ENHANCED HIGH-CURRENT ECR PROTON SOURCE

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Abstract

The success of the high-current electron cyclotron resonance proton source installed on the 75 mA cw RFQ1 accelerator just over a year ago has encouraged the development of an enhanced version. Only the plasma chamber remains at the extraction potential. A dc waveguide break isolates the microwave source, while the solenoids, along with their dc power supplies, are isolated by an acrylic insulator. The coupling of the microwave power into the plasma has been substantially improved by a rectangular-to-ridged waveguide transition. A single-layer aluminum nitride window provides a vacuum seal and, in addition, dissipates the energy of the backstreaming electrons. The extraction system has been completely redesigned to facilitate installation and maintenance and to ensure that the electrostatic field enhancement in the extraction gap is minimized. A beam current of 100 mA has been extracted from a single 5 mm diameter aperture.

Introduction

Electron cyclotron resonance (ECR) ion sources have been used for some years to generate high-charge-state beams for heavy ion physics [1]. Recent work at Chalk River Laboratories [2] has demonstrated that high-current cw accelerator injectors can also benefit from the advantages of ECR plasma generators. The extended lifetime that results from the absence of a cathode is particularly significant in a production situation. An exceptionally large fraction of the beam from a microwave ion source may consist of the desired species, reducing the drain on the high-voltage power supply and, in some cases, eliminating the need for magnetic separation [3]. The unusually high efficiency of microwave ion sources leads to significant reductions in vacuum pumping requirements. Provided that the magnetic field is small, low-emittance ion beams can be extracted from microwave ion sources [4].

This paper describes an enhanced version of the ECR proton source first installed on the 75 mA cw RFQ1 proton accelerator [5]. The modifications have simplified the configuration and increased the microwave efficiency of the ion source.

Design

The present configuration of the Chalk River ECR proton source system is illustrated in Fig. 1. The microwave line is driven by a 2.45 GHz magnetron. A circulator protects the microwave generator. The reverse microwave power is monitored by a directional coupler. A three-stub tuner is used to compensate for the unavoidable variations in the impedance of the plasma. A 50 kV dc waveguide break, consisting of a Teflon sheet clamped between a choke flange and a standard

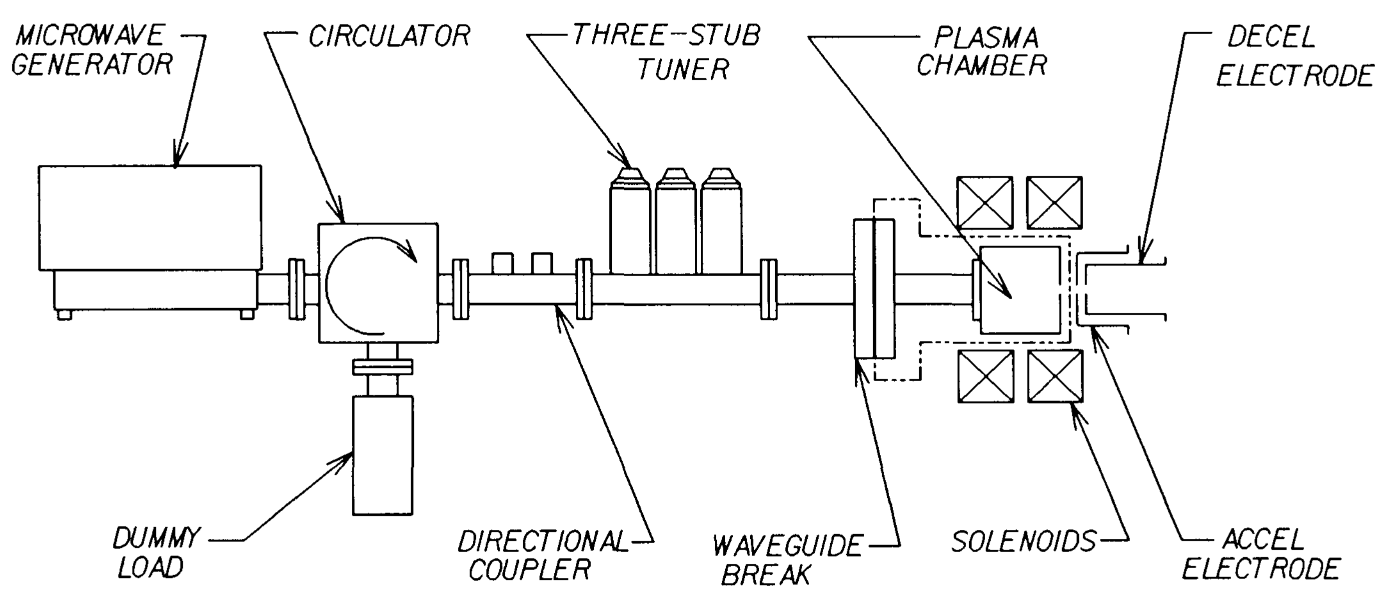

Fig. 1 Chalk River ECR ion source system. Only the components enclosed by the dashed line are at the extraction potential.

flange, has been developed to isolate the microwave line from the plasma chamber. A stepped ridged waveguide has been introduced to couple the microwaves into the plasma more efficiently.

