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Authors
Brown, I.G.
Galvin, J.E.
MacGill, R.A.
et al.

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I.G. Brown, J.E. Galvin, R.A. MacGill, and F.J. Paoloni

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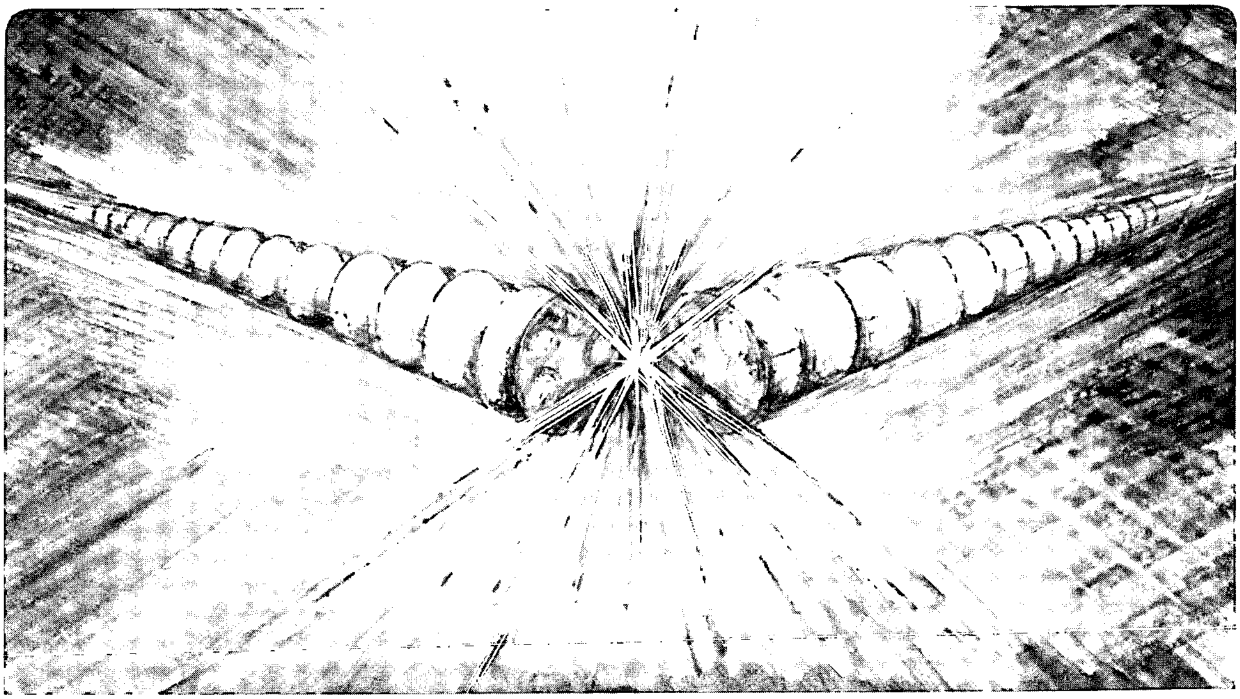

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BROAD-BEAM MULTI-AMPERE METAL ION SOURCE

Ian G. Brown, James E. Galvin and Robert A. MacGill,
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

and

Frank J. Paoloni
Electrical Engineering Department
University of Wollongong
Wollongong, NSW 2500
Australia

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Electrical Engineering Department
University of Wollongong
Wollongong, NSW 2500
Australia

ABSTRACT

An embodiment of the MEVVA (metal vapor vacuum arc) high current metal ion source has been developed in which the beam is formed from a 10-cm diameter set of extractor grids and which produces a peak beam current of up to several Amperes. The source, MEVVA V, operates in a pulsed mode with a pulse width at present 0.25 ms and a repetition rate of up to several tens of pulses per second (power supply limited). The multi-cathode feature that was developed for the prior source version, MEVVA IV, has been incorporated here also; one can switch between any of 18 separate cathodes and thus metallic beam species. Maximum beam extraction voltage is over 90 kV, and since the ion charge states typically from Q = 1 to 5, depending on the metal employed, the ion energy in the extracted beam can thus be up to several hundred keV. This source is a new addition to the MEVVA family of metal ion sources, and we are at present investigating the operational regimes and the limits to the source performance. In this paper we describe the source and present some preliminary results.

