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Author
Brown, I.G.

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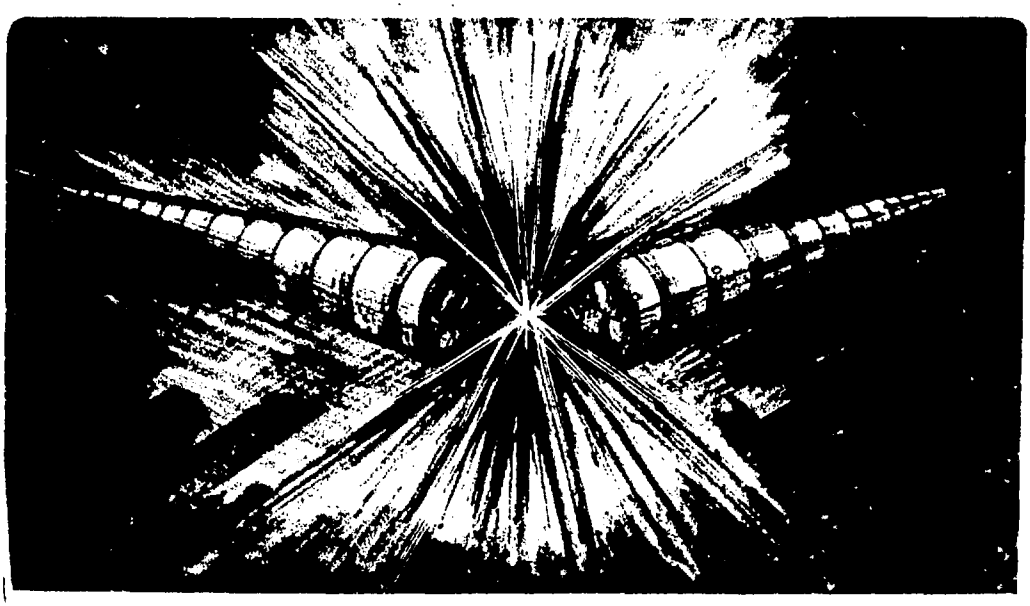

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APPLICATIONS OF THE MEVVA HIGH CURRENT METAL ION SOURCE*

Ian G. Brown

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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DISCLAIMER

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ABSTRACT

A new kind of ion source has been developed in which a metal vapor vacuum arc (MEVVA) is used to produce the plasma from which the ion beam is extracted. The novel and exciting feature of this source is the very high metal ion beam current attainable. A total ion beam current of over 1 Ampere has been extracted from the embodiment of the concept that we're presently using, and this is not a limit of the method. The source was developed to upgrade the uranium ion beam intensity of the Bevatron, LBL's heavy ion synchrotron, for basic nuclear physics research. Other important applications include its use within the Heavy Ion Fusion research effort; for ion implantation; and for other basic research uses. In this paper the source is described briefly, its performance outlined, and its potential and limitations for a variety of applications is discussed.

1. INTRODUCTION

The MEVVA ion source has been developed recently at the Lawrence Berkeley Laboratory to produce high current beams of uranium ions to upgrade the heavy ion accelerator facilities. Because the source can produce metal ion beam currents which are much greater than what has hitherto been possible, it seems likely that it will find application in a number of other fields, beyond that for which it was developed. In this paper we describe the MEVVA source and how it works, and summarize the source and beam performance characteristics. The potentials and limitations of the use of the source in several applications are discussed.

2. DESCRIPTION OF THE MEVVA SOURCE

A full description of the MEVVA ion source has been presented 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 [4], 'cathode spots' - minute regions of intense current concentration - form on the cathode surface, together constituting a prolific source of metal plasma which plumes away from the cathode toward the anode and persists for the duration of the arc current. 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. The partially disassembled MEVVA II source is shown in Figure 1; the various components and features refered to can be seen.

