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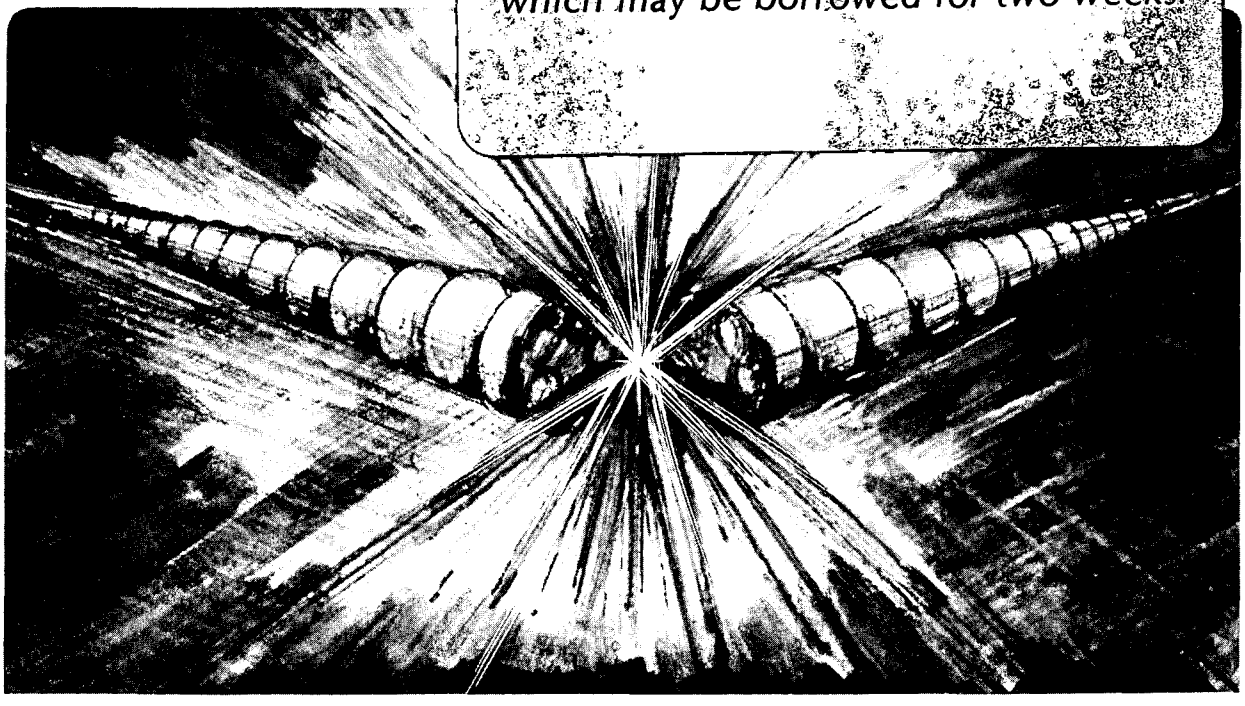

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THE MEVVA ION SOURCE

FOR

HIGH CURRENT METAL ION IMPLANTATION*

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July 1986

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ABSTRACT

The MEVVA (Metal Vapor Vacuum Arc) ion source is a new kind of source which can produce high current beams of metal ions. Beams of a wide range of elements have been produced, spanning the periodic table from lithium up to and including uranium. The source extraction voltage is up to 60 kV, and we are increasing this up to 120 kV. A total ion beam current of over 1 Ampere has been extracted from the present embodiment of the concept, and this is not an inherent limit. The ion charge state distribution varies with cathode material and arc current, and beams like Li^{+}, $Co^{+,2+,3+}$ and $U^{3+,4+,5+,6+}$ for example, are typical; thus the implantation energy can be up to several hundred kilovolts without additional acceleration.

The ion source has potential applications for ion implantation and ion beam mixing for achievment of improved corrosion resistance or wear resistance in metals or surface modification of ceramic materials and semiconductors.

Here we outline the source and its performance, and describe some very preliminary implantation work using this source.

