Presented at the Particle Accelerator Conference, Vancouver, B.C., Canada, May 13-16, 1985

A COMPACT MICROWAVE ION SOURCE

K.N. Leung, S. Walther, and H.W. Owren

May 1985

For Reference

Not to be taken from this room

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
A COMPACT MICROWAVE ION SOURCE*
K. N. Leung, S. Walther, and H. W. Owren
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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/cm² 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 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 millitorr 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

---

* This work is supported by the Air Force Office of Scientific Research and the U.S. DOE under Contract No. DE-AC03-76SF00098.
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.

An attempt has been made to operate the microwave source as a small multicusp plasma generator. Eight ceramic bar magnets, 40 mm long and 1.5 x 2.5 mm² 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 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/cm² 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/cm² can be obtained when the absorbed power is 400 W.

(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 to provide a transverse B-field near the extractor. This arrangement lowers the plasma potential and the ion species distribution as a function of the absorbed microwave power (Fig. 5) is similar to those of dc discharge ion sources. At low microwave power, the ion species is dominated by H⁺. As the power increases, the percentage of H⁺ decreases while the concentration of H₂ increases. The percentage of the H₂ 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 (a) for other gases support this observation.
electron temperature near plasma electrode. As a result, a much larger H\textsuperscript+ signal is observed [Fig. 4(b)]. Compared to the positive ion species, the H\textsuperscript+ signal is about two orders smaller in magnitude, indicating that the concentration of H\textsuperscript+ ions in this type of source is very small.

![Graph showing current density as a function of absorbed microwave power.](image)

**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\textsubscript{2}, Ne and Ar. The gas flow rate required for stable operation ranges from 1 sccm for O\textsubscript{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\textsubscript{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\textsuperscript{2} can be achieved by employing 300 W of power.

![Images showing the distribution of oxygen ion species.](image)

**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\textsubscript{2}, both O\textsuperscript{+} and O\textsuperscript{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\textsuperscript{+}. When higher power is used, Fig. 7(b) shows that O\textsuperscript{2+} 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\textsuperscript{+}, Ne\textsuperscript{2+} and Ne\textsuperscript{3+} are all present in the extracted beam. Since the production of Ne\textsuperscript{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.

**Acknowledgement**

We would like to thank D. Moussa and D. Kippenhan for all technical assistance and Dr. J. Trow for calculating the B-field distribution.

**References**

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.