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### Publication Date

1986-05-01



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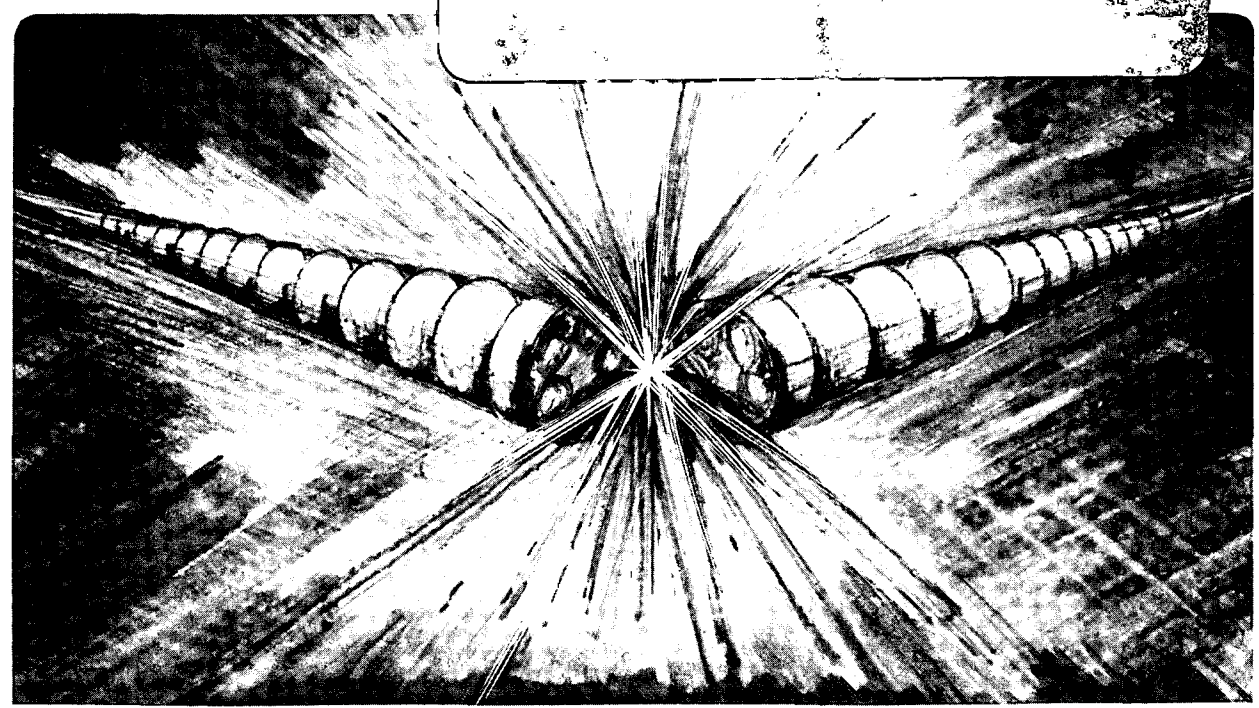
Submitted to Applied Physics Letters

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May 1986

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## DEVELOPMENT OF LOW ENERGY OXYGEN ION BEAMS FOR SURFACE STUDIES\*

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A small microwave ion source has been constructed to generate low energy (5-10 eV) oxygen beams. The source is fabricated from a quartz tube and is enclosed by a microwave cavity. The source is operated without an external extraction voltage. Positive ions effuse from the source with energies equal to the plasma potential. The source has been operated in a cw mode producing an atomic oxygen ion fluence  $> 1 \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1}$  with energies as low as 5.5 eV. The "self-extracted" ion beam can be used to simulate the oxygen environment encountered in low earth orbits.

\*This work is supported by the Hughes Aircraft Co. and the U.S. DOE under Contract No. DE-AC03-76SF00098.

