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## Authors
Brown, I.G.
Dickinson, M.R.
Galvin, J.E.
et al.

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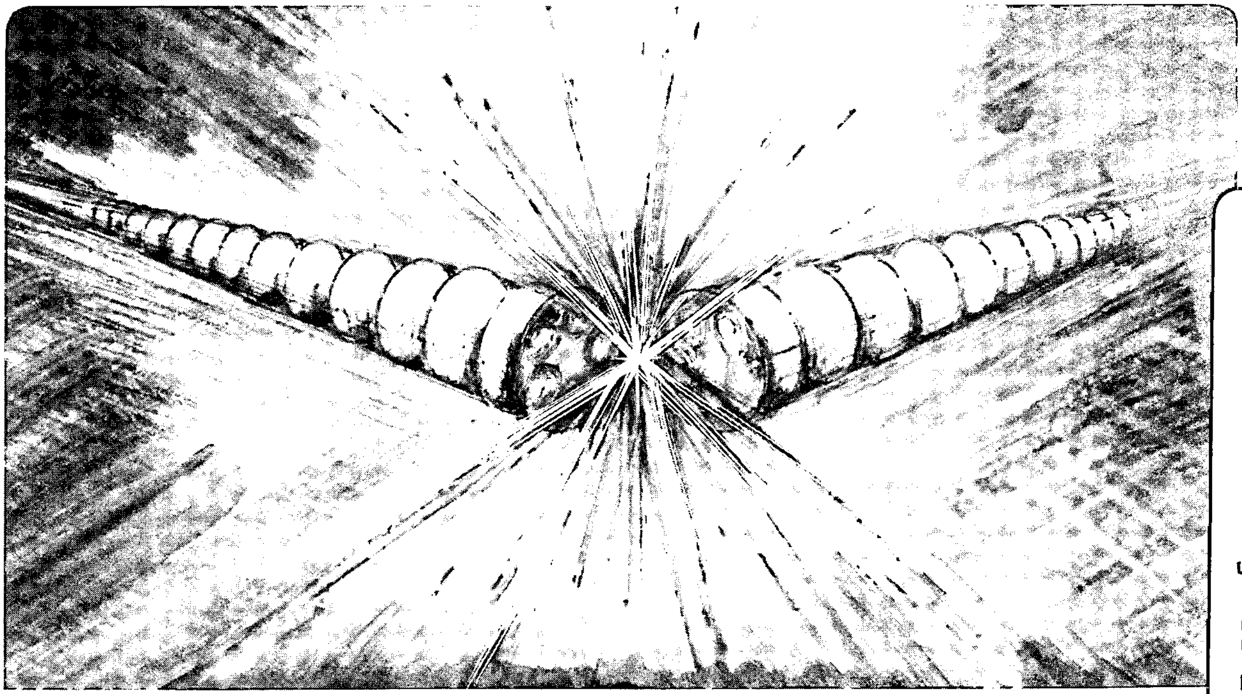

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I. G. Brown, M. R. Dickinson, J. E. Galvin and R. A. MacGill

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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# DEVELOPMENT OF A DC, BROAD BEAM, MEVVA ION SOURCE

I. G. Brown, M. R. Dickinson, J. E. Galvin and R. A. MacGill

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

## ABSTRACT

We are developing an embodiment of metal vapor vacuum arc (Mevva) ion source which will operate dc and have very large area beam. In preliminary testing, a dc titanium ion beam was formed with a current of approximately 0.6 amperes at an extraction voltage of 9kV (about 18 keV ion energy, by virtue of the ion charge state distribution) and using an 18 cm diameter set of multi-aperture extraction grids. Separately, we have tested and formed beam from a 50 cm diameter (2000 $cm^2$) set of grids using a pulsed plasma gun. This configuration appears to be very efficient in terms of plasma utilization, and we have formed beams with diameter 33 cm (FWHM) and ion current up to 7 amperes at an extraction voltage of 50 kV (about 100 keV mean ion energy) and up to 20 amperes peak at the current overshoot part of the beam pulse. Here we describe this part of our Mevva development program and summarize the results obtained to-date.

