Lawrence Berkeley National Laboratory
Recent Work

Title
ADVANCES IN METAL ION SOURCES

Permalink
https://escholarship.org/uc/item/6mn814jz

Author
Brown, I .G.

Publication Date
1988-05-01

eScholarship.org Powered by the California Digital Library
University of California

LBL-24734 c2

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

RECEIVED
LAWRENCE
BERKELEY LABORATORY

JUL 1988

LIBRARY AND
DOCUMENTS SECTION

Invited paper presented at the 7th International Conference on Ion Implantation Technology, Kyoto, Japan, June 7–10, 1988

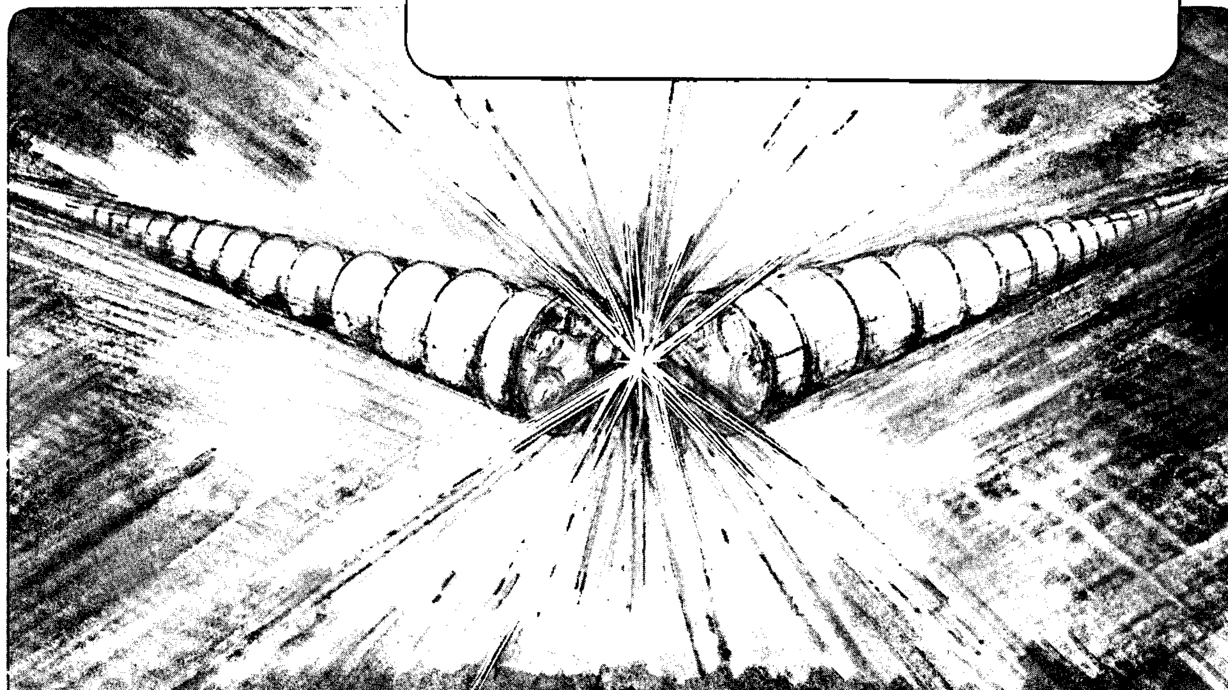
Advances in Metal Ion Sources

I.G. Brown

May 1988

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks.



LBL-24734 c.2

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-24734

ADVANCES IN METAL ION SOURCES*

Ian G. Brown

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

May 1988

* Work supported by U.S. DOE Contract No. DE-AC03-76SF00098.

Invited paper presented at the 7th International Conference on Ion Implantation Technology, Kyoto, Japan, June 7-10, 1988.

LBL-24734

ADVANCES IN METAL ION SOURCES*

Ian G. Brown

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABSTRACT

Beams of metallic ion species can be produced by the ECR (electron cyclotron resonance) ion source and by the MEVVA (metal vapor vacuum arc) ion source. Although the ECR source is fundamentally a gaseous ion source, metal ion beams can be produced by introducing metallic feed material into the plasma discharge using a number of techniques. The ion charge states can be very high, which is a significant advantage to most applications. The MEVVA ion source, on the other hand, is specifically a metal ion source. It has produced metallic ion beams from virtually all the solid metallic elements at a current of typically hundreds of milliamperes; the ions produced are in general multiply ionized, but not as highly stripped as those generated in the ECR source. Although the MEVVA source at present operates in a pulsed mode with a low duty cycle ($\leq 1\%$), work is in progress to increase the duty cycle significantly.

In this paper the operation and performance of the LBL ECR and MEVVA ion sources, with respect to metal ion generation, are described.

* Work supported by U.S. DOE Contract No. DE-AC03-76SF00098.

