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Abstracts

Lawrence Berkeley Laboratory

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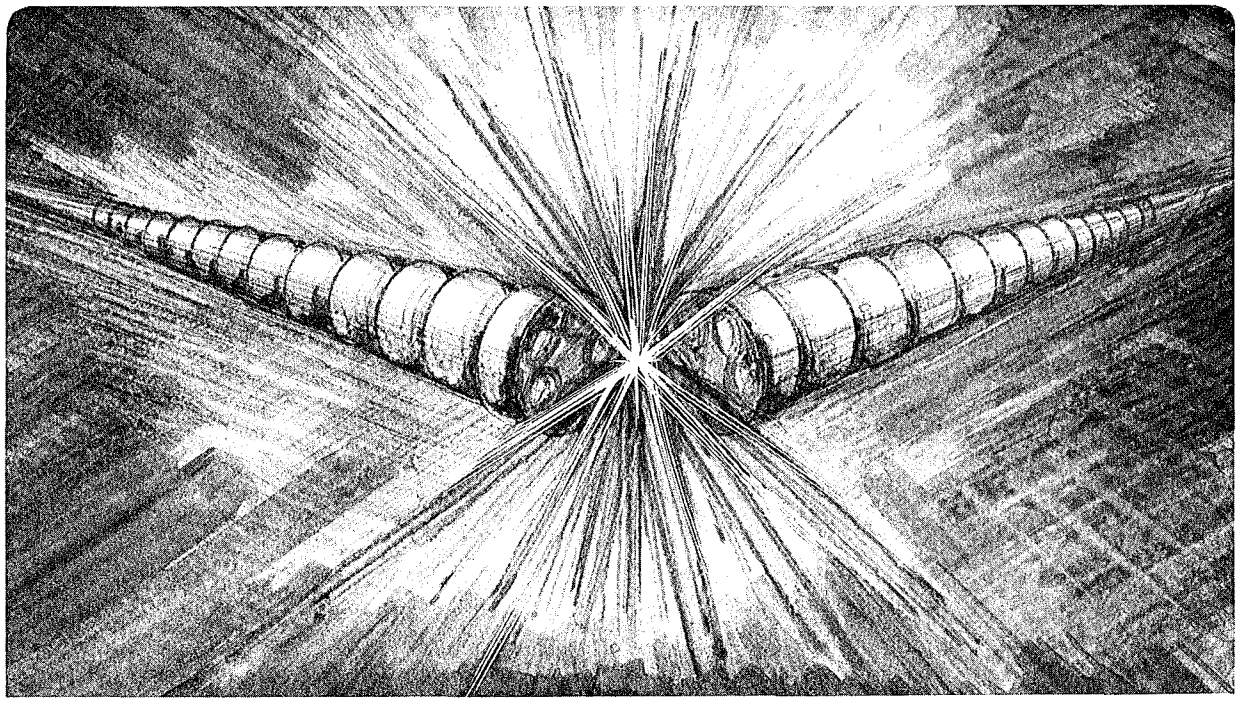
Presented at the Workshop on Metal Vapor Vacuum Arc Ion Sources, Berkeley, CA, September 5-6, 1985

WORKSHOP ON METAL VAPOR VACUUM ARC ION SOURCES: SUMMARY OF ABSTRACTS

September 1985



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SUMMARY OF ABSTRACTS

WORKSHOP* ON

METAL VAPOR VACUUM ARC ION SOURCES

September 5 & 6, 1985

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INTRODUCTION

The metal vapor vacuum arc ion source is a new addition to the gamut of ion sources available to the experimenter, the unique features of which lie in the unusually high current beams of metal ions that can be produced. Work on this new kind of source has evolved independently at several laboratories over the last few years, and we thought that it would be good for us to get together for a small and informal workshop to discuss our work. This get-together was held at Lawrence Berkeley Lab on September 5 and 6, 1985.

We decided at the end of the workshop that, in view of the smallness and informality of our meeting, it would be more appropriate (and less of a burden on us all!) to assemble a summary of abstracts of the papers presented, as opposed to a proceedings containing full papers. This is that summary.

