STATUS OF THE MEVVA HIGH CURRENT METAL ION SOURCE*

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Abstract

The MEVVA (Metal Vapor Vacuum Arc) ion source that has been developed at LBL was reported on for the first time at the 1985 Particle Accelerator Conference [1]. This source can produce hundreds of milliamperes of beam current of metal species from lithium up to uranium. In the period since then we have developed the source further, and this work is summarized here. We have now run the source with over 30 different beam species, and with an extraction voltage up to 110 kV. We have made and operated a miniature source, the MicroMEVVA. A multi-cathode version, in which one can switch rapidly between cathodes of different materials, has recently been constructed and tested. Applications of the source include: as a synchrotron ion source, as an ion source for heavy ion fusion, and for metallurgical ion implantation; we have done some preliminary work in these directions.

Introduction

In the MEVVA ion source a metal vapor vacuum arc plasma discharge is used to create a dense, highly ionized, metal plasma from which an impressively intense beam of metal ions is then extracted. The source works in a vacuum ambient, typically 10^{-5} - 10^{-6} Torr, since a background gas is not required to establish a primary plasma and the metal ions do not depend on sputtering for their generation; furthermore, the complication of an oven to produce metallic vapor is avoided, and the source runs cool. The principle of operation is simple, and indeed it is hard to make the source not work. The associated power supplies and other electronics are not complicated. The source has been described in several publications [1-3].

The motivation for developing this source was to provide a means of upgrading the particle accelerator facilities at LBL, in particular the intensity of heavy ion beams such as uranium. This upgrade project is well underway, and is described by Feinberg et al in this Conference [4]. The viability of the MEVVA source as a means for producing accelerator-useful beams of metal ions is evident from the following brief summary of the performance actually obtained to-date: The source works with all the metallic cathode materials we've tried, spanning the periodic table from lithium to uranium. Beam has been extracted at a voltage from a low of about 10 kV up to a maximum (power supply limited) of 110 kV. The beam current is typically 100 - 300 ema, and can be varied from a practical minimum of a few milliamperes up to about 1 Ampere. Beam emittance is usually no more than about 0.05 π cm. mrad. (normalized) (measured to the half intensity point 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 containing significant fractions (say over about 10%) of Q = 3+, 4+ and 5+ ionization states for high-Z species like Ta and U. We've operated the source at a beam pulse length of about 250 microseconds for most of our development work, and up to 3 milliseconds on occasions; the repetition rate has been up to 30 pulses per second for extended periods (hours), and up to 100 pps for shorter periods.

We present here a summary of some of the highlights of our MEVVA activities in the last two-year period.

Source Development

The MEVVA II device was described in detail in the previous Particle Accelerator Conference [1]. Several improvements have been made to the original design, and this improved version, which we've called the MEVVA IIb source, has evolved to be our "workhorse" with which most of the work done in the two year period has been done. The main improvement is in the cooling; freon coolant is now circulated efficiently in the anode region as well as near the cathode. This allows the source to be operated at higher average arc power than previously, which in turn means higher duty cycle. We've also changed the arc trigger. Whereas previously the trigger was a thin pin, or wire, on axis and surrounded coaxially by the cathode, now it is a short cylinder, or annulus, coaxially surrounding the cathode on the outside and separated from it by a closely fitting length of alumina tubing. This change has resulted in much more reliable triggering and in a longer lifetime between triggering failures. The MEVVA IIb device is shown in Figure 1. A IIb source has been set up and tested at the GSI Laboratory at Darmstadt, Germany, and the initial work done there has been reported [5]. Keller has improved the way in which the beam is extracted from this source, greatly increasing the beam brightness [6].

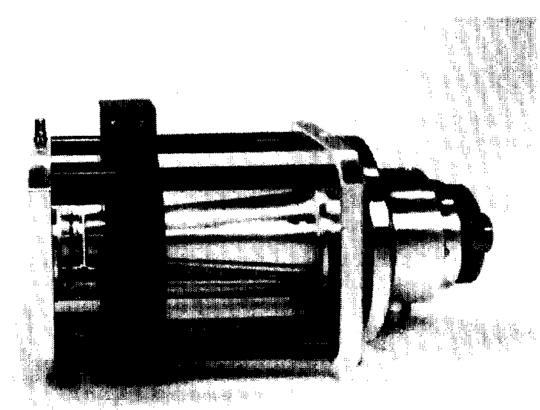

Fig. 1. The MEVVA IIb device. Overall length is 16 inches.

