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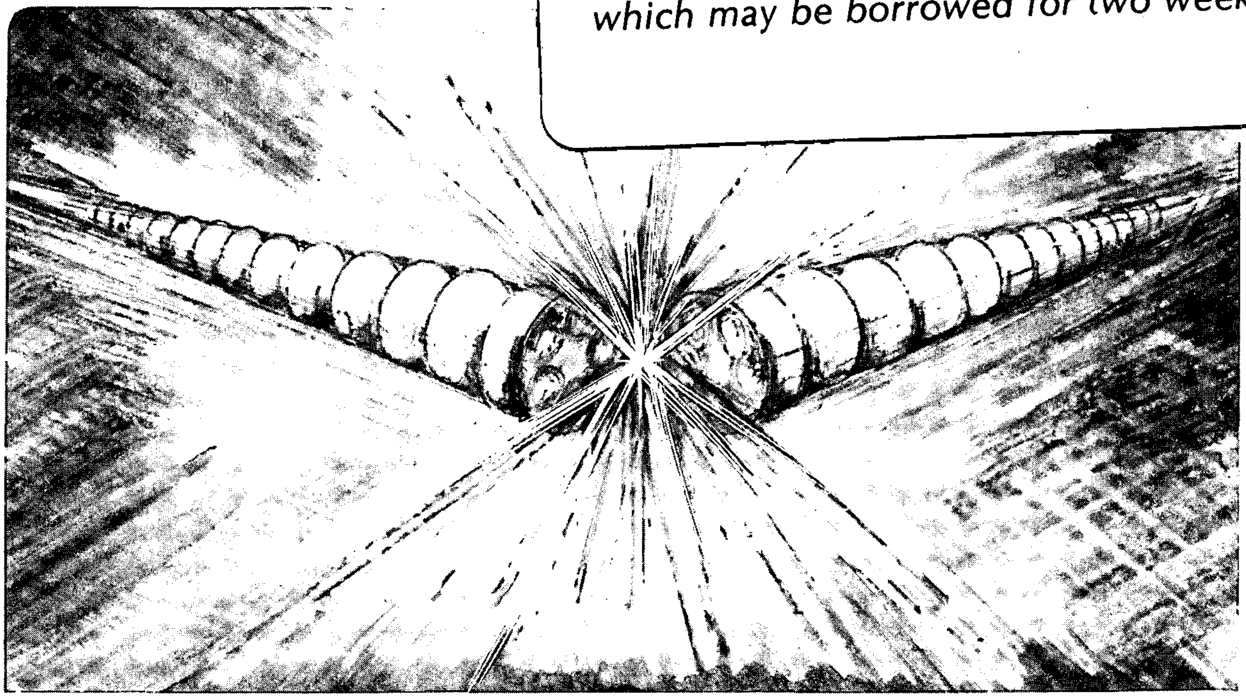

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MEASUREMENTS OF VACUUM ARC ION CHARGE STATE DISTRIBUTIONS

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Abstract: - We have measured the charge state distribution of ions generated in the metal vapor vacuum arc under a wide range of experimental conditions. The experiments were carried out using an ion source in which the metal vapor vacuum arc is used as the method of plasma production and by which a high quality, high current beam of metal ions is produced. Charge state spectra were measured using a time-of-flight diagnostic; arc voltages were also measured. Parameters varied include: cathode material, arc current, axial magnetic field strength, neutral gas pressure, and arc geometry.

INTRODUCTION

Measurements of the charge state distribution of ions generated by the metal vapor vacuum arc have been reported by several workers [1-3], and it is well recognized that the distributions in general contain a high fraction of multiply stripped species. We have developed an ion source in which the metal vapor vacuum arc is used as the method of plasma production and from which high quality, high current beams of metal ions can be extracted [4-7]. We have called this source the MEVVA ion source, as an acronym for the mechanism employed. With this source we have produced beams at voltages up to 100 kV and with ion currents up to 1 Ampere. Beams of a wide range of ion species have been produced, including Li, C, Mg, Al, Si, Ti, Cr, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Rh, Pd, Ag, In, Sn, Gd, Ho, Ta, W, Pt, Au, Pb, Th, U.