## I. INTRODUCTION

The Mevva (metal vapor vacuum arc) high current metal ion source development program at the Lawrence Berkeley Laboratory was started initially for the production of high current uranium ion beams for fundamental heavy ion nuclear physics research [1-3]. For this application the source is used in a pulsed mode of operation and at low duty cycle so as to match the injection requirments of the LBL heavy ion synchrotron, the Bevatron [4]. As it became clear that this kind of ion source could offer some advantages not only for accelerator injection but also for ion implantation, the need for changing the source parameters in several different ways became apparent. For example, whereas for accelerator injection a small area, low emittance beam is required to be delivered at a pulse length and duty cycle to match that of the accelerator, for ion implantation for materials surface modification it is usual that a large area beam of high duty cycle is required and beam emittance is not very important.

For this reason the early Mevva source embodiments [5-8] were designed with a relatively small beam extractor size (about 1 cm radius), a pulse length of 0.25 - 5 msec, and a pulse repetition rate of 1 - 10 pps. The Mevva V source [9] was the first to be made specifically for ion implantation application. It has a 10 cm diameter extractor and is well cooled so as to allow operation at the highest duty cycle that our electrical system can support. Like the Mevva IV (made for accelerator injection), it also incorporates a multi-cathode design, and one can switch rapidly between any of 18 separate cathode species. The ion implantation facility that has been built up around the Mevva V has performed excellently and is described elsewhere [10-12].

The metal vapor vacuum arc is an efficient and prolific generator of metal plasma. It is in principle possible to form dc beams of metal ions with beam current two or three orders of magnitude higher than the mean currents presently obtained with the repetitively pulsed Mevva source versions. This would be a very significant step toward the industrial utilization of Mevva ion implantation technology, as well as being important from the perspective of fundamental ion source development.

We have made a dc Mevva ion source and carried out some preliminary tests demonstrating satisfactory operation. Separately but as part of the same overall program objectives, we have also made and tested a set of very large area beam formation electrodes. Here we describe the philosophy behind our approach to this next step in Mevva evolution, the tests we have carried out, and the results we have obtained.

## II. APPROACH

Repetitively pulsed operation of a Mevva ion source typically entails parameters in the following range: arc current 100 A pulsed, arc voltage (burning voltage, during the arc-on time) 20 V, beam current 1 A pulsed, beam voltage 50 kV, beam energy 100 keV (due to an ion mean charge state which is typically about 2 [13,14]). Duty cycle might typically be of order 1%, and therefore the time-averaged arc power dissipation within the source is 20 W and the time-averaged beam power is 500 W. Cooling of the ion source and of the implantation target needs to be adequate for this amount of heat dissipation.

For dc operation, the approximate range of these parameters is increased by the inverse duty cycle, ie, by a factor of approximately 100. Then the arc power dissipation is around 2 kW and the beam power is around 50 kW. Note that it is not possible to reduce the arc current to arbitrarily low levels; for example one might wish to reduce the arc current to 1% of its previous (pulsed operation) value so as to maintain the same mean power values. However the arc will not operate at a current level of 1 A - it extinguishes well before this value is obtained. It is a well-established property of vacuum arcs that there is a minimum current level at which they will stay alive and below which the cathode spots are not maintained [15]. For an acceptably low probability of plasma extinction over long periods of dc operation, this minimum arc current can be taken as approximately 100 A; for some cathode materials a higher current will be required and for others a lower current may be possible. Thus power dissipation and cooling is a primary concern that determines the choice of parameters such as cathode configuration and extractor size.

Heat is generated at the front face of the cathode, so a flat cylindrical geometry is used with efficient water cooling at the rear surface. The rate of removal of cathode mass by arc erosion has been studied by a number of authors [15-17]. For most metals with not-too-low melting points the erosion rate is in the range 20 - 60 micrograms per Coulomb of arc current. The necessary cathode mass can then be estimated to be of order 1 kG per day of steady operation.

The dc beam power is high. We want to design for a large beam area so as not to melt the implantation target (if implantation is the application), and also for not-too-high beam power density dissipation in the beam formation electrodes themselves. Thus part of our design approach for a dc source is to use a very large area beam, and to obtain this large cross-sectional area by expanding the metal plasma prior to extraction and using very large area beam formation electrodes (extractor grids).