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The MicroMEVVA source is a miniature embodiment of the MEVVA concept. This source is less than "thumb size" - 1.5 cm in diameter and 6 cm in overall length. Beam current of up to 15 ma at 15 kV has been produced. The power dissipation capability of this source is minimal, since there is very poor heat removal. None-the-less the source can run at, for example, a pulse length of about 100 microseconds and a repetition rate of about 1 pps. This source is shown in Figure 2, and it has been described in the literature [7]. One application of this embodiment is as an injector of metal ions into an EBIS (Electron Beam Ion Source), where they are further stripped to very high charge state.

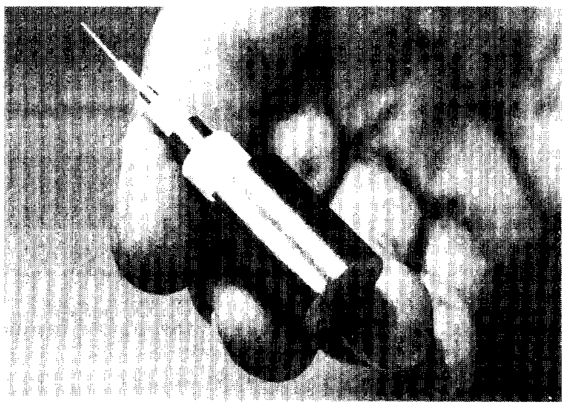

Fig. 2 MicroMEVVA

MEVVA IV is our latest source development. There are a number of novel features in this embodiment, the most significant of which is the multi-cathode design. The MEVVA IV contains an array of 16 cathodes, any one of which can be switched into operation while under vacuum and in the space of a second or so; soon we will add the ability to make this change remotely. The source is designed to run at very high voltage, and in our tests to-date beam has been extracted at 110 kV without source breakdown. A photograph of this source is shown in Figure 3.

Fig. 3 MEVVA IV

Source And Beam Performance

The range of cathode materials with which we've run, and therefore the range of beam species produced, is now quite extensive. We've run with Li, C, Mg, Al, Si, Ti, Cr, Fe, Co, Ni, Zr, Nb, Mo, Rh, Sn, La, Gd, Ho, Ta, W, Pt, Au, Pb, Th, U, LaB_6, CdSe, PbS, SiC, TiC, and WC.. All of these materials produce intense beams. Soft materials like Li, Sn and Pb tend to have a shorter lifetime before we experience triggering problems due to plating over of the cathode/trigger insulator, but this depends on how the source is run. The compound cathodes produce a beam containing ions of the molecular constituents, and it is very interesting to note that beams containing non-metallic elements, like B and S, can be made by using conducting compound electrodes of which the non-metal is a constituent.

We've steadily increased the extractor power supply voltage, and the maximum voltage at which we have now extracted beam is 110 kV. The MEVVA IV device can hold off this voltage without apparent problem, and the limitation is in power supply voltage. We have no plans for increasing the extraction voltage any further at the present time. For all cathode materials, we have obtained charge state distribution data using a time-of-flight system, and we find that low-Z elements like Li and C produce singly ionized species, Li^+ and C^+, only, medium-Z elements like Co and Rh produce spectra containing Co^+, Co^{2+}, Co^{3+} and Rh^+, Rh^{2+}, Rh^{3+} (at a level greater than about 10%), and high-Z elements like W and U produce spectra containing W^{2+}, W^{3+}, W^{4+} and U^{3+}, U^{4+}, U^{5+}, U^{6+}, for example. It is interesting to note that this implies ion energies in the several hundred keV range, an important concern for deep layer ion implantation.