1. INTRODUCTION

An ion source has been developed [1-3] with which high current beams of metal ions can be produced. This source, called the MEVVA ion source (for metal vapor vacuum arc - the kind of plasma discharge used), was developed at the Lawrence Berkeley Laboratory as part of a continuing program to upgrade the heavy ion accelerator facilities at LBL [4]. Because the source can produce metal ion beam currents which are vastly greater than what has hitherto been possible, it seems likely that it will find wide application for high current metal ion implantation. In this paper we describe the MEVVA source and how it works, and summarize the source and beam performance characteristics. Then we report on some measurements of a first, simple, test implantation. The results are encouraging, and further development of the source for ion implantation will be pursued.

2. PRINCIPLE AND DESCRIPTION OF THE MEVVA SOURCE

The MEVVA ion source has been described elsewhere [1-3]. Briefly, in this source the plasma from which the ions are to be extracted is created directly from the solid by means of a metal vapor arc discharge between two metallic electrodes in vacuum. In this kind of discharge, 'cathode spots' - minute regions of intense current concentration (many megamps/cm^2 over a spot of diameter of order microns) - are formed, and it is at these spots that the metal plasma is generated from the solid surface [5-9]. In general many cathode spots participate in the arc, and the assemblage of spots constitutes a prolific source of metal plasma produced from the cathode material. This quasi-neutral plasma plumes away from the cathode toward the anode and persists for the duration of the arc current drive. The anode of the discharge is located on axis with respect to the cylindrical cathode and has a central hole in it through which a part of the plasma plume streams; it is this component of the plasma that forms the medium from which the ions are extracted. The plasma plume drifts through the post-anode region to the set of grids that comprise the extractor - a three-grid, accel-decel, multi-aperture design. A small magnetic field, produced by a simple coil surrounding the arc region and of magnitude up to about 100 gauss, serves to help duct the plasma plume in the forward direction, but this is not an essential ingredient to the source.

A schematic of the embodiment of the concept with which we've done most of our work is shown in Figure 1, and the partially disassembled source in Figure 2. This is the device called MEVVA II. The various components and features refered to above can be seen. The extractor diameter is 2 cm, and so also is the initial beam diameter. The work described here has been done using the MEVVA II ion source.

We've also made other versions of MEVVA ion source. One of these is the MicroMEVVA; this is a miniature source - about 6 cm long and 1.5 cm diameter - which can produce pulsed low emittance metal ion beams up to the 10 ma level [10]. MEVVA IV is another version which is presently in fabrication and which has an array of 16 cathodes disposed in a Gatling gun -like arrangement so that one can switch between cathodes rapidly and while under vacuum.

3. SOURCE PERFORMANCE AND BEAM PARAMETERS

The source has operated well with a wide range of cathode materials and has produced high current beams of Li, C, Mg, Al, Si, Ti, Cr, Fe, Co, Ni, Cu, Nb, Mo, Sn, La, Gd, Ho, Ta, W, Au, Pb, and U. The cathode may also be made from a conducting compound, and in this case the beam contains a mixture of the component species; we've made beams from FeS, PbS, LaB_6, CdSe, SmCo, SiC, and WC. It is noteworthy that in this way beams can be made which contain non-metallic species - eg, B from LaB_6 and S from FeS and PbS; the requirement seems to be just that the cathode material be a conductor. So far the source has worked with every cathode material we've tried.

The record high beam current measured to-date is 1.1 Amperes (electrical current in all charge states), and beams of a few hundred milliamperes can be produced routinely. These beam currents can be obtained from all cathode materials/beam species. Operationally, the arc current is varied so as to maximize the beam current measured into the acceptance of a Faraday cup, which occurs when the plasma density is best matched to the extractor parameters [11,12].

The beam emittance has been estimated from the geometry of the source and beam-monitoring Faraday cup and other source and beam parameters, and also by using a 'pepper-pot' diagnostic [13]. We find that typically half the beam current resides within a normalized emittance of from 0.2 to 0.5 π mm. mrad. We remark parenthetically that the MicroMEVVA source shows an emittance of about 0.1 π mm. mrad. (normalized), as an upper limit [10].

