RECENT RESULTS WITH AU IONS EXTRACTED FROM AN EBIS USING AN 8A ELECTRON BEAM AT BNL *

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Abstract

All design goals of the original proposal [1,2] have been reached in the operation of the BNL Electron Beam Ion Source (EBIS), which is a prototype for an EBIS that could meet requirements for a RHIC preinjector. RHIC requires 3.4x10^9 ions Au^{32+} per pulse, or about 85 nC total positive charge yield, assuming a 20 % abundance of the selected charge state. Stable operation of a 10 A, 50 ms electron beam through the EBIS trap has been achieved. Ion injection of low charge gold ions from a low energy vacuum arc ion source (LEVA) [3] and subsequent extraction of high charge state Au has been demonstrated with electron beams up to 8A. Gold spectra with dominant charge state 34+ and total ion charge of 55 nC measured on a current transformer at the EBIS exit has been obtained after a 30 ms confinement period. This corresponds to ~85% of the theoretical ion trap capacity, and exceeds our goal of 50% neutralization. Time-of-flight spectra indicate that 20% of the gold charge is concentrated in charge state 34+. The collected ion charge is proportional to the electron current and the gold charge state scales with the electron current density.

1 INTRODUCTION

At Brookhaven National Laboratory an EBIS is being developed to provide gold ions with charge state 32+ sufficient for injection into the Booster without stripping. Requirements for the intensity of the ion beam extracted from the EBIS will be met with an electron beam current of 10 A. For an electron energy of 20 kV, the capacity of the ion trap in the prototype ion source (EBTS) with the length of ion trap 72 cm in this case is 5.3x10^{11} elementary charges. With the conservative assumption that only 50% of this capacity can be filled with gold ions and only 20% of ions will have the desired charge state 32+, the number of extracted ions Au^{32+} from EBTS ion trap would be 1.65x10^9/pulse. These ions can be extracted in pulses 10-40 μs with corresponding electrical currents of ions Au^{32+} 0.85-0.2 mA and total ion current five times higher. The construction and previous experimental results of EBTS have been published elsewhere [4-7]. EBTS is a full electron current version of the planned RHIC EBIS, which will have 2.1 times longer ion trap and consequently more than double the intensity.
The emphasis in recent experiments has been on initial measurements of the emittance of the extracted ion beam. In addition, some modifications of EBTS have been done to improve its vacuum performance, reliability and diagnostics capability.

2 EBTS MODIFICATION

The internal bucking coil positioned before the electron collector was limiting the ultimate vacuum in the central region because of a limitation on bakeout temperature. To improve the vacuum in this region and to avoid a chance of water leak inside the central vacuum chamber the custom made vacuum chamber containing the internal coil has been replaced with a combination of standard 8” 6-way cross and a spool piece with a new bucking coil positioned outside the vacuum volume (Fig. 1). To compensate for the increased distance between this coil and the main solenoid the inner diameter of the new coil was made 36% larger than the old one, so the magnet field extends farther. The new vacuum chamber has permanent external transverse steering coils capable of being baked at temperatures up to 400^0C.

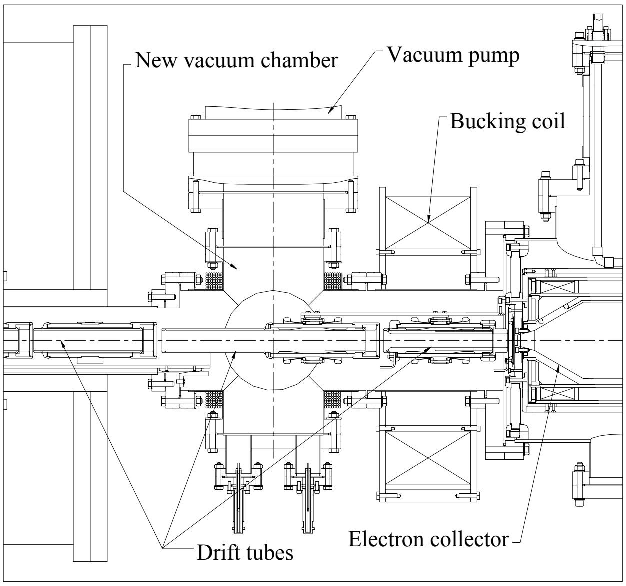

Figure 1: New configuration of the exit part of EBTS.