In our work at LBL, the beam emittance remains typically in the range 0.02 - 0.05 π cm. mrad. (normalized), depending on the extractor geometry and other source parameters. We are presently bringing the GSI "Axcel" code [8] onto line, to do ray-tracing in the extractor region of the source and thus to optimize the emittance.

We have significantly increased the upper limit to duty cycle at which the source can be run. The limitations here were the electronics, both triggering and arc supply, and heat removal from the arc region. A high repetition rate triggering system, employing spark gaps instead of thyratron, has been developed which can operate at up to several hundred pulses per second, and the arc supply charging efficiency has been increased. With these changes, and using the better cooling capacity of the MEVVA IIb or MEVVA IV, we have run at 30 pps for periods of several hours. The pulse width was the usual 250 microseconds, and so the duty cycle was 0.75%. The beam current was moderate, in the 100 ma range. The limit to still higher rep rate and duty cycle was again set by the power supplies.

The beam noise is an important performance parameter for many applications. We have not yet studied the parametric behavior of beam noise in any detail, but we have made some interesting observations. For optimal beam extraction, the plasma density must be matched to the grid geometry, so that the plasma meniscus is correctly located; for the MEVVA, the plasma density is directly and simply controlled by the arc current. We have found that when the plasma density is properly matched to the extractor grids employed, then the beam is not only maximum in current (measured into the fixed divergence defined by the Faraday cup), but also the beam noise is minimum. This may be a feature common to other kinds of sources also. Figure 4 shows an oscillogram of the beam current and arc current for this optimized condition. Here the beam noise is less than 5% rms, which is quite good.

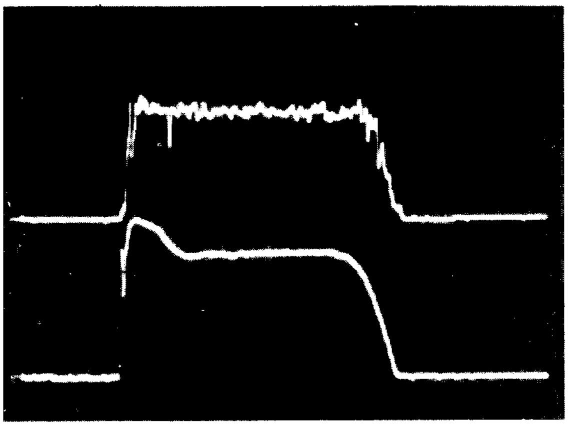

Fig. 4 Oscillogram showing quiescence of the ion beam when the plasma density is optimized to the extractor. Upper trace: beam current, 40 ma/cm. Lower trace: arc current, 50 A/cm. Sweep speed: 50 microseconds/cm.

Applications

The main thrust of our work has been and still remains directed towards particle accelerator injection. At the present time the SuperHILAC is being upgraded to deliver the 8.5 MeV/amu beam at a current five times greater than previously. A key ingredient to this upgrade is the MEVVA source; refer to Feinberg and Brown [4] for a full description. The present MEVVA/SuperHILAC work will allow for source operation at the rep rate and duty cycle called for by the Bevatron; ie, the MEVVA will feed the SuperHILAC for the case when the SuperHILAC is used as injector for the Bevatron. High on our agenda is to increase the efficiency of the source (i_{beam}/i_{arc}) and the duty cycle at which it runs, so as to be able to use the source at a SuperHILAC duty cycle of perhaps 20% - 30%. This performance would be important, for example, to experiments to explore Super Heavy Element synthesis.

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 have done some work looking at the utility of the MEVVA source for this purpose [9]. There is considerable potential for the source here, and further work is warranted.

We have done some very preliminary ion implantation work [10]. Metallurgical surface modification, 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 high current metal ion beam even at the present duty cycle limit. We hope to attract support for this line of work, and to develop this application to its fullest potential.

Conclusion

The MEVVA ion source concept has been developed significantly since its inception several years ago. Beams of a wide range of materials have been produced at over 100 kV extraction voltage and currents of hundreds of milliamperes. The maximum duty cycle at which the source can operate has been increased to near 1% and we anticipate a further increase of over an order of magnitude. Applications for the source are apparent besides that of particle accelerator injection. We plan on continuing to develop the source to its full potential.

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