

HEAVY ION EXTRACTION FROM THE BNL HIGH CURRENT EBIS TESTSTAND*

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Abstract

As part of a new, compact heavy ion injector for AGS/RHIC complex at Brookhaven National Laboratory we are developing an Electron Beam Ion Source (EBIS) capable of producing intensities of e.g. Au³⁵⁺ ions of about 3×10^9 particles/pulse or U⁴⁵⁺ of about 2×10^9 particles/pulse, requiring a total extracted ion charge ~ 85 nC/pulse. The required e-beam intensity is 10A and the ion pulse repetition rate is 7.5 Hz. The EBIS test stand has the full electron beam power and 1/2 the trap length of an EBIS for RHIC. Pulsed e-beams greater than 10A have been demonstrated. 30.5nC light ion pulses of residual gas have been extracted with 3.3mA peak current and 10 μ s FWHM, using a 6A electron beam (57% neutralization). Heavy ion production studies have been done using continuous injection of xenon gas, and studies with externally produced and injected Cs¹⁺ ions are under way. Results include: 16nC xenon ion pulses extracted from a 4.0A electron beam (45% neutralization) and time-of-flight spectra peaked at Xe²⁰⁺ which are consistent with current density and confinement time.

1 INTRODUCTION

The goal of this project is to demonstrate that an EBIS source capable of meeting the RHIC requirements can be built. Our approach has been to construct a full power and close to 1/2 length prototype test stand (EBTS), show that each subsystem can work, and finally demonstrate the production of heavy ions with $q/A \sim 0.19$ in a narrow charge state distribution with a suitable abundance of the required charge state. The rule of thumb for achieving this goal has been to maintain 50% neutralization of the electron beam with heavy ions and produce 20% of ions in a selected charge state. We reached several milestones, including essentially 100% transmission of 10A, 28.6kV electron beam with pulse length ~ 10 ms, production of heavy ions (xenon) with multi-ampere electron beams, fast ion extraction, and the production of narrow heavy ion charge state distribution through external ion injection. The project goals, the required parameters and source construction have been described previously. [1, 2, 3, 4] Here we give experimental results of electron and ion beam tests, and discuss external ion injection.

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2 EXPERIMENTAL RESULTS

In the course of our recent work, we have dealt with electron beams of higher average power rather than high instantaneous power. For example we have concentrated on electron beams suitable for ion beam production studies such as 6A, 55 ms and 2.5 amps, 2 s pulse widths and a duty factor $> 50\%$, with an average power of ~ 16 kW on a 50kW (design) collector. Initially, we were hesitant to proceed to higher average power because infrared detectors were indicating unexpectedly high temperatures. Recently, we correlated these readings to high local pressure in the collector, and believe that a large component of the signal was due to atomic processes. We have improved the collector cooling and intend to operate close to the 50kW limit in the near future as our program develops.

2.1 Xenon Neutral Gas Injection

We have used a 6A, 17.6keV electron beam to produce a 30.5 nC ion pulse of residual gas ions with a 10ms confinement time. Fast extraction using a Behlke switch was performed in order to squeeze the output charge into a 3.3mA peak with less than 10 μ s FWHM, as shown in figure 1. To show the EBIS performance with heavy ions we selected xenon gas injection. The BNL EBIS source

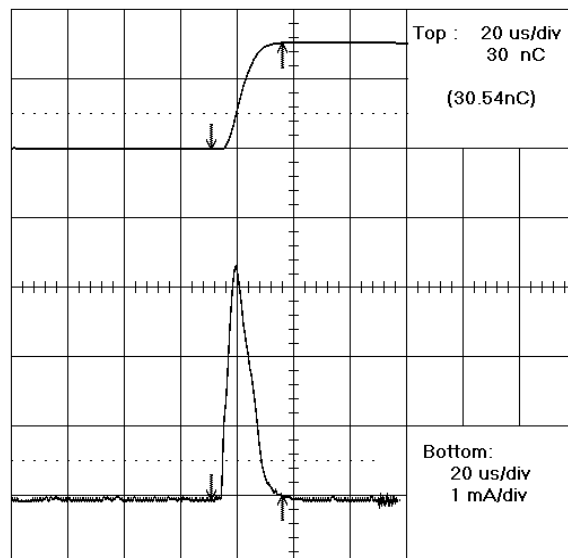


Figure 1: Bottom trace: 3.3mA, 10 μ s ion pulse extracted from the EBIS with a 6A, 17.6 kV electron beam and 10ms confinement time. Top: Integral of bottom trace (30.5 nC)

