Operational characteristics of a metal vapor vacuum arc ion source

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The MEVVA ion source can produce high current pulsed beams of metallic ions using a metal vapor vacuum arc discharge as the plasma medium from which the ions are extracted. In this study, the operational characteristics of the MEVVA IV ion sources are summarized. Results are presented of measurements of the ion beam current as a function of arc current over a range of extraction voltage. Ti, Ta, and Pb were examined as the cathode materials. The arc current ranged from 50 to 250 A and the extraction voltage from 10 to 80 kV. The ion beam current was measured at two different distances from the ion source using Faraday cups, so as to investigate the beam divergence. Additionally, the cathode erosion rates were measured. Optimum operating conditions of the MEVVA ion source were determined.

INTRODUCTION

Several different embodiments of the MEVVA ion source have been designed and described.[1–4] Here we outline some studies we have carried out of the operational performance of the MEVVA IV ion source. The metal ion beam current has been measured as a function of arc current, extractor voltage, metal species, extractor grid spacing, and position of the beam current measuring Faraday cup. The results characterize the beam performance that can be obtained.

I. EXPERIMENTAL SETUP

For the experiments reported on here, cathodes of Ti, Ta, and Pb were used. The beam formation electrodes ("extractor grids") were a quite conventional set of multi-aperture, accel–decel grids in the form of a circular array of 31 holes, each of diameter 0.3 cm, with array diameter approximately 2 cm. The extractor gap was set at either 0.89 or 0.38 cm.

The extraction voltage was varied from 5 to 80 kV. A voltage of -3 kV was applied to the suppressor grid to impede electron backstreaming. The arc current was of magnitude 50–250 A, and was supplied from an LC pulse line of impedance 1.5 Ω and pulse length 250 μs. For these experiments the pulse repetition rate was several pulses per second, although the source has been operated at up to 100 pps.

The source was located on a vacuum chamber with a base pressure of about 5×10^{-7} Torr. Magnetically suppressed Faraday cups were positioned within the vessel to monitor the ion beam current. The first Faraday cup, FC1, had a rectangular entrance aperture of dimensions 7.3×15 cm^2, and was positioned at an axial distance of 20 cm from the ion source extractor to the collector plate of the Faraday cup; this geometry is such that FC1 monitors essentially the entire beam produced (i.e., all the beam is collected). A second Faraday cup, FC2, was positioned at an axial distance of 59 cm from the source and could be used to monitor the beam current when FC1 was retracted. FC2 had a circular entrance aperture of diameter 5 cm; this geometry is such that FC2 monitors only the beam current within a half-angle of approximately 2.5°. A schematic of the experimental configuration is shown in Fig. 1.

II. RESULTS

We measured the beam current, $I_{\rm beam}$, using the two Faraday cups, FC1 and FC2, as a function of extractor voltage $V_{\rm ext}$ and arc current $I_{\rm arc}$, for the three different cathode materials Ti, Ta, and Pb, and for two different extractor grid spacing, $g = 0.89$ cm ($g1$) and 0.38 cm ($g2$).

The beam current measured at the first Faraday cup FC1 as a function of extractor voltage is shown in Fig. 2 for Ti, Ta, and Pb cathodes with an arc current of 200 A and for an extractor gap of 0.89 cm. Note that the size and location of FC1 is such that essentially all of the beam current is measured independent of beam divergence. It can be seen that the beam current increases with extractor voltage and decreases with ion mass.

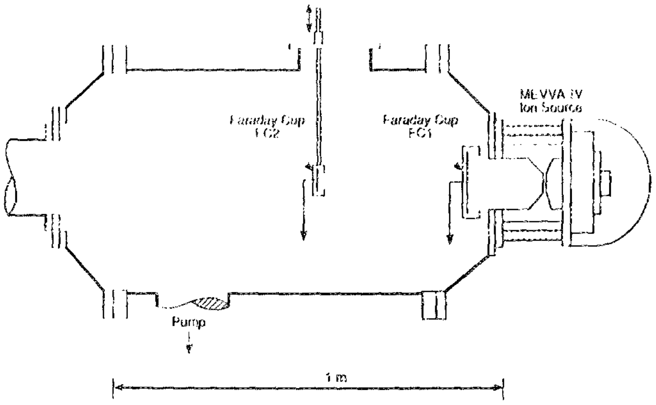

FIG. 1. Schematic of the experimental configuration.

