Preparations to Investigate Charge Multiplication via the 1^+-n^+ Scheme in a Large Volume ECR Ion Source

D. P. May, *Cyclotron Inst., Texas A&M Univ*, R. C. Pardo and R. C. Vondrasek,
Argonne National Laboratory, Physics Division

Abstract

A 1^+- ion-source test stand and transport line are being designed with the plan of injecting singly charged ion beams into the Texas A&M 6.4 GHz ECR ion source and eventually into the Texas A&M 14.5 GHz ECRIS. To explore this avenue for the reacceleration of radioactive ion beams, measurements will be made both on the 1^+ beam and on the beam produced by the ECRIS. The determination of input acceptance and output charge-state intensities are important for high efficiencies, and the measurement of output time-structure is important for determining hold-up times within the ECRIS. One aim is to determine if the use of a large volume ECRIS, like those at Texas A&M, increases the acceptance for charge-multiplication of singly charged beams that are broad in both emittance and in energy-spread. Another is to investigate the differences between using the lower and the higher microwave frequencies.

Introduction

Both ISOL and ion guide techniques create a 1^+ ion beam from reaction products. For RIA this beam will be formed at low energy for further acceleration by a multistage linac. Charge stripping of the beam at various stages of the acceleration will save linac length as well as cavity voltage. The opportunity will exist that when a low-energy radioactive beam is being delivered to an experiment, some fraction of the original 1^+ beam could be shunted to a 1^+-n^+ ECR ion source. The resulting high-charge-state beam could then be injected into one of the linac stages beyond the low-energy section so that a higher energy beam could be delivered to an additional experiment. This "doubling-up" strategy could add to the cost-effectiveness of RIA operation.

The idea behind the 1^+-n^+ ECR technique is that singly charged ions entering an ECR plasma will be captured by the plasma if their velocity approaches zero as they enter. The injected beam can have a small energy spread and still be captured due to collisions with the plasma. Captured ions should behave the same as 1^+ ions formed from neutrals, and for a given element the extracted charge-state distributions should be the same. The technique [1] involves injecting a 1^+ beam, with a slightly higher potential than the extraction potential of the ECR ion source, along axis into the ECR where it is decelerated by the source potential and by the plasma potential and captured by the ECR plasma. (The source potential is usually on the order of ten to thirty kilovolts while the plasma potential is a few tens of volts.) The ions are then further stripped by hot electrons in the ECR plasma and eventually re-accelerated through the extraction of the ECR ion source. The total efficiency for conversion into high-charge states has been shown to be high, up to 65% [2].

The goal of an investigation of this technique would be to maximize the efficiency of the charge boosting into the highest possible charge states for any given injected beam. The questions that need to be addressed are:

1. What parameters affect the efficiency of conversion to a given charge state?
2. Given that radioactive ions have limited lifetimes, what affects the rate of conversion?
3. What are the limits to the capture acceptance of a given singly charged beam in energy dispersion and emittance?

The first question is important because certain parameters of the ECR ion source may have contrary effects. For example, high pressure of a mixing gas, most typically oxygen, might serve to capture more 1^+ ions but would interfere with the production of the highest charge states. The second question is important because the time for each ionization step (on the order of a few milliseconds) might be minimized with higher microwave power, but high power requires more complicated cooling of the plasma chamber. The third question is important because the higher frequency, higher field ECR ion sources have tended towards more compact designs, and this compactness may be the opposite of what is required for matching to ISOL and ion guide type ion beams.

The Texas A&M 6.4 GHz ECR1 ion source [3] and 14.5 GHz ECR2 ion source [4] have similarly dimensioned plasma chambers with approximately double the linear dimensions of either of the two ECR ion sources used up to this time for 1^+-n^+, MINIMAFIOS [1] and PHOENIX [5]. There are several reasons that the larger size would be an advantage for 1^+-n^+. First, the geometrical requirements for injection of the 1^+ beam will be more relaxed by the simple fact that the channel leading into the ECRIS for injection can be wider. Second, the increased distance to the walls in the plasma chamber decreases the chance that a scattered 1^+ ion would encounter the wall before being thermalized. Third, the longer length over which the 1^+ ions can be thermalized also should increase the acceptance of a broader energy spread of 1^+ ions.

The high-charge-state performance of the 6.4 GHz, high-B ECR1 ion source [3] is comparable to that of the 14 GHz performance of PHOENIX [5], as it is to the performances of several 14 GHz ECR ion sources. This brings up the possibility that a charge-boosting ECRIS might ideally operate at 6.4 GHz. The comparison of ECR1 and ECR2 for 1^+-n^+ should help in the exploration of this possibility.

Program

A program to investigate the charge-boosting characteristics of an ECR plasma has recently received some initial funding at Texas A&M where we are first planning to inject the beam from a singly charged, low-intensity alkali ion source into the Texas A&M 6.4 GHz ECR1 ion source. The ion gun assembly and power supply along with insertable aluminosilicate buttons for the production of lithium, sodium, potassium, cesium and rubidium 1^+ ions have been acquired, and the injection beam line is being designed. Beam simulations on the injected beam are being performed with the program SIMION at Argonne. Initially, they indicate that the deceleration of the injected beam must be considered carefully. If not done properly, a part of the beam can be reflected by the magnetic mirror field on the injection end of the ECRIS.

To be able to inject the singly charged beam into the ECR axially, the steel on the injection end of the source is being redesigned. Since the shape of this steel affects the magnetic field in the plasma chamber, POISSON calculations are being performed to predict new coils currents that will allow an approximation of the original field. Calculations already show that with coil currents remaining the same a 2.0-in. diameter hole through the center of the injection end steel plug decreases the mirror field at this end by 20%. The source will be operated with normal gas and metal injection with the modified steel in place to determine the effects of the modification.

We also will use an intense 1^+ gaseous ion source supplied by Argonne National Laboratory to investigate limits to the intensity and purity of the injected ion beam. This is important because more intense beams of contaminating ions from the singly charged ion sources might be difficult to separate from the ions of interest without sacrificing intensity. There are also larger aluminosilicate buttons available for alkali ion production. We plan to obtain a selection of 0.6-in. diam. buttons to compare with the 0.25-in. diam. buttons already purchased. With these we can investigate larger emittance beams for charge boosting. The emittances of the injected beams will be measured on-line.

This investigation will subsequently be extended to the ECR2 ion source at Texas A&M. ECR2 uses 14.5 GHz microwaves and consequently has higher axial and hexapolar magnetic fields [4]. The axial magnetic mirror field on the injection end will have to be proportionally more compromised to allow for 1^+ injection. Finally, dual microwave frequency heating, using 14.5 GHz and 10 GHz transmitters, will be tried in ECR2 in order to investigate whether this improves the charge conversion efficiency, as it should the overall performance of the source, by increasing the overall plasma density.

Future Program

In the future, we intend to construct an ECR ion source that has been optimized for charge boosting. Such a source could operate at 6.4 GHz and have the requisite coils to produce an axial magnetic field on injection comparable to our unmodified ECR1 ion source. It would also have a removable aluminum liner similar to our ECR2 ion source. This would be suitable for water-cooling the plasma chamber and for separating radioactive contamination from the rest of the source. It would also have no radial ports, which will greatly simplify the construction. In addition, it would have a simple gas system for optimizing the source before injection and for providing support gas for the charge boosting.

References

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