RF Driven Multicusp Ion Source for Particle Accelerator Applications*

K. N. Leung, D. A. Bachman and D. S. McDonald

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720 USA

Abstract

An RF driven multicusp source has been operated in both cw and pulsed modes to generate H^- and various positive ion beams. By employing a porcelain-coated antenna, the lifetime of the source is much enhanced and a clean plasma can be maintained for a long period of operation. A total H^- current of 40 mA can be obtained with a 5.6-mm-diam extraction aperture. For inert gas plasmas such as He, Ne, Ar, Kr and Xe, the extractable current density is higher than 1 A/cm^2. When diatomic gases, such as H_2, N_2 and O_2 are used for the discharge, the extracted beam contains almost pure atomic ions.

1. INTRODUCTION

It has been demonstrated that a multicusp source can be operated with RF induction discharge to generate positive or negative ions. There are several advantages of the RF driven plasma over the dc filament discharge plasma: (1) the RF discharge can be operated with all gases (including oxygen which can easily poison tungsten filament cathodes); (2) power for heating the cathode is avoided; (3) there are no short life components in the source; (4) a clean plasma free from contamination from the cathode material can be maintained; and (5) the RF power supplies operate conveniently at ground potential. For this reason, the RF driven multicusp source is very attractive for particle accelerators and for neurtral beam systems in fusion research. At LBL, an RF driven source has been operated in both cw and pulsed mode to generate H^- as well as various positive ion beams. This paper describes recent results of the RF ion source development.

2. EXPERIMENTAL APPARATUS

A schematic diagram of the RF ion source is shown in Fig. 1. The source chamber is a copper cylinder (10 cm diameter by 10 cm long) surrounded by 20 columns of samarium-cobalt magnets that form a longitudinal line cusp configuration. The magnets are enclosed by an anodized aluminum cylinder with cooling water circulating between the magnets and the inner housing. The back flange has four rows of magnets cooled by drilled water passages in the copper.

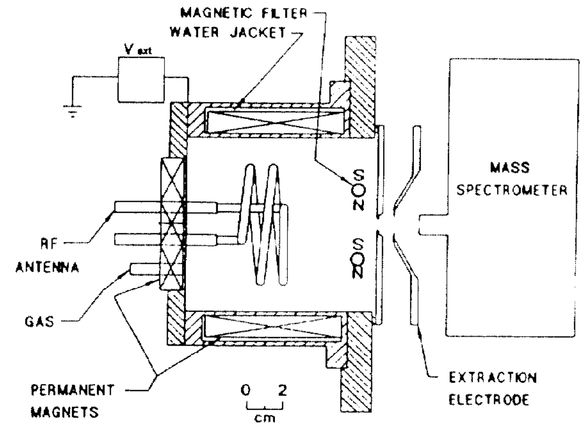

Fig. 1 Schematic diagram of the RF multicusp ion source.

In order to enhance the H^- yield, a pair of water-cooled permanent magnet filter rods is installed near the extraction region. The filter rods provide a narrow region of transverse magnetic field which divides the entire source chamber into a discharge and extraction region. The filter field is strong enough to prevent energetic electrons from reaching the extraction chamber. Excitation and ionization of the gas molecules take place in the discharge chamber. Positive and negative ions, together with cold electrons are present in the extraction region, and they form a plasma with lower electron temperature, which is favorable for the generation of H^- and positive atomic ions such as H^+, N^+ and O^+.

The open end of the source chamber is enclosed by a two-electrode extraction system. Positive or negative ion beams are normally extracted from the source through a 2-mm-diam aperture. A permanent-magnet mass analyzer is used with a Faraday cup to measure the electron, H^- ion or positive ion currents in the accelerated beam. When multiple ion species are present, a electro-magnetic mass analyzer is used to determine the species distribution.

The RF antenna is fabricated from 4.7-mm-diam copper tubing and is coated with a thin layer of hard porcelain material. The thin coating is slightly flexible and resistant to cracking. It has maintained a clean plasma in cw operation for periods of a week or more; the antenna life expectancy has not yet been determined.

A sine-wave oscillator drives a gated 400 W solid state amplifier at a nominal operating frequency of 1.8 MHz.

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The resulting RF pulses then drive a Class C tube amplifier with a maximum pulse output power of 50 kW. In order to couple the RF power efficiently into the source plasma, a matching network (which is a tunable resonant parallel LC circuit) is employed. In this experiment, a small hairpin tungsten filament is used as a starter for the RF induction discharge.