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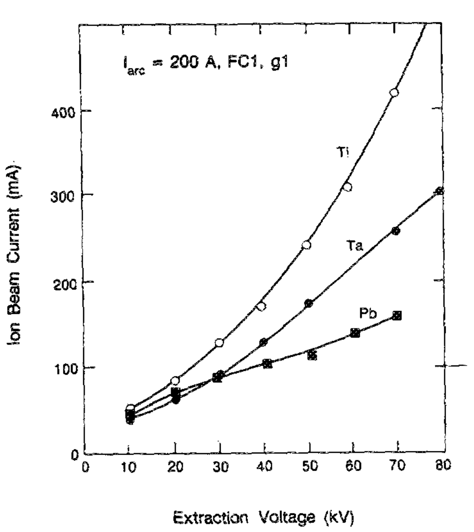

FIG. 2. Ion beam current as a function of extraction voltage for Ti, Ta, and Pb cathodes. Arc current = 200 A; measured with FC1 and for an extraction gap $g = 0.89$ cm.

The beam current can be plotted as a function of arc current, with the extractor voltage varied as a parameter, and this kind of presentation is shown in Fig. 3 for Ti. An optimum extraction condition can clearly be seen, as is indicated by the dashed line; there is an arc current (i.e., plasma density) for which the beam current is a maximum for a given extraction voltage.

The half-angle subtended by the 5-cm-diam Faraday cup FC2 at its distance of 59 cm from the ion source is 2.5°, implying a moderately tight ion beam, and the beam current at FC2 is only a fraction of the total beam current. Thus, the current measured at FC2 is a function of the beam divergence also, whereas that measured by FC1 is not. The ratio of the beam current collected by FC2 to that collected by FC1 is shown in Fig. 4 for the case of a titanium ion beam. There is a clear effect of arc current and extraction voltage, and a modest arc current of about 100 A provides the right conditions for optimum extraction optics.

The extractor gap width was decreased to $g = 0.38$ cm,

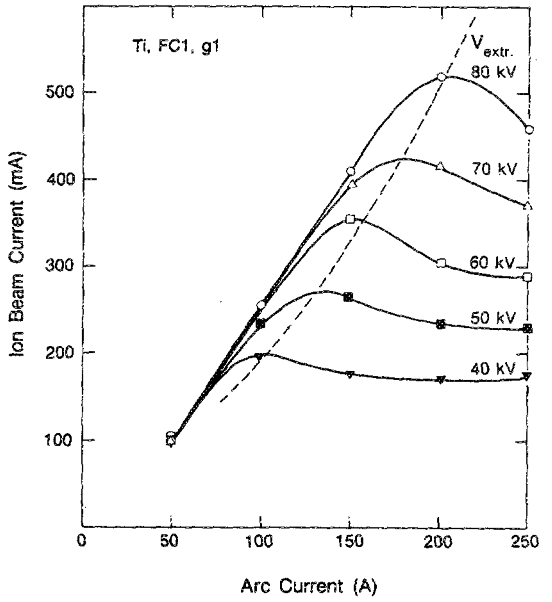

FIG. 3. Ion beam current as a function of arc current for a range of extraction voltage. Titanium cathode; measured with FC1 and for an extraction gap $g = 0.89$ cm.

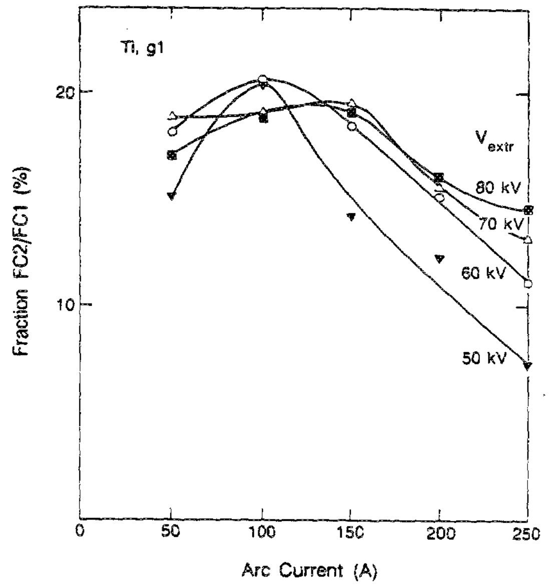

FIG. 4. Ratio of the ion beam current measured by FC2 to that measured by FC1 as a function of arc current, for a range of extraction voltage. Titanium cathode; extraction gap $g = 0.89$ cm.

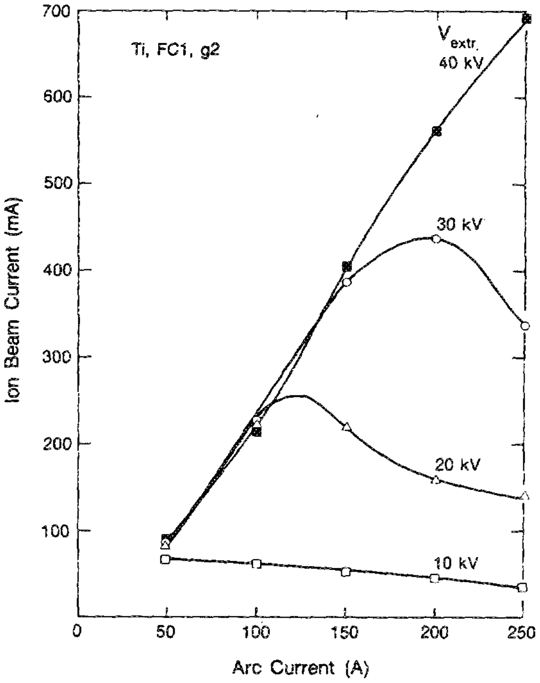

FIG. 5. Ion beam current as a function of arc current, for the smaller extraction gap spacing, $g = 0.38$ cm. Titanium cathode; measured with FC1.