Simulations demonstrated that in this new geometry with longer gap between the main solenoid and new bucking coil the magnet field would be sufficient to transport the electron beam through this region and into the electron collector.

First experiments showed an improved vacuum in the new chamber when compared to the previous one, and it can also be achieved more quickly. Electron beam transmission through the transition area and the entrance diaphragm into the electron collector is the same as it was before the modification and the losses of electron beam did not increase. The new bucking coil is more powerful

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than the previous one and poses no risk to vacuum inside EBTS.

3 EXPERIMENTAL RESULTS

3.1 Extracted Ion Beam

Low charged gold ions from LEVA were injected into the EBTS ion trap using optics and method as described previously [7]. Injected ions were held in the trap for a time sufficient to strip them to the required charge state and were then extracted at a controlled rate. The current of extracted ions was measured with a current transformer at the exit of EBTS, and the charge state distribution of the extracted ion beam was measured with a time-of-flight mass spectrometer. Information on the parameters of the extracted ion pulse is presented in Figure 2. Ions were extracted from EBTS with electron current of 8 A, after confinement for 20 ms.

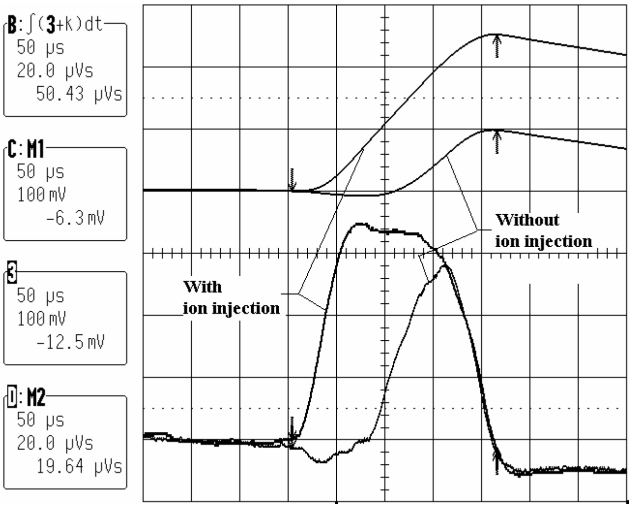

Figure 2: Ion current signals from the current transformer. Bottom: oscillograms of ion current with and without gold ion injection, scale 100 µA/box. Top: integrals of these signals, scale: 20 nC/box. Time scale: 50 µs/box.

As one can see, in this case the total ion charge extracted from the ion trap with gold ion injection is 50.4 nC, which is significantly more than without ion injection (19.6 nC). For an 8 A electron beam with energy 21 keV this extracted ion charge of 50.4 nC constitutes 76% of electron space charge within the volume of ion trap. The extraction time (FWHM) in this case is 150 µs and the total ion current is 350 µA. In this case, no attempt was made to achieve fast ion extraction, and the pulse width was limited by the power supply switching time. The maximum total extracted ion charge with gold injection from an 8 A electron beam after 30 ms confinement was 62.3 nC, which corresponds to a neutralization of electron space charge by ions of 94%. With increased confinement time the difference between extracted total ion charge with and without ion injection becomes smaller but the share of injected heavy ions in the extracted ion beam stays higher than this difference. With higher intensity of the extracted ion beam the width (FWHM) of the ion pulse is longer than with lower intensity. At low neutralization level ion are concentrated at the bottom of the radial potential well, while at higher neutralization they occupy its larger portion. This can explain why it takes a longer time to extract higher ion space charge than the lower one with the same rate of ramping of drift tubes potential: the time of crossing larger ΔU is longer than for the lower value. Much shorter pulse widths can easily be achieved, as demonstrated in previous experiments, by controlling the trap with power supplies having faster switching times.