EXPERIMENTAL SET-UP

The MEVVA ion source has been described elsewhere [4-7]. Briefly, in this source we make use 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. The plasma plume drifts through the post-anode region to the set of grids that comprise the extractor - a three grid, accel-decel, multiaperture design.

A schematic of an embodiment of the concept with which we've done much of our work is shown in Fig. 1; this is the MEVVA II ion source. In the MEVVA IV ion source, 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 compared 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. 2.

The arc is driven by a simple LC pulse line of impedance about 1 Ohm and pulse length typically 250 microseconds. For the measurements reported on here the arc current was mostly in the range 100 - 200 A, and the ion beam extraction voltage was 20 - 60 kV. The source is operated on a test-stand equipped with various diagnostics to monitor the source performance and the parameters of the extracted beam, including a time-of-flight diagnostic for measurement of the ion charge state spectrum [8].

RESULTS

Some General Observations. - No special preparation of the cathode material was done; the cathodes were simply "as-machined". We observed that the charge state spectra initially showed contamination (eg, C, N, O, Al), but became quite clean after typically less than 100 or so shots, showing only the charge states belonging to the cathode material. For one case (uranium) we prepared a well-outgassed cathode by a 24-hour vacuum bake at 600C, and found no difference in the charge state spectra between this cathode and an unbaked cathode.

The background pressure in the vacuum vessel was maintained at about 1×10^{-6} Torr. To confirm that the spectra were not being degraded to lower charge states by charge exchange with the background gas, we varied the ambient pressure over a range from 1×10^{-6} to 1×10^{-4} Torr. There was a slow decrease in the mean charge state of the distribution with increasing pressure, as expected. Most of this effect is due to the long flight path (>2m) in the time-of-flight diagnostic.

We varied the geometry of the arc in the following ways: cathode diameter over a range from 1 mm to 1 cm; cathode shape from flat (flat-faced cylinder) to inverted conical; cathode-anode spacing from 1 cm to 5 cm; anode hole diameter from 1 mm to 1.5 cm. In all cases the charge state spectrum remained essentially the same. We note that these observations are consistent with the hypothesis that the ion charge state distribution is determined by the plasma within the cathode spots, and that the configuration of the arc region external to the cathode spots has only minor bearing on the determination of the ion charge state distribution.

We can scan the time-of-flight gating pulse through the complete time history of the arc pulse, thus measuring the charge state distribution throughout the arc pulse duration. We find that the spectrum remains essentially unchanged over the middle (approximately flat) portion of the current pulse, but that there is a major and very significant change in the distribution during the early-time current rise. The mean charge state $\bar{Q}$ during the current rise can be greater than the $\bar{Q}$ during the latter part of the arc current by as much as a factor of two. We believe that this effect is associated with the higher voltage that is then present across the anode-cathode gap, as the voltage falls from its pre-breakdown value of typically 200 V to its burning value of typically 20 V. Further investigation of the early-time charge state behavior is in progress.

Range of cathode materials: - Some examples of the measured charge state distributions are shown in Figure 3. These were all taken for the same arc current, $I_{arc} = 200$ A. The 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,

$I_{elec} = QI_{part}$. In order to obtain spectral data that would be visually intercomparable, the oscilloscope gain was adjusted for each cathode material; the current scale is within a factor of several of 100 A/cm for all the oscillograms shown. These measurements have been compared to the predictions of a theoretical model elsewhere [9]. We find that the mean charge state (with respect to particle current) can be fitted reasonably well by the completely empirical expression, $\bar{Q}_p = 0.38(T_{BP}/1000) + 0.6$, where T_{BP} is the boiling point of the cathode metal in °K.