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 low emittance metal ion beams of over 10 ma [5]. 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. ION BEAM CHARACTERISTICS

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, LaB6, CdSe, SmCo, SiC, and WC. In this way beams can be made which contain non-metallic species - eg, B^+ from LaB6 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 beam current can be as high as about 1 Ampere (electrical current in all charge states), and beams of a few hundred milliamperes can be produced routinely. These 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 [6]. The beam emittance (HWHM) is typically 0.2 to 0.5 π mm. mrad. (normalized).

Beam composition has been measured with 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 cases by a more conventional magnetic analysis. As an example, the charge state spectrum obtained for the case of cobalt is shown in Figure 2. In this case the distribution contains Co^+, Co^{2+}, and Co^{3+}. 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. We have obtained charge state distribution data such as shown in Figure 2 for all cathode materials; in general the lower Z materials show lower charge states and the higher Z materials show higher charge states [7].

4. APPLICATIONS

The characteristic of the MEVVA source that makes it of special interest is the high beam current of metal ion species that can be produced. Table 1 lists some of the areas of possible application, together with those particular source or beam qualities that are peculiar and important to a particular application.

Accelerators

The source is well suited as a synchrotron ion source, and this is the use for which it was initially designed. The pulse length and duty cycle requirements for synchrotron injection are typically around 1 millisecond at 1 pps, and this is ideal for the present embodiment, MEVVA II. There is a need in heavy ion nuclear physics for intense beams of heavy ions of all kinds, including metals up to uranium, and the MEVVA source fills this need well [8]. A MEVVA source has been operated on the GSI facilities, including a high current beam line test stand and the first sections of the RFQ accelerator, MAXILAC [9].

Its use as an injector for heavy ion linear accelerators may in some cases be restricted at present if the linac calls for duty cycles of up to several tens of percent, as for example does the LBL SuperHILAC. This is not an inherent limitation of the source, however, and it is probable that further source development will upgrade the cooling of the arc region and allow high duty cycle operation, at least for extracted beam currents of less than 100 ma or so. We anticipate adapting the MEVVA source to SuperHILAC use.

A cyclotron ion source is generally a dc source, and this is a mode of MEVVA operation that has not yet been attempted. Although the beam current requirements for cyclotron injection are very small by MEVVA standards, the beam current cannot be continuously reduced to arbitrarily small value: as the arc current is reduced, the number of cathode spots participating in the arc decreases until there is only one spot, and when the arc current falls below the minimum current needed to maintain the spot, the arc extinguishes. The minimum current depends on the cathode material, but for the MEVVA source is typically a few tens of amps arc current and a few tens of milliamps beam current.

Ion Implantation

The use of ion implantation for semiconductor doping and circuit fabrication is a well developed industrial field, and the requirements placed on the ion source are severe. The beam needs to be quiet and reproducible on a short and long term basis to about the 1% level, and the source lifetime between servicings needs to be long. There is on the other hand a continuous need for higher current sources, and there is a growing need also for metallic species. The MEVVA source holds promise for this application by virtue of its high beam current and metallic species production, but the beam quality and duty cycle need further development before this potential can be satisfied.

Metallurgical ion implantation, whereby exotic surface alloys can be created with improved resistance to wear and corrosion, for example, is a field which can make use of the MEVVA source in its present embodiment. There has been a need for a high current source of metal species, and the MEVVA source can fill this need. The duty cycle should be as high as is possible, and development of this parameter would help; but even at the present level of up to about 1%, the source is of value for research and developmental application within the metallurgical surface modification field. We have started some preliminary work in this direction [10]. Also, a high current, multi-MeV accelerator system incorporating a MEVVA ion source and an RFQ accelerator is being developed at Texas A&M University [11].

Similarly, ion implantation into ceramic surfaces, and other research implantations, have need for high current beams of metal ions, and the MEVVA source can be of use.

Heavy Ion Fusion

Heavy ion drivers for the development of inertially confined fusion call for an ion source which can produce high current, high quality, short pulse beams of heavy ions. We've done some work looking at the application of the MEVVA source within this research area [12]. Figure 3 shows the MEVVA ion beam pulse output in a short-pulse mode of operation; here the beam current is 650 ma in a pulse of width about 12 microseconds. There is considerable potential for the source and further development is warranted.

