A COMPACT MICROWAVE ION SOURCE*

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Abstract

A small microwave ion source has been fabricated from a quartz tube with one end enclosed by a two grid accelerator. The source is also enclosed by a cavity operated at a frequency of 2.45 GHz. Microwave power as high as 500 W can be coupled to the source plasma. The source has been operated with and without multicusp fields for different gases. In the case of hydrogen, ion current density of 200 mA/cm^{-2} with atomic ion species concentration as high as 80% has been extracted from the source.

Introduction

During the last decade, there has been extensive research and development of ion sources for neutral beam heating in fusion research and other applications. Positive and negative ion sources using different gases, different principles of operation, and with various ion extraction methods have been developed and tested. In virtually all of these cases, direct current discharge from a cathode to an anode are normally employed. For long pulse or cw source operation, the life-time of the cathode or filament is always limited. In some cases, it is even difficult to generate a stable plasma (for example oxygen) by using hot tungsten filaments. Therefore, it is obviously desirable to develop an ion source that operates without filaments. A microwave ion source probably can provide part of the solution. Such a source can be made quite small, and requires only one power supply for the whole source operation. In this paper, we present the characteristics of a compact microwave source when it is operated with different gases to generate positive or negative ion beams. It is also shown that permanent magnet multicusp fields can be incorporated with this kind of source to provide plasma confinement.

Experimental Setup

Figure 1 shows a diagramatic drawing of the apparatus. The small ion source is fabricated from a quartz tube with a two grid extractor at one end and gas inlet at the other end. Two sizes of quartz tubes have been tested, one has an outside diameter of 10 mm and the other 14 mm. The quartz tube is enclosed by an Evanson microwave cavity[1] operated at a frequency of 2.45 GHz. Microwave power as high as 500 watts can be coupled to the cavity from a Micro-Now Model 420B generator by means of a coaxial cable. Cooling air is directed on the discharge through a tube located in the body of the cavity. The removable end cap of the cavity allows the unit to be positioned without breaking the vacuum system. Ionization of the gas in the tube is initiated by a hand-held Tesla coil. When properly adjusted, the cavity will maintain a discharge in various gases at pressures ranging from a few milli-torr to several hundred torr. A tuning stub and a coupling slider are provided in the cavity to properly match the impedance of the discharge to that of the generator, and once adjusted no further adjustments are necessary unless the flow conditions are changed. The reflected, as well as the incident power, was measured using a bi-directional power meter located at the output of the microwave power generator.

The open end of the quartz tube is enclosed by a two-electrode accelerator system. The first or

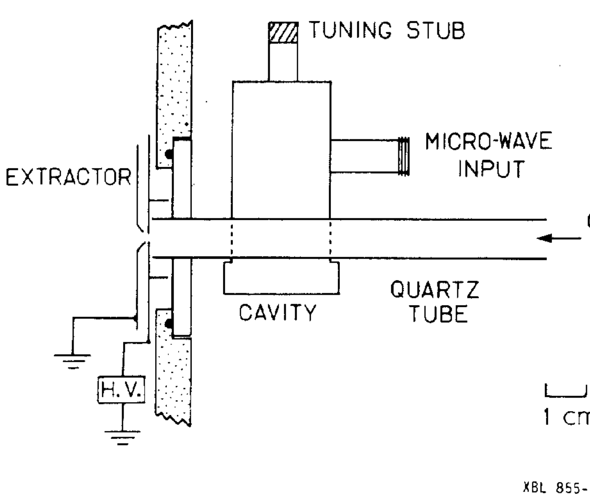

Fig. 1 A Schematic diagram of the microwave ion source

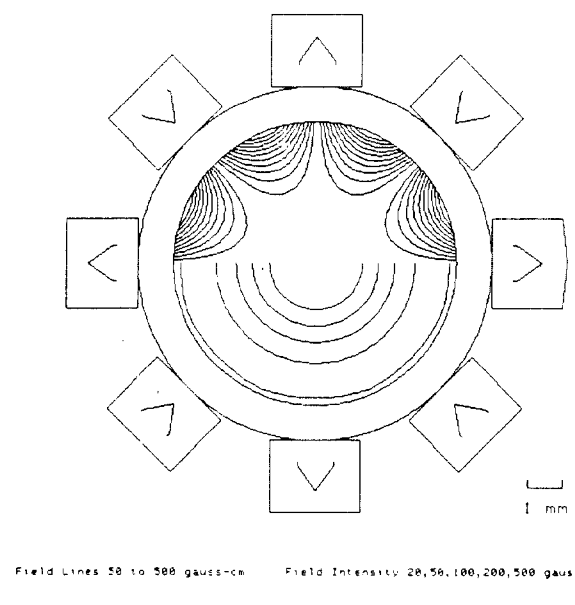

Fig. 2 The B-field distribution inside the source when it is surrouned by ceramic bar magnets.

