PRODUCTION OF HIGH PROTON FRACTIONS FROM ECR SOURCES BY PLASMA MODIFICATION*

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Abstract

A program has beem initiated to increase the proton fractions extracted from ECR sources by modifying the atom concentration in the source using minor additives to the plasma. A progress report is given.

Introduction

A number of positive-ion sources have recently been described in the literature which have very high proton fractions in the extracted beam. For example, an arc-driven multi-cusp generator developed for the Basic Technology Accelerator (BTA) at JAERI has demonstrated[1] a proton fraction of greater than 80% of the extracted beam, whilst an Electron Cyclotron Resonance (ECR) source developed by Chalk River Nuclear Laboratory (CRNL) for injection into a radio frequency quadrupole (RFQI) has demonstrated an extracted proton fraction of greater than 90% under optimal conditions[2].

Nevertheless, despite the high proton fractions generated by these advanced sources, the remaining 10 to 20% of extracted ions contains H_2^+ and H_3^+ species. Generally, these unwanted species must be removed by magnetic analysis prior to injection into a high current linac, although direct injection into a room temperature RFQ has been demonstrated by the CRNL group using their ECR source[3]. However, unless the proton fraction can be increased to more than 99%, direct injection into a superconducting RFQ does not appear too likely. Unfortunately, magnetic separation of ion species usually leads to emittance growth and loss of beam brightness, a situation which also may not be acceptable in high current continuous wave (cw) superconducting accelerators. If sources of sufficient proton purity could be developed, then the cost and complexity of medical and other accelerators could be reduced considerably, especially with the introduction of superconducting structures. Towards this end, we have initiated a program to increase beam purity by modification of the source plasma by the addition of minor, environmentally benign, constituents to the plasma.

Background

Although the introduction of cesium into ion sources has long been used to increase the ion yield in both negative and positive ion sources, it's use is not without difficulty, though we do note the successful use of cesium dispensers by the Berkely group in the case of pulsed H^- sources.

It is known, however, that other minor constituents, which are both permanent gases and are environmental benign, can greatly modify the species composition of microwave generated plasmas, and specifically, increase the neutral atomic/molecular composition of such plasmas[4]. Obviously, any increase in the neutral atomic/molecular composition of the plasma can only increase the atomic/molecular ion species ratio in an extracted beam. The family of minor constituents which can be added to the plasma to achieve this end, and which are probably suitable for accelerator applications, include N_2, O_2 and SF_6.

In the case of cesium, it is believed that the ion enhancement in the plasma is caused by surface effects and in particular by a reduction of the surface work function. The action of permanent gases to increase atom content is believed to result from a reduction of the recombination coefficient of the surface. If this is so, then an ion source to test out the veracity of atom concentration by permanent gases should probably run thermally cool in order to retain these gases on the surface. The advantages of microwave driven ECR sources for generation of low emittance, high current cw proton beams has been demonstrated some time ago[5]. One advantage of this source for our application is that its total power consumption is very low, of the order of a few hundred watts. Thus it is very easy to keep the source components cool and thus retain the permanent gases on the surface of the source.

The Experimental Setup.

An overall schematic of our experimental setup is shown in Fig. 1. The major components of our apparatus include an ECR source purchased from AECL which is powered by a 2.45 Ghz microwave generator rated at 2.0 kW. The microwave generator is coupled to the source via a circulator and a four-stub autotuner. When the source is tuned to the ECR resonance by adjustment of the magnetic field, the autotuner maintains a low Voltage Standing Wave Ratio (VSWR) such that the reflected power is typically less than 7 watts for 1kW forward power. The ion source is attached to a large, flexible designed, high vacuum, oil free diagnostic chamber which is pumped by three cryopumps and a turbo pump giving a base pressure of 1.0×10^{-8} torr without baking.

Beam Diagnostics

The diagnostic chamber shown in Fig. 1 is configured to accept a wide variety of diagnostics for plasma-surface studies, but the principal diagnostic used in the present work is a quadrupole mass spectrometer with a novel ion extraction/imaging lens for sampling the extracted beam.