The plasma generator, detailed in Fig. 2, is simply a hydrogen-filled chamber with a rectangular waveguide window encircled by two solenoids. The ion beam is extracted by a 50 kV three-electrode system.

A waveguide window consisting only of a thin aluminum nitride plate has replaced the multi-layered window [5]. The high thermal conductivity of aluminum nitride is essential to dissipate the power deposited by electrons back-streaming from the extraction column. Although the present window is O-ring sealed, a method of brazing copper to aluminum nitride has recently been demonstrated at Chalk River.

The proton fraction of the ion source is dramatically enhanced by lining the plasma chamber with any one of several materials that discourage the recombination of hydrogen atoms into molecules [5]. Recent experiments have demonstrated that, because the plasma density declines rapidly with radius, only the components adjacent to the axis of the source need to be lined.

In the revised configuration, the solenoids are electrically isolated from the plasma chamber by an acrylic tube so that all of the power supplies, both microwave and dc, are at ground potential. Consequently, the isolation transformers have become superfluous and the control system may be dramatically simplified. Only the plasma chamber and the flow controller remain at high voltage.

The extraction column has been completely redesigned to facilitate assembly and servicing. The alumina insulators are glued to the electrode holders with polyvinylacetate. The electrodes were reshaped to reduce voltage breakdowns induced by electrostatic field enhancements. (The POISSON computer simulation provided essential guidance.) The single 5 mm diameter aperture in the plasma electrode is recessed to increase the matched perveance [6]. The nominal 5 mm width of the extraction gap can easily be increased for applications where the minimization of voltage breakdowns takes precedence over the production of high-perveance ion beams.

Performance

The solenoid currents and the positions of the solenoids were optimized with respect to the beam current. The best results were obtained with a relatively uniform magnetic induction on the axis of the plasma chamber. Two stable modes of operation were identified. The first is referred to as "on-resonance", because the ECR condition is satisfied adjacent to the microwave window, and the second is referred to as "off-resonance". The magnetic induction on the plasma chamber axis is plotted for the two cases in Fig. 3.

The total beam current and the proton fraction were measured using the system described in Ref. 7 for a large number of combinations of hydrogen mass flow and microwave power. Figures 4 and 5 present only a small sample of the results. A total beam current of 100 mA with a proton fraction of 90% was generated at a microwave power of only 900 W with a hydrogen mass flow of just 1.5 sccm (2.3 μg/s).

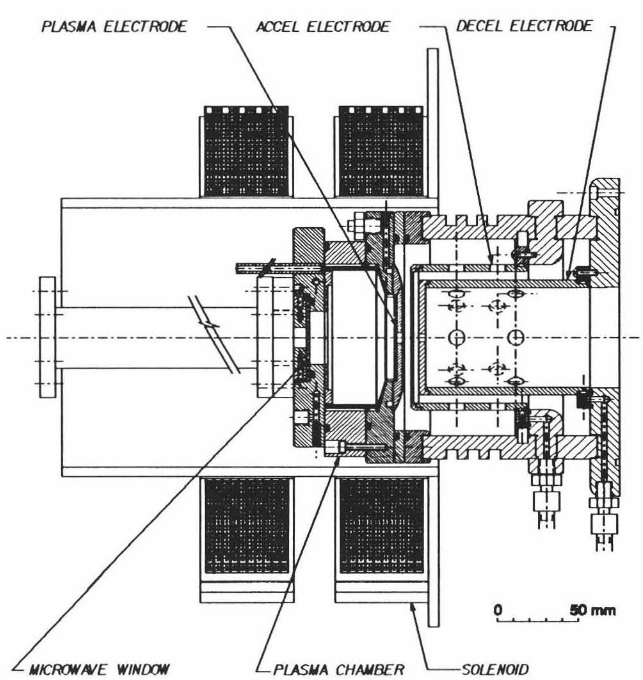

Fig. 2 Enhanced Chalk River ECR ion source.