Laboratory Ion "Feedstock"

There is a steady need in basic atomic physics experiments for ion sources of all kinds, including sources of metal ions. The MicroMEVVA source is of particular interest here because of its extreme simplicity and small size [5]. The MEVVA source is an addition to the gamut of ion sources available to the laboratory experimentalist.

5. CONCLUSION

The MEVVA ion source provides a means of producing high current beams of metal ions. The source is simple, and easily fabricated and operated. In its present embodiment it is a pulsed device with a duty cycle up to about 1%; this is not an inherent limitation, and operation at around 10% or more should be possible with improved cooling of the arc region. As a unique high current source of metal ions, the source finds ready application as a synchrotron ion source, for metallurgical ion implantation, for heavy ion fusion research, and as a laboratory tool for basic studies.

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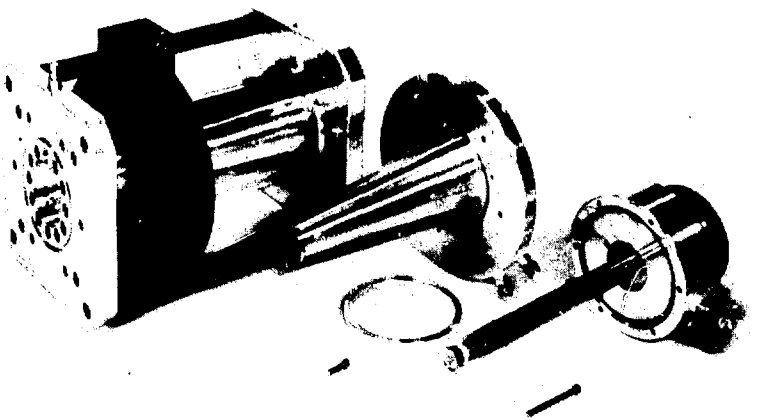

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Fig. 1 The MEVVA II ion source partially disassembled.