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plasma electrode has a 0.8-mm-diam extraction aperture. This electrode is water-cooled, and is biased at a potential either positive or negative relative to the ground potential for the extraction of a positive or a negative ion beam from the source. The second electrode is connected to ground. Since the quartz tube is electrically floating, the potential of the source plasma is "tied" to that of the plasma electrode. Thus the energy acquired by the extracted ions is equal to the potential applied on the plasma electrode plus or minus the plasma potential. A compact magnetic-deflection spectrometer located just outside the extractor is used to measure the positive and negative ion species of the small extracted beam.

An attempt has been made to operate the microwave source as a small multicusp plasma generator.[2] Eight ceramic bar magnets, 40 mm long and 1.5 x 2.5 mm^2 cross-section, are mounted longitudinally on the surface of the quartz tube to produce the multidipole fields for plasma confinement. An enlarged view of the quartz tube, the bar magnets, and the calculated B-field[3] are illustrated in Fig. 2. Preliminary study seems to indicate that there is no significant difference when the source is operated with or without the bar magnets. The data presented in the following sections are all obtained without the use of the permanent magnets.

Experimental Results

(a) Source operation with hydrogen

When the source is operated with hydrogen, the extracted positive ion current increases almost linearly with the absorbed microwave power (which is defined as: forward power - reflected power) when the 10-mm-diam tube is used. Figure 3 shows a plot of the current density versus the absorbed power for an extraction voltage of 2 kV and a flow rate of ~ 9 sccm. It can be seen that the current density exceeds 200 mA/cm^2 when the microwave power is 400 W. However, the coupling efficiency is much reduced when the larger 14-mm-diam tube is employed. Figure 3 shows that a current density of ~20 mA/cm^2 can be obtained when the absorbed power is 400 W.

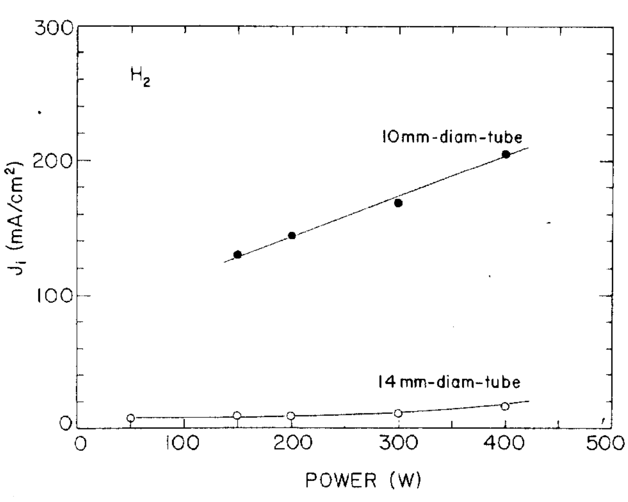

Fig. 3 Extracted current density versus absorbed microwave power for two sizes of quartz tubes.

The hydrogen ion species is measured by the mass spectrometer when the 10-mm-diam tube is used. Figure 4(a) shows a typical mass spectrum of the extracted positive ion beam. The evolution of the ion species distribution as a function of the absorbed microwave power (Fig. 5) is similar to those of dc discharge ion sources.[2] At low micro-wave power, the ion species is dominated by H_3^+. As the power increases, the percentage of H_3^+ decreases while the concentration of H^+ increases. The percentage of the H_2^+ ions

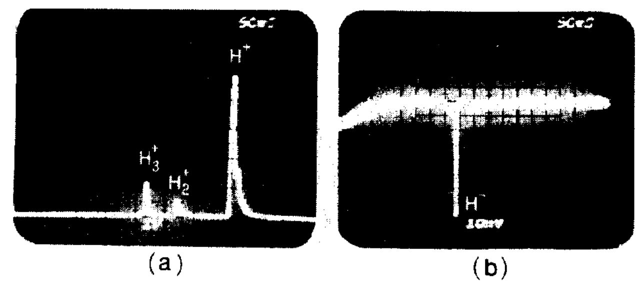

Fig. 4 Spectrometer output signal showing (a) the three positive hydrogen ion species, and (b) the H^- ions.

varies between 5 to 8% throughout the range of power tested. Higher atomic ion percentage (> 80%) can be obtained if the wall of the quartz tube is kept very cold so that the recombination rate for atoms on the wall is low.

The potential of the source plasma can be estimated from the energy of the ions when the extraction voltage is adjusted to zero. The spectrometer output signal shows that the ions left the source with energies as high as 70 eV. This result suggests that the electron temperature of the source plasma can be very high. The data presented in section (c) for other gases support this observation.