The beam composition, both purity and charge state distribution, has been measured using a time-of-flight diagnostic; (a submicrosecond sample of the beam pulse is drifted down a field-free region where it separates into its different charge-to-mass components; it is a Q/A diagnostic). The beam spectra obtained in this way have been confirmed for a few special cases by a more conventional magnetic analysis. As an example, the charge state spectrum obtained for the case of chromium is shown in Figure 3. In this case the distribution contains about 80% of Cr^{2+} and only about 10% each of Cr^{+} and Cr^{3+}. The charge state distribution can be varied to a small extent via the arc current, but this effect is small. (As the arc current is increased more cathode spots form to participate in the arc, but the plasma physics of each spot is not greatly changed). The spectrum is fairly clean, showing no contamination from the stainless steel trigger, the alumina trigger/cathode insulator, or other components of the source, presumably reflecting the fact that the origin of the plasma is indeed the cathode spots, which form only on the cathode. A small amount of H^{+} can be seen; this is a common contaminant and can be removed by vacuum baking the cathode. We have obtained charge state distribution data such as shown in Figure 3 for all of the cathode materials we've tried, listed above. In general the lower Z materials show lower charge states and the higher Z materials show higher charge states.

4. PRELIMINARY IMPLANTATION WORK.

We have carried out some very preliminary ion implantation work using the MEVVA ion source. In these implantations we've run the source with beam pulse width about 300 microseconds and a repetition rate of from 1 to 10 pulses per second. Note that the source operates at a low duty cycle as required for injection of beams into the LBL heavy ion synchrotron, the Bevalac [4]; this is not an inherent limitation of the source.

For the measurements described here, the target was a 4 inch silicon wafer and the beam was molybdenum. The wafer was tilted off normal to the beam by about 10° to avoid channeling, and was positioned 45 cm from the ion source extractor. We have also run with stainless steel and aluminum targets, and with titanium (mostly Ti^{2+} and Ti^{3+}), chromium (mostly Cr^{2+}) and titanium carbide (mostly Ti^{2+} and C^{+}, C^{2+}) beams. The vacuum system was cryogenically pumped and essentially oil-free; no carbon contamination was detectable in the implanted sample.

Figure 4 shows the results of a Rutherford backscattering (RBS) scan with 2 MeV alphas as a function of radial position across the wafer. The dose profile is well approximated by a Gaussian with a width (FWHM) of 5 cm. This is the width expected for a beam of initial diameter 2 cm located 45 cm distant and with a divergence half-angle of 2°. A future more complete facility will incorporate the ability to scan the target.

The depth profile of the implanted molybdenum, at radial position r = 2.5 cm, was measured; the range was 390 ± 80 A and the straggling 200 ± 35 A. It is interesting to compare these measured values with those calculated from the known charge state distribution of the beam, shown in Figure 5. The extraction voltage for these measurements was 25 kV, and so the energy distribution of the molybdenum beam is as shown in Table 1, where the range and straggling for molybdenum into silicon is also listed [14]. The depth profile for each charge state component can be approximated by a Gaussian, and the resultant total molybdenum depth profile calculated. The result of this exercise is shown in Figure 6, from which the range of 400 A and straggling of 200 A is extracted. The agreement with the measured values is excellent.

5. CONCLUSION

The MEVVA ion source provides a means of creating high current, low emittance, metal ion beams that can be of use for ion implantation application. High dose implants of virtually all metal ion species can be carried out. In general the beam metal ions are multiply stripped, and thus the effective energy of the implantation is several times greater than the ion source extraction voltage. Further development of this new kind of source is needed, to increase the beam duty cycle and to further quantify the beam properties.

This new kind of source provides a unique and exciting tool for the implantation field, whereby metal implants can be performed at currents not previously possible.

