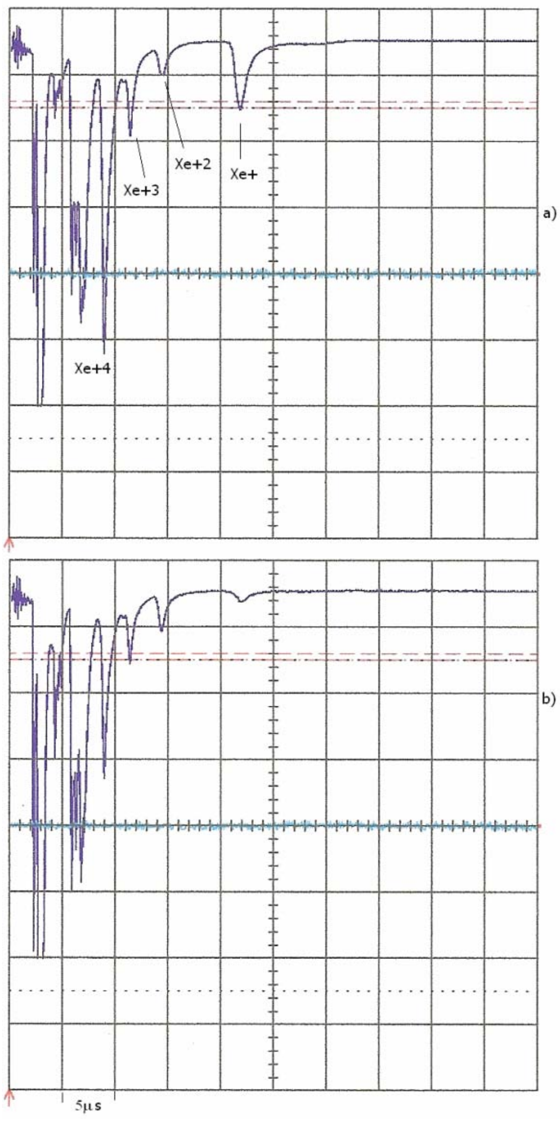

Figure 2: TOF ion mass spectrum after the injection of Xe gas: a) the case without rf signal; b) the case with the RF signal (f_{RF} = *0.6 MHz*, V_{RF}= *40 V*). On the abscissa has been chosen 5µs/sq. to see also the Xe^{+} and Xe^{2+} peaks.

The electron beam parameters and the TOF parameters are practically the same of the measurements done for Ar [6]. The most important ones are shortly resumed in the following.

Electron energy: *Ve= 2.5 keV*; Electron current: *Ie= 0.25 A;* Solenidal guiding field: B_0 = *1.6 kG* .

Those values give a current density of about 5A/cm^2 and then, this low value, with the short interaction time (20 ms) available could allow of reaching very low ion charge state but enough for our test on selective containment. In fact, from fig. 2 it can be seen that when the quadrupolar RF signal is applied on the BRIC trap, the ions with larger values of *A/e* (in our case Xe^{+}, Xe^{2+}, Xe^{3+}, Xe^{4+}) were sensitively reduced while the peaks with smaller values (see the peaks close to H_2 that dominate the spectrum) increase their value almost of a factor 4.

CONCLUSION

Simulations and measurements on the Xe gas, carried out on BRIC have shown that the selective containment is possible also for heavy ions as are the most part of the radioactive element produced by The ISOL technique.

Unfortunately, problems on the ion chamber vacuum, due to some leakages occurred on the electrode feedthoroughs, allowed the injection of a very low quantity of Xe gas making very difficult the measurements. In fact, we could not repeate the experiments because of a vacuum degradation in the ion chamber. We have also to mention, that during the measurements our large rf band amplifier was broken and then we had to use a home made RF generator capable only to give RF signals in the range *0.5 MHz ÷ 3 MHz* and a signal amplitude up to 40 V. The selective containment effect of the quadrupolar RF signal, however, has been evident also with the low RF amplitude value (*<40 V*) available while the usual values used for Ar gas measurement [6] and foreseen by simulations was about *100 V*. Further measurements are planned after that the vacuum problem will be fixed.

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