PROGRAM

Thursday, September 5

● Welcoming address	Jay Marx
● "Vacuum Arc Ion Extraction in a Magnetic Field"	Richard Adler
● "Grid Controlled Extraction of Ion Beams"	Stan Humphries
● "Multiple Vacuum Arc Source for Neutralized Beam Transport Experiment"	Craig Burkhart
● "Generation and Measurement of Ion Species for Vacuum Arcs"	Lek Len
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● Tour of Facilities	
● "Thin film Deposition with the Arc Source"	Jonathan Storer
● "Performance of the LBL MEVVA Ion Source"	Ian Brown
● "Accelerator Use of the MEVVA Ion Source"	Ben Feinberg
● "Mass Transfer in the MEVVA Ion Source"	Jim Galvin

Friday, September 6

● "High Current Pulsed Ion Beam Transport and Acceleration"	Stan Humphries
● "Collective Focussing of Intense Ion Beams"	Geoff Krafft
● "The LBL MEVVA Ion Source Hardware"	Ian Brown
● Concluding Remarks	Ian Brown

GRID-CONTROLLED EXTRACTION OF PULSED ION BEAMS*

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Experimental results are presented on a method for extracting well-focused ion beams from plasma sources with time-varying properties. An electrostatic grid was used to stop the flow of plasma electrons so that only ions entered the extraction gap. In this case, ion flow in the gap was controlled by space charge effects as it would be with a thermionic ion source. Constant extracted current was observed even with large variations of source flux. An insulator spark source and a metal vapor vacuum arc were used to generate pulsed ion beams. With a hydrocarbon spark, current densities of 44 mA/cm^2 were achieved at 20 kV extractor voltage for an 8 microsecond pulse. With an aluminum vapor arc, a current density of 15 mA/cm^2 (0.3 A total) was measured for a 50 microsecond pulse.

*Paper to be published, Journal of Applied Physics

MULTIPLE VACUUM ARC SOURCE FOR NEUTRALIZED BEAM TRANSPORT EXPERIMENT

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Development to date of a long pulse, high current density ion source is reviewed. This device employs an array of 12 vacuum metal arcs to generate a plasma anode for magnetically insulated ion extraction. Design parameters for this device call for a 1 A/cm^2 fluence over a 1 ms pulse at 50 kV energy. The vacuum arc plasma source has recently been modified and only preliminary results are available. These results do indicate an azimuthally uniform plasma. The advantages of enhanced efficiency and extractable current density are reviewed and the criterion for magnetic insulation for the gap is presented. Magnetic insulation has been shown for the gap at 20 kV with no measureable leakage current over a 5 ms pulse.

GENERATION AND MEASUREMENTS OF ION SPECIES FROM METAL VACUUM ARCS

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Different species of ion have been generated from a metal vacuum arc using different cathode materials. The arc has a simple point-plane geometry, with the cathode mounted on a micrometer vacuum feedthrough for precise adjustment of the inter-electrode spacing. A time-of-flight spectrometer was used to identify the ion species in the plasma generated in the arcs. Ion species generated to date include those of D, C, Mg, Al, Ti, Ni, Cu, Zn, and In. The ions were predominately in the singly and doubly charged states. The ion flux was found to be directly proportional to the inter-electrode gap spacing. A four stage pulse forming network with a total capacitance of 24 μF at 3 kV charge produced an ion flux of up to 300 mA cm^{-2} for 150 μs at ~10 cm away from the source. The flux falls off as the square of the distance from the arc.

THIN FILM DEPOSITION WITH THE ARC SOURCE

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The cathode arc is potentially a new and important method for thin film deposition. Several advantages are realized with cathodic arc deposition.

- No fractionation. The stoichiometry of the resultant film should be the same as the cathode alloy. This does not happen with evaporation where there is a molten inventory.
- High rate.
- Attitude insensitivity. No molten pool means downwards deposition is possible.
- Highly ionized flux. Can be used to control film properties.

A description of the apparatus will be given and a description of the currently commercialized process for hard-coating tools with Titanium Nitride will be given. A serious disadvantage of the method will be discussed. This problem is caused by macroscopic (few microns dia.) particles which are a component of the metal flux. Several schemes for eliminating these macroparticles will be mentioned. These schemes involve bending the plasma through a plasma duct using ion optics principles.

