Title

OPERATIONAL CHARACTERISTIC OF A COMPACT MICROWAVE ION SOURCE

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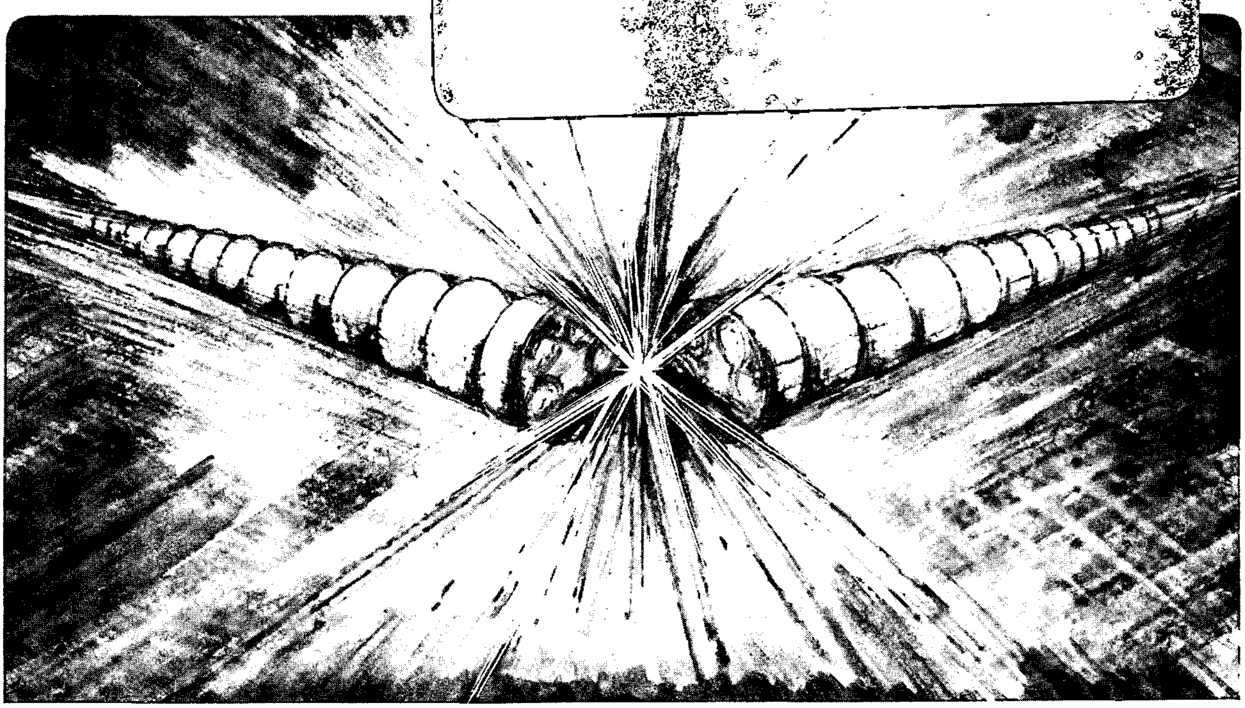

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Operational Characteristic of a Compact Microwave Ion Source

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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 different geometries and for various gases in a cw mode. For hydrogen, ion current density of 200 mA/cm^2 with atomic ion species concentration as high as 80% has been extracted from the source. It has also been demonstrated that low energy oxygen ion beams (5-10 eV) can also be extracted from the source.

I. 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. In virtually all 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. Therefore, it is 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[1] when it is operated with different gases to generate positive or negative ion beams.

II. Experimental Setup

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. The source has been operated with two different quartz tube configurations, the straight tube geometry and the expansion cup geometry. The straight quartz tube (Fig. 1a) has an outside diameter of 10 mm while the expansion cup (Fig. 1b) uses a section of 10 mm tube joined to a section of a larger tube with an outside diameter of 27 mm. In both cases the quartz tube is enclosed by a microwave cavity operated at a frequency of 2.45 GHz. Microwave power as high as 500 watts can be coupled to the cavity by means of a coaxial cable. Cooling air is directed at the discharge through an opening in the body of the cavity. Additional cooling of the source is provided by an air blower. Ionization of the gas in the tube is initiated by a hand-held Tesla coil. To properly match the impedance of the discharge to that of the generator, a tuning stub and a coupling slider are provided in the cavity, and once adjusted no further adjustments are necessary unless the flow conditions are changed. When properly adjusted, the cavity will maintain a discharge in various gases at pressures ranging from a few milli-torr to several hundred torr.