REFERENCES

1. I. G. Brown, J. E. Galvin and R. A. MacGill, Appl. Phys. Lett. 47, 358 (1985).
2. I. G. Brown, IEEE Trans. Nucl. Sci. NS-32, 1723 (1985).
3. I. G. Brown, J. E. Galvin, B. F. Gavin, and R. A. MacGill, Rev. Sci. Instrum. 57, 1069 (1986).
4. J. R. Alonso, Nucl. Instrum. and Methods A244, 262 (1986).
5. J. M. Lafferty, ed., "Vacuum Arcs - Theory and Application", John Wiley and Sons, New York, 1980.
6. A. A. Plyutto, V. N. Ryzhhov and A. T. Kapin, Sov. Phys. JETP 20(2), 328 (1965).
7. W. D. Davis and H. C. Miller, J. Appl. Phys. 40, 2212 (1969).
8. IEEE Trans. on Plasma Science, special issue on vacuum discharge plasmas, IEEE PS-11, Sep. 1983.
9. IEEE Trans. on Plasma Science, special issue on vacuum discharge plasmas, IEEE PS-13, Oct. 1985.
10. I. G. Brown, J. E. Galvin, R. A. MacGill and R. T. Wright, Lawrence Berkeley Laboratory Report LBL-21487; to be published.
11. T. S. Green, Reports on Progress in Physics 37, 1257 (1974).
12. T. S. Green, IEEE Trans. Nucl. Sci. NS-23, 918 (1976).
13. R. Keller, GSI 1980 Annual Report, GSI Report 81-2, p.263.
14. We have used the TRIM-86 code; see "The Stopping and Range of Ions in Solids" by J. F. Ziegler, J. P. Biersack and U. Littmark, Pergamon Press, N.Y., 1985.

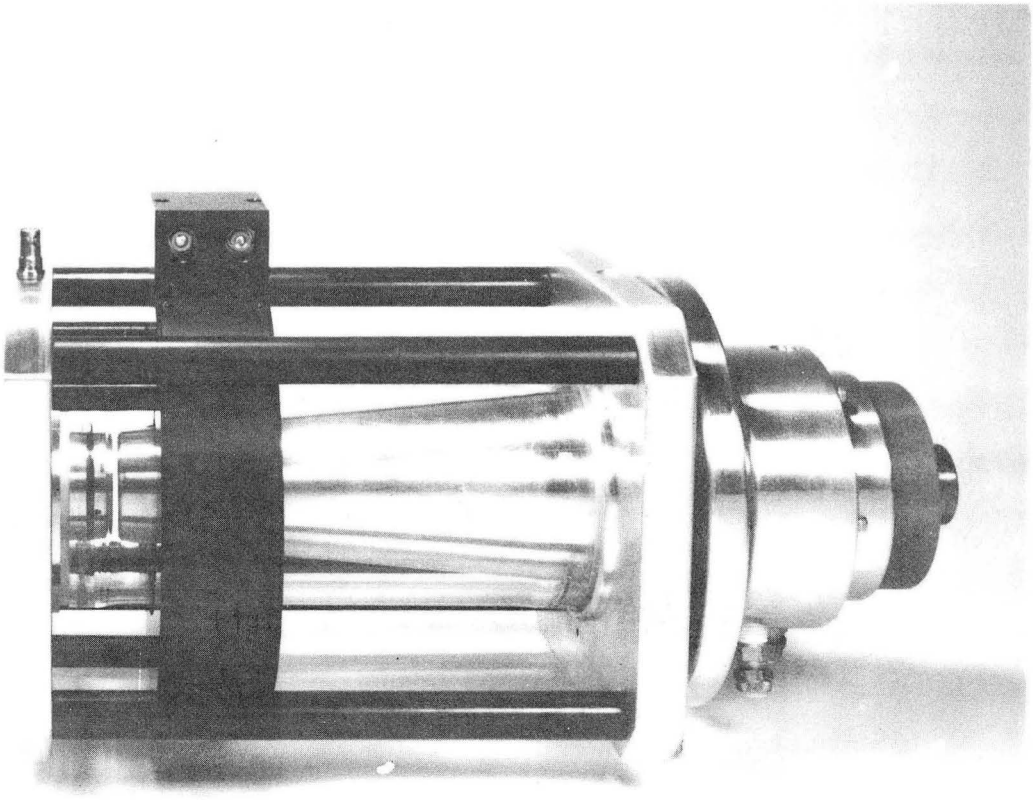

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Fig. 1 The MEVVA II ion source.