1. Introduction

The production of beams of metal ions poses challenges in ion source design that do not occur for gaseous ion sources. Whereas a dense, highly ionized plasma can be formed from a gas by a variety of techniques (eg, electron bombardment, rf, microwave, etc.), methods of plasma formation from solid metals are more restrictive. Techniques that have been used include surface ionization, vaporization of the metal into the gaseous state, sputtering, laser-solid interaction, and metal vapor vacuum arc discharges. These various methods have their separate strengths and limitations.

The LBL ECR ion source is used as an injector for the Berkeley 88-inch cyclotron for nuclear physics experiments [1]. It operates at microwave frequencies of 9.2 and 6.4 GHz in the first and second stages (respectively), and has produced dc beams of a variety of metal species at very high charge state, eg 10 eμA Ti^{10+} and 2.5 eμA Bi^{28+}.

The MEVVA (Metal Vapor Vacuum Arc) ion source was developed at LBL for heavy ion synchrotron application, and a number of embodiments of the source have been built and tested [2]. High current pulsed beams of a wide range of metallic ion species have been produced. The ions are in general multiply-stripped, and the ion implantation energy can be greater than the extraction voltage by a factor of several. Thus, for example, we have implanted uranium into silicon at an ion mean energy of over 200 keV. Beam ion species that have been produced to-date include: Li, C, Mg, Al, Si, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Rh, Pd, Ag, In, Sn, Gd, Ho, Hf, Ta, W, Pt, Au, Pb, Th, and U.

In this paper we review some recent results obtained at Berkeley with the ECR and MEVVA ion sources.

2. Source Operation

In the ECR ion source [3] the plasma is produced by microwave breakdown of gas at low pressure (10^{-4} - 10^{-5} Torr) and confined in a stabilized magnetic mirror plasma trap. The plasma electrons are heated by resonant coupling of the microwave power at the electron cyclotron frequency, $\omega = \omega_{ce}$, and the electron population acquires a high temperature of many keV. The ions are then stripped to successively higher charge state by the high energy plasma electrons. A small fraction of the plasma is lost axially from the mirror confinement geometry, and it is this loss flux from which the ions are extracted to form an energetic, high charge state, dc ion beam. Note that the "ECR ion source" is not to be confused with the "microwave ion source" of the kind described by Sakudo [4,5] and others. While similar in some respects, there are many significant differences between these two kinds of sources, and the ion beams produced are vastly different - whereas the ECR ion source produces low current beams of very highly charged ions, the microwave ion source produces high current beams of low charge state ions, mostly singly ionized.

The performance of ECR ion sources has increased steadily, and about a dozen or so ECR ion sources are in operation around the world [3,6]. ECR ion source performance improved greatly, and the device took on the configuration in which it exists today, following the introduction of two important innovations. Firstly, a multipole (eg, hexapole) magnetic field, conveniently established by samarium cobalt permanent magnets, was added to produce a minimum-B plasma confinement geometry which is

stable against MHD plasma instabilities. Secondly, the plasma was separated into two regions - a first stage operating at higher pressure and producing dense, cold plasma that then flows into the second stage where the hot electrons are created and confined. Both the minimum-B configuration and the two stages appear to be crucial for optimum high charge state performance.

The LBL ECR source is illustrated in fig. 1. The first stage uses a 9.2 GHz klystron (1 kW rated, typical power 100 W) and the second stage uses a 6.4 GHz klystron (3 kW rated, typical power 400 W). The hexapole magnetic field is produced by a samarium cobalt structure with radial slots for vacuum pumping and the axial magnetic field is produced by copper coils each powered individually; typical total magnet power is 30 kW.

In the MEVVA ion source [2, 7-10], use is made of the intense plume of highly ionized metal plasma that is created at the cathode spots of a metal vapor vacuum arc discharge to provide the plasma feedstock from which the ion beam is extracted. The 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 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 axial magnetic field of up to about 100 gauss produced by a simple coil surrounding the arc region serves to help duct the plasma plume in the forward direction, but this is not essential to the source operation. A schematic of the MEVVA IIb ion source is shown in fig 2.

MEVVA IV is a version in which 16 separate cathodes are mounted in a single cathode assembly, allowing the operational cathode to be changed simply by rotating a knob so as to position the desired cathode in line with the anode and extractor of the device. Thus many different cathode materials can be used in a relatively short experimental run and with confidence in maintaining the same experimental conditions. A photograph of the MEVVA IV source is shown in fig 3.

The MEVVA source is operated in a pulsed mode as required for synchrotron application, typically with a pulse length of order 0.25 msec and a repetition rate of several pulses per second up to a maximum of near 100 pulses per second; we are presently increasing the duty cycle at which the source will run. The source is operated at a vacuum pressure in the low 10^{-6} Torr range.

3. Source Performance

The general performance of ECR ion sources using gaseous ion species has been described by a number of authors [1,3,6,11,12]; here we limit our concern to the performance using metal ion species. The MEVVA ion source, on the other hand, is specifically a metal ion source, although it is also possible to create beams containing non-metallic species, like S^{+} from an FeS cathode.

