Progress on the light ion guide

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Introduction

The Light Ion Guide Project [1] continued to advance through the last reporting period. Work focused on the charge-breeding efficiency and on the radioactive ion output of the gas cell coupled with the rf-only sextupole ion guide (SPIG).

Accelerated Injection

The SPIG was extended from the target cell towards the Charge-Breeder ECR ion source (CB-ECRIS), and an improved design of the final acceleration gap assembly was made, making the operation at higher voltages (8 to 10 kV) more stable and free of breakdowns. Extending the SPIG allowed to transition the final acceleration of the radioactive ions from a region of poor vacuum (10^{-3} – 10^{-4} torr) to a region of better vacuum region (10^{-5} – 10^{-6} torr). At the same time, transport of ions through low grade vacuum is more efficient using the SPIG compared with a classical and simplistic vacuum tube. Precise alignment of the gas cell, the SPIG and the two Einzel lenses was made also.

The injection into CB-ECRIS was modified as well, by extending the plasma chamber and coupling the microwave tube in a different place (Fig. 1). Consequently, a better vacuum inside the plasma chamber is present now. The transport of the ions into the plasma chamber was modelled

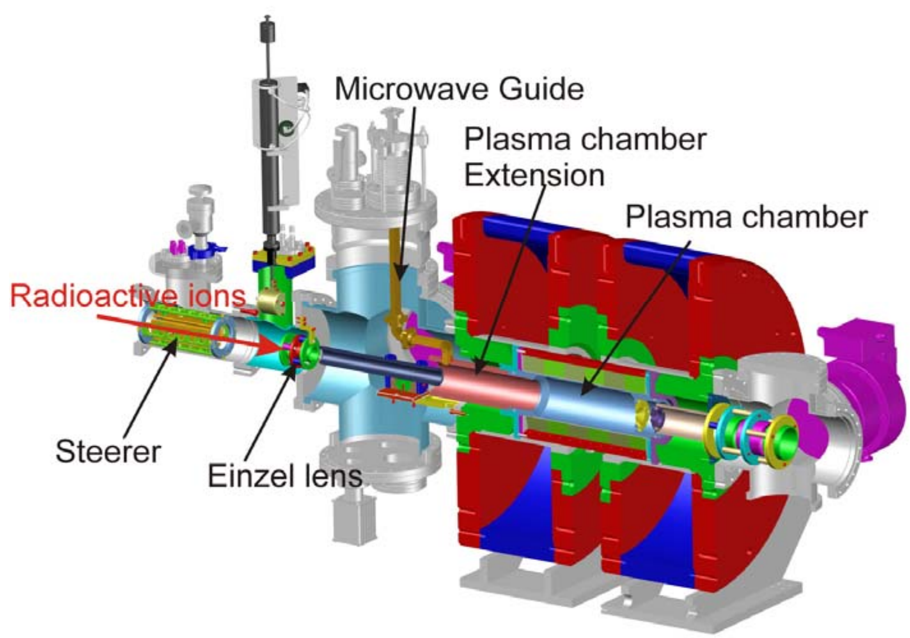

FIG. 1. View of the CB-ECR and the new injection design.

incorporating the injection-end magnetic field of CB-ECRIS using the SIMION [2] code (Fig. 2). The