The design of the ion extraction system is slightly complicated by the need to extract sufficient current from the source that space-charge-limited conditions are met, i.e. fairly large energy, combined with the rather stringent requirements which must be met to perform *quantitative* mass spectrometry with a QMS[6]. Specifically, mass analysis of the beam must be performed at very low energy (typically <20eV.), the beam image at the entrance

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plane of the QMS must be as small as possible, and the beam must be quite parallel.

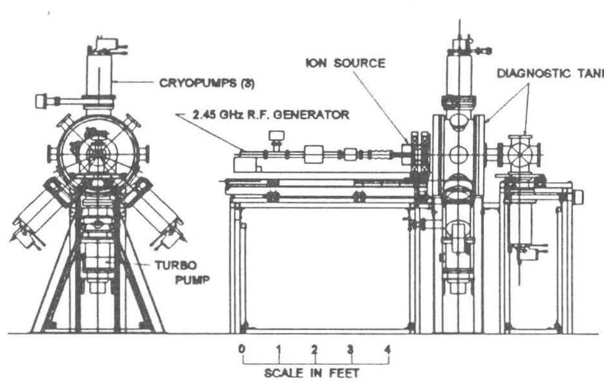

Fig. 1. Schematic diagram of the apparatus.

These requirements are met with the lens system shown schematically in Fig. 2. Extraction from the source at 3kV is performed by an accel-decel arrangement, with the main beam being collected and monitored on the decel electrode. The beam trajectories for an extracted current density of 20mA/cm^2, which are shown in Fig. 2, were calculated using SNOW[7]. A small hole in the decel electrode allows a portion of the beam to be imaged at the entrance plane of the QMS by means of a three element zoom lens whose design is based on focal properties of such lenses and which are tabulated by Harting and Read[8]. The zoom lens gradually decelerates the beam which emerges from the decel electrode at 2 keV energy, to the 20 eV required by the QMS. The beam trajectories for the zoom lens were calculated using SIMION[9]. With the typical operating voltages shown in Fig. 2, 50% of the sampled beam lies in a circle of diameter only 0.25 mm dia. at the entrance plane of the QMS, and the resulting rays within this circle easily meet the parallelicity requirements for *quantitative* mass spectrometry.

Status

At this point, the QMS and its sampling system are undergoing final assembly and checkout. No quantitative measurements have yet been made but are expected within a month. However, the source has been operated both with and without a proton enhancing additive, (specificallyN_2), and visual observations of the plasma indicate that the atom concentration of the source is enhanced by the addition of this additive. This observation is based on the increase in Balmar Alpha radiation intensity from excited H in the source and which is visible to the eye, and also on past experience with much smaller sources.

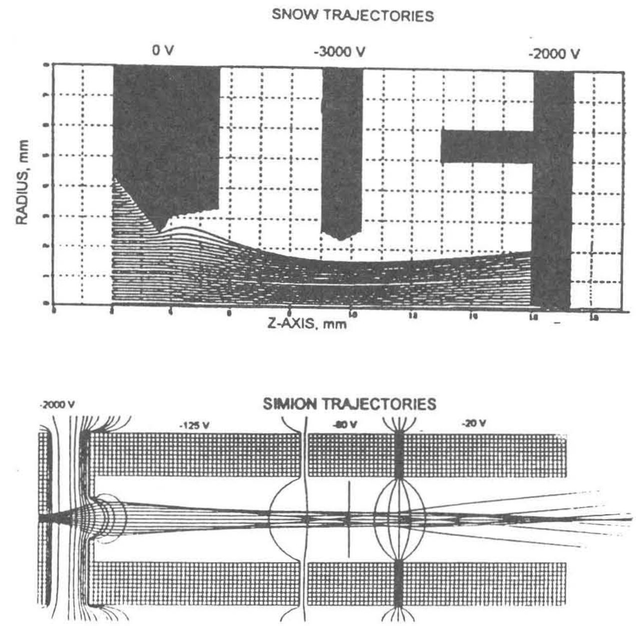

Fig. 2. Upper figure shows ion source plasma electrode, accel and decel electrode and calculated tragectories. Ions are collected on the decel electrode with a small portion passing through a 0.5 mm hole to the zoom lens shown below. The zoom lens decelerates the sampled beam from 2000 eV to 20 eV for injection to the QMS (not shown). At the entrance plane of the QMS, 50% of the sampled beam lies in a circle of radius 0.25 mm and is quite parallel.

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