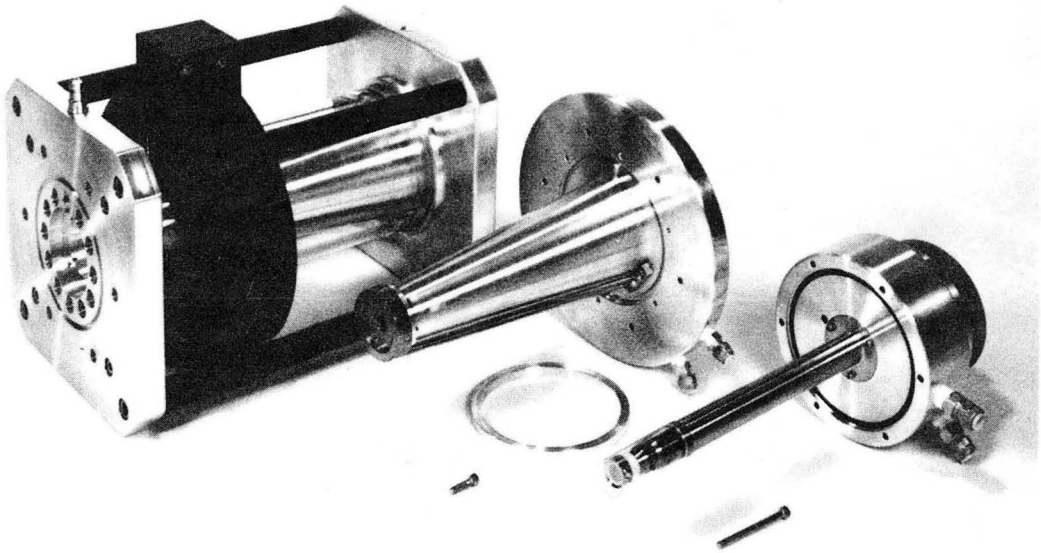

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Fig. 2 MEVVA II partially disassembled.