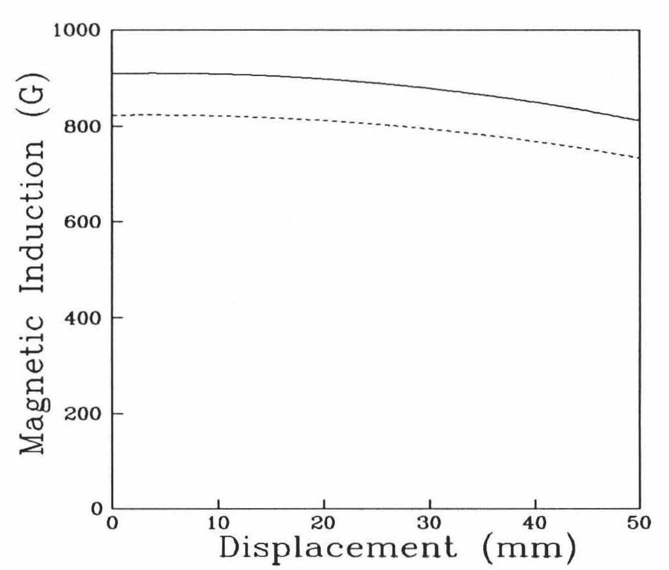

Fig. 3 Magnetic induction on the axis of the ion source as a function of the displacement from the microwave window. The solid and dashed lines correspond, respectively, to on- and off-resonance operation.

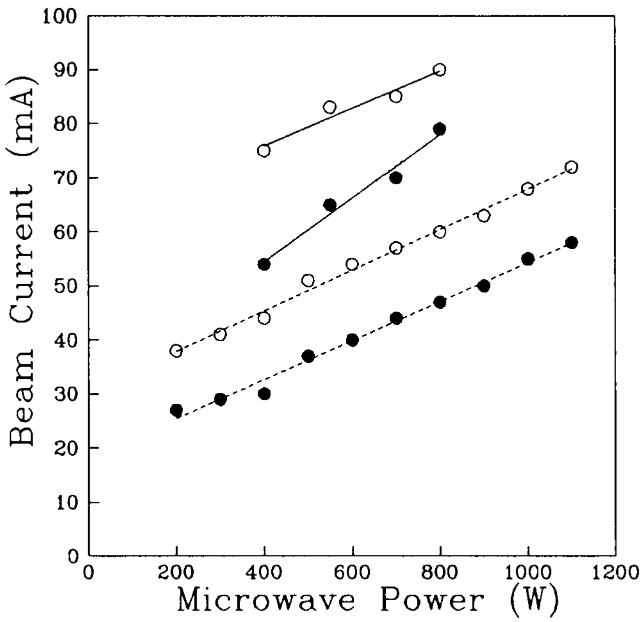

Fig. 4 Total beam current (open symbols) and proton beam current (closed symbols) on-resonance (solid lines) and off-resonance (dashed lines) as a function of microwave power at a hydrogen mass flow of 1.0 sccm (1.5 μg/s).

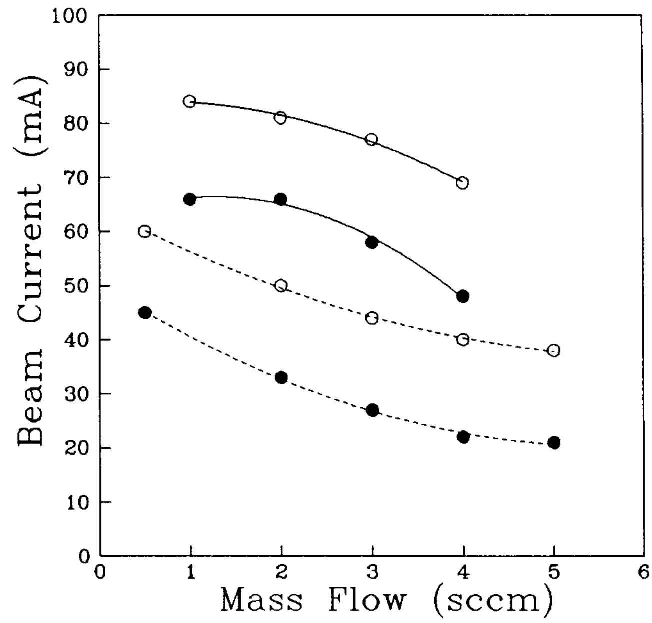

Fig. 5 Total beam current (open symbols) and proton beam current (closed symbols) on-resonance (solid lines) and off-resonance (dashed lines) as a function of hydrogen mass flow at a microwave power of 600 W.

A two-slit system [7] was used to measure the phase space distribution of the beam as a function of the perveance with a 7 mm wide extraction gap. The normalized rms emittance at the matched perveance was 0.10 π mm mrad. The minimum rms divergence was 16 mrad at the emittance measuring unit 570 mm downstream, with a background hydrogen gas pressure of 4×10^{-5} Torr.

Conclusions

Recent developments have led to a simpler high-current ECR ion source with a higher microwave efficiency. An ECR ion source, operating at an order of magnitude lower feed rate, is capable of generating a proton beam with three times the brightness of the proton beam produced by a comparable arc discharge ion source. The ECR ion source will probably become the ion source of choice for high-current cw accelerator applications.

References

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