Since the arc current cannot be reduced arbitrarily and we none-the-less want to provide a means for varying the beam current over a wide range and to levels considerably less than 1 A, we include into our approach alternative methods of controlling the amount of plasma that is presented to the extractor grids: (i) the dc plasma gun is located at a distance from the extractor grids that can be varied from about 10 cm up to about 1 m, and (ii) this plasma transport region is immersed in a solenoidal magnetic field whose strength is continuously variable from zero up to about 100 G. These means, separately and together, provide straightforward control of the amount of plasma that is transported to the extractor grids, and thereby of the magnitude of the beam current produced.

There are other considerations. Because of the large mass of material that is transported away from the cathode, the plasma transport region is also considered to be a kind of "ash collection" region. For the same reason, the extractor grids may be needed to be replaced relatively often, and so they are designed to be both inexpensive and easily replaced. Triggering of the vacuum arc discharge is now done using an electromechanical approach rather than the high voltage pulsing method used for the pulsed sources.

## III. EXPERIMENTAL

We have made several different experimental configurations to test different parts of our approach. These are: (i) dc plasma source, (ii) dc ion source, and (iii) very large area extractor. Because of the constraints of our program, these different aspects of the dc Mevva development strategy were only partially overlapping. For example, the large area extractor tests were done using a pulsed metal plasma source and not a dc source, and the dc ion source tests were done at lower extraction voltage than the large extractor tests and at a lower beam current than was obtained in the dc plasma source tests.

A schematic of the set-up used for the dc plasma and ion source tests is shown in Figure 1. The plasma is created by a dc plasma gun and drifted through a region of variable length (0.1 - 1 m) and of variable field strength (0 - 100 G) to a biased collector plate of diameter approximately 20 cm. For all of the experiments reported on here we used a titanium cathode.

For the dc ion source tests, the simple biased collector plate was replaced by a 2-grid, multi-aperture, 18 cm diameter set of beam formation electrodes, followed by a beam collector plate at a distance from the grids of only some 7 cm; ie, the ion beam drift region was very short. To simplify the electrical requirements the plasma gun and plasma drift region were operated at ground potential and the ion beam drift region and collector plate were biased at high voltage; by this means we were able to operate at high arc current and to form a high current ion beam without biasing the high power arc supply to high voltage. The beam current was measured by monitoring the currents to various electrodes, including the beam collector plate, and by monitoring the temperature rise of the collector plate.

A photograph of the very large area extractor grids is shown in Figure 2. They are a 3-grid, multi-aperture, 50 cm diameter configuration fabricated from 4.76 mm thick aluminum. The beamlet holes are 1 cm in diameter and there are about 1000 of them; the extractor gap is 1 cm. The optical transparency is 40%. The grids and the conical plasma expansion region to which they are attached were positioned within our 60 cm diameter vacuum vessel together with a pulsed titanium vacuum arc plasma gun. A radially moveable, magnetically suppressed, 5 cm diameter Faraday cup was positioned approximately 10 cm in front of the extractor and used for measuring the beam and its radial profile.

## IV. RESULTS

Best operation of the dc plasma gun was obtained with an arc current of 150 A; for currents lower than this the arc sometimes spontaneously extinguished after on-times of order tens of minutes. At 150 A we operated for continuous on-times of about an hour (operator terminated). The vacuum pressure during operation was in the range $5 \times 10^{-7}$ to $1 \times 10^{-6}$ Torr. The collector plate bias was varied from 0 to -20 V to confirm that a saturation in collected ion current was being obtained (ion saturation current). We measured an ion current at the collector plate that could be varied from a low of 0.4 A to a high of over 5 A. The plasma current could be controlled both by the distance of the plasma gun to the collector and by the magnitude of the applied solenoidal magnetic field.

When the simple collector plate was replaced by a 2-grid extractor as described above, a dc titanium ion beam was produced. For this experiment the maximum voltage and current at which we could operate was severely limited by the dc power supply that was available to us. We measured a dc titanium ion beam current of approximately 600 mA at an extraction voltage of 9 kV, corresponding to a mean ion beam energy of about 19 keV because of the titanium ion charge state distribution ($\overline{Q} = 2.1$).

