RESULTS FROM ZMEVVA: A NEW SOURCE FOR HEAVY-ION ACCELERATORS

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Abstract

We are developing a new approach for heavy ion beam injection (e.g., into the Relativistic Heavy Ion Collider [RHIC] at BNL). While conventional Metal Vapor Vacuum Arc (MEVVA) ion sources (I.G. Brown, Rev. Sci. Instrum. 65, 3061 (1994).) can produce up to hundreds of milliamps or more of several-times-ionized metal ions (e.g., U^{3+}), the recent results from Batalin et al. (V.A. Batalin et al. ITEP, Moscow, Reprints 18-93 (1993), 33-94 (1994); Proc. EPAC 1994, p. 1453.) indicate that the addition of an energetic electron beam (EMEVVA) may lead to considerably higher charge states (e.g., U^{17+}). An alternative way to produce the electron beam is ZMEVVA, in which a z-discharge plasma is used to enhance multiple ionization. As the vacuum arc plasma plume expands into a magnetized drift region, a z-discharge is triggered in the drifting metal plasma. The ions are then extracted and analyzed using a time-of-flight system. We report recent results using applied discharge voltages from 1 to 2 kV.

1 INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) [1], now under construction at BNL, is expected to become operational early in calendar year 1999. Initially, the RHIC physics program will concentrate on Au+Au collisions with 100 GeV in each beam. However, there is physics justification for eventually colliding uranium beams in RHIC. The tandem preinjector is quite adequate and reliable for the Au+Au collision program, but the tandems are not expected to produce sufficient beam currents for uranium ions. Encouraging recent results lead us to believe that a viable preinjector for RHIC can be developed using EMEVVA and/or ZMEVVA, which are enhanced versions of the well-known Metal Vapor Vacuum Arc ion source [2].

1.1 Uranium Beams in RHIC?

The first physics program at RHIC will study Au+Au collisions with 100 GeV in each beam, which is predicted to produce sufficiently high energy densities and temperatures to explore a new state of matter: the quark-gluon plasma (QGP). Characterizing the physics of the QGP will be a formidable experimental challenge, because theoretical guidance is qualitative at best. Planned comparisons of experimental results for Au+Au collisions with those obtained for p+p, p+A, and A+A collisions for lower mass species will help, but it could be very important to study a heavier collision system, such as U+U.

The mass of uranium is 20% higher than gold (238/197 = 1.21), but it is estimated [3] that the energy density in U+U collisions at RHIC will be 1.8 times higher than for Au+Au. This nearly factor of two enhancement occurs because the U nucleus is deformed (cigar shaped), while the Au nucleus is spherical. The randomly tumbling U nuclei will sometimes collide end to end producing the much higher energy densities and a 20% increase in the initial temperature. In addition, for central U+U collisions the range of transverse energies and particle multiplicities (due to the variation from end-to-end to side-to-side interactions) will be much larger than for central collisions of spherical nuclei, like Au.

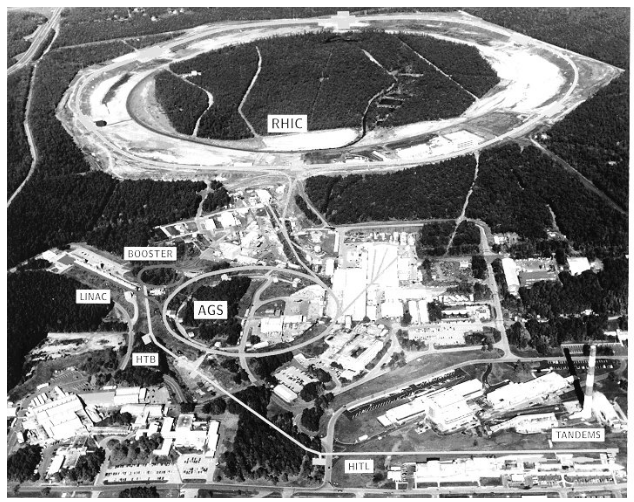

Figure: 1 The RHIC accelerator complex at BNL. The tandem Van de Graaff facility (lower right) is the initial RHIC preinjector for Au ion beams.

1.2 Long-term options for a RHIC preinjector.

In 1986 a BNL committee [4] explored various options for a RHIC preinjector, including approaches based on the BNL tandem Van de Graaff versus an advanced heavy ion source like a laser source, an electron-cyclotron resonance (ECR), or an electron-beam ion source (EBIS). As illustrated in Fig. 1, the committee recommended that the tandem Van de Graaff should be the initial heavy-ion preinjector for RHIC. For the long term RHIC program (up to 25 years) the recommendation was to develop an EBIS-based preinjector. However, it was recognized that state of the art EBIS sources produced roughly two orders of magnitude less ion current than would be needed for RHIC. The 1986 committee concluded that low charge-state heavy-ion sources, like the Penning ionization gauge (PIG), Metal Vapor Vacuum Arc (MEVVA), and various sputter sources did not warrant serious consideration as a

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basis for a preinjector (other than their potential for providing primary ions to an advanced source).

