Light ion guide - a new approach

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Introduction

Accel-decel injection from the light-ion guide (LIG) target cell to the plasma chamber of the charge-breeding ECR ion source (CB-ECRIS) was studied intensively in the previous reporting period [1]. A number of radioactive ion beams were developed for acceleration by the K500 cyclotron as summarized below:

Reaction studied	History
$^{58}Ni(p,n)^{58}Cu$	$^{58}Cu^{14+}$ was separated with a total yield of 21 ions/μC.
$^{27}Al(p,n)^{27}Si$	$^{27}Si^{5+}$ first time observed and separated with a very low efficiency 0.03 ions/μC.
$^{64}Zn(p,n)^{64}Ga$	Multiple experiments were performed on this reaction. $^{64}Ga^{17+}$ had a total yield of approximately 62 ions/μC. Contaminants in CB-ECRIS made it impossible to separate radioactive ^{64}Ga after acceleration.
$^{64}Zn(p,d)^{63}Zn$	Radioactive $^{63}Zn^{17+}$ was separated and an attempt to accelerate was made. Contaminants from CB-ECRIS (^{63}Cu) made it impossible to clearly identify radioactive ^{63}Zn after acceleration.
$^{114}Cd(p,n)^{114}In$	$^{114}In^{19+}$ was separated with an estimated charge-breeding efficiency of 1%.

These results were clearly disappointing. However, the previously reported study of direct injection via a 40 cm long rf-only, sextupole ion guide (SPIG) [1] demonstrated much higher efficiency for charge-breeding of ions produced by an alkali button source, so the decision was made to attempt direct injection via SPIG from the LIG target chamber to CB-ECRIS.

Direct injection from LIG to CB-ECRIS

A SPIG system with 5 sections and approximately 2.5 m long, spanning the distance from the LIG target-cell to the plasma chamber entrance of CB-ECRIS, was installed in the chambers of the existing transfer line with the purpose of simplifying injection and increasing the efficiency of charge-breeding ions coming from the target cell (Figs. 1 and 2). The dividing of the SPIG into sections allowed for the efficient bypassing of the helium gas from the target cell into pumps along the line such that no elevated pressure from the helium flow through the target cell could be detected in the chamber immediately before CB-ECRIS injection.

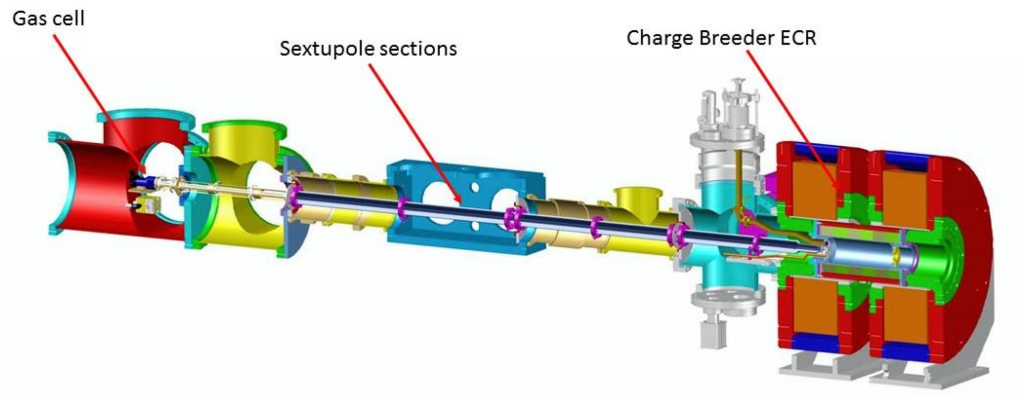

FIG. 1. View of the new SPIG injection system.