A. ECR Ion Source

Three main methods for the production of high charge state metallic ions using ECR sources are: use of gaseous compounds in which the metal is an atomic component; use of atomic ovens to vaporize the

solid metal; and direct insertion of solids into the plasma. The use of gaseous compounds is rather limited, while the direct insertion works well with high temperature materials such as iron, nickel, niobium, tantalum and tungsten, and the oven works well with low temperature materials such as lithium, magnesium, calcium and bismuth. These three methods are now described in more detail.

Beams containing carbon and silicon can be produced using gaseous compounds such as CH_4 and SiH_4, respectively. In general, compounds with lighter atoms bonded to the desired element are chosen. For the LBL ECR geometry, injecting the compound gas into the second stage and the mixing gas (to establish the background plasma) into the first stage produces the most consistent results; an additional advantage to injecting into the second stage comes from the reduced gas flow required.

A variety of metallic ion beams have been produced from the LBL ECR using a simple resistance heated oven. Metal vapor from the oven is fed radially into the second stage so that the vapor stream is directed into the ECR plasma and the metal atoms are ionized and stripped by electron impact. Typically with oven operation, the plasma is maintained by running either oxygen or nitrogen as a support gas in the first stage. The amount of metal in the plasma is adjusted by varying the oven temperature; a proportional temperature controller is used to maintain the oven temperature constant. The resultant beam stability is quite remarkable: a number of cyclotron runs lasting several days have been made, during which no adjustment of the ECR source or oven was required.

Another technique used to produce beams from solids is to insert a rod or thin paddle into the edge of the plasma. This technique has been used in the LBL ECR source to produce Al, Fe, Ti, Cu, Nb, and Th beams. The solid rod is inserted radially into the second stage plasma until it is heated to sufficient temperature by the hot electrons in the plasma to produce the required metal vapor pressure. With careful tuning it is possible to produce stable beams over several hours; a feedback control system would further stabilize the operation.

These techniques for producing metal ion beams from the ECR source are listed in Table 1. The performance of the LBL ECR ion source for a range of metallic ions is summarized in Table 2. The currents represent the best results taken from many tests for which the source was readjusted to optimize some of the individual charge states. Some further results on ECR metal ion beams have been presented by the Grenoble group [13,14].

B. MEVVA Ion Source

The MEVVA ion source has produced beams of a wide range of metal ions, as listed above. Beam has been extracted at a voltage from a low of about 5 kV up to a maximum (power supply limited) of 110 kV. The beam current is typically 100 - 500 ema, and can be varied from a practical minimum of a few milliamperes up to about 1 Ampere. Beam divergence is usually a few degrees, corresponding to a beam emittance of about 0.05 π cm. mrad (normalized) (measured to the half intensity points of the beam current radial profile), and can be much less when the extraction is properly optimized. The charge state distribution of the beam metal ions varies from singly ionized only for low-Z species like Li and C, up to a spectrum which is peaked at Q = 2+ or 3+ for high-Z elements. Some examples of the measured charge state distributions are shown in fig. 4. The time-of-flight spectra were obtained as ion current collected by a Faraday cup, and the amplitudes of the charge state peaks in the oscillograms are proportional to electrical current; the electrical current is greater than particle current by the

charge state Q, $I_{elec} = QI_{part}$. The data shown in the oscillograms of fig. 4 are summarized in Table 3. The ion charge state distributions have been discussed in more detail in ref [15].

We have recently found that the charge state distributions can be significantly improved (charge states increased upwards) by operating the source in a strong magnetic field. The mean charge state increases with field strength, and new highly-stripped components are seen in the spectrum. This effect is shown in fig. 5. The shift to higher charge states with increasing field strength is clearly seen. We are currently increasing the magnetic field strength further, to probe the limits to this phenomenon, and investigating various possible explanations for this important effect. We hope to report more on this work in the literature soon.

4. Outlook

The ECR ion source has been well developed and its suitability for applications such as cyclotron injection is well established. That it can produce beams of metal ions has been demonstrated, and continuing work will expand this mode of operation. The very high charge states produced make the source very attractive for high energy ion implantation application, but the relatively low beam current is a drawback. It is probable, however, that the next few years will see research activity directed towards increasing the beam current by means of increased microwave frequency, microwave power, and magnetic field strength. Future sources of this kind might tend to use superconducting magnets and high power gyrotrons for the rf generation.

The MEVVA ion source is a fairly recent entry to the ion source arena, and there is much source development that needs to be done. The source stands alone in terms of its ability to produce very high current beams of metal ions, but the low duty cycle is a concern. This kind of ion source is now being developed at several laboratories around the world, and it is probable that the duty cycle, as well as other source parameters, such as the ion charge state, will undergo significant improvement as this work proceeds.