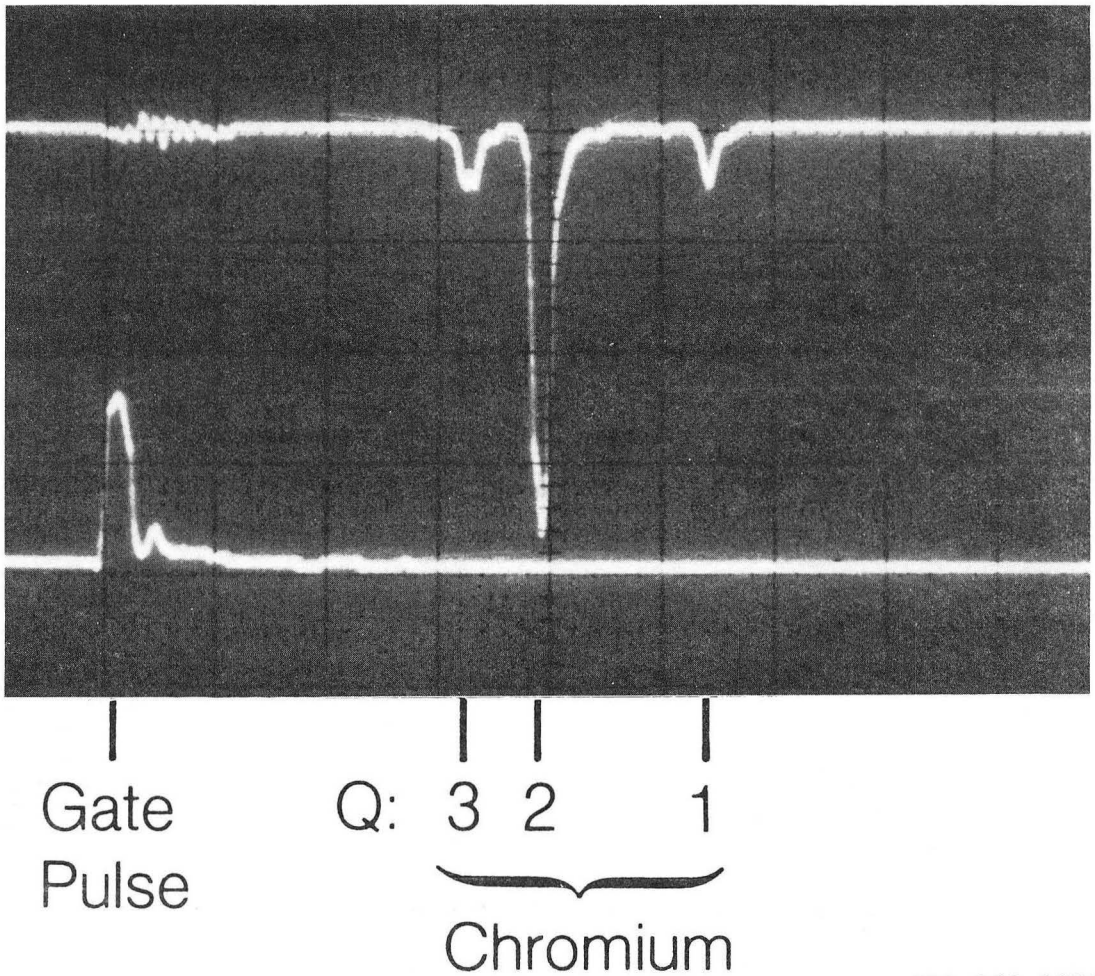

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Fig. 3 Charge state distribution measured for a chromium beam.