Since 1986 a number of significant new developments have occurred, which strongly suggest that MEVVA-based approaches [5] could be viable for a future RHIC preinjector. Among these are the success of the Positive Ion Injector (PII) low β LINAC for ATLAS [6], great improvements in MEVVA sources [7], and encouraging results from an electron-beam injected EMEVVA ion source [8]. The latter was reported to generate large currents (several mA) of heavy metallic ions (e.g., U^{17+}).

2 THE MEVVA ION SOURCE

The MEVVA is a prolific generator of highly ionized metal plasma, from which metallic ions are extracted. A generic MEVVA consists of a series of electrodes (usually concentric) that are separated by ceramic insulators. The usual configuration is a solid electrode of the desired metal, followed by a trigger electrode, an anode, a suppressor, and a three-grid extractor. Triggering of the vacuum arc is accomplished by applying a short high voltage pulse between the trigger electrode and the cathode across an insulating surface. Discharge occurs due to formation of cathode spots, which are micron-sized spots on the cathode surface characterized by extremely high current densities. Cathode material is vaporized and ionized, producing a plasma plume. A good general reference on the MEVVA is the review by Ian Brown [2]. Recent improvements are described in [7].

3 THE FIRST EMEVVA (BATALIN, *et al.*)

The principle of EMEVVA is the same as for ECR or EBIS, namely stepwise ionization, in which an energetic electron "beam" successively removes bound electrons to reach the desired stage of ionization. To achieve very high ion charge states two things are needed: (1) high $j\tau$, which is the product of electron current density and electron-ion interaction time, and (2) high **E**, which is the effective electron "beam" energy. Donets [9] is credited with illustrating that the maximum charge state achievable for any element can be predicted on a plot of $j\tau$ versus **E**.

The first step toward EMEVVA was the addition of an 0.7 meter long magnetized drift channel between a MEVVA anode and extractor, into which the plasma plume expands. Recent results include 200 mA of extracted uranium ion current (40% of which was U^{4+}) with a drift channel [8] and 32 mA of U^{4+} for a magnetized MEVVA without a drift channel [10].

For the first EMEVVA [8] an electron gun was added behind the hollow cathode. Impressive results were reported for copper ion production, in which a substantial component of the extracted beam was identified as being between Cu^{13+} and Cu^{21+}! Experiments with uranium ions [8] yielded a 5 mA component of relatively high charge state uranium ions, 60% of which was identified [11] to be U^{17+}.

4 THE FIRST ZMEVVA (BNL/LBNL)

The encouraging initial EMEVVA results prompted us to pursue further approaches to enhance MEVVA. First we noticed that the EMEVVA electron beam, which was injected through the cathode, was co-propagating with the drifting ions. Therefore, the poloidal field of the high-current electron beam would produce a radially defocusing force on the ions. Batalin et al. have agreed to attempt to reverse the electron beam direction in their EMEVVA to see if performance can be improved. In the meantime, we decided to pursue a complimentary approach, ZMEVVA, in which a magnetized z-discharge would produce counter-propagating energetic electrons.

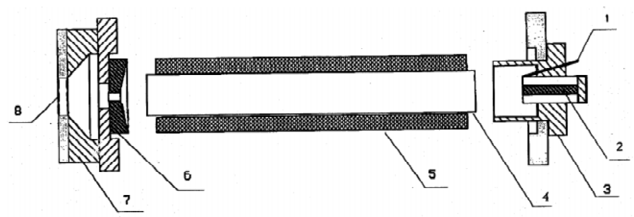

Figure: 2 Schematic layout of our initial ZMEVVA. The labeled elements are: (1) Trigger, (2) Cathode, (3) Anode, (4) Glass tube, (5) Coil, (6) Reflector, (7) Expander, and (8) Extraction grids.

Figure 2 illustrates our initial ZMEVVA setup. At the right is a conventional MEVVA plasma gun. While a 100 μsec pulse is applied to the coil (5), the trigger electrode is fired to produce a vacuum arc plasma plume (about 50 μsec long), which moves to the left into a magnetized drift region. Then, with external applied voltages of between 1 and 2 kV, a z-discharge is triggered in the drifting metal plasma. The voltage polarity is arranged so that the z-discharge forms an energetic "electron beam" moving from left to right. The hot electrons then counter-propagate with the drifting ions to hopefully maximize the effective $j\tau$. Highly charged ions are then extracted to the left and analyzed using a time-of-flight system (see Fig. 3).