It is a pleasure to acknowledge the invaluable contributions of Jim Galvin, Bob MacGill, Mark West, and Bob Wright to the fabrication and development of the MEVVA ion sources and the execution of the MEVVA research program. I am also greatly indebted to Claude Lyneis for providing information on the LBL ECR ion source.

References

1. C. M. Lyneis, in Proceedings of the 11th International Conference on Cyclotrons and Their Applications, Tokyo, 1986, (Ionics Publishing Co., Tokyo, 1987), p. 707.
2. I. G. Brown, J. E. Galvin, R. A. MacGill and R. T. Wright, 1987 Particle Accelerator Conference, Washington, D.C., March 1987; IEEE Cat. No. 87CH2387-9, p.343.
3. Y. Jongen and C. M. Lyneis, in "The Physics and Technology of Ion Sources", ed. I. G. Brown (Wiley, N.Y., to be published Fall 1988).
4. N. Sakudo, Nucl. Instr. and Meth. B21 (1987) 168.
5. N. Sakudo, in "The Physics and Technology of Ion Sources", ed. I. G. Brown (Wiley, N.Y., to be published Fall 1988).
6. C. M. Lyneis, paper presented at RCNP-Kikuchi Summer School on Accelerator Technology, Osaka, Japan, October 1986; also Lawrence Berkeley Laboratory Report LBL-22450 (1986).
7. I. G. Brown, in "The Physics and Technology of Ion Sources", ed. I. G. Brown (Wiley, N.Y., to be published Fall 1988).
8. I. G. Brown, J. E. Galvin and R. A. MacGill, Appl. Phys. Lett. 47 (1985) 358.
9. I. G. Brown, IEEE Trans. Nucl. Sci. NS-32, (1985) 1723.
10. I. G. Brown, J. E. Galvin, B. F. Gavin and R. A. MacGill, Rev. Sci. Instrum. 57 (1986) 1069.
11. R. Geller, in Proceedings of the 11th International Conference on Cyclotrons and Their Applications, Tokyko, 1986, (Ionics Publishing Co., Tokyo, 1987), p. 699.
12. C. M. Lyneis 1987 Particle Accelerator Conference, Washington, D.C., March 1987; IEEE Cat. No. 87CH2387-9, p.254.
13. F. Bourg, R. Geller and B. Jacquot, Nucl. Instr. and Meth. A254 (1987) 13.
14. B. Jacquot and R. Geller, International Conference on ECR Ion Sources and their Applications, Nov. 1987, East Lansing, Michigan.
15. I. G. Brown, B. Feinberg and J. E. Galvin, J. Appl. Phys. (scheduled for publication about May 1, 1988).

Table 1

Techniques used to produce metal ion beams from the LBL ECR ion source.

Beam	Starting Material	Method
C	CO_2 or CH_4	Gas feed into stage-2
Mg	Mg metal	Oven (400C)
Al	Al_2O_3 rod	Rod into stage-2 plasma
Si	SiH_4	Gas feed into stage-2
K	KCl & Ca	Oven (450C)
Ca	Ca metal	Oven (480-570C)
Ti	TiF_4 powder	Oven (100C)
Nb	Nb rod	Rod into stage-2 plasma
Bi	Bi metal	Oven (525C)

Table 2

Charge state distributions of some metal ion beams from the LBL ECR ion source. Currents are in electrical microamperes; 10 kV extraction voltage.
* indicates not measured because of a mixture of two ions with the same Q/A.

Q	C	Mg	Si	K	Ca	Ti	Bi
1	27						
2	37	32	20				
3	*	34	33	4	23		
4	31	28	69	4	24		
5	6	44	72	5	*		
6		34	47	8	37		
7		18	30	11	38	2	
8		8	17	18	36	*	
9		6	7	37	31	12	
10		2	3	22	*	10	
11			0.5	12	22	8	
12				2	11	*	
13					3	1	
14					1		
≈							
21							2
22							3
23							3
24							4
25							4
26							*
27							3
28							3
29							2
30							*
31							0.5

Table 3

Charge state fractions, expressed in terms of particle current, and mean charge state, for a range of MEVVA cathode materials; 200 A arc current.

Element	Charge state fraction (%)					
Q =	1	2	3	4	5	$\bar{Q}_p$
C	100					1
Mg	37	63				1.63
Al	56	39	5			1.48
Si	56	42	2			1.46
Ti	6	82	12			2.05
Cr	25	67	8			1.82
Fe	31	64	5			1.73
Co	47	49	4			1.57
Ni	53	44	3			1.51
Cu	44	42	14			1.70
Zn	86	14				1.14
Zr	9	55	30	6		2.33
Nb	5	46	37	12		2.56
Mo	14	47	28	11		2.35
Rh	46	43	10	1		1.65
Pd	39	57	4			1.64
Ag	32	59	9			1.77
In	88	12				1.12
Sn	53	47				1.47
Gd	6	81	13			2.07
Ho	15	76	9			1.93
Ta	13	39	28	18	2	2.58
W	8	34	36	19	3	2.74
Pt	69	29	2			1.33
Au	44	54	2			1.58
Pb	64	36				1.36
Th	3	15	70	12		2.92
U	3	38	54	5		2.62