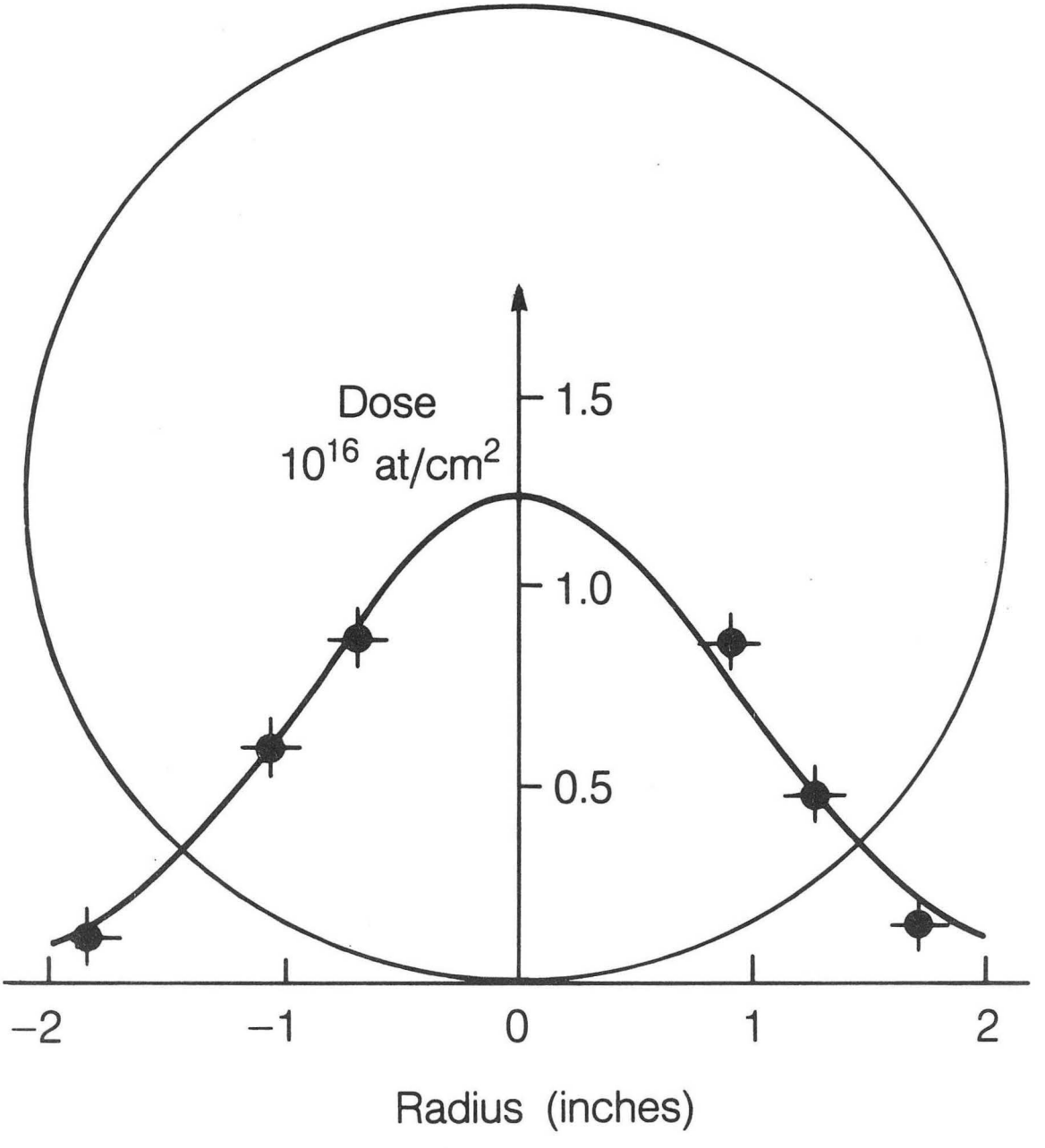

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Fig. 4 Radial profile of implanted molybdenum dose, measured by 2 MeV alpha RBS.

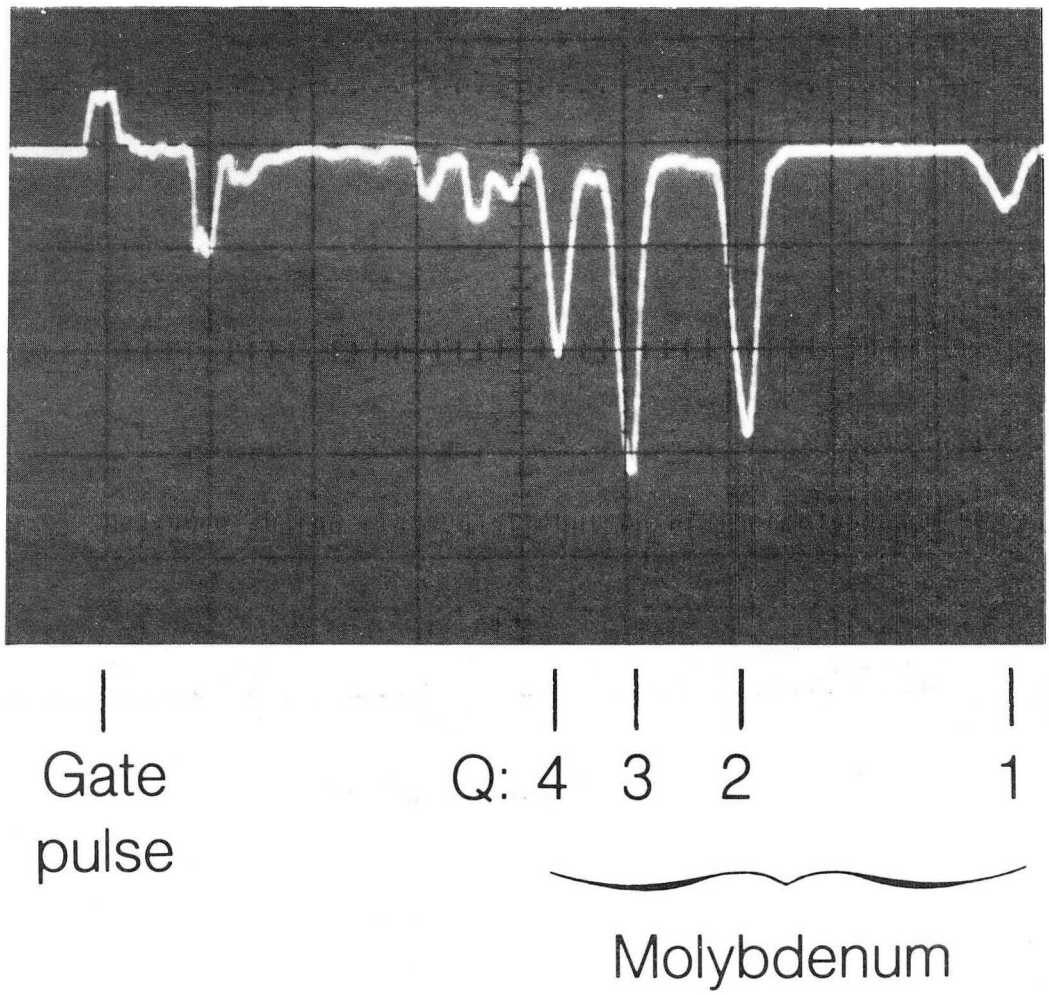

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Fig. 5 Measured charge state distribution of the molybdenum beam.