I. INTRODUCTION

The MEVVA ion source has been developed at LBL for particle accelerator injection and for ion implantation, and several different embodiments have been constructed and described in the literature [1-5]. Beam extraction voltage has been up to 100 kV, and the pulsed ion beam current has been typically a few hundred milliamperes. Beams of virtually all the solid metallic elements and some metallic alloys and compounds have been produced.

For use for metallurgical ion implantation, there is need for the time-averaged beam current to be practically as high as possible. For this purpose we have designed and fabricated an embodiment of the MEVVA source in which the electrical efficiency (ratio of beam current to arc current) and the ion beam current have been increased over earlier versions by allowing the plasma to expand to large diameter and forming the beam with a set of large area extractor grids. A pulsed metal ion beam with current up to several Amperes can be produced.

II. SOURCE DESCRIPTION

The metal vapor vacuum arc is a prolific generator of metal plasma. So much so, that in earlier versions of MEVVA ion sources it has been necessary to limit the amount of plasma presented to the extractor. That is, in order to form a directed ion beam from a plasma by means of a set of extractor grids, the plasma density at the extractor must not be too high, or else the beam will be of poor quality and/or the grids will break down (plasma between the grids will cause electrical breakdown between them). Thus the geometry of the sources in the region between the arc, where the plasma is formed, and the extractor, where the beam is formed, has been such as to allow a considerable loss of plasma.

It has been shown in prior work using a slightly modified MEVVA II that by more efficiently utilizing the vacuum arc plasma, it might be possible to produce an ion beam of current approaching 10 Amperes, without any increase in the arc current drive [6]. This was demonstrated by applying a magnetic field of up to 200 Gauss so as to effectively duct all of the plasma that is created at the cathode to the extractor (or collector plate, for these measurements). It was shown that the ratio of ion current (at the collector) produced by the vacuum arc to the arc current increases with field strength up to a saturation value of somewhat more than 5%. This is consistent with the results of earlier workers, who have found that the ratio of total ion current to arc current in the vacuum arc is, quite generally, about 8 - 12% [7-9]. The plasma is much too dense for a practical extraction, and for full utilization of all the plasma that is produced it is necessary to reduce the equivalent ion current density at the extractor location by increasing the size of the extractor grids and allowing the plasma to expand to fill this enlarged cross-sectional area.

In the MEVVA V a tapered magnetic bucket, formed from a multipole array of samarium cobalt permanent magnets, is used to radially confine the expanding metal plasma as it drifts from the cathode and through a drift region toward the beam formation electrodes. The virtue of doing the plasma expansion in this way is that the radial uniformity of the plasma density distribution can be kept relatively flat; it is a condition for optimum beam formation that the plasma density profile at the extractor be uniform. However, the source can also operate well without the magnets, in which case the plasma simply expands to fill the expansion chamber.

The extractor grid configuration chosen was a 3-grid, multi-aperture, accel-decel design that is quite conventional apart from their relatively large size. The extractor diameter is 10 cm and the individual holes in the grids are of diameter either 4.7 or 5.6 mm.

The multi-cathode concept that was developed for the MEVVA IV ion source [1,10] was incorporated into the MEVVA V also. The present cathode assembly holds 18 individual cathodes, between which one can switch simply and rapidly. Thus the source can produce beams of up to 18 separate metallic ion species with a single 'loading' of the cathode assembly. Furthermore, removing the cathode assembly, changing the individual cathodes, and re-mounting the assembly can be done quite quickly also.