PERFORMANCE OF THE LBL MEVVA ION SOURCE

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Work on metal vapor vacuum arc ion source development at LBL has been directed toward providing a high current, heavy metal ion beam for injecting into the Bevalac heavy ion accelerator system. This application has largely determined the parameter goals we've headed towards: 1 msec pulses at a rate of up to several pulses per second, with uranium the species of primary interest and U^{5+} the wanted charge state; initially we would like an extracted beam current $\geq$ 100 ema of U^{5+}. The MEVVA II source has met these goals.

Our measurements have included operation with a wide variety of cathode materials, spanning the periodic table from lithium through uranium. We have measured charge state distribution, beam current, ion temperature, source efficiency, beam emittance, beam noise and reproducibility, and have varied the operating parameters over a wide range. A total beam current of over 1 Ampere at an extraction voltage of 20 kV has been obtained.

ACCELERATOR USE OF THE MEVVA ION SOURCE

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A new high current MEtal Vapor Vacuum Arc (MEVVA) ion source (described in these proceedings) is to be installed in the third injector (Abel) at the SuperHILAC. To use this source additional optical elements will be necessary along with an improved high current Cockcroft-Walton power supply to handle the increased beam current. The upgrade project is expected to increase the beam intensity by a factor of five for the heaviest ions, resulting in a uranium output of $5x10^7$ ions/pulse at the Bevatron.

This upgrade will focus on the Abel injector. The chief concerns of the project are the production and transport of low energy, high current, heavy ion beams. The MEVVA ion source is capable of delivering more than 100 emA of U^{5+} which must be successfully transported to the entrance of the Wideroe to use the full capability of the SuperHILAC.

Beams sent to the Bevatron need a source capable of a 1 msec pulse length and a repetition rate of two Hz, yielding a duty factor of only 0.2%. If the source intensity fluctuates during a pulse, the neutralizing electron level fluctuates as well, which can result in amplification of the source fluctuations, so these must be kept to a minimum. The source reproducibility on a pulse-to-pulse basis is also important for tuning the beam, so it should therefore be good to better than a few percent.

MASS TRANSFER IN THE MEVVA ION SOURCE

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Measurements of the distribution of the mass evolved from the MEVVA cathode are presented. The source was run under typical conditions for a large number of shots and the mass deposited on various components within the source was determined. The distribution of the total mass is approximately a cosine, with the peak of the distribution directed forward from the cathode. An implanted silicon wafer receives about 2% of the cathode mass loss, with less than 0.1% of that mass in macroparticles with size in the micron range. The macroparticles are shown to contribute negligible beam current ($\ll 10^{-6}$ of the total beam current). Photographs of the used cathode show many separate small arc craters, rather than tracks.

THE COLLECTIVE FOCUSING OF A NEUTRALIZED CESIUM BEAM

G. A. Krafft

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This talk summarizes the results of an experiment performed using the large Cs^{+1} ion source at LBL.[1] The purpose of the experiment was to test an idea of Robertson in which a charge and current neutralized beam is focused by a weak solenoid magnet.[2] The main conclusion of the work was that for focusing to be observed, the neutralizing electron temperature must be small so that electron reflection by the fringe field of the solenoid is small.

The experiment was analyzed by comparing to the results of particle in cell simulations. It was found that particles with positive canonical angular momentum are reflected, distorting the space charge electric field from that predicted on the basis of fluid theories. The distortion was reduced by reducing the temperature of the neutralizing electrons. In the experiment, this was achieved by using thermionic emission of electrons from a hot wire that intercepted the beam path.

1. G. A. Krafft, C. H. Kim, and L. Smith, IEEE Trans. Nucl. Sci., NS-32, 2486 (1985).

2. S. Robertson, Phys. Rev. Lett., 48, 149 (1982).

THE LBL MEVVA ION SOURCE HARDWARE

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We have made and tested three versions of metal vapor vacuum arc ion source, in the course of our R&D program at LBL. The first version, MEVVA I, was essentially a 'string and sealing wax' device which we used to test our basic ideas and to demonstrate that the MEVVA ion source concept held merit; this source was limited to low extraction voltage because of breakdown problems. MEVVA II was designed and constructed much more carefully, and is the version we've used for most of our experimental work. It is water cooled, and can run at high extraction voltage (up to 30 kV to-date). The ion beam generated is high current and low divergence. Cathode materials can be changed simply and quickly. MEVVA III is a small version that we made for a test-run in the SuperHILAC injector terminal. These sources are described.

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Note: Received too late to include in Summary.