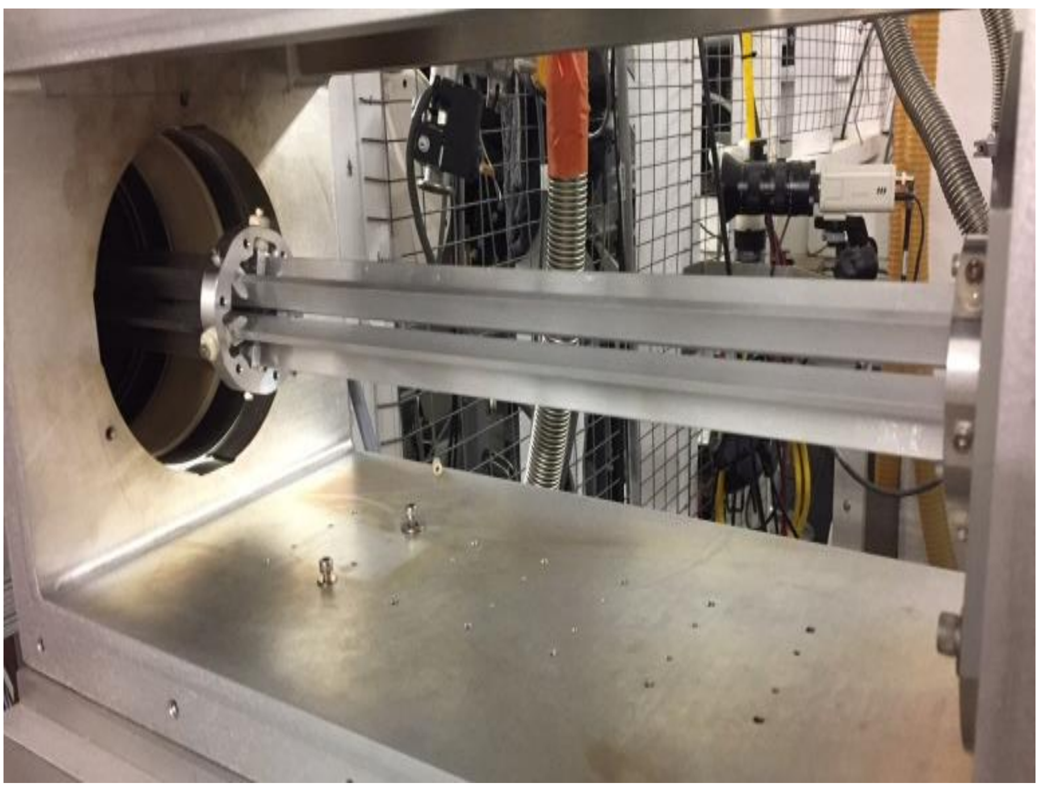

FIG. 2. Middle section of the SPIG.

The first experiment made with this new injection system was the charge-breeding of Cs 1^+ ions from an alkali source. The charge-breeding efficiency was high, estimated to be approximately 50%. The charge-state distribution of Cs peaked around 24^+, 25^+ and 26^+ (Fig. 3).

