INITIAL PERFORMANCE OF A 6 GHZ "VOLUME" ECR ION SOURCE

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Abstract

An all-permanent-magnet, 6-GHz "volume-type" ECR ion source has been constructed and evaluated. This source employs a novel magnetic field configuration with an extended central flat region to form a large, on-axis, ECR volume. It can also be converted to a traditional minimum-*B* source where the ECR zones are surfaces. Comparisons are made of the performance of the source when operated in both "volume" and "surface" modes. According to the preliminary results, the "volume" mode is superior in terms of ion beam intensities and charge-state distributions.

1 INTRODUCTION

In electron-cyclotron-resonance (ECR) ion sources with traditional minimum-*B* magnetic-field profiles, ECR zones are thin annular, ellipsoidal-shaped surfaces when powered by narrow bandwidth, single frequency microwave radiation. These ECR surfaces constitute a small percentage of the plasma volume and consequently, the efficiency of RF power coupling as well as the performance of the sources are limited by the sizes of their ECR surfaces. It has been suggested that the performances of ECR ion sources can be improved by increasing the physical sizes of the ECR zones in relation to the sizes of their plasma volumes [1-4]. This can be done by flattening the central magnetic field such that a large ECR volume on the axis can be formed [1] or by injecting multiple-discrete or broadband microwave radiation into conventional minimum-*B* ECR ion sources [2-5].

Multi-frequency heating has proven to be an effective way to enhance the performances of ECR ion sources and is being used in many ECR ion sources [4,5]. The volume ECR technique employs a novel magnetic field configuration with an extended central flat region that is tuned to be in resonance with single-frequency microwave radiation [1], resulting in a significantly larger ECR volume. Thus, more RF power can be coupled into the plasma, heating electrons over a much larger volume than possible in conventional ECR ion sources. All other parameters being equal, the volume-type ECR sources should result in higher charge-state distributions, and higher beam intensities.

Heinen et al., have successfully demonstrated that volume-type ECR ion sources can out perform conventional minimum-*B* sources in terms of charge-state distributions and intensities within a particular charge state [6,7]. An all-permanent-magnet, 6-GHz "volume-type" ECR ion source that incorporates the flat-field concept has been constructed at the Holifield Radioactive Ion Beam Facility, Oak Ridge National Laboratory. The source is designed to be convertible from the flat-*B* configuration to a traditional minimum-*B* configuration and vice versa, so that comparisons can be made of the performance of the source in "volume" ECR and "surface" ECR modes under similar operation conditions. Initial results of charge-state spectra and intensity distributions of the source are presented. The performances of the source are compared in terms of the charge-state distributions and intensities within a particular charge-state for the "volume" and minimum-*B* configurations.

2 SOURCE DESCRIPTION

A schematic representation of the source is shown in Fig. 1. The axial mirror field is produced by two, 50-mm thick, annular NdFeB permanent magnets radially magnetized in opposite directions. With specially designed and positioned iron cylinders, magnetic field profiles can be formed with flat central region for volume ECR operation and parabolic central region for conventional minimum-*B* operation. The corresponding axial magnetic field profiles are shown in Fig. 2. A 12-pole multicusp radial magnetic field is used for the volume ECR configuration in order to increase the ECR volume in the radial direction. In combination with the axial mirror field, a magnetic-field strength of 5 kG, approximately equal to that of the axial mirror field, is generated at the inner wall of the plasma chamber. The multicusp field can also be changed to a $N = 6$ field distribution when the source is configured as a conventional minimum-*B* source. The plasma chamber is made of *Al* and is 15.6 cm in length and 5.4 cm in diameter. The source is designed to operate at a central frequency of 6 GHz and features the ability to tune the central flat magnetic-field region by mechanical means to the resonance condition within the limits of 5.6 to 6.6 GHz. Microwave radiation is coupled into the plasma chamber via a tapered rectangular-to-circular transition, starting from a rectangular WR137 waveguide and ending with a circular diameter that matches the dimension of the plasma chamber. Design details of the source can be found in [8]. The RF power supply consists of an RF signal generator and a klystron power amplifier (KPA). The RF frequency can be varied between 5.85 to 6.40 GHz with output power up to 3 kW. The ion source is

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mounted on a high voltage platform and a three-electrode extraction has been designed for the source [9].