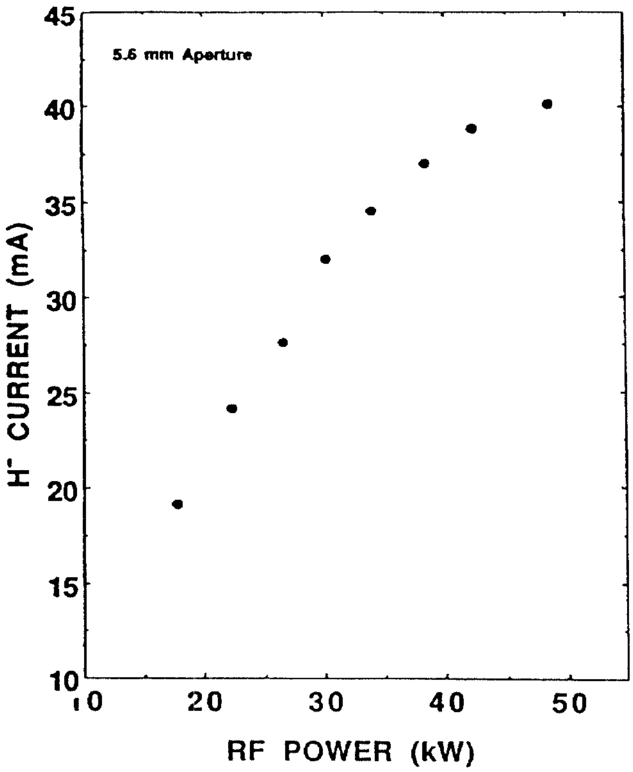

Fig. 2 H^- output as a function of RF power for a 5.6-mm-diam extraction aperture.

3. EXPERIMENTAL RESULTS

3.1 Volume H^- ion production

Multicusp plasma generators have been operated successfully as volume-production H^- sources. The H^- ions formed by volume processes have lower beam emittance and therefore are useful for the generation of high-brightness beams. In order to achieve high current densities, volume H^- sources require high discharge power. As a result, the lifetime of the ordinary filament cathodes is short for steady-state or high repetition rate pulse operations.

An RF driven H^- source has been developed at LBL for use in the Superconducting Super Collider (SSC). Operation of this RF driven multicusp H^- ion source has been previously reported [1,2]. Recently, we optimized the filter and the collar geometries to obtain higher H^- output and lower electron current in the extracted beam. Figure 2 is a plot of the extracted H^- current as a function of RF input power. An H^- current of ~40 mA can be obtained from a 5.6-mm-diam aperture with the source operated at a pressure of about 12 mTorr and 50 kW of RF power. The ratio of electron to H^- ions in the extracted beam varies from 8 to 12 as the RF power is changed from 20 to 50 kW. Based on these experimental results, along with previous emittance measurements [3], we have designed a simple four-electrode electrostatic injector system for the SSC RFQ [4].

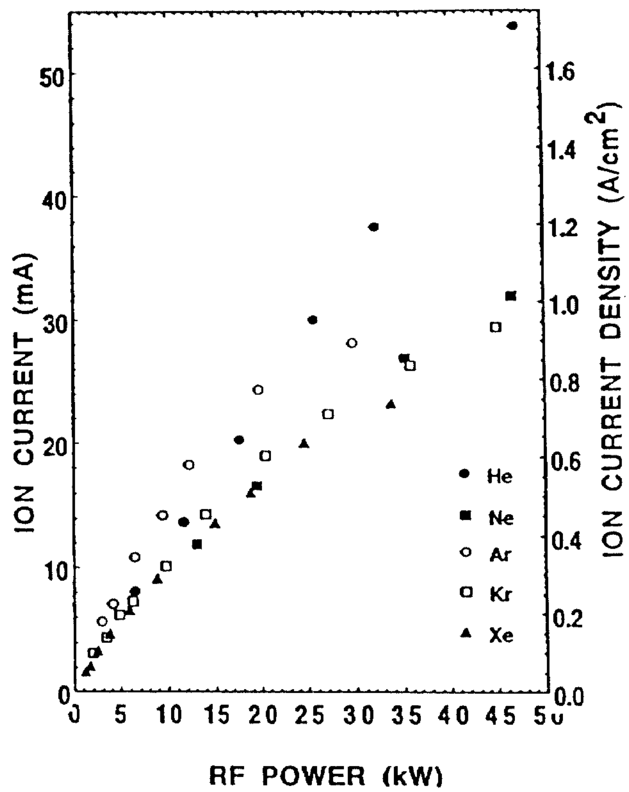

Fig. 3 Extracted beam current and density as a function of RF power for various inert gas plasmas.

3.2 Source operation with inert gases

The same RF multicusp source has also been tested with inert gas plasmas such as He, Ne, Ar, Kr and Xe. Figure 3 shows the extractable positive ion current (and current density) as a function of RF power when the filter rods are removed. The optimum source pressure is typically below 1 mTorr. It can be seen that the output currents increase almost linearly with RF input power. In most cases, the extractable ion current density can be as high as 1 A/cm^2. If the beam emittance is proven to be small, then this RF driven ion source will be extremely useful for projection ion beam lithography and ion beam machining applications.