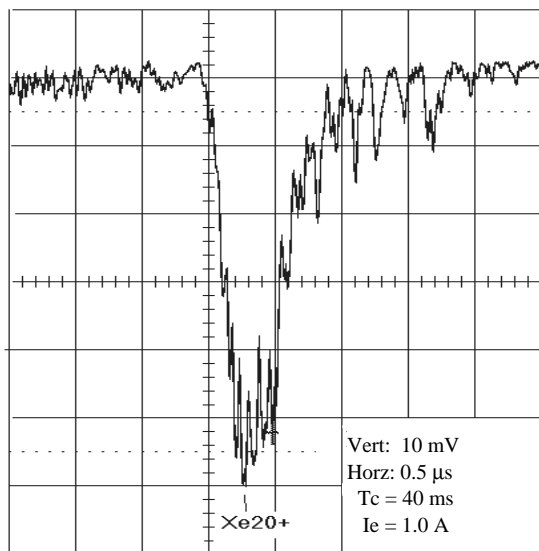


Figure 2: Xenon charge state spectrum, peaked at 20+, produced using a 1A, 17.5 kV electron beam and a confinement time of 40ms.

has a warm bore without a special gas handling system as in cryogenic sources. The xenon was leaked in continuously via a valve on the gun side of the ionisation region. The gun transition region pressure was allowed to rise from a gauge reading of $7.5 \cdot 10^{-10}$ mb to $3 \cdot 10^{-9}$ mb. The two xenon spectra shown both have maxima close to Xe^{20+} . The spectrum in figure 2 was produced with a 1A, 17.5kV electron beam during a confinement period of 40ms and represents about 50% neutralization. The second spectrum was produced with a 4A, 19.4kV electron beam in a confinement time of 20ms. The total neutralization is about 45%. A noticeable feature of these spectra

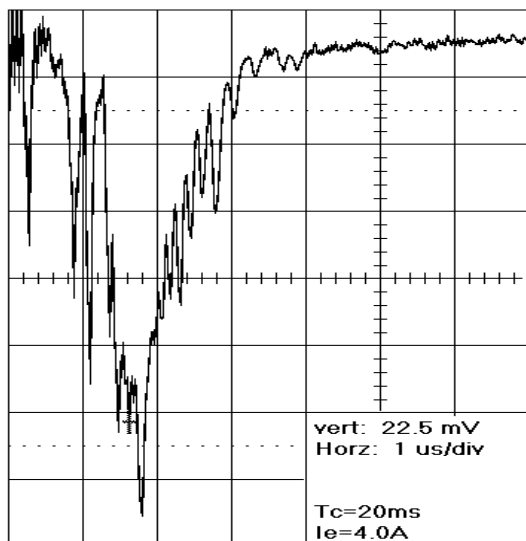


Figure 3 Xenon charge state spectrum peaked at 20+ produced using a 4A, 19.4 kV electron beam and confinement time of 20 ms.

is the tailing towards low charge states due to the continuous injection. The source can produce high neutralization of heavy ions, but it is not well suited for gas injection. To introduce ions in a more controlled fashion, ion injection has been used.

2.2 External Ion Injection

To demonstrate that a narrow spectrum of ion charge states can be produced with the EBTS we used an auxiliary ion source equipped with a thermionic emitter. We chose to use cesium ions because they are relatively easy to produce and are comparable in mass to xenon. We typically operated with 15-30 μA Cs^{1+} ion beams measured at the auxiliary source exit. For alignment purposes we transported the Cs^{1+} beam through the EBTS and collected up to 2 μA on the electron gun cathode. (This was done without the electron beam and with reduced drift tube potentials). During injection tests, the BNL EBTS was operated with a 1A, 16.5 keV electron beam and 0.7m trap length. To reach 50% neutralization of the electron beam after a lossless confinement period resulting in average charge state of Cs^{20+} , the trapping efficiency of the 2 μA Cs^{1+} ion beam decelerated to 50eV would have to be 70%.

Two basic modes of ion injection are fast and slow capture. The primary ion beam is in the former allowed to make a roundtrip traversal of the trap region before the second barrier closing the axial trap is imposed. It is thus advantageous to retard the injected beam as much as possible to increase the linear charge density within the trap. In the slow mode, ions are injected over one of the trap barriers and are captured if they are ionised while traversing the trap region. This mode is useful when a longer accumulation time is permissible to compensate for low intensity or inefficient injection.