Magnetic Field Effect: - The source was located within a strong axial magnetic field established by a large magnetic field coil surrounding the entire ion source. The dc field could be varied up to 3.2 kG. We found that the magnetic field had a pronounced effect on the charge state distributions. The mean charge state increased with field strength, and new highly-stripped components were produced. This effect is shown in Fig. 4. The shift to higher charge states with increasing field strength is clearly seen, and the general shape of this family of curves is typical of that expected for improved plasma ionization conditions. 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.

Arc Current Effect: - The measured charge state spectra are influenced by the magnitude of the arc current. In general the dependence is rather weak over the range covered in our work, approximately $100 < I_{arc} < 1200$ A. This is consistent with a picture in which the main effect of increasing the arc current is simply the creation of more cathode spots, rather than a change in the plasma parameters within the spots. There is a shift to slightly higher charge states as the current is increased, but this trend often reverses for sufficiently high arc current. The detailed variation, $Q(I_{arc})$, seems to depend on the precise geometry with which the ion source is configured. We do not have an explanation for this variation at the present time.

CONCLUSION

The charge state spectra of ions generated in the vacuum arc have been measured as a function of many experimental parameters. The mean charge state is observed to increase with boiling point of the cathode material, and with magnitude of an applied axial magnetic field. The arc current also plays a role in determining the charge state distribution, but in a complicated way. The lack of a dependence of the spectra on the arc geometry implies that the charge state spectra are determined by the plasma conditions within the cathode spots, and that the plasma in the extended arc beyond the spots does not play a major role.

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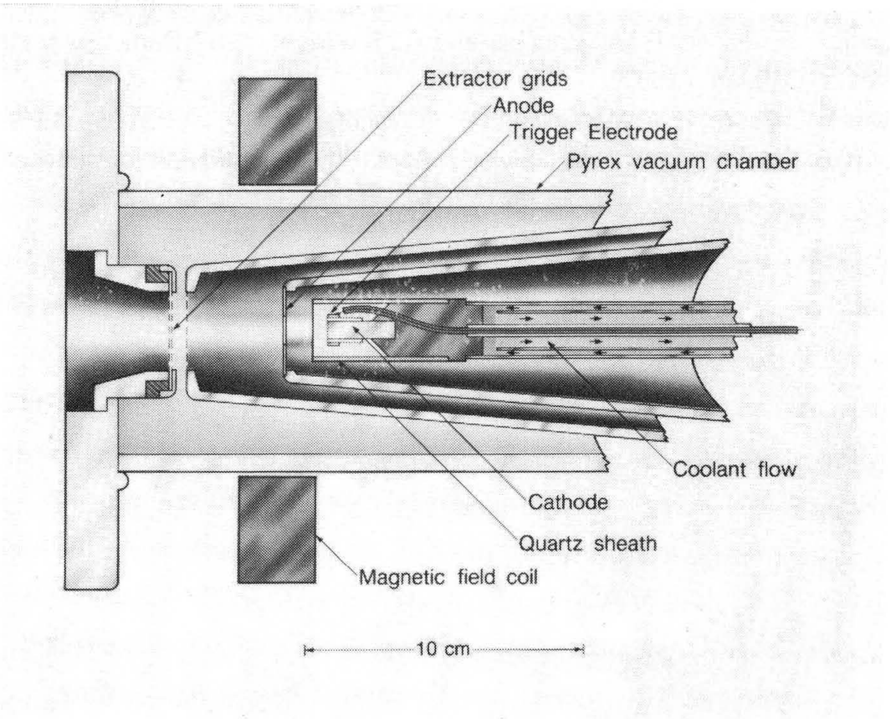

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Fig. 1 Schematic of the MEVVA II ion source.