## I. Introduction

Surfaces in low earth orbits (LEO, 200-600 km altitude) undergo bombardment by oxygen atoms with relative energies of approximately 5 eV. A laboratory source of low energy atomic oxygen is therefore desirable to access the effects of the LEO environment on material surfaces. Requirements for such a source are that it model the LEO environment as closely as possible which entails a high percentage of atomic oxygen in the beam, low beam energy spread, flux rates equivalent to LEO rates, and continuous long-life operation. The properties of a microwave ion source<sup>1</sup> are well suited to these requirements. There are no lifetime-limited components such as filaments or cathodes, so stable cw operation is possible for long periods of time. The beam contains both atomic and molecular oxygen ions that are neutralized on the target surface. Beam energies as low as 5.5 eV have been demonstrated. Atomic oxygen ion percentage is approximately 50% for all test conditions and atomic ion fluxes  $> 1 \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1}$  are generated. Experiments conducted at the Los Alamos National Laboratory demonstrated that the ion energy spread for the source to be extremely low ( $< 1 \text{ eV}$ ).<sup>2</sup>

## II. Experimental Setup

A small microwave ion source (Fig. 1) has been fabricated from a quartz tube with one end enclosed by a gridded plasma electrode and a gas inlet at the other end. This tube is formed by joining a section of quartz tube with a 10 mm outside diameter to a section of a larger tube with a 27 mm outside diameter. The smaller tube is enclosed by a microwave cavity operating at a frequency of 2.45 GHz. Microwave power as high as 500 W can be coupled to the cavity via a coaxial cable. Cooling air is directed on 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. A tuning stub and coupling slider are provided in the cavity to properly match the impedance of the discharge to that of the generator. Forward and reflected microwave power are measured using a bi-directional power meter. With this arrangement, it is possible to generate a stable discharge for a wide range of gas pressures and microwave power levels.

The source is operated without any externally applied extraction voltage. The positive ions (and some electrons) are self-extracted from the source due to the positive plasma potential. The energy of the beam ions striking a target surface is equal to the difference between the plasma potential and the target potential. If the target is an insulator, then it can be charged to a positive potential and the resultant ion impact energy is reduced. For a conducting target, however, it can be at ground or zero potential and the ion impact energy is equal to the plasma potential. Ion energy and species composition were both determined with a compact magnetic-deflection spectrometer.<sup>3</sup> The "self-extracted" beam current was measured with a current meter attached to a 6.45 cm<sup>2</sup> copper target located outside the source.

### III. Experimental Results

#### (a) Low energy positive oxygen ion beams

Initial plasma potential measurements showed that the oxygen ions were escaping from the source with energies between 15 and 20 eV. In order to achieve a lower ion energy, the source plasma potential must be reduced. Both

gas flow and microwave power were varied to obtain the lowest possible plasma potential. Consequently, the ion energy was reduced to approximately 9.7 eV but at the cost of lowering the beam flux. To further reduce the plasma potential, a magnetic filter<sup>4</sup> consisting of two ceramic bar magnets was installed in front of the plasma electrode to create a B-field perpendicular to the axis of the quartz tube (Fig. 1). The filter produces a field of approximately 50 gauss, which lowers the potential of the plasma in the expansion cup region, resulting in a further reduction of the beam current.

(b) Increasing the beam current

A single 0.8 mm diameter hole was initially employed to extract a positive ion beam from the microwave source. However, this geometry does not produce an adequate ion flux over a large target surface. In order to increase the flux, (for the purpose of simulating the LEO environment) a new extractor with twenty-five 0.8 mm-diam holes distributed uniformly within a circle of 1 cm diameter was fabricated. The resulting beam current was approximately 18 times larger than that of the single aperture geometry and it could be used to irradiate large target areas.

With the multiple-hole plasma electrode, the beam current was found to be too small to provide an adequate ion flux to the target when the beam energy was very low. Figure 2 is a plot of the beam profile (by collecting positive ion current in a moveable probe) and it shows a large dip in the center. The apparent reduction in the positive current is caused by the high energy electrons escaping from the source. A second magnetic filter was installed just outside the extractor to eliminate the high energy electrons in the beam. This filter produced a maximum B-field of ~ 100 gauss which is just

strong enough to deflect away electrons with energies as high as 100 eV, while oxygen ion deflection was negligible.