The open end of the quartz tube is enclosed by a two-electrode accelerator system. The first or plasma 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[2] located just outside the extractor is used to determine the plasma potential as well as the positive and negative ion species of the small extracted beam.

III. Experimental Results for Straight Tube Geometry

When the source is operated with hydrogen, the extracted positive ion current increases almost linearly with the absorbed microwave power. The extracted current density exceeds 200 mA/cm^2 when the microwave power is about 400 W. Hydrogen ion species are measured by the mass spectrometer. At low microwave power, the ion species is dominated by H_3^+ (~ 65%). As the power increases, the percentage of H_3^+ decreases while the concentration of H^+ increases, reaching ~ 75% at 400 W. Higher H^+ 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.[3]

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. Compared to the positive ion species, the H^- signal is about two orders smaller in magnitude.

The straight tube microwave source has also been operated with other gases such as O_2, Ne and Ar. In all cases, current density higher than 35 mA/cm^2 can be achieved by employing 300 W of power. 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. 2a shows that the majority of the ions are O_2^+. When higher power is used, Fig. 2b shows that O^+ becomes the dominant species. For Ne and Ar gases, ions with higher charge state are present in the plasma.

IV. Experimental Results for Expansion Cup Geometry

(a) Single hole extraction system

The expansion cup source geometry (Fig. 1b) provides a larger usable extraction area when a large diameter beam is needed. Figure 3 shows the extracted current density versus absorbed microwave power for optimum gas flow rates. It can be seen that the current density increases with power for all gases. As expected, the current density is typically lower (40 to 60%) for this geometry as compared to that of the straight tube configuration. The lower current density is due to the increased volume of the expansion cup geometry and the increased distance from cavity to extraction grid. However, the useful extraction area has increased from 0.5 cm^2 to over 3 cm^2 with the expansion cup geometry.

The effect of mounting magnets columns around the expansion cup is shown in Fig. 4 when neon gas is used. In this arrangement, the expansion cup geometry is operated as a small multicusp ion source. The effect of the magnets is most notable at lower power levels. It is observed that a 100% increase in current density occurs at 100 W for neon, tapering off to a 36% increase at 400 W of absorbed microwave power. For other gases, this multicusp source geometry improves the extracted current density by 10 to 40% at high power levels.

(b) <u>25-hole and screen extraction systems</u>

In order to increase beam current, an extractor with twenty-five .8 mm diameter holes was fabricated for the expansion cup source geometry. The resulting beam current is ~ 18 times greater than that of the single aperture. A further improvement of ~ 6 times in beam current was achieved with an extractor using a screen electrode. The electrode was fabricated using a 1 cm diameter tungsten screen of 70% transparency in place of the extraction holes.

The screen electrode was used to generate very low energy (5-10 eV) oxygen ion beams for material surface studies. No bias was applied to the plasma electrode and hence the ions were "self-extracted" from the source (the source plasma potential is the accelerating potential). This source generated an O^+ ion flux > 2×10^{14} $cm^{-2}s^{-1}$ with beam energies as low as 5.6 eV. Figure 5 shows a radial beam profile obtained downstream from the plasma electrode. The beam is symmetrical about the axis and is approximately gaussian in shape. In conclusion, we have presented some of the characteristics of a small microwave ion source. The source operation is simple and it has only a few components. Limited lifetime elements such as filaments and cathodes are eliminated, allowing stable long life operation even for reactive gases such as oxygen. Future plans for this source include the production of metallic ion beams as well as further measurements of the ion source characteristics.

Acknowledgments

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Figure Captions

Fig. 1 (a) Schematic diagram of the straight tube microwave ion source, (b) Schematic diagram of the expansion cup microwave ion source with confining magnets.