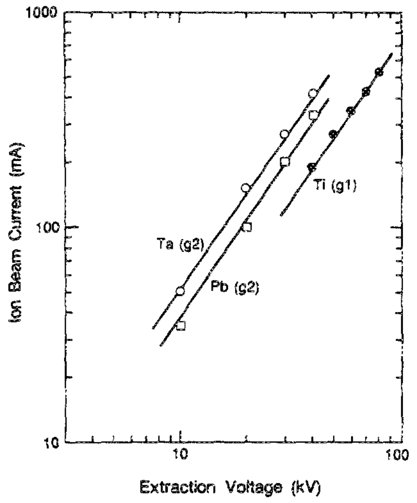

FIG. 6. Measured beam current vs extraction voltage, showing the $V^{3/2}$ variation.

and the results of a limited data set are shown in Fig. 5 for the case of a titanium cathode and using FC1. The beam current is greater than that obtained for the larger extractor spacing, and an optimum arc current, for which the beam current is maximum for a given extractor voltage, is evident.

The variation of beam current with extractor voltage is shown in Fig. 6. These data correspond to optimal extraction conditions as indicated by the maxima in the I_{beam} vs V_{extr} curves. The Child–Langmuir equation for the current I under space-charge-limited conditions is[5,6]

$$I = \frac{4}{9}\epsilon_0 S \left(\frac{2q_i}{M_i}\right)^{1/2} \frac{V^{3/2}}{d^2},$$

where S is the extractor (open) area, $q_i = eQ$ is the ion charge, M_i is the ion mass, V is the applied extraction voltage, and d is the extractor gap width. For the present case we note that it has been experimentally demonstrated that the charge state distribution remains constant throughout the beam pulse (after an early-time transient behavior), and that there is only a quite weak dependence of the charge state distribution on the arc current; thus, the factor q_i in the equation above can be taken as a constant. The straight lines drawn in Fig. 6 have a $V^{3/2}$ variation, and the excellent fit of the data to this slope is evident.

Finally, we also measured the rate of erosion of cathode material for a number of different metals. For these measurements the arc current was 100 A. The cathode mass was measured using an accurate beam balance before and after operating the source for a known number of discharges, typically several thousand. The measured erosion rates were compared with the rates predicted by a simple estimate based on the known ion generation rates.[7–9] The agreement was good for the more refractory metals, while for the low boiling point metals there is evidence for an additional mass loss, as, for example, might be associated with an intense macroparticle and neutral vapor generation.

Further experimental results of the kind presented here and quantitative analyses of those results are in preparation and will be presented in a future publication.

III. CONCLUSION

The beam current produced by the MEVVA IV ion source has been measured over a range of operating conditions as a function of the primary source parameters including extraction voltage, arc current, extraction gap, and metal ion species. The metal ion beam current varied up to a maximum of 700 mA over the range of parameters investigated here. Source performance can be optimized in terms of maximum beam current produced and minimum beam divergence by judicious choice of operational parameters, and can conveniently be adjusted by control of the arc current magnitude.

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[1] I. G. Brown, in *The Physics and Technology of Ion Sources*, edited by I. G. Brown (Wiley, New York, 1989).

[2] R. A. MacGill, I. G. Brown, and J. E. Galvin (these proceedings).

[3] I. G. Brown, J. E. Galvin, B. F. Gavin, and R. A. MacGill, Rev. Sci. Instrum. **57**, 1069 (1986).

[4] I. G. Brown, J. E. Galvin, R. A. MacGill, and R. T. Wright, *1987 Particle Accelerator Conference*, Washington, DC, March 1987 (IEEE, New York, 1987), p. 343.

[5] I. Langmuir and K. T. Compton, Rev. Mod. Phys. **3**, 251 (1931).

[6] R. Keller, in *The Physics and Technology of Ion Sources*, edited by I. G. Brown (Wiley, New York, 1989).

[7] C. W. Kimblin, J. Appl. Phys. **44**, 3074 (1973).

[8] J. M. Lafferty, Ed. *Vacuum Arcs—Theory and Application* (Wiley, New York, 1980).

[9] C. W. Kimblin, J. Appl. Phys. **45**, 5235 (1974).