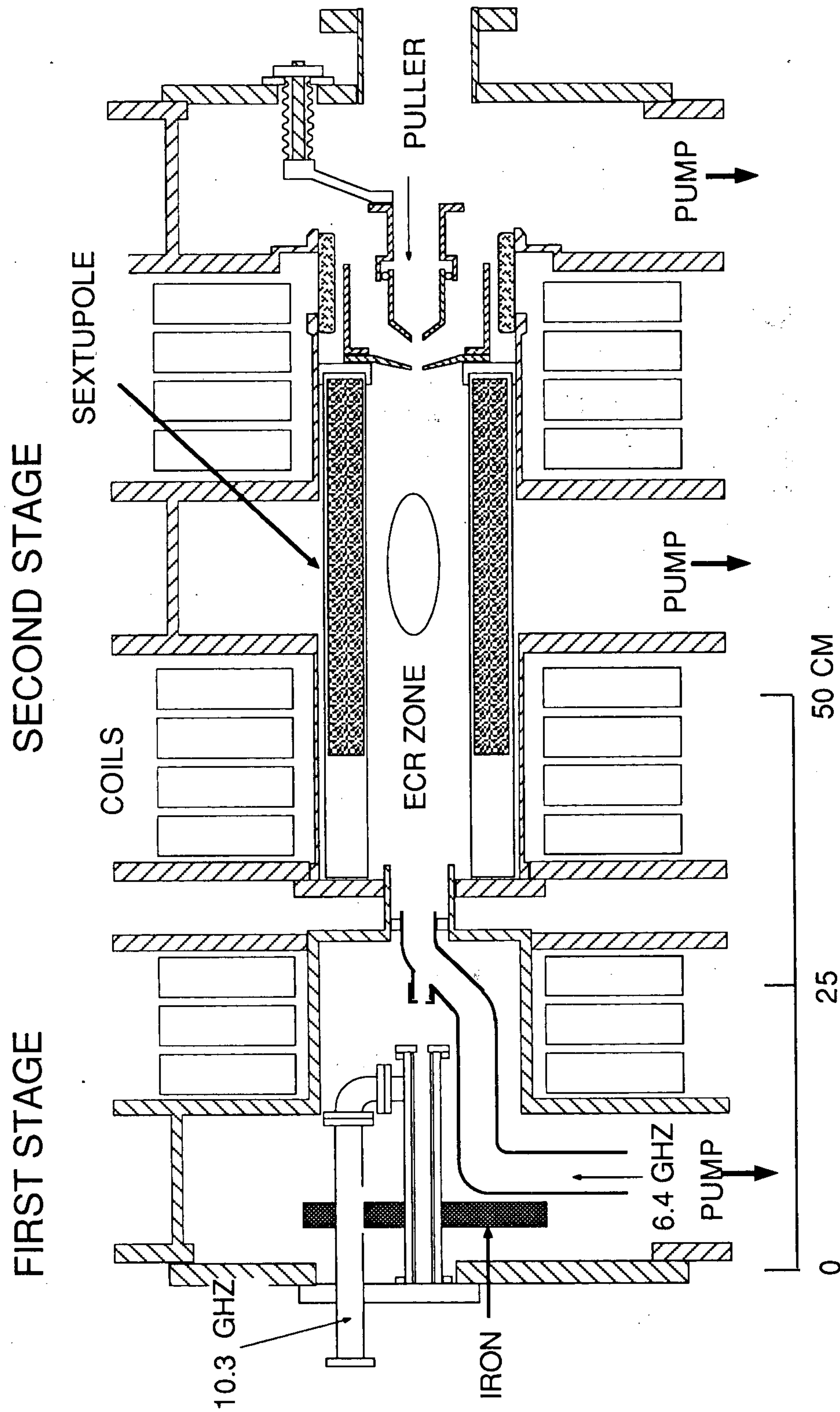


Fig. 1. Schematic showing the main features of the LBL ECR ion source.