PULSED VACUUM ARC IMPLANTER STUDIES

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The purpose of our study is to investigate the production of high current metal ion beams using pulsed beam techniques. The specific applications which motivate our work are the use of metal ion beams to improve the surface properties of metals, including such properties as corrosion resistance, wear, fatigue lifetime, and friction. Traditionally, ion implanters have operated continuously using ion sources which rely on gases as the source material. This technique is effectve for gases such as nitrogen, but less effective for metals. In general, however, it is metal ions which will find the greatest applications in modification of metal surfaces. Specific examples include the use of titanium to reduce friction in stainless steels, the use of yttrium in reducing oxidation, and the use of chromium in reducing bearing corrosion.

It is this requirement which motivates our work. High currents of metal ions of high purity are produced in vacuum arcs between metal electrodes. Our initial studies demonstrated that this technique was useful as an intense pulsed ion source for ion implantation. Due to arc minimum current requirements and arc gas evolution, we believe that this ion source approach can best be applied by using pulsed technology. We have used radar modulator pulsed power technology to provide the accelerating voltage and current.

We have studied the use of both point-plane high voltage induced vacuum arcs, as well as the use of surface flashover induced vacuum arcs (MEVVA type[1] geometry). Ion acceleration has been studied in the presence and in the absence of a strong magnetic field. This magnetic field is designed to suppress the flow of secondary electrons in the accelerating gap.

A cross section of a point-plane arc geometry is shown in Figure 1. In this geometry, the ion flux was found to be localized within ±3 cm (radially) of the arc origin with an applied 500 Gauss field. The ion source discharge was struck approximately 2-5 μsec before the main accelerating voltage was applied to the ion source. In this mode, where the ion source plasma flow is axial, and the ion acceleration is radial, the accelerated ion current density was found to approach the Child Langmuir value early in time, and to rapidly decrease after that time.

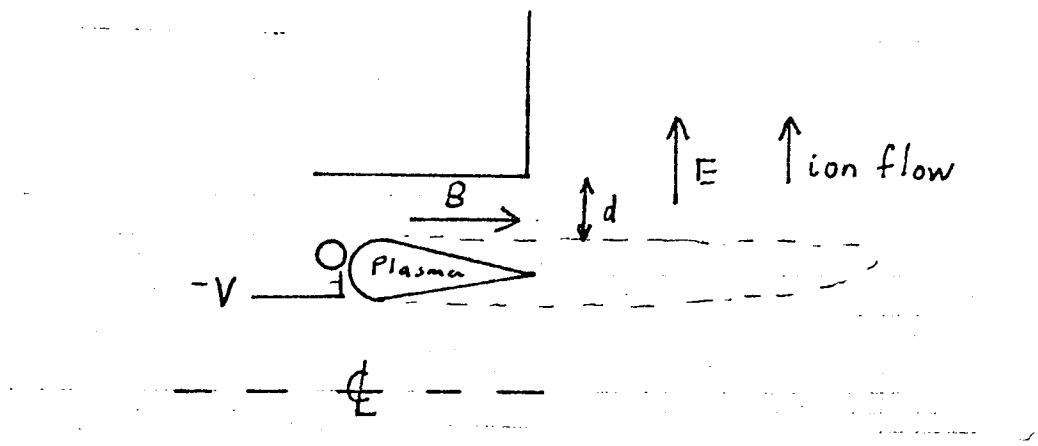

Figure 1. Point-plane acceleration geometry

We attribute this behavior to acceleration of the ions at the plasma edge which increases the effective anode-cathode gap spacing and reduces the limiting current. Average currents of approximately .75 mA of copper ions were achieved with this technique. (This corresponds to peak pulsed currents of approximately 10 Amperes.)

A second configuration using a MEVVA source with no magnetic fields, extractor grids, etc. was studied. In this geometry, the plasma from the MEVVA source expands to near the target surface, and a Langmuir sheath is formed at the plasma edge. Ions are accelerated across the sheath, and the sheath conforms to the shape of the target. This technique was found to be successful at all voltages applied (up to 100 kV). Of most interest, no macroparticle deposition was observed on the target surface. This is important for surface modification applications. Useful ion currents in excess of 3 mA average (copper) were observed in this mode.

REFERENCES

1. I. Brown, et. al, IEEE Trans. Nucl. Sci., Oct. 1985.

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