Further Development of a Low Inductance Metal Vapor Vacuum Arc (LIZ-MEVVA) Ion Source

B. Johnson, A. Hershcovitch, E.P. Garate, R. McWilliams, J. Sprunck, A. Van Drie

Presented at the Tenth European Particle Accelerator Conference (EPAC’06)
Edinburgh, Scotland, UK
June 11-16, 2006

Collider-Accelerator Department, Accelerator Division
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

This preprint is intended for publication in a journal or proceedings. Since changes may be made before publication, it may not be cited or reproduced without the author's permission.
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party’s use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Abstract
We are continuing development of a Low Impedance Z-Discharge Metal Vapor Vacuum Arc (LIZ-MeWA) to produce multiply ionized metallic ions. The arc can be operated in both an LC dominated ‘ringing current’ mode and a critically damped ‘pulsed current’ mode. Ions are extracted and analyzed using Time-of-Flight (TOF), with similar results for either type of discharge. Using aluminum electrodes we have detected Al\(^+\) and Al\(^+\)\(^+\).

INTRODUCTION
The Metal Vacuum Vapor Arc (MeVVA) is a high current source of metal ions produced in a vacuum plasma diode, with typical average charge states of +1 to +3 [1]. To increase the average charge state of ions produced in a MeVVA, the Z-discharge MeVVA (Z-MeVVA) was developed [2]. The Z-MeVVA generates metal plasma tens of microseconds in duration, followed by an electric Z-discharge to enhance average charge state via stepwise ionization.

The Low Impedance Z-MeVVA (LIZ-MeVVA) reduces inductance in the arc discharge transmission line and incorporates the Z-discharge into the arc. Previously, the LIZ-MeVVA was co-developed at Brookhaven National Laboratories and University of California, Irvine [3] as an alternative pre-injector for the Brookhaven Relativistic Heavy Ion Collider [4].

The experiment described in this paper uses a LIZ-MeVVA with significantly modified geometry from the previous apparatus. This experiment generates an arc of 12 to 30 kA, producing metal plasma. Ions are extracted from the plasma using pulsed extraction electrodes and the charge state is determined by time-of-flight (TOF).

EXPERIMENTAL APPARATUS
The Plasma Arc

Figure 1 shows the experimental layout of the LIZ-MeVVA. The plasma arc occurs in a plasma diode connected by a transmission line to a pair of capacitors. The capacitors (total 1.384 \(\mu\)F) are charged to between 6 and 12 kV and store between 25 to 100 \(J\) of energy. The transmission line and supply capacitor behave as a damped LC oscillator. The addition of a 0.5 \(\Omega\) resistor critically damps the arc, transforming it into a ‘pulsed’ arc.

A small electrode concentric with the inner conductor of the transmission line acts as the trigger pin for the plasma diode. A thyatron switches a 2-to-1 step-up transformer to initiate the arc with a pulse of up to 35 kV. A Pearson probe is used to measure arc currents of the system. Typically, the arc currents measured are 12 kA (pulsed regime) and 30 kA (ringing arc) for a 10 kV

Figure 1: The LIZ-MeVVA plasma diode

*Work supported by research contract with BNL under the DOE IPP2 program.
Figure 6: TOF data and theoretical TOF curves for $Z=+1$ and $Z=+2$; pulsed arcs.

Figure 6 shows collected TOF data at 2 μs for 14 kA pulsed arc with 2 μs extraction voltage delay, along with curves for theoretical TOF arrival times. Times are measured from the time for 90% extraction voltage to the first half-max point of the respective ion peaks.

Recently, a Thomson parabola has been installed and is undergoing testing. Figure 7 shows the layout. The Thomson parabola spatially resolves ions by $q/m$ components in a region between two magnetic poles of approximately 8 cm length and 1 cm separation. Magnetic fields of up to 800 gauss are shaped by ferromagnetic materials and directed into the 1 cm gap, while voltage applied to the magnetic poles generates an E-field parallel to the magnetic field at up to ~200 V/cm.

After exiting the Thomson parabola, ions impinge upon a micro-channel plate with an 18 mm diameter operating surface, producing an electron current with up to $10^6$ amplification. During testing, a Faraday cup uses TOF to determine operational characteristics of the Thomson parabola. A phosphor screen of 25 mm diameter will replace the Faraday cup to collect data on the spatially resolved ion components; this data is captured by a fast camera and will provide a verification of observed charge states of the LIZ-MeVVA and improved diagnostics for the detection of charge states with $Z>2+$.

REFERENCES


Figure 7: Thomson parabola layout.
charge voltage on the supply capacitors. The Pearson probe signal is used to trigger a second thyatron, which switches a 1 μs pulse forming network to drive extraction grids. The resulting pulsed extraction voltage ranges up to 10 kV, and the delay of the extraction pulse can be controlled with respect to the arc current.

The plasma diode consists of two 2.54 cm diameter coplanar aluminum electrodes. Separation of the electrodes can vary but typically is set to 0.5 – 1.0 cm. Total transmission line inductance is measured to be 166 nH; about 1/10th of this inductance is due to the plasma diode.

**Ion Extraction**

The aluminum plasma generated in the arc exits the plasma diode through one of the aluminum electrodes, which is a grid with about 25% transparency. Plasma moves from the grid down a 1 cm unmagnetized drift region until it reaches a pair of extraction grids. The extraction grids used are typically steel mesh with 37% transparency and separated by 0.5 cm. The extraction grids can be biased at several hundred volts negative with respect to ground in order to partially suppress the motion of plasma electrons.

**Data Collection**

Accelerated ions propagate down a 16 to 78 cm drift tube where they are collected by a Faraday cup biased at -47 V. A pair of permanent magnets generates a 450 Gauss transverse field across the Faraday cup surface to suppress secondary electrons.

It is found that ion signals can be obtained without additional electromagnetic optics for beam shaping or transport. The Faraday cup is terminated in a 10k resistor, with a 50Ω unity-gain line driver for small signal detection. Since the fast arc produces large noise emission, all electronics are shielded.

**RESULTS AND DISCUSSION**

TOF results at the Faraday cup are similar for the 'pulsed' and the 'ringing' regimes, as can be seen in Figs. 2 to 5. Figures 2 and 4 shows currents and voltages measured at the plasma diode and extraction gap, while Figs. 3 and 5 show the corresponding signal at the Faraday cup.

Due to fast recombination times for high charge state ions (Z > 2+), it is expected that the average charge state of extracted ions decreases later in the plasma lifetime. Extraction voltage pulses typically are fired with 5 μs delay for the ringing arc and 2 μs delay for the pulsed arc, corresponding to the minimum delays necessary to reliably prevent plasma from short circuiting the extraction power supply. Data have been collected with the extraction voltage firing successfully earlier in the arc, but for Z > 2+ contributions the diagnostics interpretation of the resulting signals presently are ambiguous.