3.3 Source operation with diatomic gases

Multicusp generators are capable of producing large volumes of uniform and quiescent plasmas with densities exceeding 10^{12} ions $/cm^3$. For this reason, there was a great interest in the early 1980s in applying such devices as ion sources for neutral beam injection systems and for particle accelerators. To increase plasma penetration by a neutral beam, a high percentage of H^+ or D^+ ions is required. It has been demonstrated that atomic species as high as 85% can be obtained routinely if a multicusp source is operated with a magnetic filter. The magnetic field generated by the filter magnets is strong enough to prevent the primary electrons from reaching the extraction region. The absence of energetic electrons will prevent the formation of H_2^+ in the extraction region and thus enhance the atomic ion species percentage in the extracted beam.

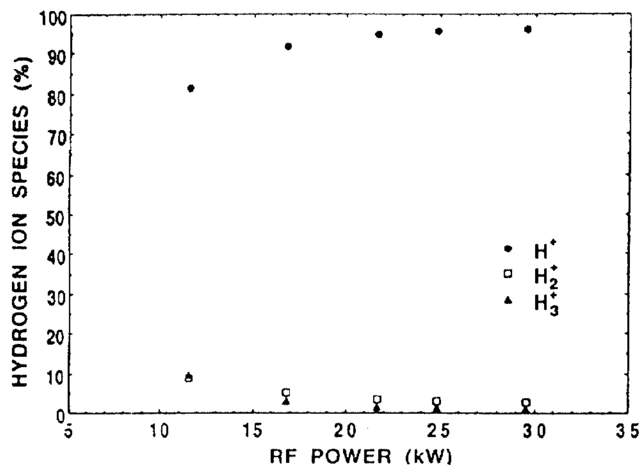

Fig. 4 Hydrogen ion species as a function of RF power when the source is operated with the filter.

We have investigated the hydrogen ion species composition in the RF driven source with and without the magnetic filter. Figure 4 shows the hydrogen ion species distribution as a function of RF power when the filter is in place. The H^+ ion concentration increases from 80 to 97% as the RF input power is varied from 12 to 30 kW. The highest current density achieved is about 1.5 A/cm^2.

Nitrogen ion implantation has been used successfully to increase the surface hardness and wear resistance of metals. Deep implants are always preferred, and for this reason N^+ ions are more desirable than N_2^+ ions. If there is a high concentration of N^+ ions in the extracted beam, then the usual mass separation process needed to remove the molecular ions can be avoided. We have operated the RF driven source with a *nitrogen* plasma. Similar to the hydrogen discharge, the atomic ion concentration increases with the RF input power. A nearly pure (>98%) N^+ ion beam with current densities in excess of 500 mA/cm^2 has been obtained when the magnetic filter is employed.

In addition to hydrogen and nitrogen, we have also operated this ion source with other diatomic gases such as *oxygen*. Oxygen plasmas are usually produced by either RF or microwave discharges. It is difficult to use a dc discharge with tungsten filaments because electron emission deteriorates very fast when oxygen is present. The porcelain-coated antenna has been operated very successfully with an oxygen plasma both in pulsed and cw modes. Figure 5 shows a plot of the oxygen ion species as a function of RF power. Atomic ion concentration higher than 93% can be achieved with approximately 16 kW of RF power. The extractable ion current density is found to be greater than 500 mA/cm^2.

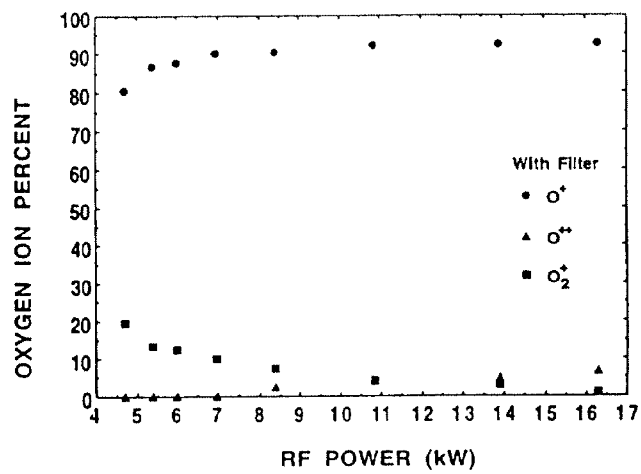

Fig. 5 Oxygen ion species as a function of RF power when the source is operated with the filter.

The above results demonstrate that a simple and more compact oxygen implanter can be designed with the use of a magnetically filtered RF driven multicusp source. In particular, this type of ion source should be very useful for SIMOX (Separation by Implantation of Oxygen) technology [5]. It produces almost pure O^+ ions and can provide a much higher current density than conventional sources and thus reduces the time required to form a buried silicon oxide layer.

4. REFERENCES

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