CHARGE-BREEDING AT THE TEXAS A&M UNIVERSITY CYCLOTRON INSTITUTE *

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Abstract

The Cyclotron Institute of Texas A&M University is currently involved in an upgrade that is intended to produce beams of radioactive ions suitable for injection into the K500 superconducting cyclotron. As an integral part of this upgrade an electron-cyclotron-resonance ion source (CB-ECRIS) has been specially constructed for charge-breeding. This CB-ECRIS incorporates a hexapole of the Halbach style. Since radial injection of microwave power is ruled out, this presents special problems for the axial injection of low-charge-state ions for charge-breeding. In preparation for the injection of radioactive ions, low charge-state rubidium ions have been successfully charge-bred and subsequently accelerated by the cyclotron.

INTRODUCTION

Reference 1 gives a complete description of the Texas A&M upgrade. As part of the upgrade the K150 cyclotron has been re-commissioned to use as a driver for the production of radioactive ions. The primary method is to first stop radioactive products from beam-target collisions in a helium-filled cell and then to transport them as low-charge-state ions. For products resulting from K150 light-ion beams, Texas A&M is developing a suitable light-ion guide (LIG). For products resulting from K150 heavy-ion beams, a heavy-ion guide (HIG) based on the ion-guide program at Argonne National Laboratory is also being developed. These low-charge-state ions will be injected into an ECR ion source (CB-ECRIS) for charge-breeding to higher charge states. A beam of ions of one selected charge-state will then be transported to the injection line of the K500 superconducting cyclotron and finally accelerated by the K500. Figure 1 illustrates the scheme including the driver K150 cyclotron.

CHARGE-BREEDING

Charge-breeding of ions injected into an ECR ion source presents special problems. The goals are first efficiency and second fast breeding times, holding radioactive species in mind. Efficiency depends upon, among other things, matching the injected beam to the optical acceptance of the source. Also, as when in our case injection occurs opposite to extraction in the ECRIS, efficiency depends upon minimizing losses due to charge-bred ions lost to extraction back along the injection path. For acceptable efficiencies optical matching and minimizing losses must be made compatible.

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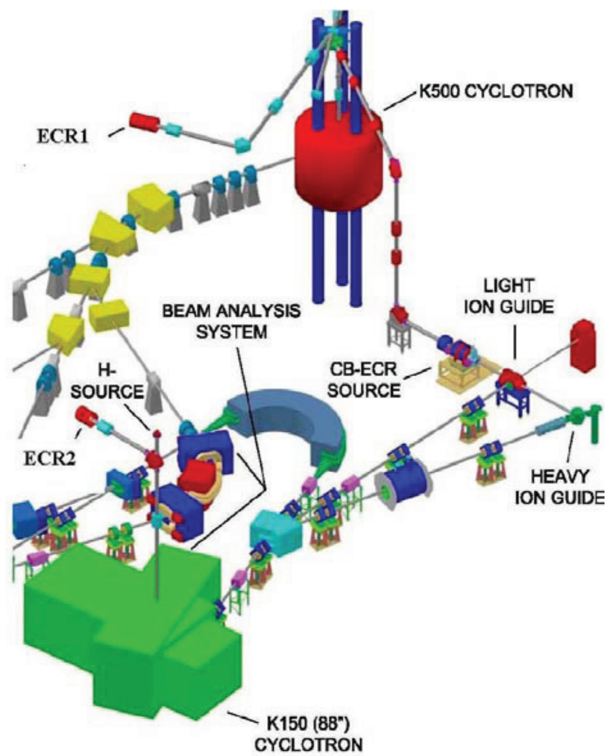

Figure 1: Layout of the Texas A&M Radioactive Beam Facility.

CB-ECRIS

The 14.5 GHz CB-ECRIS was designed and built by Scientific Solutions of San Diego, California with a Phase I and a Phase II Small Business Innovative Research grant from the U. S. Department of Energy [2] and first operated in 2009 [3]. The 9 cm ID, aluminum plasma chamber is surrounded by a Halbach style, NdFeB, permanent-magnet hexapole with a peak field of 1.1 Tesla at the inner wall. The two copper axial coils are encased in steel yokes and are capable of producing peak confinement fields of 2.5•B(ECR) at 500 A of excitation.