In order to improve the self-extracted beam current, a 70% transparent tungsten screen of 1 cm diameter was used in place of the 25 small holes. The combination of the magnetic filter and the tungsten screen extraction system produced a nearly gaussian beam profile as illustrated in Fig. 3. The extracted beam current has improved dramatically (approximately 6 times greater) with the tungsten screen plasma electrode, achieving high flux rates ( $> 1 \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1}$ ) at even the lowest beam energies.

Table I shows the source operating parameters for both conducting and insulating targets when low energy positive oxygen ion beams are produced. In the case of an insulating target, the ion impact energy is modified. The target surface is charged to a positive potential of 1 to 3 volts and therefore the ion impact energy and flux will be reduced. This potential was determined by simulating the insulating target with an isolated metal target surface. A high impedance voltmeter was connected to the metal target to measure its potential. The output signal from the mass spectrometer shows the presence of  $\text{O}^+$  and  $\text{O}_2^+$  ions, and the distribution of these two ion species is about equal.

### (c) Low Energy Negative Oxygen Ion Beams

The possibility of utilizing negative oxygen ions to form a low energy beam has also been investigated. In this scheme, the plasma electrode was biased negative to extract the negative oxygen ions. Preliminary studies have shown that the available beam current should be comparable to the positive ion



beam current. However, the lowest beam energy obtained was higher (16-25 eV) and it varied only slightly with discharge parameters and plasma electrode bias. This limitation could be overcome with an accel-decel arrangement if no other scheme for lowering the ion energy is found. Electrons in the extracted beam were filtered with a pair of ceramic bar magnets as previously described. The output signal from the mass spectrometer showed that the dominant negative ion species to be  $O^-$ , and the lowest  $O^-$  ion beam energy achieved was approximately 16 eV.

#### IV. Conclusion

A source of low energy oxygen ions has been developed to simulate LEO environmental conditions. This system has produced a large positive oxygen ion flux ( $> 1 \times 10^{14} \text{ cm}^{-2} \text{ s}^{-1}$ ) with energies as low as 5 eV. Stable long-life operation is achieved with a microwave ion source using no filaments or cathodes. Preliminary studies also demonstrated that the same source is capable of generating low energy negative oxygen ion beams ( $\sim 15$  eV) with flux comparable to that of the positive oxygen ion beams.

#### Acknowledgments

We would like to thank D. Moussa, D. Kippenhan, and M. D. Williams for technical assistance, and Dr. E. Chamberlin for the ion beam energy spread measurement at Los Alamos National Laboratory. This work is supported by the Hughes Aircraft Company and the U.S. DOE under Contract No. DE-AC03-76SF00098.

## References

1. K. N. Leung, S. Walther, and H. W. Owen, IEEE Trans. on Nuc. Sci. NS-32, No. 5, 1803 (1985).
2. E. Chamberlin, Los Alamos National Laboratory (Private Communication).
3. K. W. Ehlers, K. N. Leung, and M. D. Williams, Rev. Sci. Instrum. 50, 1031 (1979).
4. K. N. Leung, K. W. Ehlers, and M. Bacal, Rev. Sci. Instrum. 54, 56 (1983).