Fig. 2 Spectrometer output signal showing the distribution of the extracted positive oxygen ion species using (a) 100 watts and (b) 200 watts of absorbed microwave power.

Fig. 3 A plot of the extracted positive ion current density as a function of absorbed microwave power for oxygen, neon and argon using the expansion cup ion source.

Fig. 4 A plot of the extracted neon ion current density as a function of the absorbed microwave power using the expansion cup ion source with and without the confining magnets.

Fig. 5 A radial profile of low energy oxygen beam current taken near the plasma electrode.

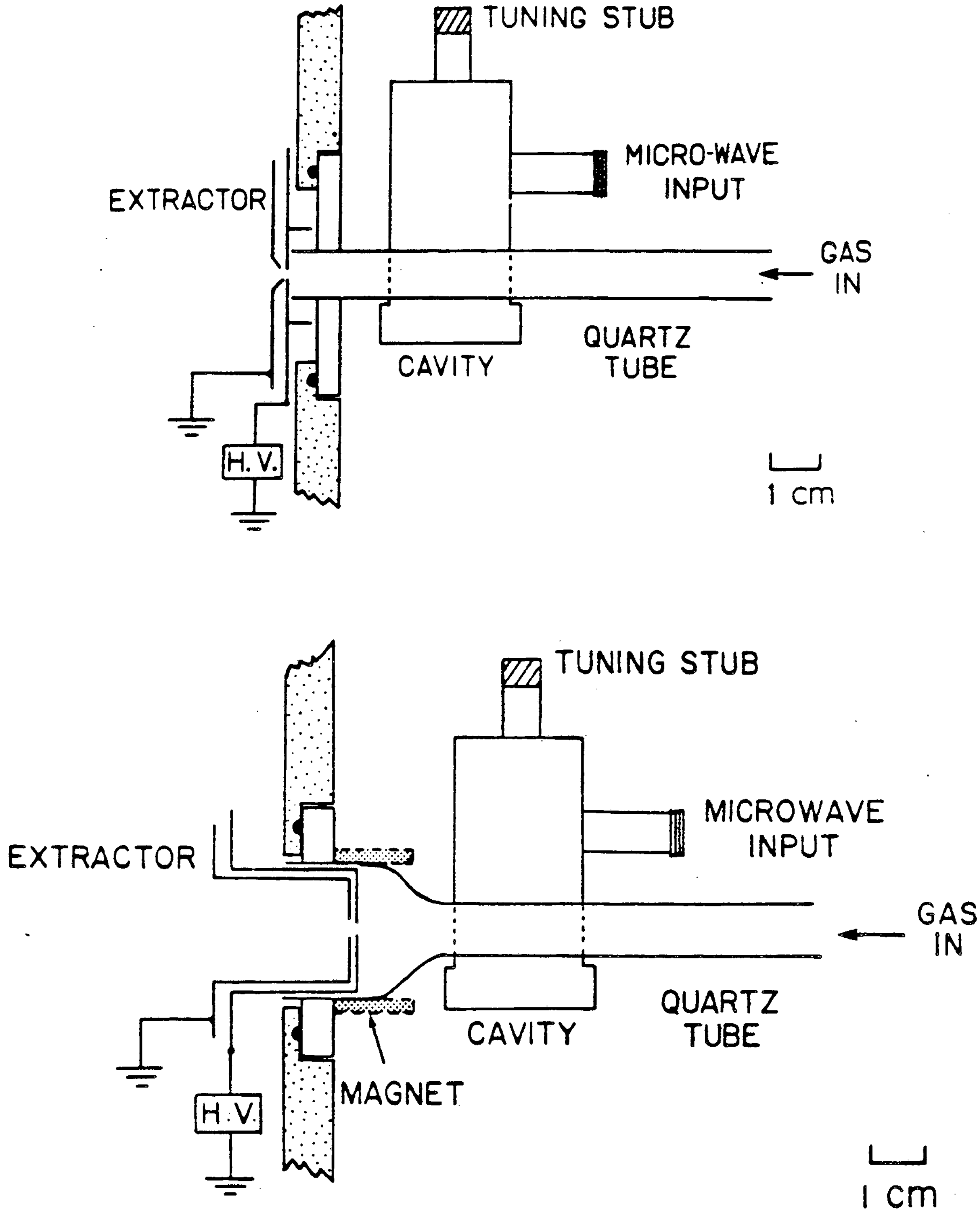

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Fig. 1

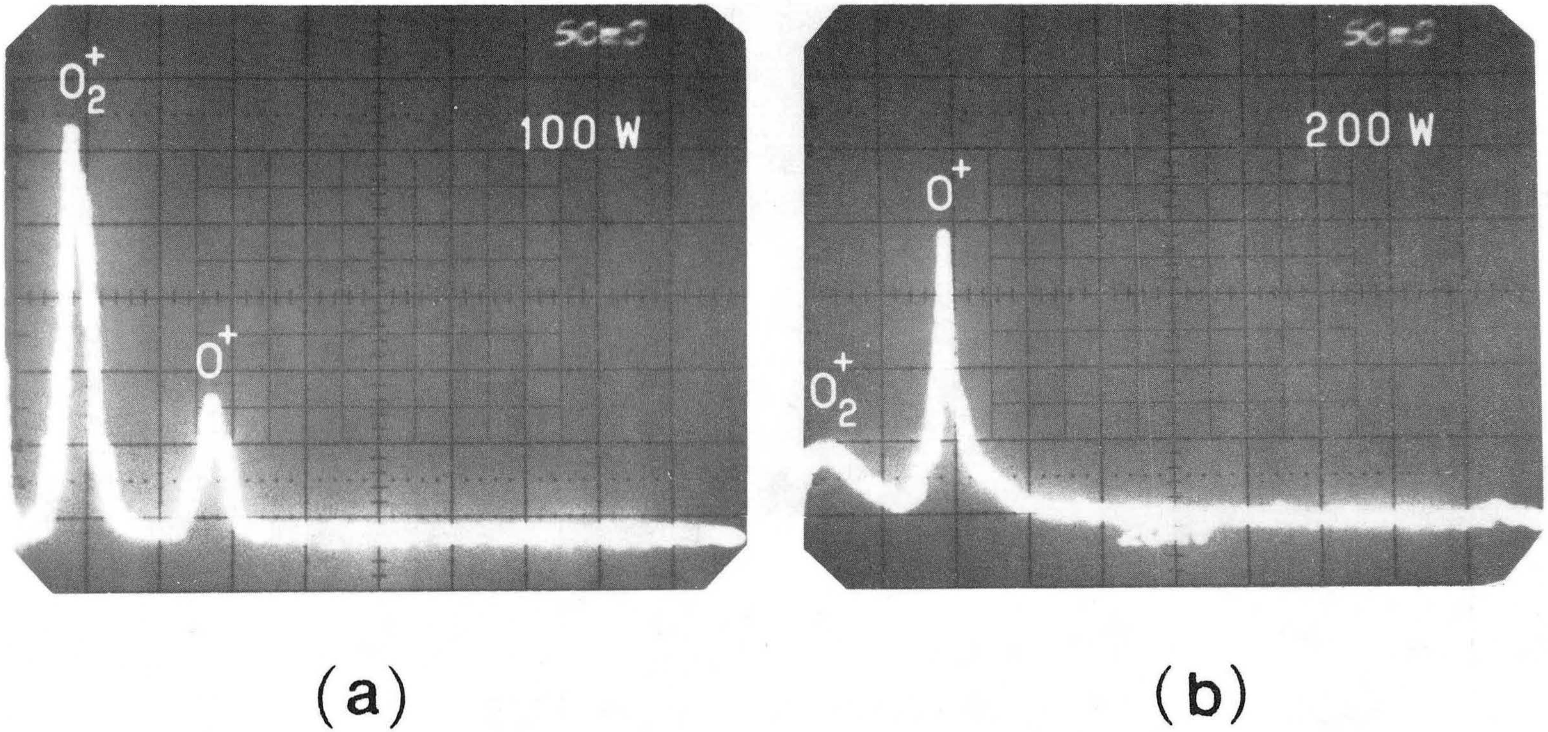

Fig. 2

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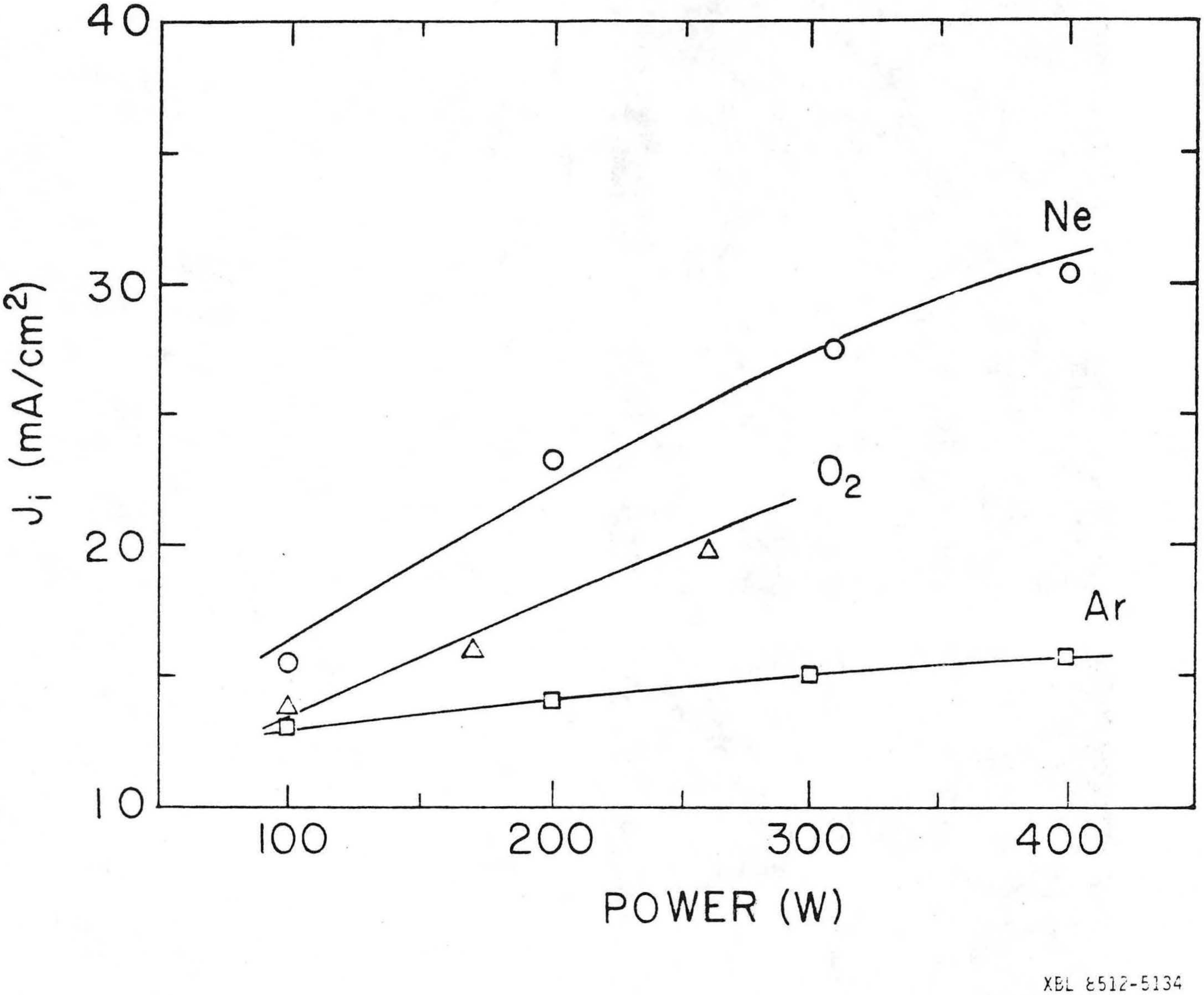