The 50-cm extractor was installed and operated in a "conventional" mode with a pulsed titanium Mevva plasma gun as described above. The radial profile of the extracted ion beam was measured with a suppressed Faraday cup, for an arc current of 100 A and an extraction voltage of 40 kV. The profile so obtained is shown in Figure 3. The FWHM of this profile is 33 cm, and the numerically integrated beam current is 1.5 A. The maximum extraction voltage at which we operated during these tests was 50 kV. At 50 kV and at an arc current of 300 A our record beam current was obtained, and an oscillogram of this condition is shown in Figure 4. Here the upper trace is the beam current monitored by on-axis Faraday cup and the lower trace is the arc current. By assuming the same radial profile as shown in Figure 3, the vertical current scale for the ion beam current trace is 5 A/cm. Thus the ion beam current during the relatively flat part of the pulse is approximately 7 A, and the peak current at the current overshoot part of the pulse is approximately 20 A. It is interesting to note that the figure of 7 A (at 300 A arc and 50 kV extractor) is in excellent agreement with that predicted from the figure of 1.5 A (at 100 A arc and 40 kV extractor), thus substantiating the assumption of constant beam profile (which after all is determined primarily by the plasma expansion prior to beam extraction). It is also of considerable interest to note that the ratio of beam current to arc current is 4.6% at the current overshoot or 2.3% during the current flat-top. It is known that the total ion current generated by the vacuum arc is 8% - 12%, fairly universally [15,18]. Given the 40% grid transparency, we conclude that the amount of plasma that is presented to the extractor is close to the entire amount that is generated by the plasma gun - the plasma expansion chamber and large area extractor configuration are very efficient in terms of plasma utilization.

We have described the tests we have performed and the results obtained with our first dc and very large area extractor Mevva ion source embodiments. The results are most encouraging, indicating that dc metal ion beams with beam current of order amperes to tens of amperes and with beam diameter of order a meter can be efficiently produced.

## ACKNOWLEDGMENTS

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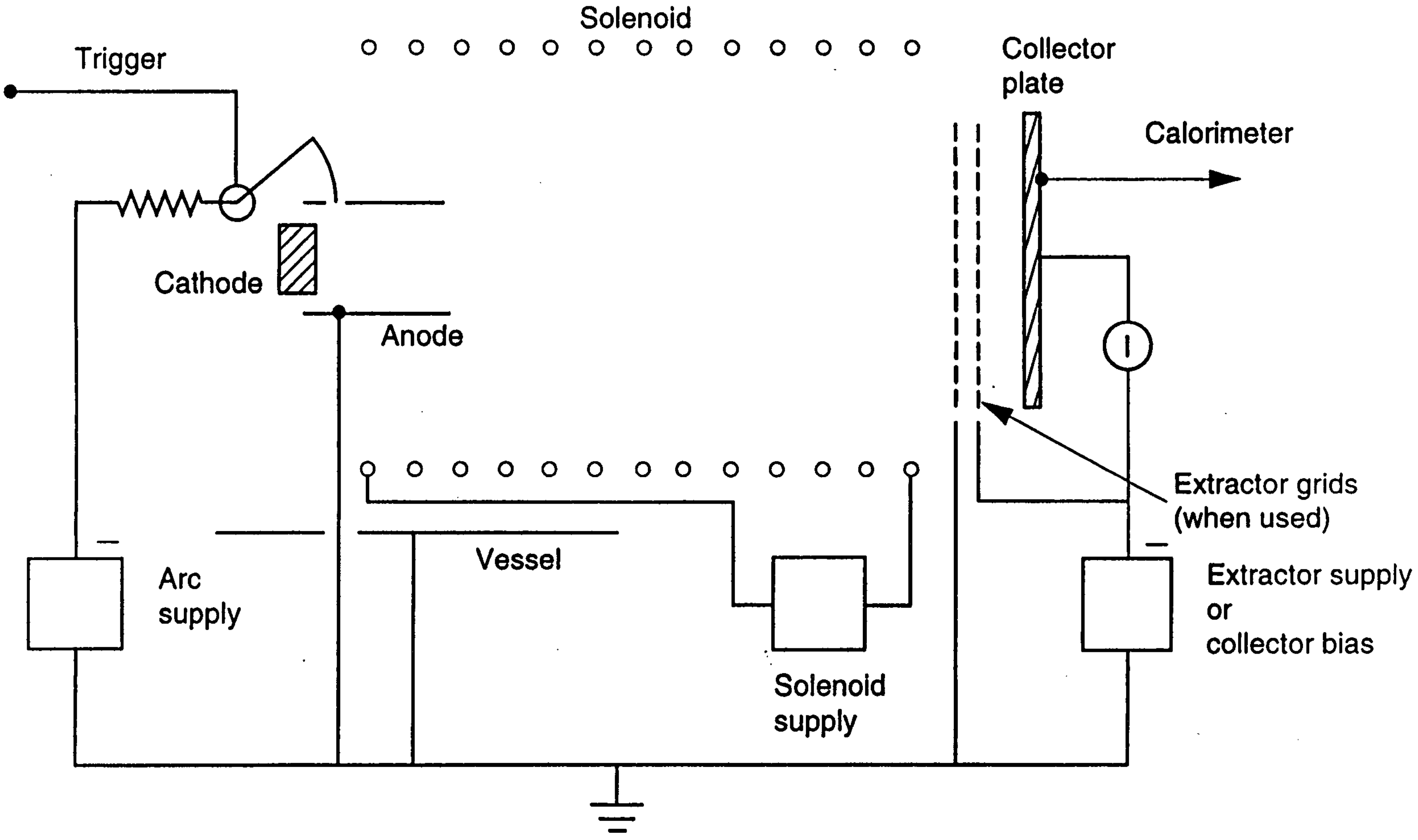
## FIGURE CAPTIONS