### Figure Captions

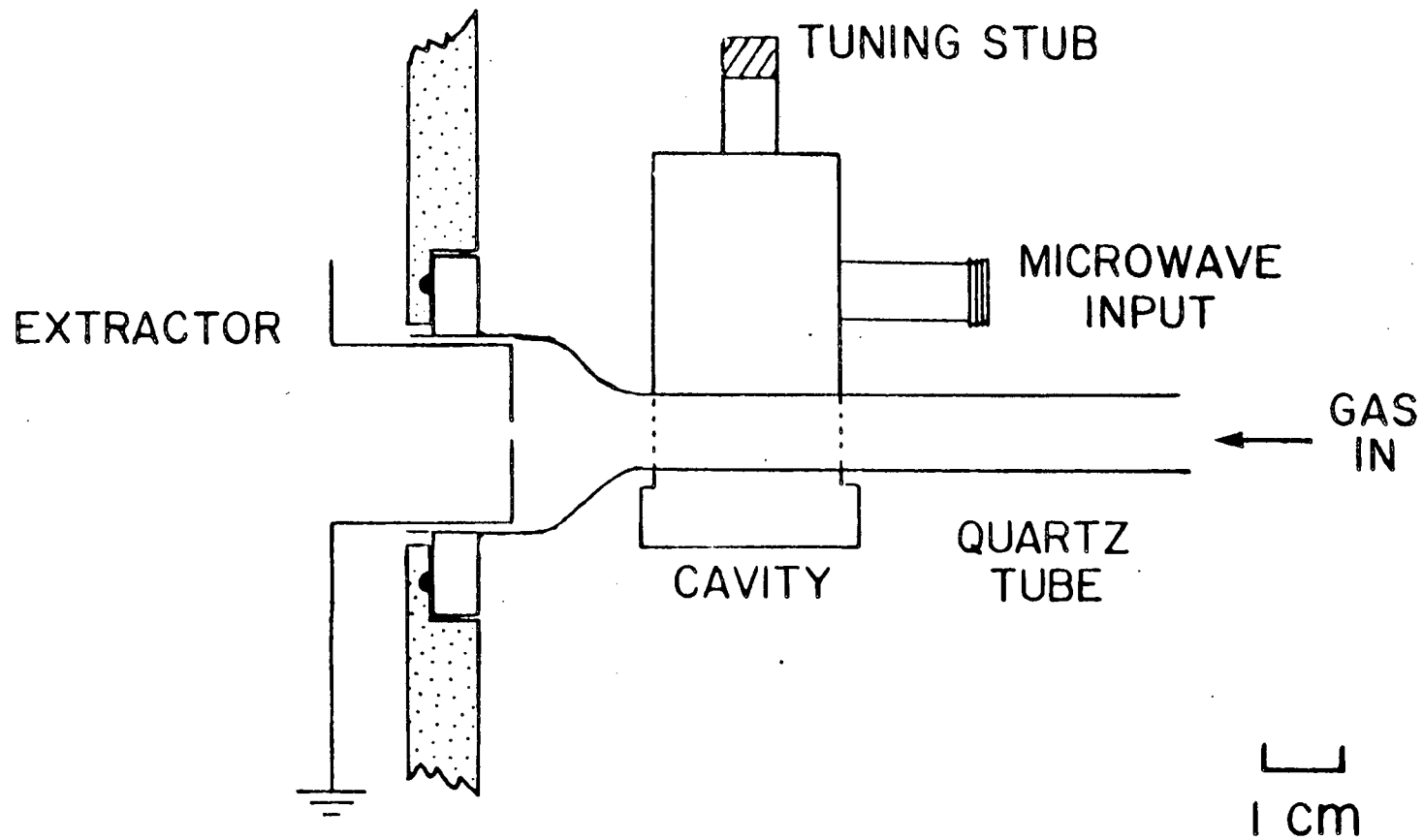
1. Schematic diagram of the low energy microwave ion source. The extractor shown is the single 0.8 mm aperture plasma electrode.
2. Beam profile of the source using the 25-hole plasma electrode. A large dip in the middle indicates the presence of high energy electrons in the beam.
3. Beam profile of the source using a tungsten screen plasma electrode and filter magnets.

Table I

## OPERATING PARAMETERS FOR THE LOW ENERGY OXYGEN ION SOURCE

Operating Point	Beam Flux*(cm <sup>-2</sup> s <sup>-1</sup> ) Conducting Target	Beam Energy (eV)	
		Conducting Target	Insulating Target
1	-	5.5	-
2	3.1 x 10 <sup>14</sup>	6.9	5.6
3	6.5 x 10 <sup>14</sup>	12	9.9
4	1.2 x 10 <sup>15</sup>	20	17.6