40
30
20
10
100
200
300
400
POWER (W)
J_i (mA/cm^2)
Ne
O_2
Ar
XBL 8512-5134

Fig. 3

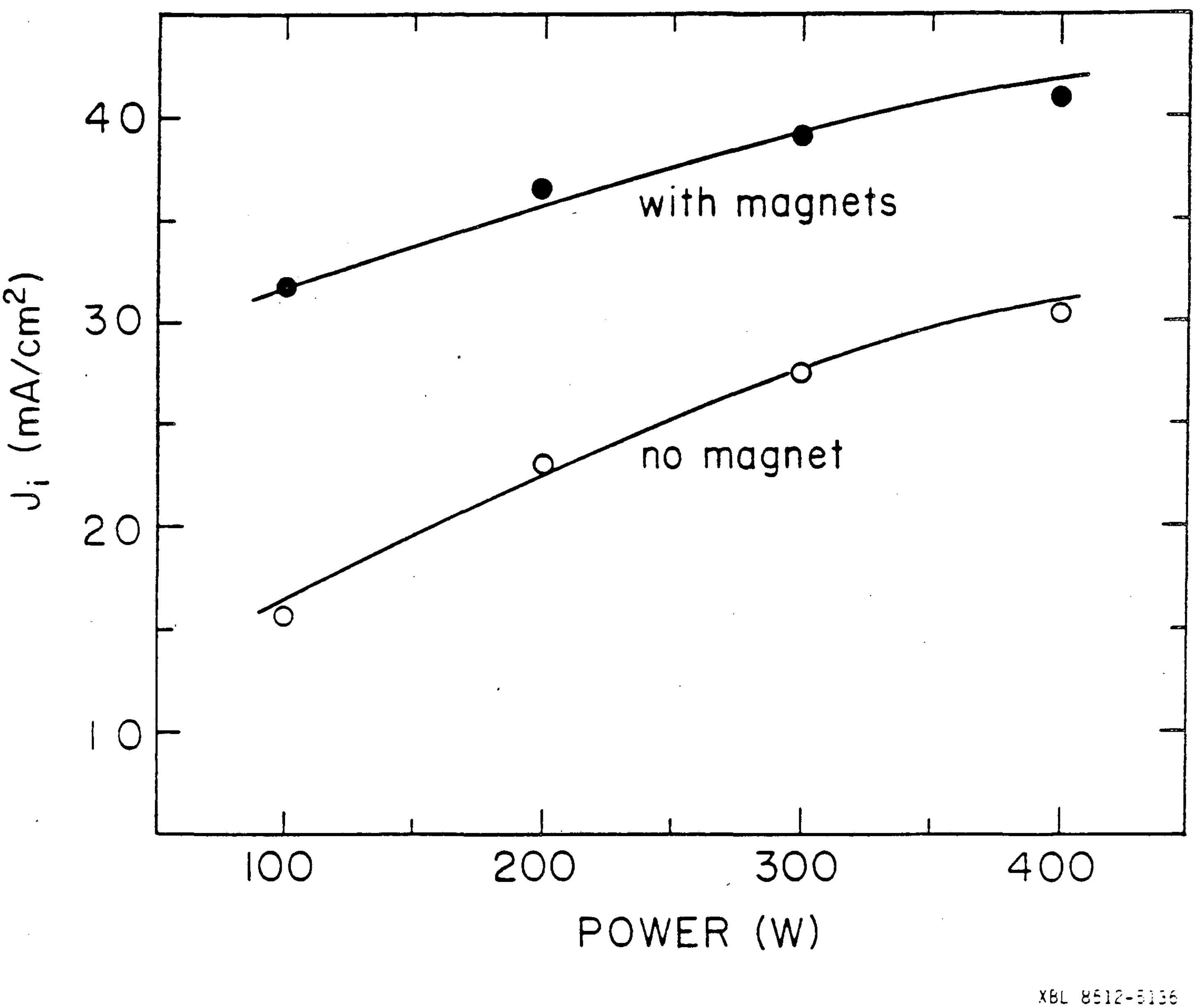
with magnets
no magnet
J_i (mA/cm^2)
10
20
30
40
100
200
300
400
POWER (W)
XBL 8512-5136