Injection of Singly-Charged Ions

At present an aluminosilicate ion gun manufactured by HeatWave Labs, Inc. for the production of a low intensity beam of singly charged alkali ions is being used to test charge-breeding. In the injection path are an electrostatic x-y steerer [4], an Einzel lens, a Faraday cup, a grounded, funnel-shaped tube and a separately biased tube

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positioned immediately before the plasma-chamber entrance aperture (Fig. 2).

In initial efforts to observe charge-breeding the injection geometry has been changed somewhat. A 12 mm aperature was added to the biased tube near the plasma-chamber entrance, and the original 6 mm diameter plasma-chamber aperature was widened to 19 mm. Not illustrated in Fig. 2 is a grounded tube on axis before the Einzel lens. This tube was recently added and proved necessary to shield the injected beam from the gas-feed tube held at the extraction voltage of the CB-ECRIS. Figure 3 is a detail of a simulation of the path of the injected ions including their deceleration into the plasma chamber.

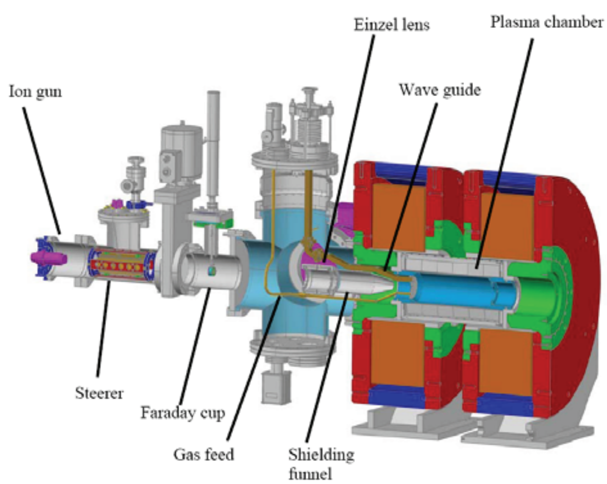

Figure 2: Injection Line into the CB-ECRIS.

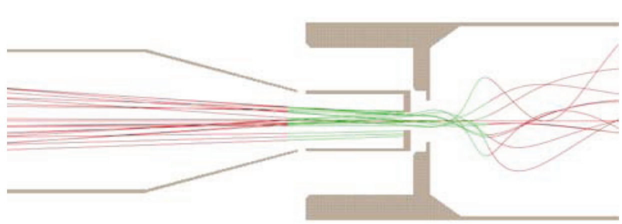

Figure 3: SIMION calculation of injection.

First Results

A 1+ rubidium beam was first transported through CB-ECRIS with coils and high voltage, but not microwaves, energized. As much as 50% could be transported in this manner. With microwaves energized the voltage difference between the two ion sources ($\Delta V = V_{ion\ gun} - V_{CB\text{-}ECRIS}$) was adjusted to maximize the rubidium peaks. These were verified as resulting from charge-breeding and not rubidium build-up in the plasma chamber by switching the alkali source on and off and also by electrostatically deflecting the injected beam and by blocking the injected beam with the Faraday cup. ΔV has been between +35 and +50 volts depending on CB-ECRIS conditions.

Figure 4 shows superimposed spectra with the rubidium beam injected and not injected. The double peaks of ^{85}Rb and ^{87}Rb are clear, with 17+ being the most dominant. The large peaks are due to the oxygen support gas and to carbon and nitrogen contaminants

For best results the tube immediately preceding the plasma chamber is now being held at ground potential. This tube is necessary to prevent the injected beam from being deflected by the electric field of the microwave guide at source potential. Since this tube acts as a puller a large back-current is presumably extracted as evidenced by a large vacuum rise and beam discoloration in the injection region. Since the plasma-chamber aperature is at the peak of the axial magnetic field, this position should enhance the back-extracted beam. When any bias is supplied to the tube, however, charge breeding disappears, perhaps due to a mismatch of the injected beam to the plasma chamber. Also the microwave power has been kept low to less than 100 watts up to now as higher power still causes significant out-gassing and a degradation in charge-breeding.

Conclusions

The power supplies, transmitter and remote controls for the CB-ECRIS and the power supplies and remote controls for the HeatWave ion gun have only recently been installed on the shielding above the ion-guide cave, so little time has been available up to this point for this investigation.