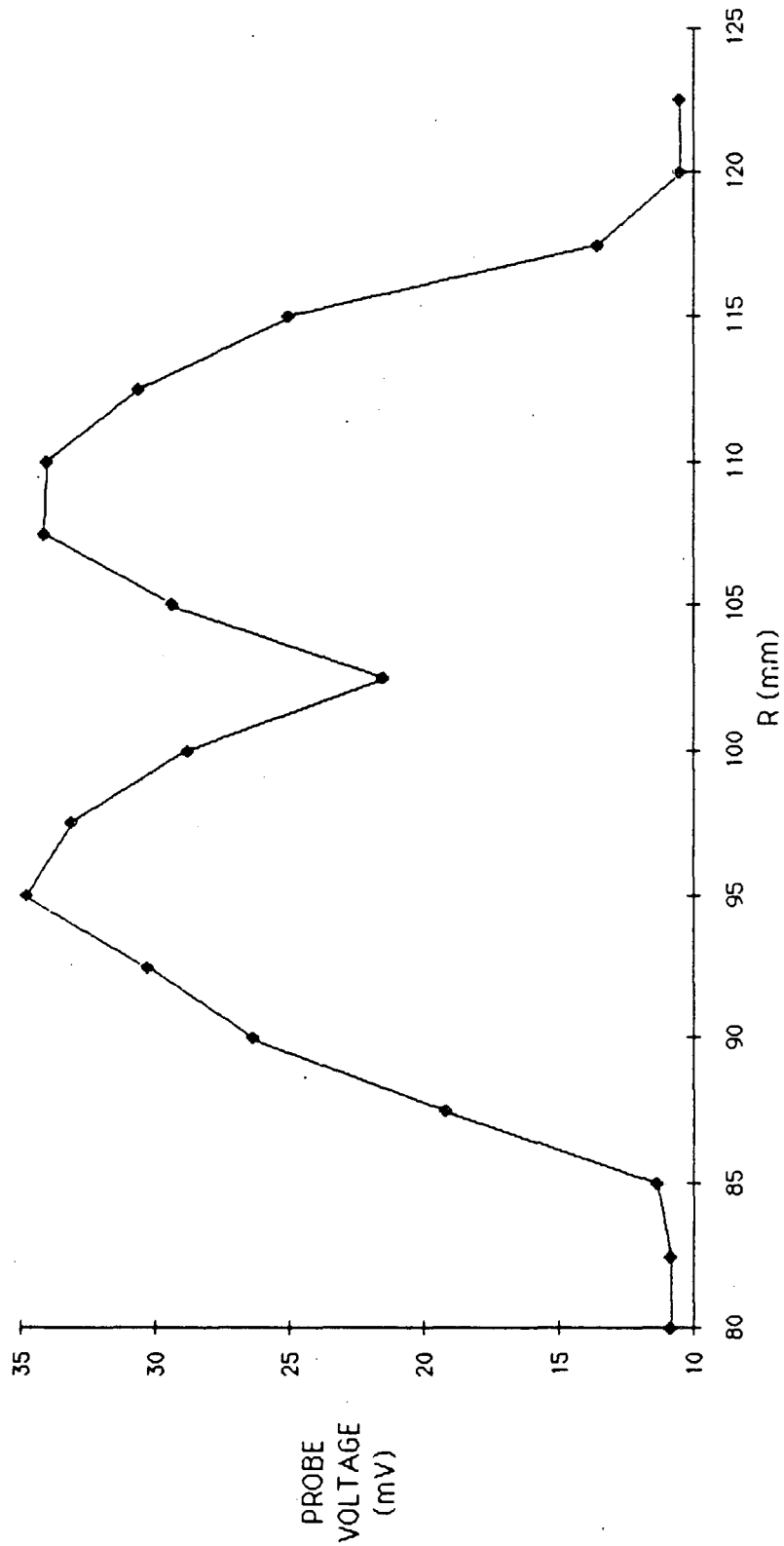
\*Atomic oxygen ion flux, molecular flux is equal to this.