Fig. 4

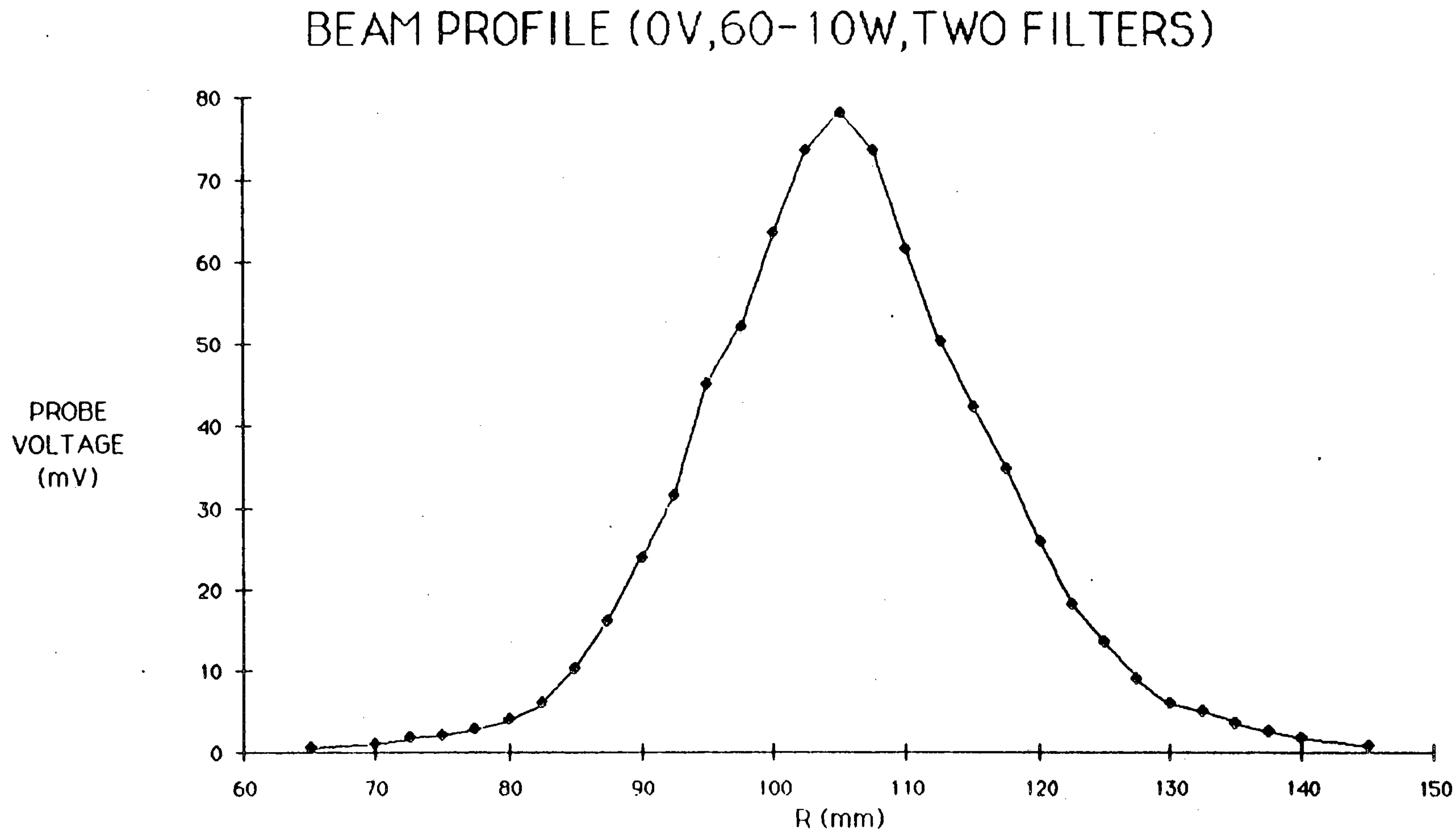

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Fig. 5