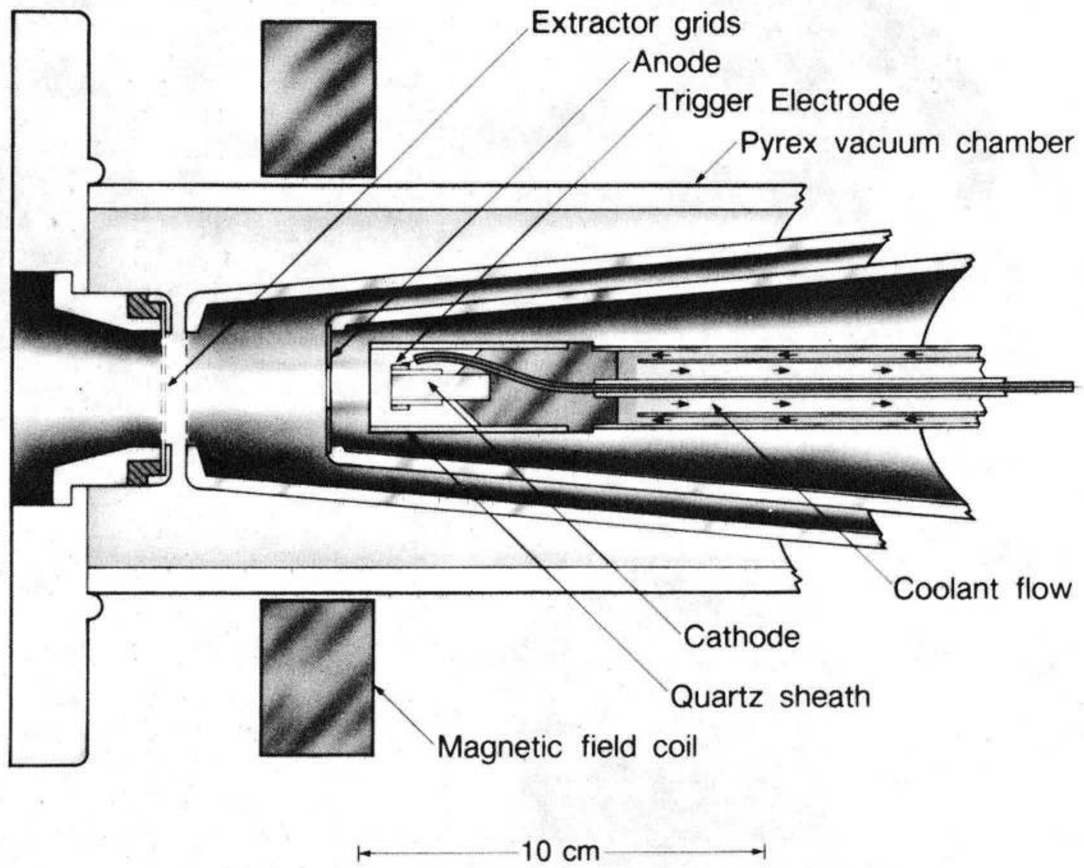
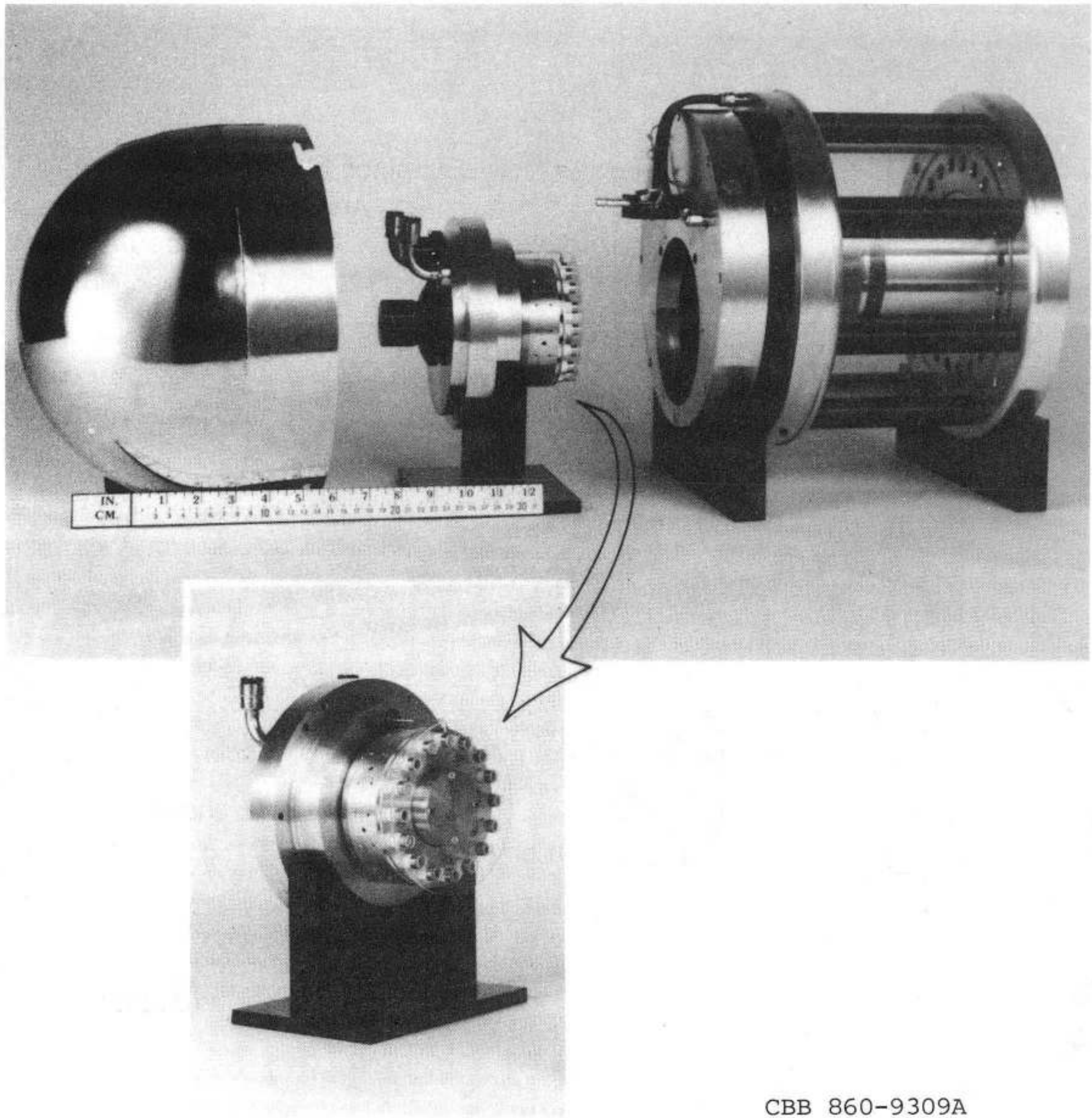