In our recent brief study of ion injection we first captured the Cs^{1+} beam in the fast mode by applying the proper axial trapping sequence but delaying the ionising electron beam pulse until capture had been achieved. This mode was apparently easier to achieve in our case because of the rather deep radial potential well formed (850V) within the drift tubes due to the electron beam. Once we obtained the cesium time of flight spectrum it was relatively easy to move to a more efficient fast injection of 200 μs by adjusting the retardation energy and ion optics. During this first trial, we found the slow injection method produced the strongest EBTS spectra. We used relatively short injection and confinement times so we could distinguish between injected ions and residual gas given relatively poor vacuum conditions in our warm, unbaked EBTS bore ($\sim 7e-10$ mb). Figure 4 shows the extracted EBTS charge for the a 2.7ms slow injection followed by 2ms confinement (large peak) and for the same case with the Cs^{1+} beam blocked (small peak). For this time frame, cesium charge is approximately equal to

half the total extracted charge of 600pC, which represents 6.5% neutralization. From the injection time of 2.7 ms and the spectrum showing average Cs charge state 8+, it follows that the average injected current was only 27nA and the neutralization due to Cs1+ was only 0.4% during this rather short time for slow injection. In general, a low efficiency for slow injection has been reported in the literature for the EBIS DIONE at Saclay [5]. It is encouraging, however, that relatively high injection efficiencies can be obtained with fast injection. A 15% efficiency was obtained at the EBIS CRYISIS in Stockholm with a nitrogen beam [6] and an efficiency of >50% at the EBIS DIONE at Saclay for nitrogen and argon beams [5].

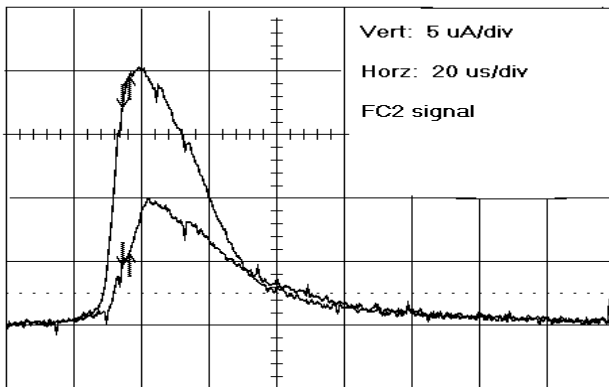


Figure 4: Faraday Cup signal of EBIS extracted ion charge without (small peak) and with (large peak) cesium injection.

We have shown that with a strong injection of heavy atoms (xenon) we have approached 50% neutralization at Xe²⁰⁺. A strong external injection will produce even better results, since injection can be shut off during the confinement period thereby eliminating the low charge state tail. It is relatively simple to manipulate the output with ion injection. Figure 5 shows the TOF spectrum without injection and then for two different slow injection times. By increasing the injection time from 0.75ms to 2.7ms the corresponding signal levels increased proportionally (note scale change from 50mV to 200 mV). We also observe that 20% of the charge is contained in the dominant peak, in this case Cs⁸⁺.

3 SUMMARY

The Electron Beam Test Stand has been operated at 10A and has produced heavy ions up to Xe²⁰⁺ at high neutralization (~50%) using multi-ampere beams (4A). Our plans are to continue our program of external ion injection and proceed with ion production tests at both higher beam current and higher average power.

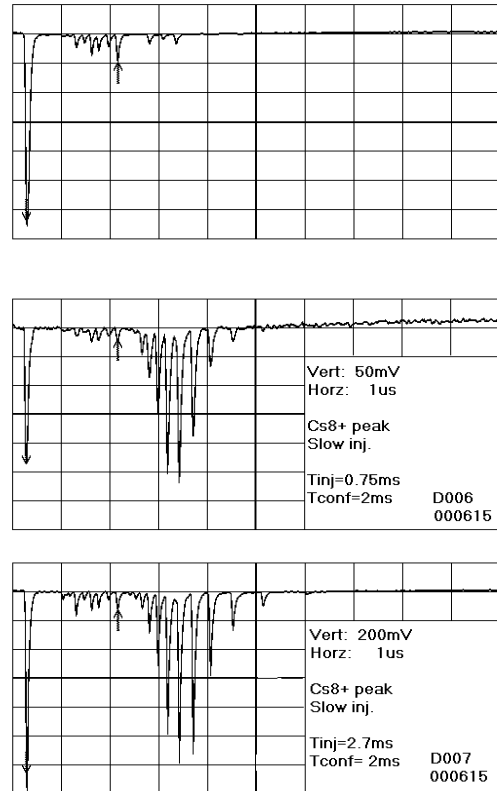


Figure 5: TOF spectra for Cs¹⁺ ion injection EBIS. Top: no injection, Mid: T_{inj}=0.75ms, Bot: T_{inj}=2.7ms.

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