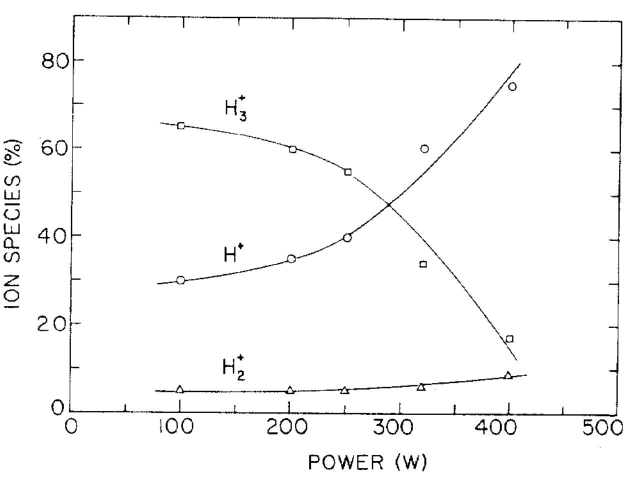

Fig. 5 The hydrogen ion species distribution as a function of absorbed microwave power.

(b) Extraction of H^- ions

In order to extract a negative ion beam from the microwave source, the plasma electrode is biased at -500 V relative to ground. The magnitude of the H^- output signal is extremely small. Since the electron temperature is high and the plasma potential ~+70 V, very few H^- ions are available for extraction near the plasma electrode. A pair of ceramic magnets is then used as a filter[4] to provide a transverse B-field near the extractor. This arrangement lowers the plasma potential and the electron temperature near plasma electrode. As a result, a much larger H^- signal is observed [Fig. 4(b)]. Compared to the positive ion species, the H^- signal is about two orders smaller in magnitude, indicating that the concentration of H^- ions in this type of source is very small.

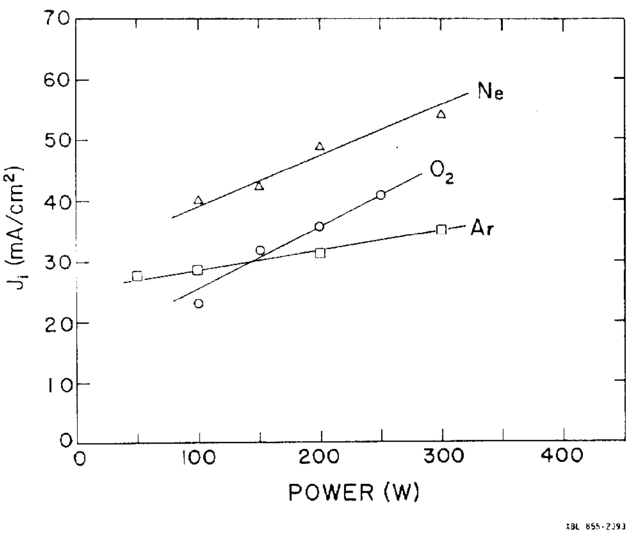

Fig. 6 The extracted current density as a function of absorbed microwave power.

(c) Source operation with other gases

The microwave source has also been operated with other gases such as O_2, Ne and Ar. The gas flow rate required for stable operation ranges from 1 sccm for O_2 to 5 sccm for Ar. The plasma formed from each of these gases produces a characteristic color which is red for Ne, white for O_2, and light blue for Ar. Figure 6 shows the current density extracted from these plasmas as a function of the absorbed microwave power. In all cases, current density higher than 35 mA/cm^2 can be achieved by employing 300 W of power.

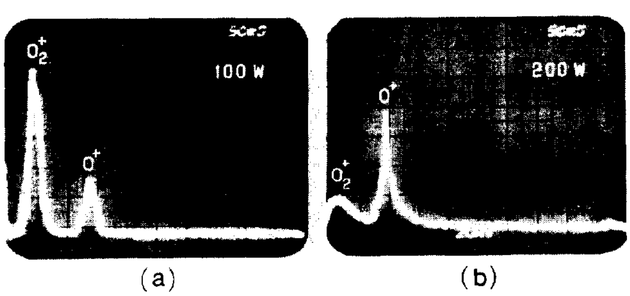

Fig. 7 The distribution of the oxygen ion species when the source is operated at (a) low, and (b) high microwave power levels.

For O_2, both O^+ and O_2^+ ions are present in the extracted beam. When the source is operated with low microwave power, the spectrometer signal in Fig. 7(a) shows that the majority of the ions are O_2^+. When higher power is used, Fig. 7(b) shows that O^+ becomes the dominant species. For Ne and Ar gases, ions with higher charge state are present in the plasma. In the case of Ne, the spectrometer shows that Ne^+, Ne^{2+} and Ne^{3+} are all present in the extracted beam. Since the production of Ne^{3+} ions requires electrons with energies greater than 64 eV, the electron temperature of the source plasma is indeed very high.

More experimental investigation is needed in order to understand the characteristics of this microwave ion source. In particular, its performance in the presence of multicusp confinement fields or in an axial B-field has to be explored. Nevertheless, the preliminary results demonstrate that this microwave ion source can be useful in ion implantation, atomic and nuclear physics experiments and neutral beam heating applications.

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