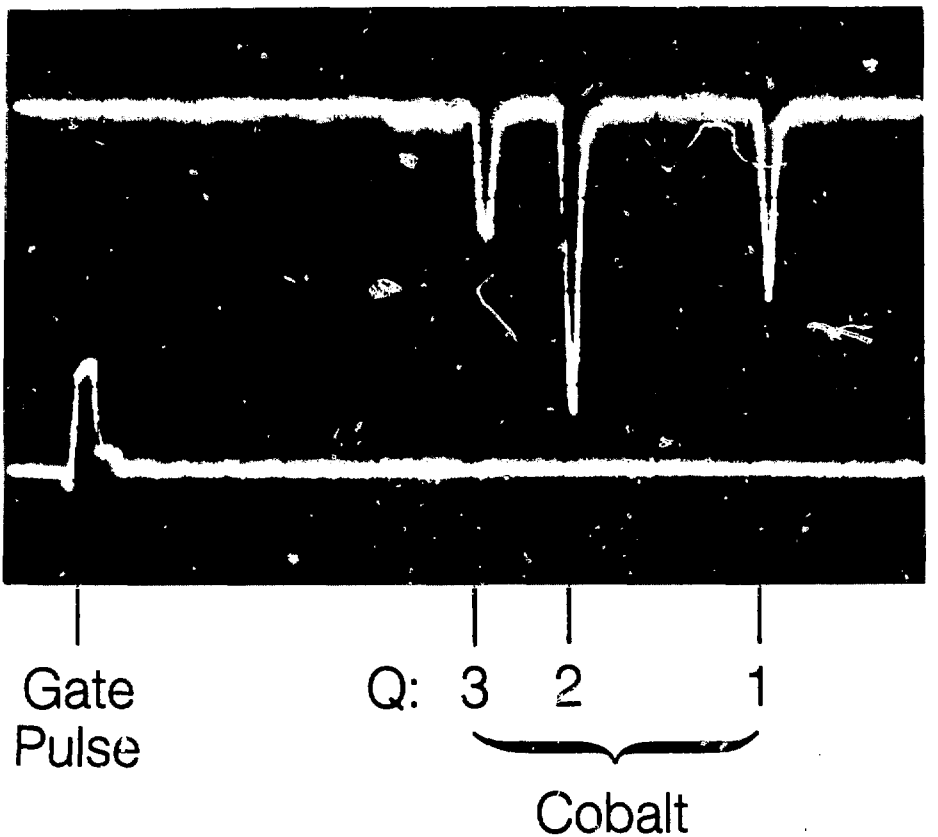

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Fig. 2 Charge state distribution for cobalt.

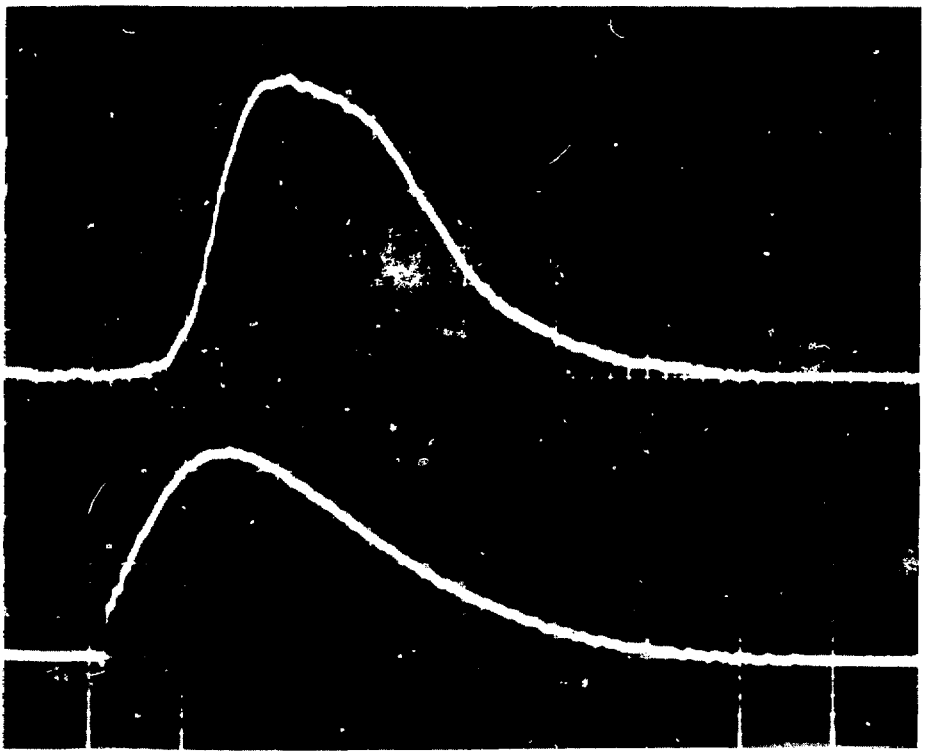

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Fig. 3 Short pulse operation. Upper trace: beam current, 200 ma/cm. Lower trace: arc current, 200 A/cm. Sweep speed 5 microseconds/cm.

Application	Distinctive Features	Suitability
Accelerators		
Synchrotron	Low duty cycle	Good
Linac	High duty cycle	(work needed)
Cyclotron	DC	Poor
Ion Implantation		
Semiconductor	High duty cycle; beam quality	(work needed)
Metallurgical	High average current	Good
Ceramics & other	Metallic and exotic species	Good
Heavy Ion Fusion	Short pulse, high current	Good
Laboratory Ion "Feedstock"		
Ion source		
Astrophysical simulations	Varied	Varied
Other		
E-M Isotope Separation	Throughput	Limited
Thruster	Mass utilization, efficiency	Poor

Table Some of the more visible potential applications of the MEVVA ion source and the requirements which make the match good or bad.