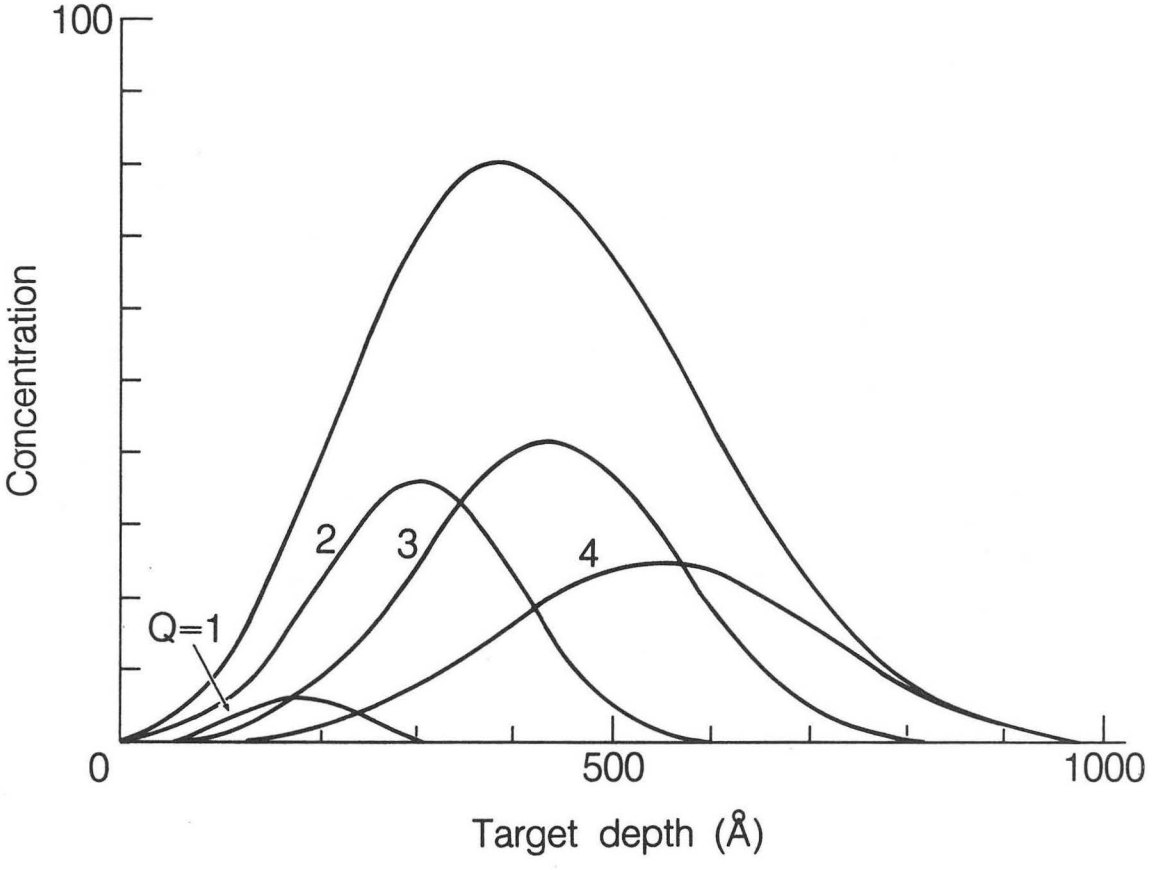

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Fig. 6 Implantation depth profiles of each of the charge state components of the molybdenum beam (approximated by Gaussians having the theoretically calculated range and straggling), and the resultant profile for the total beam.

Charge state	1	2	3	4
Energy (KeV)	25	50	75	100
Fraction (%)	6	33	38	23
Range (A)	180	300	435	550
Straggling (A)	85	145	190	235

Table Charge state and energy composition of the molybdenum ion beam for 25 kV extraction voltage, and the range and straggling for implantation into silicon.

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