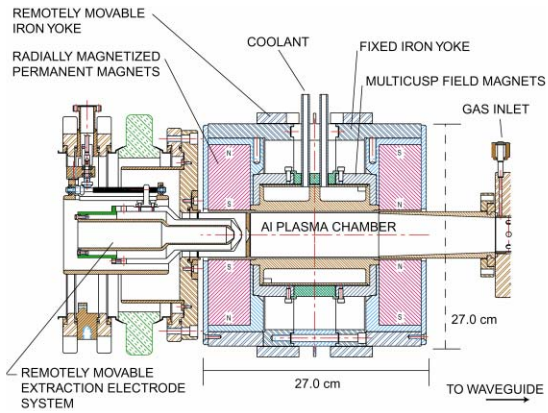

Fig. 1. Schematic view of the flat-*B* ECR ion source.

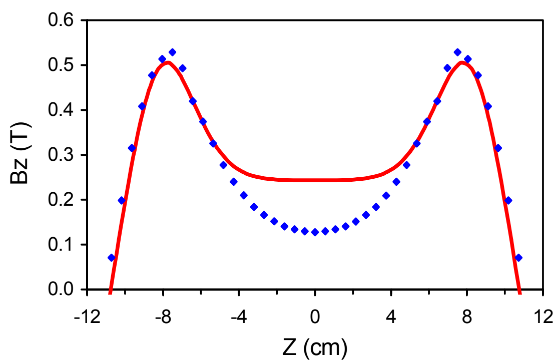

Fig. 2. Axial magnetic field profiles for the "volume" (solid) and minimum-*B* (dotted) configurations.

3 FIRST RESULTS

Initial testing of the source was conducted first for the "volume" ECR configuration, and then for the conventional minimum-*B* configuration, using *Ar* as the operating gas. Ions were extracted from the source at a voltage of 20 kV and mass analyzed with a 45º dipole magnet. Ion beam intensities were measured with Faraday cups before and after the mass analyzing magnet. The primary focus of our effort has been to commission this new source and characterize the source performance for various operating parameters including gas pressure, power and polarization of the microwave radiation, plasma electrode position and extraction gap for each configuration [10]. Operation of the source was reproducible. In general, the total beam currents and intensities of low-charge-state ions increased, while the production of high-charge-state ions (>6+) decreased, with increasing *Ar* pressure inside the plasma chamber. Our studies focused on source performance for high-charge-state ions. During the initial test phase, gas mixing was not studied and most of the data were obtained with the source operated with *Ar* gas. Fig. 3 shows an *Ar* charge-state distribution obtained with the "volume" ECR configuration without gas mixing.

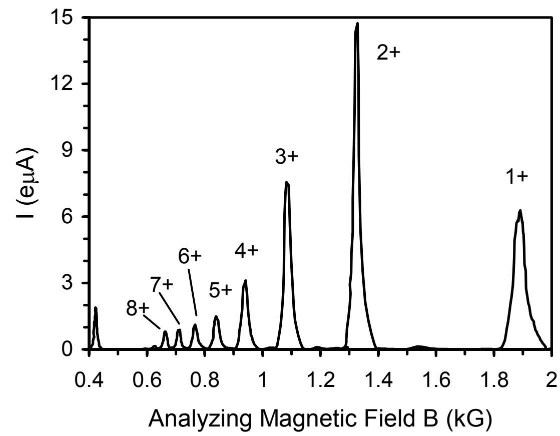

Fig. 3. *Ar* charge-state-distribution observed with the flat-*B* configuration. The source was optimized for Ar^{8+} without gas mixing at RF power of 800W.

The performances of the source in each configuration were evaluated and compared, based on the observed charge-state distributions and intensities within a given charge state, *X*-ray spectra, and high-charge-state production for *Ar* ion beams. A comparison of the best performances for *Ar* obtained with the flat-*B* and conventional minimum-*B* configurations is displayed in Fig. 4. The data were obtained under similar operating conditions for each configuration, optimized for high-charge states using *Ar* as the operating gas without gas mixing. It is clear that the "volume" ECR configuration produced higher charge states and higher intensities for each charge state than the conventional minimum-*B* configuration. In general, the flat-*B* configuration required more RF power applied to the source due to the much larger ECR zones in this configuration. It was also observed in *X*-ray measurements that much higher *X*-ray intensities and energies were generated with the flat-*B* configuration, suggesting the presence of more hot electrons in the "volume" ECR source [10].