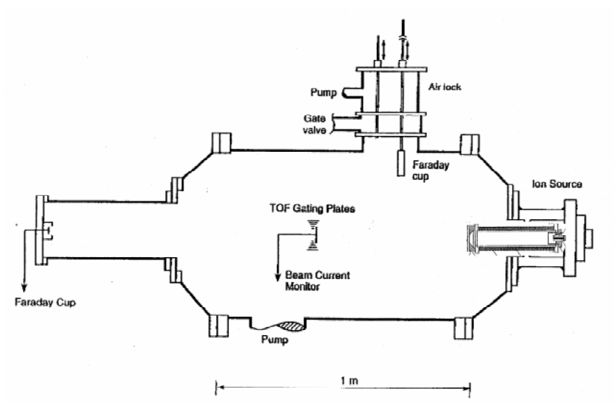

Figure: 3 Illustration of the 20-cm long ZMEVVA positioned in the MEVVA vacuum chamber at LBNL.

If we establish our goal as producing 1 mA or more of U^{20+} ion current, then based on the considerations described above in Section 3, we need a $j\tau$ of about 1.2 Coulomb/cm2 and an **E** of 1 keV. We believed that using existing equipment at LBNL we could achieve these operating parameters with an electron current of 40 kA, a τ of 8 μsec, and applied z-discharge voltages of between 1 and 2 kV. Batalin [8] used a 70-cm long drift region. For direct comparison and to explore the effect of varying τ, we constructed both a 70-cm long (see Figure 4) and a 20-cm long ZMEVVA.

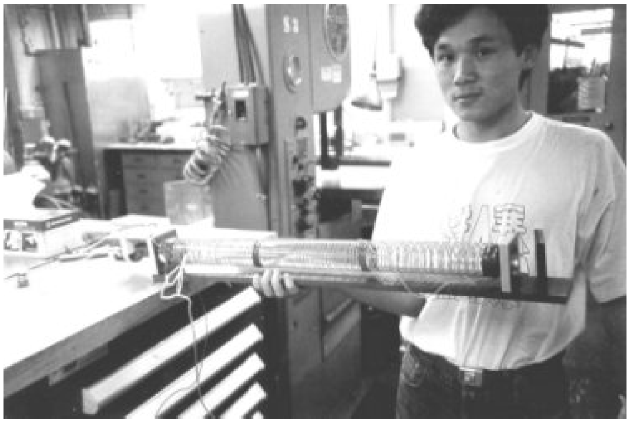

Figure: 4 Fenghua Liu holding the 70 cm long ZMEVVA during assembly and coil winding.

5 INITIAL ZMEVVA RESULTS

After only three week-long runs over the past few months we have produced encouraging, but also somewhat disappointing initial results. Our first good news was that comparison of titanium results with the 70-cm and 20-cm versions were consistent with our expectations that increased τ produced an enhanced yield of higher charge states. However, for gold ions we were disappointed to initially observe little yield above Au^{3+}. For data taken with no z-discharge we observed yields of about 20% Au^{3+}, 60% Au^{2+}, and 20% Au^{1+}. Then for data taken with applied z-discharge voltages of 1.0, 1.25, 1.5, and 2.0 kV we observed the yield of Au^{3+} grow to nearly 100%, but there was no indication of Au^{4+} or higher charge states.

Since the total Au ion yield was substantial, we assumed that the $j\tau$ was reasonable, so we suspected that somehow the effective **E** was far lower than the external voltage applied to produce the z-discharge. Consulting the Donets [9] plot we estimated that if the upper ionization limit was Au^{3+}, then the effective **E** was only 30 eV out of our applied voltage of as much as 2 kV. Upon further investigation we discovered that the capacitor bank had a measured inductance of about 2 μH, which corresponded to an impedance of 1.4 Ω when the full circuit fired. Furthermore, the length and thinness of wires from power supply to coil resulted in a total circuit impedance of about 2 Ω. Meanwhile, the resistivity of the plasma itself was estimated to be only 0.4 Ω or less. In other words, the applied external voltage was dropped almost entirely across the circuit with very little voltage drop across the plasma itself.

To test this assumption we moved the power supply closer to the ZMEVVA and made other changes to reduce the circuit impedance. With these changes we then observed significant yields up to Au^{6+}, which implies an **E** of 100 eV, or an effective voltage drop across the plasma of 100 V. With this improved circuitry we also experimented with our own version of EMEVVA and achieved comparable results. We conclude then that to achieve our objective of U^{20+}, we must build a much lower impedance z-discharge circuit, starting with a much lower inductance capacitor bank. Another problem we must address is time jitter in the z-discharge firing circuit which causes significant variations in the time-of-flight spectra.

6 CONCLUSION

There is good physics justification for eventually colliding uranium beams in RHIC, but the tandems will not be an adequate preinjector. The encouraging initial results reported here and previously [6-8] suggest that an enhanced MEVVA ion source could form the basis for a viable preinjector [5] to meet the long-term needs of the RHIC physics program. Further development of the ZMEVVA and EMEVVA concepts are needed (and are currently underway) to (1) reduce circuitry impedance to increase the effective electron energy **E** from the current estimate of ~100 eV to over 1 keV, and (2) to improve timing reliability and source stability.

7 ACKNOWLEDGEMENTS

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