The source is shown in Figures 1 and 2. The major sub-assemblies are shown partially disassembled, including the beam formation electrodes, vacuum chamber, copper anode plate, and the multiple cathode assembly. The vacuum wall is alumina and the primary fabrication material is aluminum.

III. PRELIMINARY RESULTS

The maximum extraction voltage at which the source has produced beam to-date is about 90 kV. Beam current onto target has been measured in two separate ways: (i) by means of a large-aperture, magnetically suppressed, Faraday cup positioned quite close to the source; (ii) by means of a calorimeter made from a 2 mm thick square copper plate of dimensions about 20 cm x 20 cm, adequate to collect the entire beam cross-section, and with attached thermistor for measurement of the temperature rise. The current determinations made in these two independent ways were in agreement, and the maximum current produced to-date is 3.5 Amperes, for an extraction voltage of 80 kV. Note that this current is the beam current actually delivered to the downstream target.

As an amusing visual demonstration of beam power, we increased the pulse repetition rate up to the limit set by our electrical system (by sagging of extractor and arc power supplies), so as to maximize the mean beam current, with the beam incident upon an aluminum target plate, and were able to melt a 3 cm diameter hole in the metal sheet in the space of several minutes. The aluminum sheet was of thickness 0.127 cm (0.05") and was positioned about 60 cm away from the source. The pulse repetition rate was 15 pps and the time-averaged beam current in the range 5 - 10 mA. A photograph of the target plate is shown in Figure 3.

The axial location of the cathode with respect to the permanent magnet multipole bucket structure is important to the efficiency with which the plasma plume generated at the cathode is collected by the magnetic geometry and presented to the extractor. In other words, the electrical efficiency (I_{beam}/I_{arc}) of the source varies with cathode position. This effect is shown in Figure 4, where the measured electrical efficiency is plotted as a function of location of the cathode with respect to the magnet structure. These data were obtained by temporarily replacing the multiple cathode assembly with a single, simple cathode which could be moved axially. When the multiple cathode assembly is incorporated into the source, the cathode surface is positioned at an axial location of 15 cm, in Figure 4. We have carried out some experiments geared toward modifying the magnetic field shape in the vicinity of the multiple cathode assembly by using an iron insert (a 'collar') in the region near the cathode so as to thereby increase the electrical efficiency of the source, but to-date we have not succeeded in increasing the electrical efficiency higher than indicated in the figure. There is thus a trade-off in maximum efficiency that can be obtained for the case when the multiple cathode feature is incorporated into the source design. Note, however, that the electrical efficiency refers to the beam current actually delivered onto target.

IV. CONCLUSION

A multi-Ampere, broad beam, multi-cathode, pulsed metal ion source, the MEVVA V, has been constructed and preliminary tests have been carried out. The source has produced beam at up to 90 kV and with peak ion current of up to 3.5 Amperes. This source version will be particularly useful for metallurgical ion implantation research applications. The concepts developed may find further use in the design and construction of yet larger MEVVA ion source embodiments.

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FIGURE CAPTIONS

Fig. 1 Partially dis-assembled MEVVA V showing the large area extractor grids and the multiple cathode assembly.

Fig. 2 MEVVA V. The copper anode can be seen, and the back of the multiple cathode assembly.

Fig. 3 Hole melted in aluminum target plate. Scale is in centimeters.

Fig. 4 Electrical efficiency (ratio of beam current onto target to arc current) vs. axial position of the cathode, referred to the magnetic bucket geometry. The diagram in the lower half of the figure is drawn to the same scale as indicated in the graph above; the dashed line on the left is the first extractor grid.