The efficiency of charge breeding into any one rubidium charge-state has not been measured accurately, but probably is less than 1%. The large back-extracted current may indicate that there is significant loss through this mechanism. Also, the microwave power has been low up to now, so the plasma density may be lower than ideal for efficient stopping. More optimization is clearly necessary for charge-breeding of radioactive ions. This will be pursued with more modifications to the injection design and with higher microwave input. Specifically, the micowave guide will be separately shielded so that the biased tube can be spaced further from the peak of the plasma-chamber entrance aperature, and this aperature can be moved to ouside the peak of the axial magnetic field. The clear signals of charge-breeding should aid in this optimization.

Meanwhile, the injection line from the CB-ECRIS to the K500 cyclotron has been completed. Beams of 10 AMeV and 15 AMeV rubidium charge-bred to 15+ and 17+, respectively, have been injected into, accelerated by and extracted from the K500 cyclotron. Preparations are underway for injection of radioactive products from the

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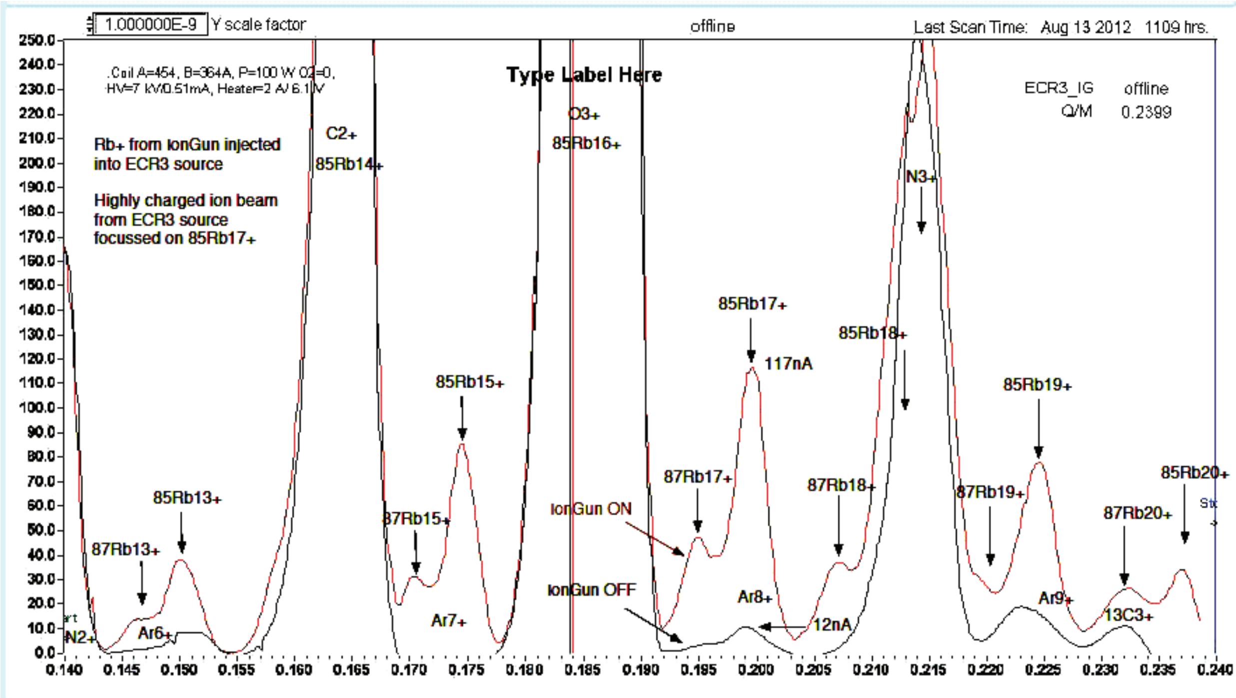

Figure 4: Superimposed spectra with the rubidium beam injected and not injected. The lower scale is charge-to-mass ratio, and the left-hand scale is intensity in nanoamperes.

light-ion guide into the CB-ECRIS. The first ions will originate from a radioactive source placed within the LIG stopping cell before attempting injection of beam-derived radioactive products.

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