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Fig. 1

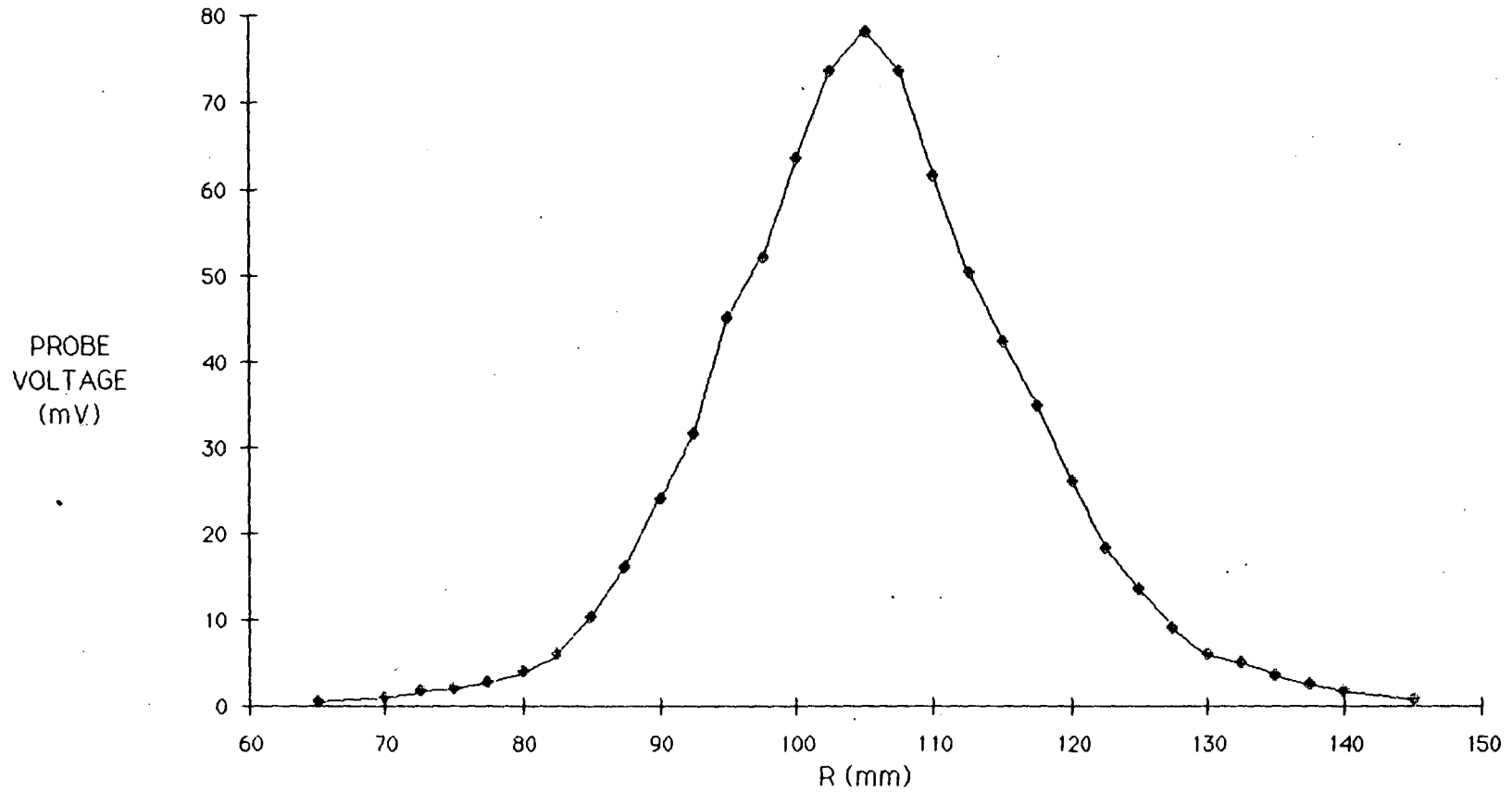
# BEAM PROFILE (50V, 240-40W)



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Fig. 2

# BEAM PROFILE (0V,60-10W,TWO FILTERS)



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XBL 863-1053

Fig. 3

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