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

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DISCLAIMER

FURTHER DEVELOPMENT OF A LOW INDUCTANCE METAL VAPOR VACUUM ARC (LIZ-MEVVA) ION SOURCE*

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Abstract

We are continuing development of a Low Impedance Z-Discharge Metal Vapor Vacuum Arc (LIZ-MeVVA) 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 μF) 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 Ω 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 thyratron 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

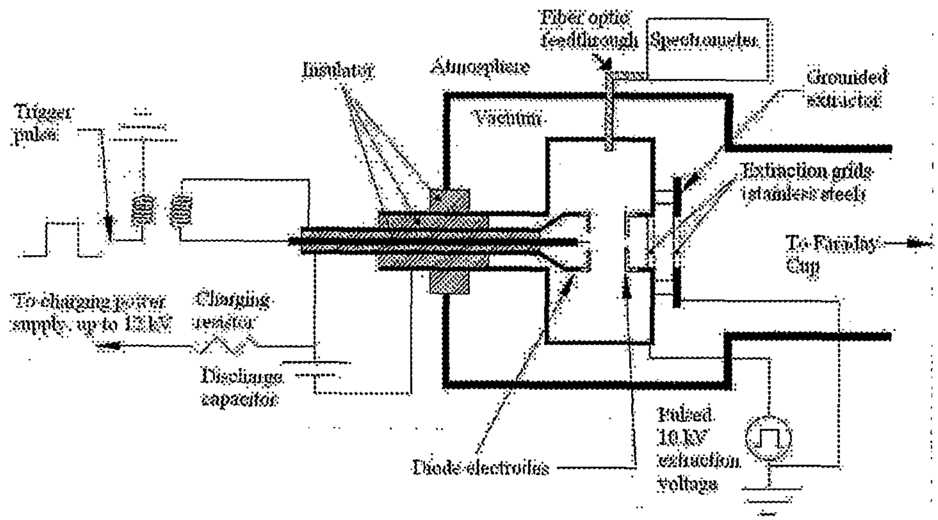

Figure 1: The LIZ-MeVVA plasma diode

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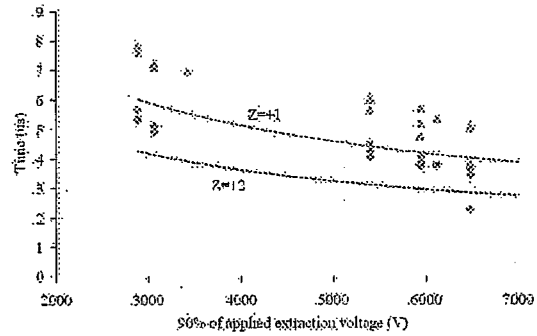

Figure 6: TOF data and theoretical TOF curves for Z=+1 and Z= +2; pulsed arcs.

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 10^4 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+.

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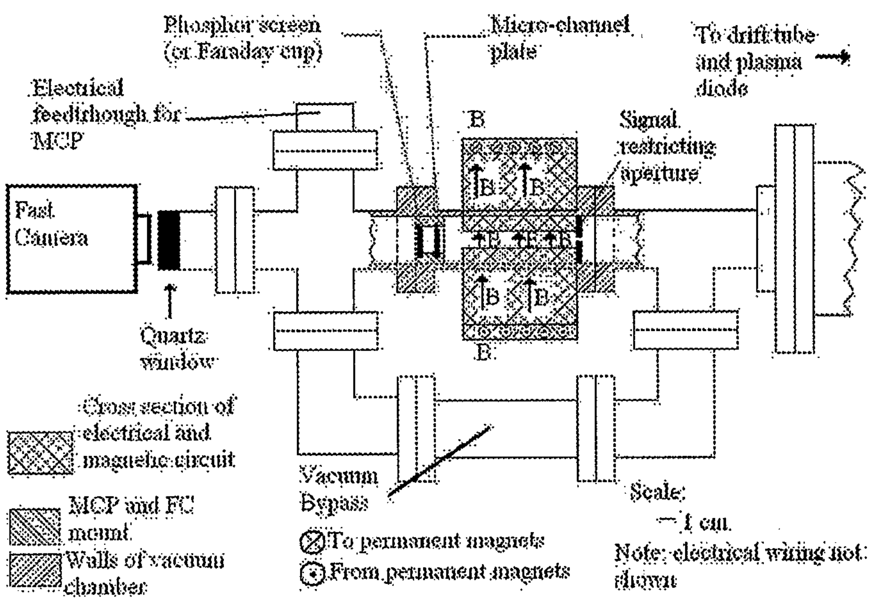

Figure 7: Thomson parabola layout.

charge voltage on the supply capacitors. The Pearson probe signal is used to trigger a second thyratron, 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.

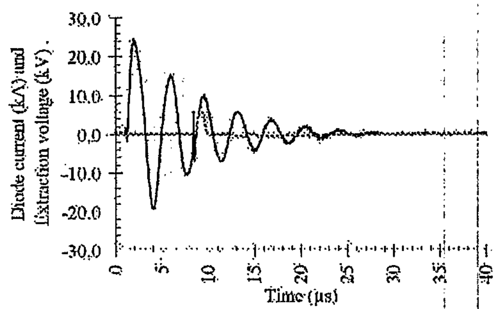

Figure 2: Arc current (black) and extraction voltage (red), ringing arc

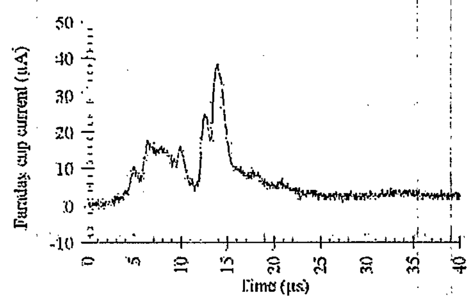

Figure 3: Faraday cup signal, ringing arc

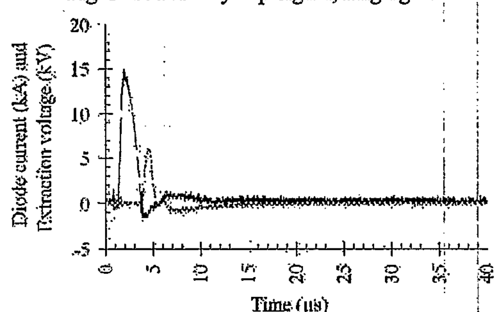

Figure 4: Arc current (black) and extraction voltage (red), pulsed arc

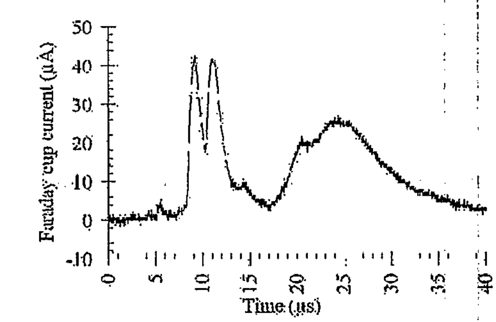

Figure 5: Faraday cup signal, pulsed arc