Fig. 1 Schematic of the dc experimental configuration. (XBL 918-7037)

Fig. 2 50 cm diameter beam formation electrodes. (CBB 913-1344)

Fig. 3 Radial profile of the ion beam current density. Extraction voltage 40 kV, arc current 100 A. (XBL 918-7038)

Fig. 4 Oscillogram of beam current and arc current.
Upper trace: beam current, 5 A/cm; Lower trace: arc current, 200 A/cm; Sweep speed 50 μs/cm. Extraction voltage 50 kV, arc current 300 A. (XBB 918-5993)



XBL918-7037

Fig. 1

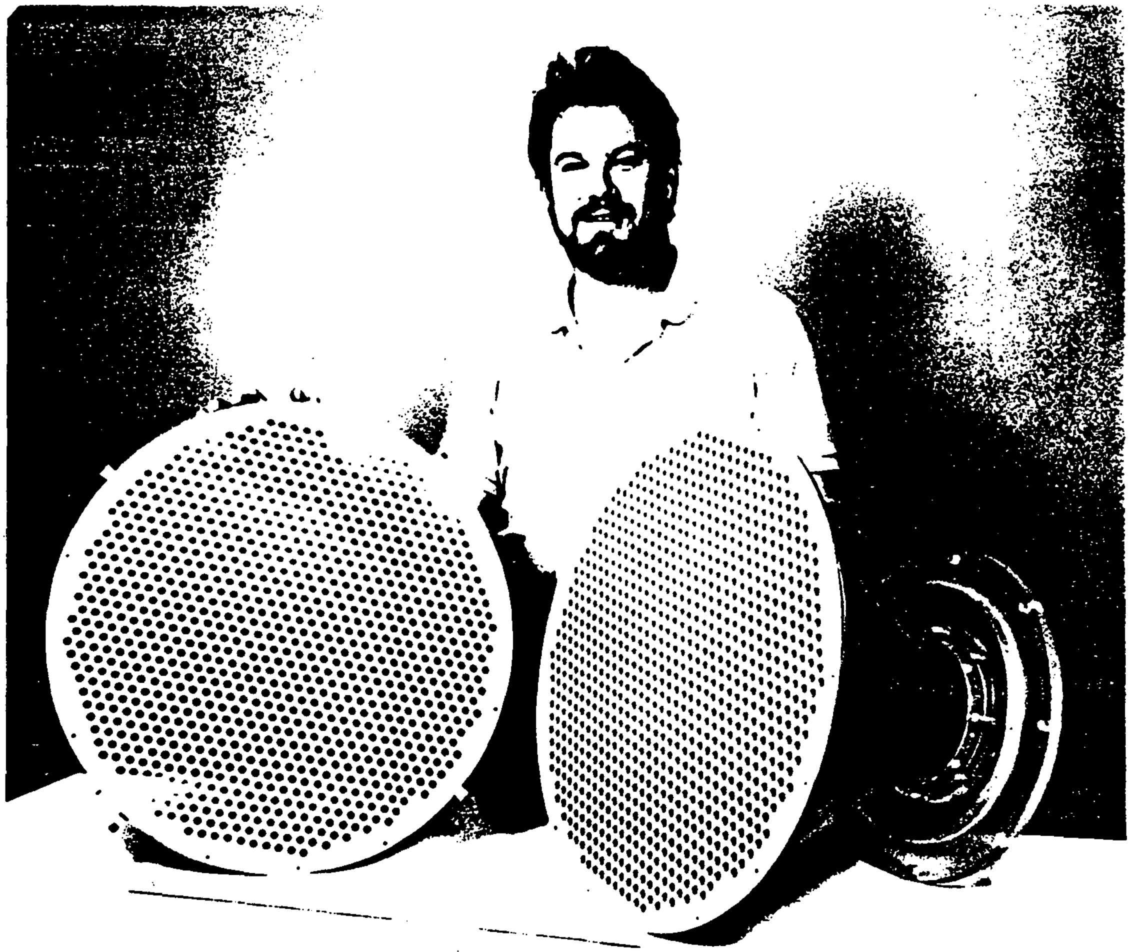


Fig. 2

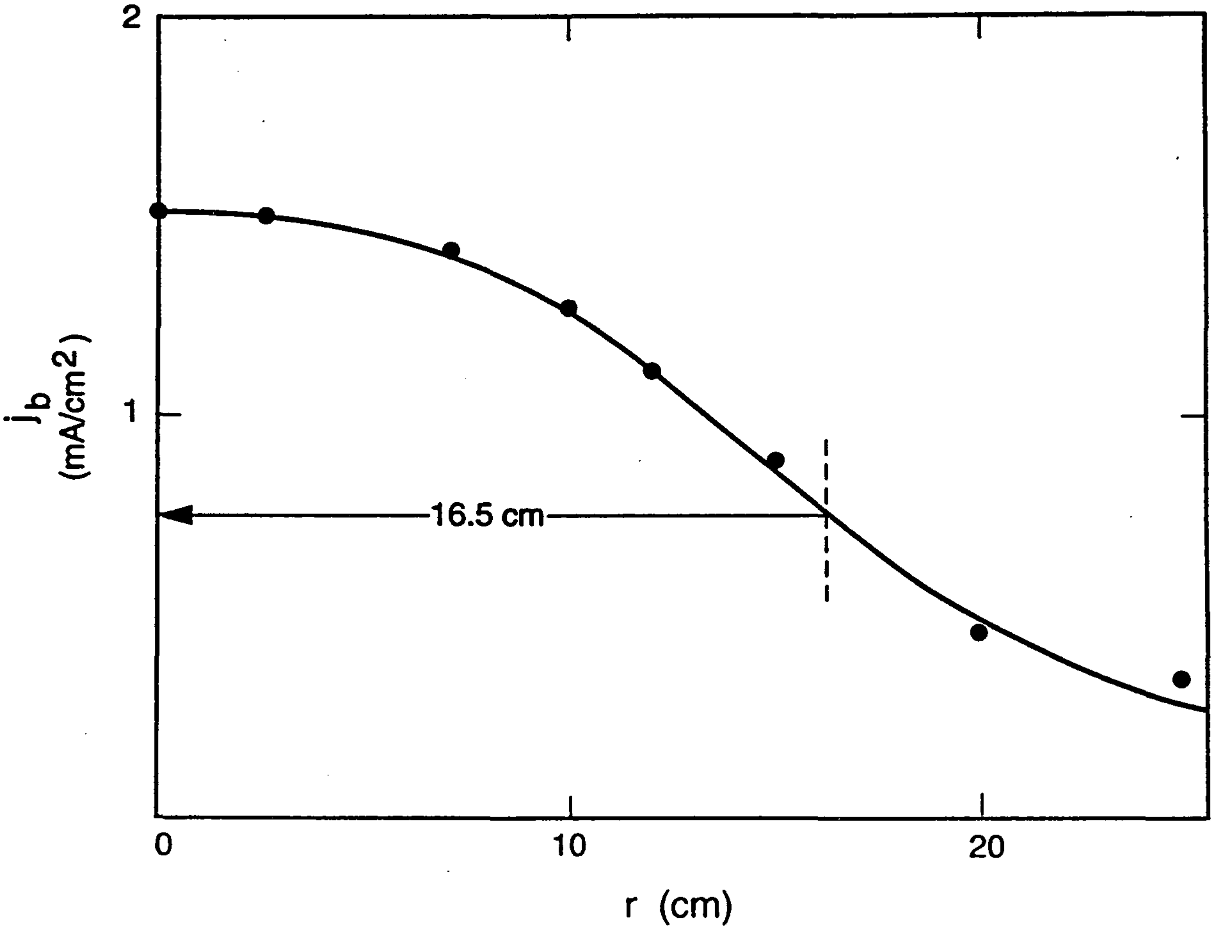


Fig. 3

XBL918-7038

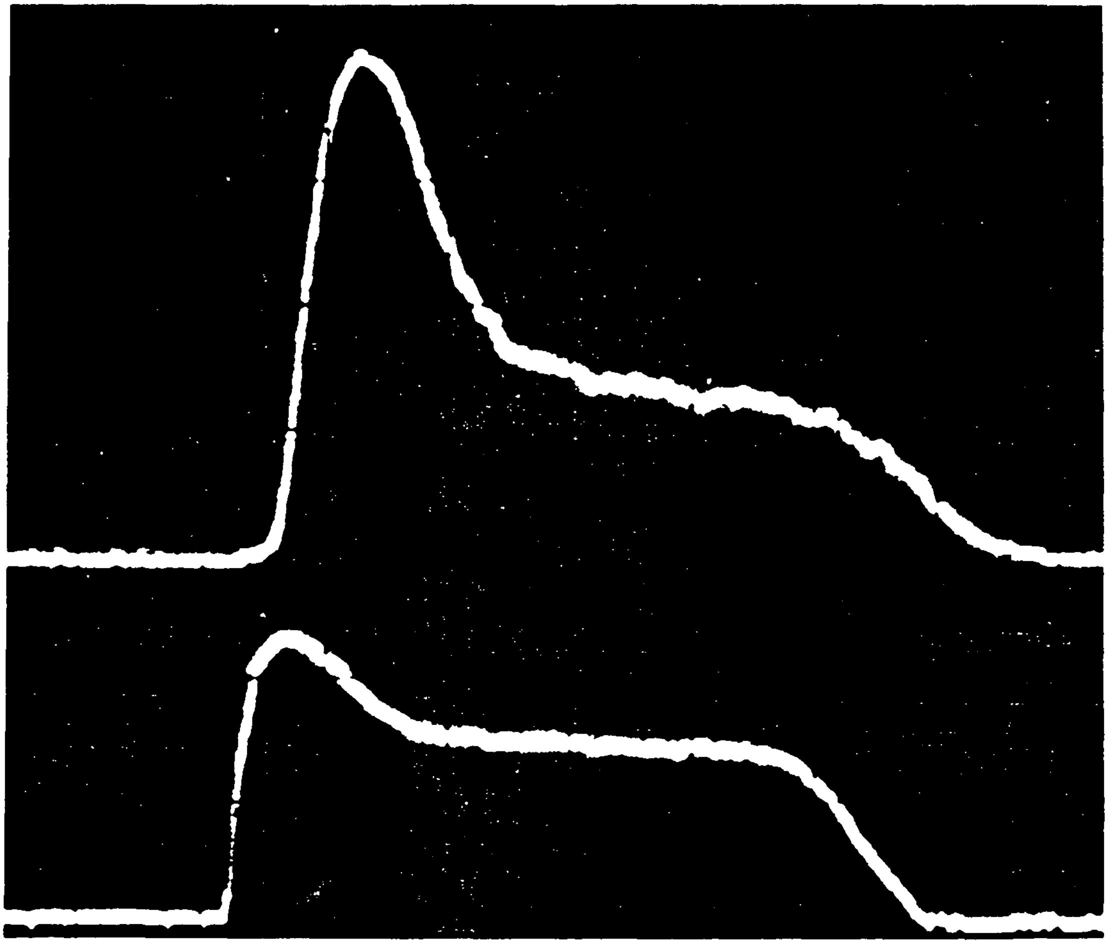


Fig. 4