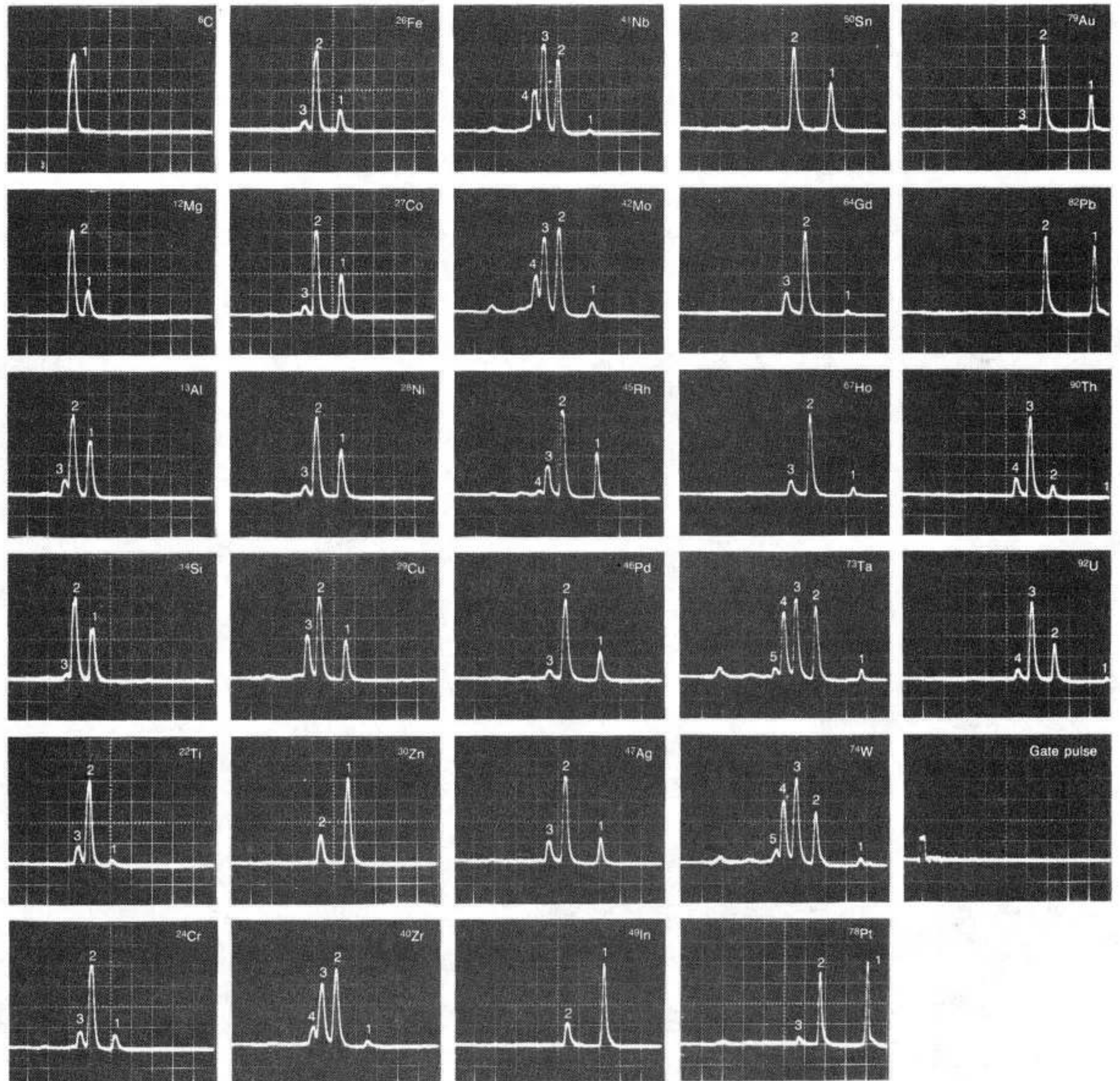