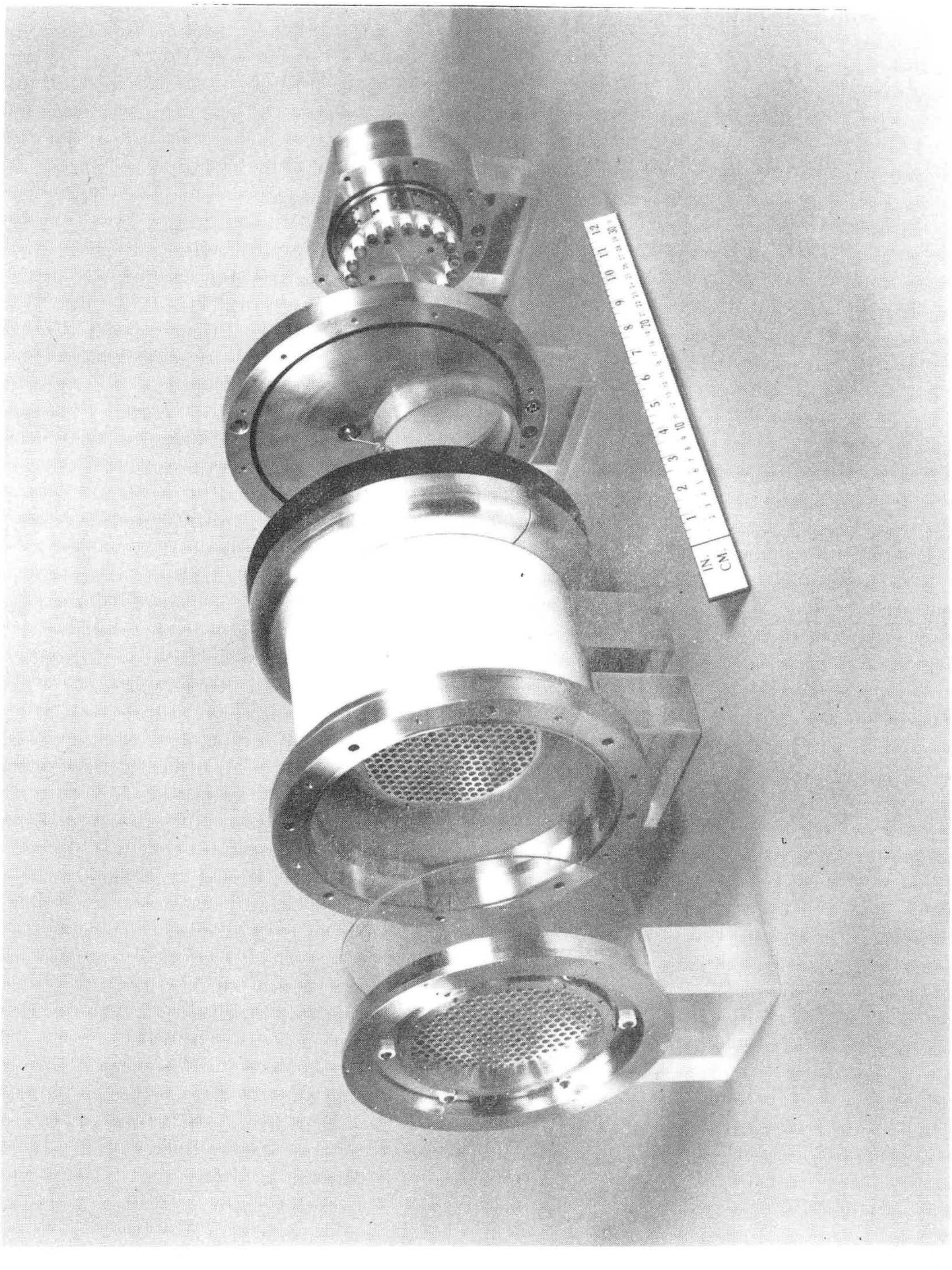

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