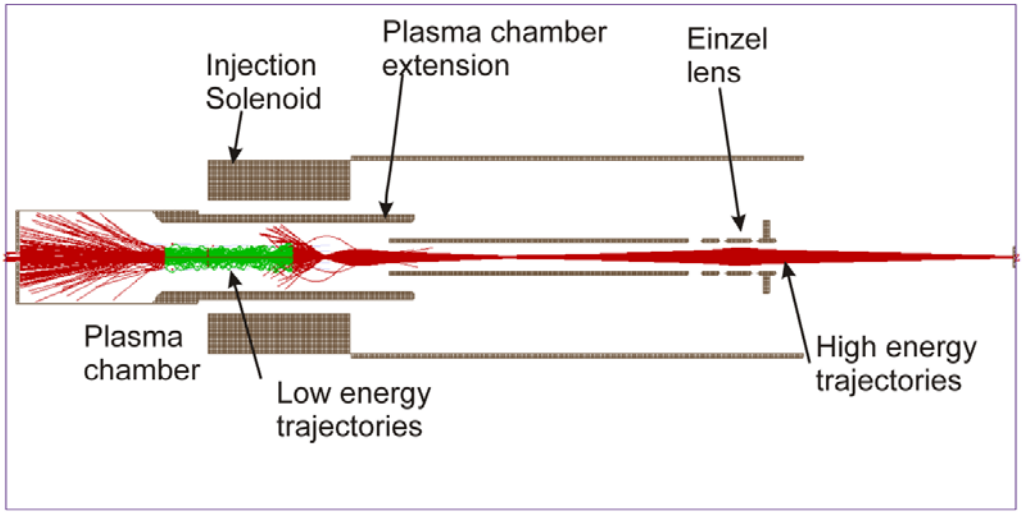

FIG. 2. SIMION ion optics calculations.

simulations showed a 98% transport efficiency of the ions injected into the plasma chamber, but in reality that could be lower due to the fact that the plasma contribution was not taken into consideration in the calculations. Another possibility is that the energy spread of the injected 1+ beam could be excessively wide. Evidence for this is that the acceptance for charge-breeding was much wider in voltage (~11 volts FWHM) than the 5.8 volts FWHM encountered with direct injection, described below.

RIB Studies

The radioactive ions production studies continued with these new improvements. We focused on four major (p,n) reactions listed in Table I, the crossection being calculated with TALYS code:

Table I. Reactions studied at the Light Ion Guide.

Reaction	Crossection [mbarn] @ Proton Energy [MeV]	Half life
$^{64}Zn(p,n)^{64}Ga$	161 @ 14.3	2.6 m
$^{58}Ni(p,n)\,^{58}Cu$	40 @ 14.3	3.2 s
$^{46}Ti(p,n)\,^{46}V$	124 @ 14.3	422 ms
$^{114}Cd(p,n)\,^{114}In$	510 @ 10.3	71.9 s

The Light Ion Guide and the CB-ECRIS were tuned carefully for each of these reactions, the final goal being the maximization of one of the higher charge state. The charge-states studied were 12+, 14+, 16+ and 17+ for ^{64}Ga, 13+ and 14+ for ^{58}Cu, 8+ for ^{46}V and 19+ for ^{114}In. Charge-breeding was observed for ^{64}Ga, ^{58}Cu, and ^{114}In with the highest efficiency obtained (approximately 1%) for $^{114}In^{19+}$, ions which were reaccelerated in the K500 cyclotron (see the B. Roeder contribution to this report). The number of radioactive ions injected into CB-ECRIS ranged between approximately $2x10^4$ ions/μCoulomb (^{64}Ga and ^{114}In) to $3x10^3$ ions/μCoulomb. The charge-breeding efficiency was low, under 1%, and this will be the next element to focus on.

Direct Injection

Direct injection of ions via a SPIG was also attempted. A HeatWave alkali source was placed at the entrance of a 0.4 meter long SPIG, and the exit end of the SPIG placed on axis near the maximum axial magnetic field at the injection end of the CB-ECRIS (Fig. 3). This arrangement resulted in a good charge-breeding efficiency (Fig. 4), although this was difficult to quantify due to the difficulty of measuring the output from the SPIG directly. An estimate of the output was made using a measurement of the current hitting the plasma chamber added to the current measured hitting a faraday cup down-stream of the CBE-ECRIS with no high voltage applied to the plasma chamber. This efficiency could be as high as 10 % into one charge-state (8.4 pnA of Cs^{24+} out of 70 pnA of Cs^{1+}) measured hitting the plasma chamber and 15 pnA hitting the down-stream faraday cup. Charge-breeding of potassium was also attempted with similar results.

Conclusions

Improvements made in the SPIG system increased the output of radioactive ions as well as the operating stability. Changes made in the injection side of the CB-ECRIS slightly increased the efficiency of the charge breeding or made the operation in the breeding mode more reliable. Radioactive ions of $^{114}In^{19+}$ were re-accelerated and few questions were answered about the methodology applied in this process. Next re-accelerated ions will be lighter and conditions might be slightly different. The charge-breeding efficiency needs to be increased substantially in order to achieve a useful re-accelerated ion beams for physics experiments. To this end a 2.5 meter long SPIG is now being constructed in order to transport the 1+ ions directly from the target cell to CB-ECRIS injection.

[1] G. Tabacaru *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2016-2017) p. IV-13.
[2] SIMION code, http://www.simion.com