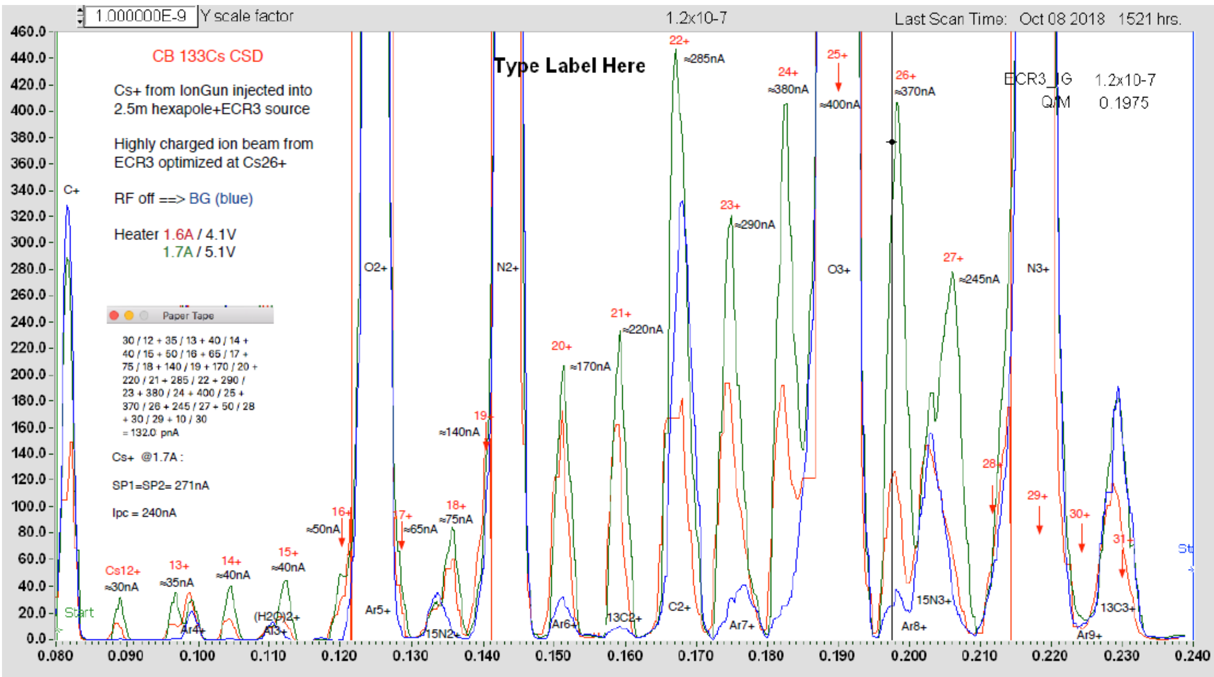

FIG. 3. Scan of the charge-state distribution in the CB-ECRIS with red labels showing locations of the Cs peaks.

Next a ^{228}Th radioactive source was used to test the system using helium gas. Alpha particles from the radioactive products ^{220}Rn and ^{216}Po of various charge states were detected. The charge-breeding efficiency was very high, estimated to be around 50 % as well. The operation of the entire apparatus was stable and the results were reproducible for the entire period of the experiment.

The next step in the development of the light-ion guide was the use of the proton beam to produce radioactive ions injected in CB-ECRIS via the new SPIG. The first reactions used were ^{114}Cd(p,n)^{114}In and ^{114}Cd(p,3n)^{112}In. The maximum outputs of ^{114}In and of ^{112}In were approximately 600 ions/μC and 900 ions/μC, respectively. The ion ^{112}In^{21+} was successfully accelerated by the K500 Cyclotron, as reported elsewhere in this progress report. Lighter nuclei production was attempted in the next campaigns: production of ^{64}Ga, ^{63}Zn, ^{90}Nb, ^{58}Cu, and ^{46}V. The most successful production was ^{64}Ga, ^{63}Zn, and relatively ^{90}Nb. Acceleration of ^{63}Zn could not be verified due to the high contamination with ^{63}Cu (stable) in the injected beam from the CB-ECRIS. Production of ^{58}Cu and ^{46}V was low and further investigations should be performed.

Conclusions

Direct injection via SPIG is proving to be a good method to increase the charge-breeding efficiency of ions coming from the light-ion guide. However, some of the inconsistencies in the operation need to be further studied and understood. Future work will be focused on resolving the irregularities in the operation and on the development of the lighter radioactive products. Fitting the SPIG into the existing transfer line has resulted in making alignment and servicing difficult and time consuming. In an effort to solve this problem, a new chamber is now being designed specifically for the SPIG. It will incorporate a single, long port through which the SPIG can easily be removed, or inserted and aligned. Also, room for diagnostics with a possible moveable section of the SPIG is being considered.

[1] G. Tabacaru *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2017-2018), p. IV-10.