Fig. 2. Schematic of the MEVVA IIb ion source.



CBB 860-9309A

Fig. 3. The MEVVA IV ion source showing the multi-cathode assembly.



XBB 875-5170

Fig. 4. Time-of-flight spectra showing the charge state distributions for a range of MEVVA cathode materials. Vertical scale: current collected by a Faraday cup, gain approx. 100 μA/cm.

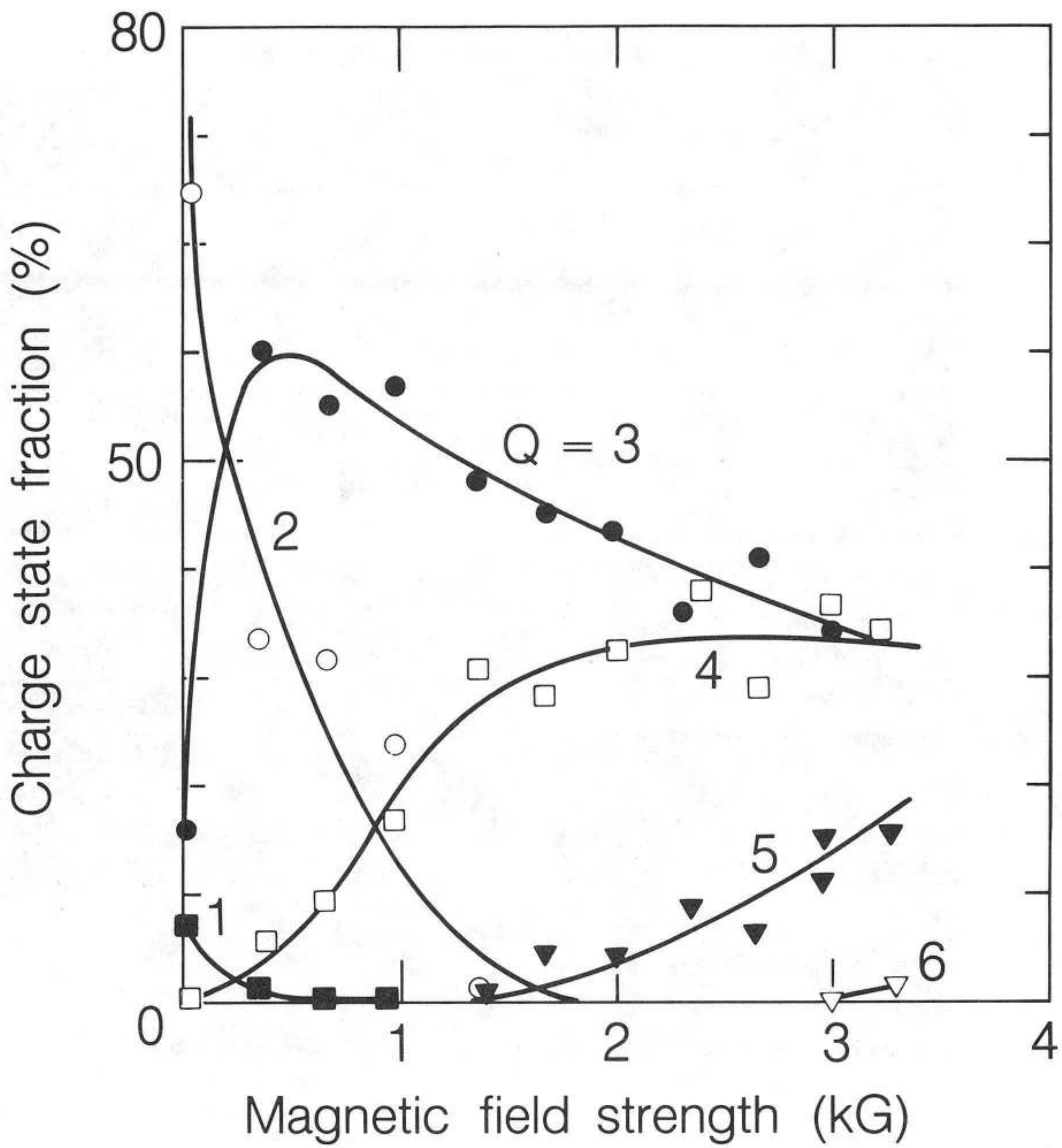


Fig. 5. Measured charge state fractions as a function of applied magnetic field strength. Uranium cathode, I_{arc} = 100 A.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720