Figure 1

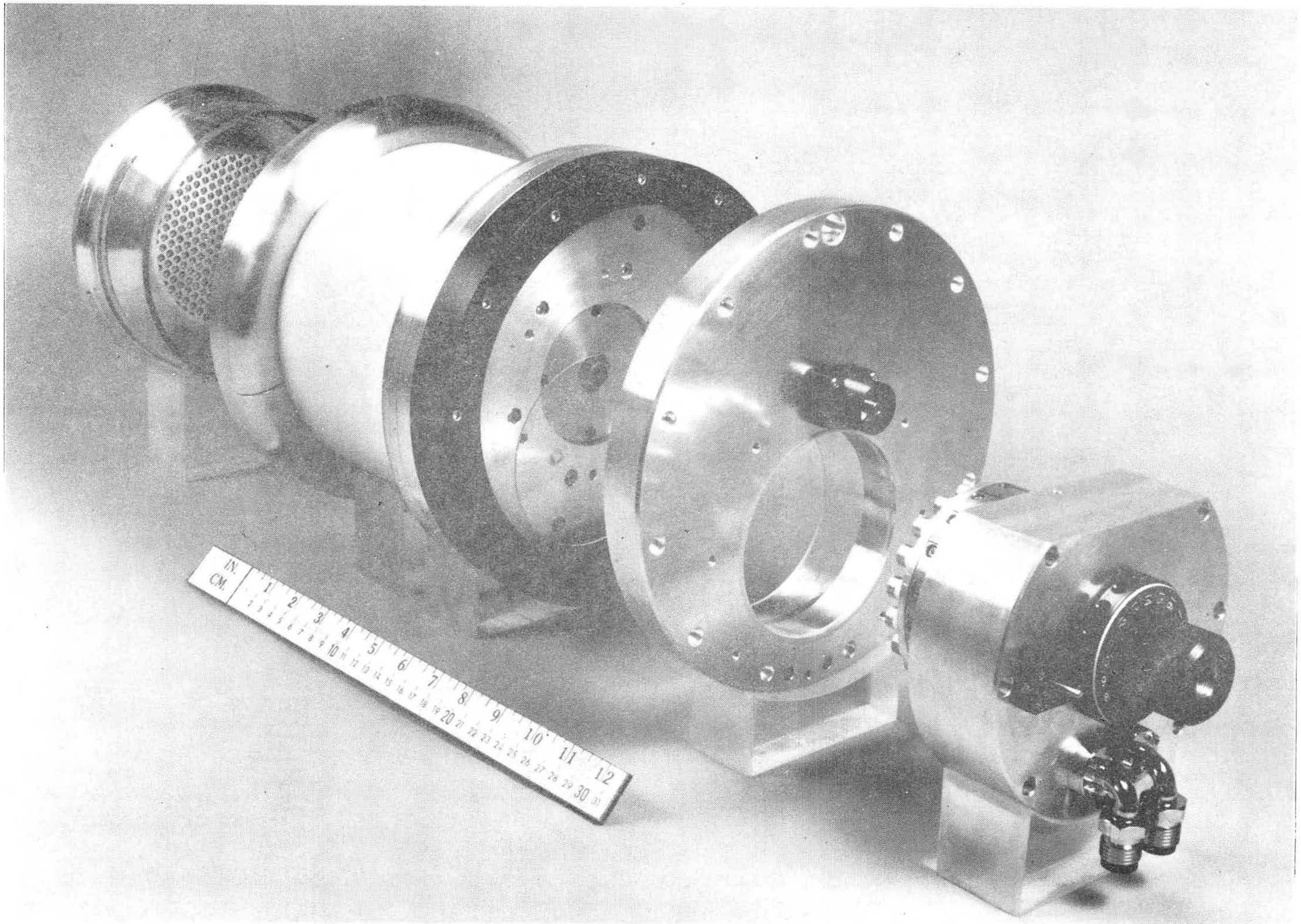

Figure 2