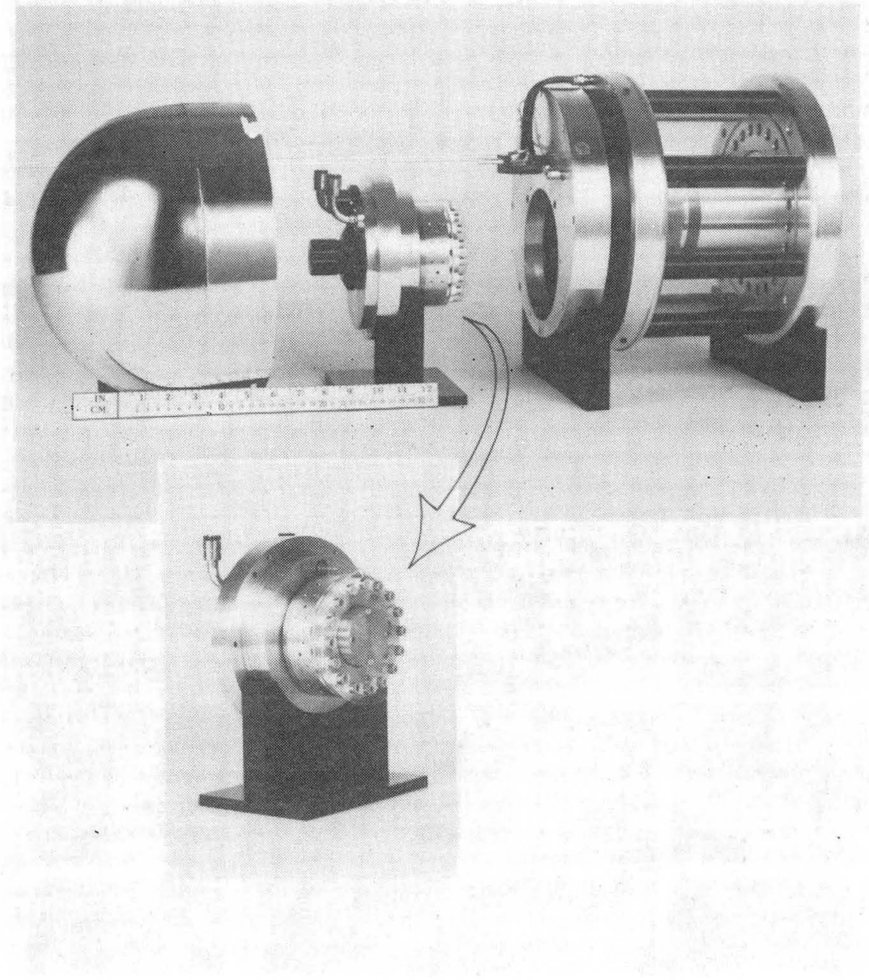

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Fig. 2 The MEVVA IV ion source, showing the multiple cathode configuration.