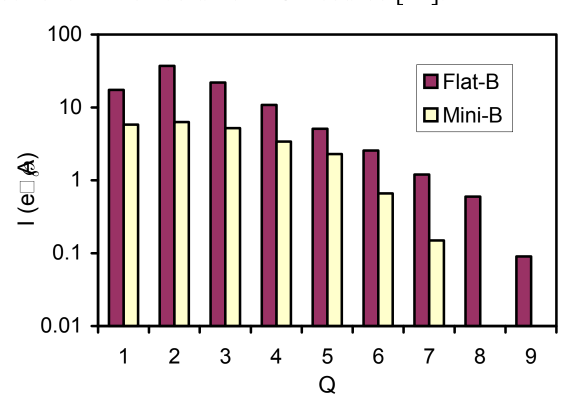

Fig. 4. A comparison of *Ar* charge states obtained with flat-*B* and conventional minimum-*B* ECR configurations.

4 SOURCE IMPROVEMENTS

The first performances of the source for high-charge-state production with both "volume" and conventional minimum-*B* configurations were poor. The total extracted currents were low, typically 200 to 300 eμA from the flat-*B* configuration, when the source was tuned for high-charge-state ions. The charge-state distributions were mostly peaked at Ar^{2+} and Ar^{9+} and Ar^{7+} were the highest charge states observed with intensities >0.1 eμA from both flat-*B* and minimum-*B* configurations, respectively. To improve its performance, several modifications were made to the source and tested with the minimum-*B* configuration. The vacuum inside the source was improved and the source operating parameters for high-charge-state ions were refined and optimized. The location of the plasma aperture was studied. It was found that the optimal aperture position was 3 cm behind the apex of the mirror magnetic field, closer to the plasma region. The optimal plasma aperture position led to several times higher total ion currents and better high-charge-state distributions. A major modification was to add a small iron plug on the axis in the RF injection region and changing the on-axis RF coupling system to an off-axis system. The RF radiation was originally coupled into the plasma chamber using an on-axis, tapered transition between the rectangular WR137 waveguide and the circular plasma chamber. The new RF coupling system consists of a transition from the on-axis WR137 waveguide to an off-axis WRD580 double ridge waveguide that ends abruptly at the location of the plasma chamber. This modification has three effects: (1) the on-axis iron plug increased the magnetic-field strength in the injection side; (2) the addition of the iron plug plus off-axis coupling eliminated a confined parasitic ECR zone in the RF injection region; (3) the plasma chamber became a cavity structure, instead of a traveling wave structure for the microwave radiation. The gas mixing technique was also studied and O_2 gas was used for ion cooling.

The performance of the source in the conventional minimum-*B* configuration was significantly enhanced with all the improvements using the new RF injection system. The total extracted *Ar* ion beam currents were increased by an order of magnitude when the source was tuned for high-charge-states. The charge-state distribution was peaked at Ar^{8+} and the highest charge state was moved to Ar^{11+}. The intensities of Ar^{7+} and higher charge-state ions were increased by more than 2 orders of magnitude. Fig. 5 shows a comparison of the *Ar* charge-state distributions before and after the improvements. Evaluation of these improvements for the flat-*B* configuration is being conducted and similar enhancement is expected.

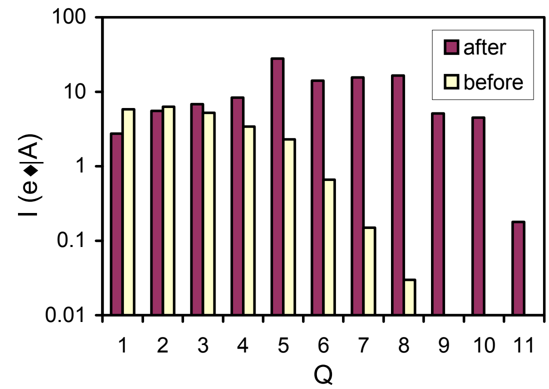

Fig. 5. Comparison of charge-state distributions for *Ar* ion beams extracted from the conventional minimum-*B* configuration before and after improvements made to the source.

5 CONCLUSION

Although much work remains to bring the source to levels competitive with existing sources, the initial comparative studies on the performance of the source clearly show that the flat-*B* configuration surpasses its conventional minimum-*B* counterpart in terms of charge-state distributions and ion-beam intensities in each *Ar* charge state. Since the initial studies, the performance of the source in the conventional minimum-*B* configuration has been significantly enhanced with various improvements and modifications made to the source and the use of a new off-axis RF coupling system. Similar enhancement in performance is expected for the flat-*B* configuration.

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