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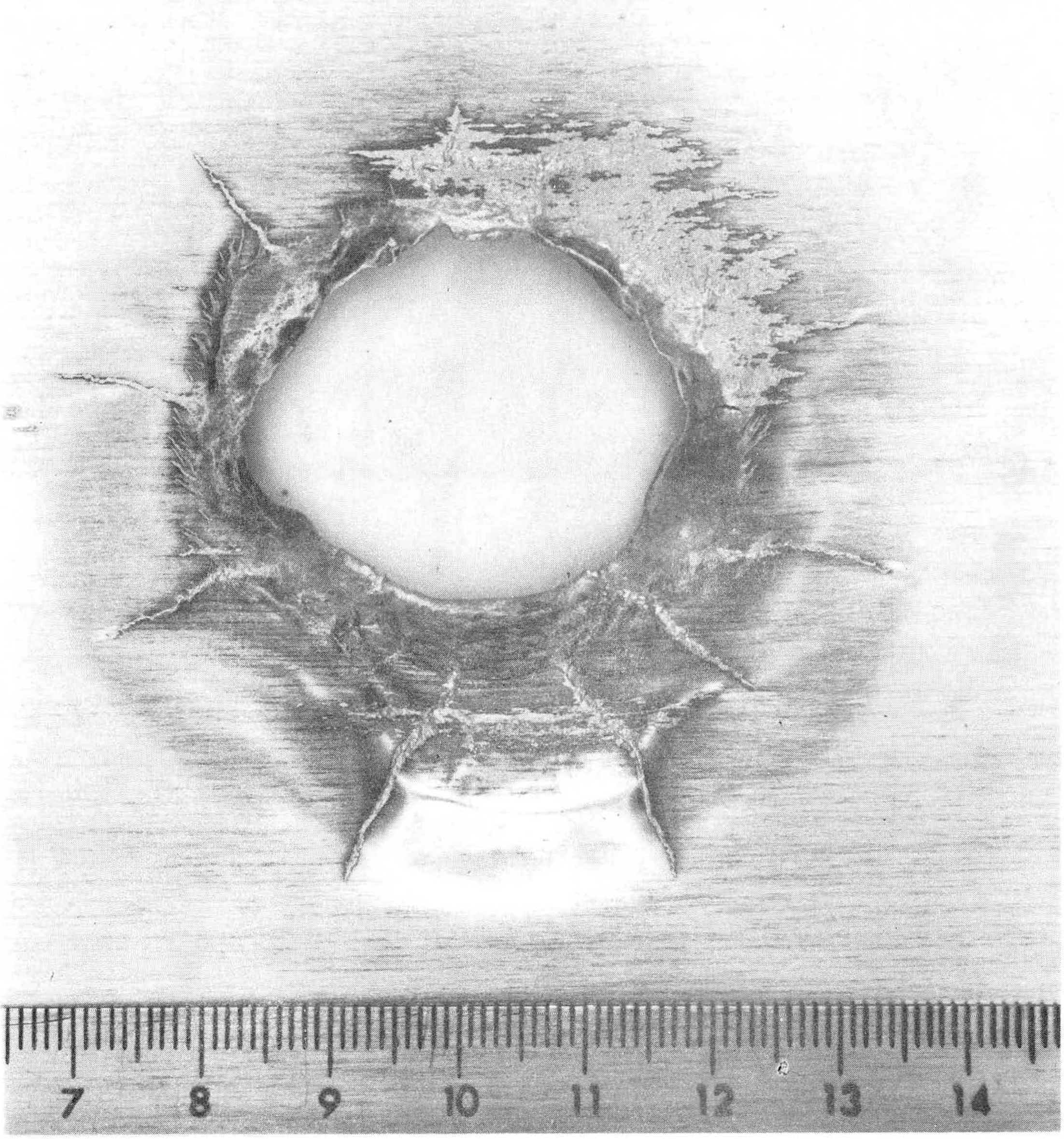