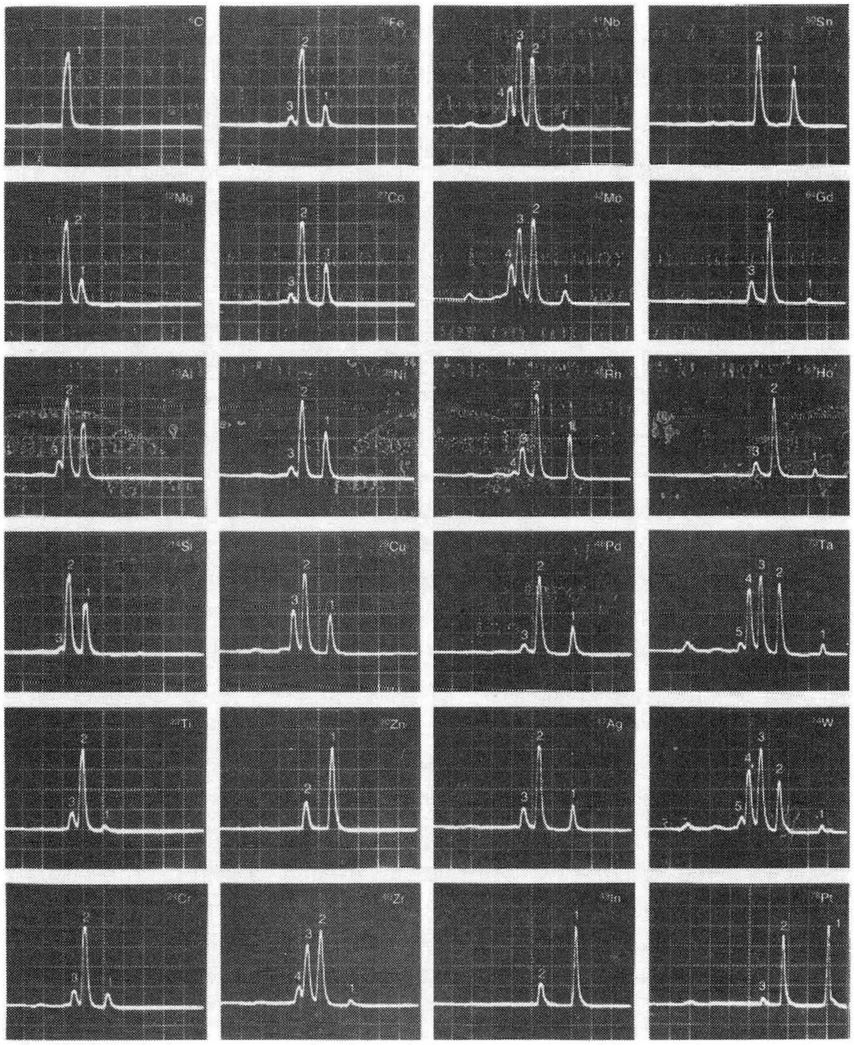

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Fig. 3 Time-of-flight spectra for some of the cathode materials investigated. Vertical scale: current collected by the Faraday cup, gain approx. 100 μA/cm. Sweep speed: 1 μs/cm.

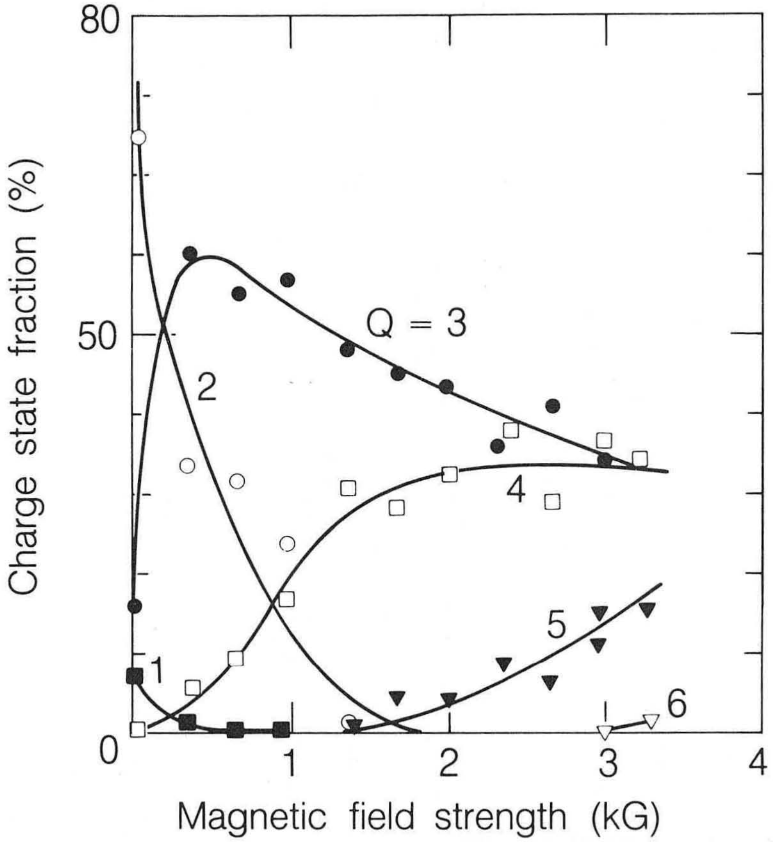

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Fig. 4 Measured charge state fractions as a function of applied magnetic field strength. Uranium cathode, I_{arc} = 100 A.