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Figure 3

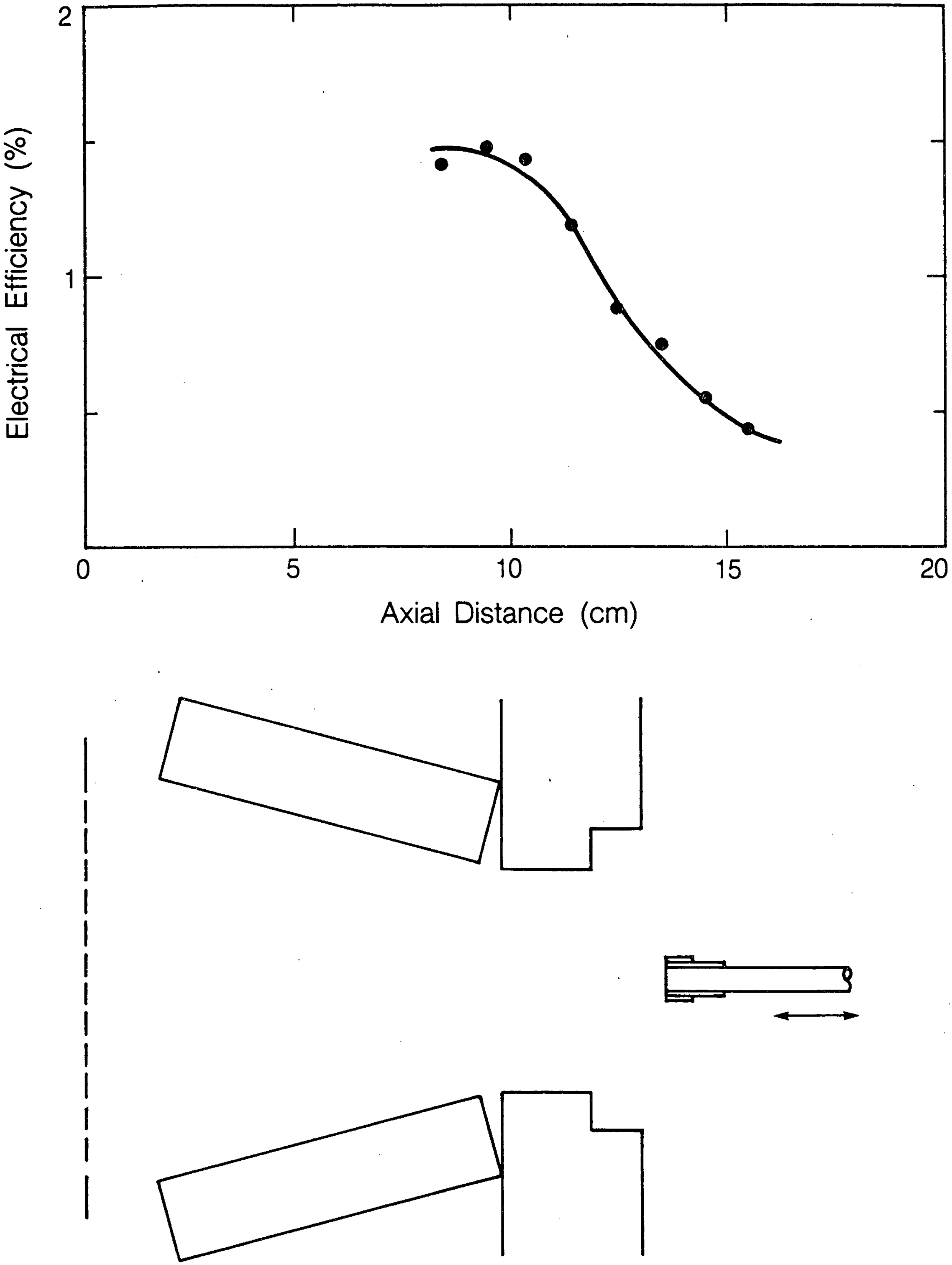

Figure 4

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720