A charge state spectrum of the extracted ion beam with gold ion injection is presented in Figure 3. Parameters of EBTS in this case were electron beam current 7.2 A, electron energy 20.5 keV, confinement time 50 ms. As one can see, the fraction of the gold ions in a total extracted ion charge is approximately 50% and charge state distribution of gold ions is peaked at 34+. Contamination of the extracted ion beam is caused by the residual gas components, mostly by H_2, CO and CO_2. Future planned modifications should reduce these components.

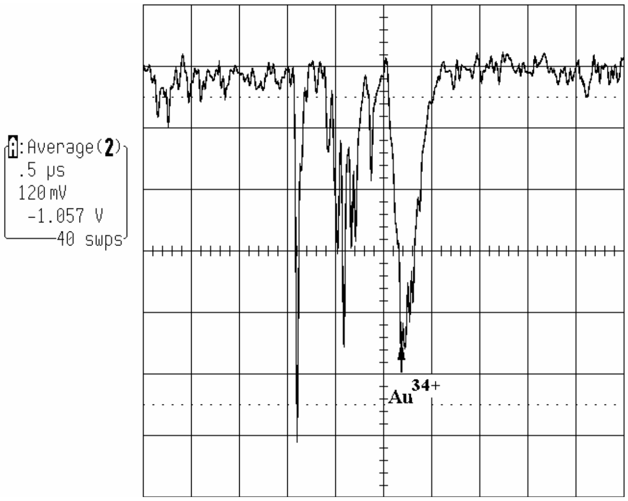

Figure 3: Time-of-flight charge state spectrum of the extracted ion beam with gold ion injection.

3.2 Emittance Measurements

The emittance of the extracted ion beam was measured at a distance of 104 cm from the EBTS exit. Only one lens located on a short distance from EBTS exit was used to focus ion beam on the emitttance meter. This lens is a electrostatic lens consisting of the central flat gridded electrode held at negative potential and two symmetrical cylindrical grounded electrodes located on both sides of the central electrode. The distance between the lens and emittance meter was 90 cm. Our emittance measuring device was a slit and collector unit, with 30 collector strips. The signal from each strip is sampled at any selected time during the beam pulse before digitization. Presently, the emittance head is set up to measure emittance only in vertical plane.

Measurements were taken under a variety of source conditions, with a 6.8 A electron beam, extracted charge of 20-40 nC, and extracted currents of 1-3 mA. Normalized rms emittance values were typically measured to be in the range of 0.08–0.1 π mm mrad. The measurement error is estimated to be in the 30% range, due to amplifier noise, drift, and bad electronics channels. In addition, there was evidence of loss due to beam scraping in many of the measurements. Improvements are required in the diagnostic before a systematic study of the source emittance can be made. The measured emittances include the full extracted beam, i.e. all ion species and charge states, so are an overestimate of the final emittance of the single desired charge state. In spite of this, the values were consistent with the emittance previously assumed when considering the RFQ and linac design [8]. An example of a measured emittance is shown in Figure 4.

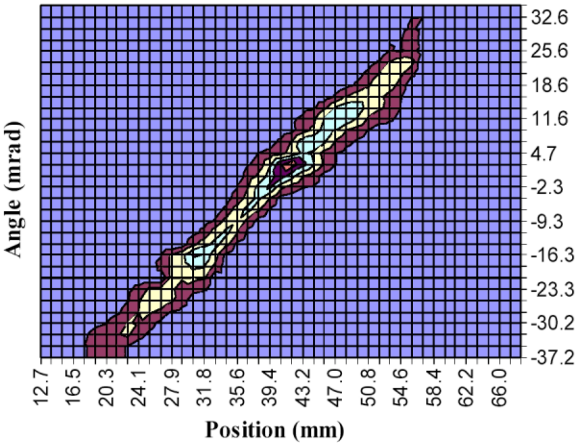

Figure 4: Emittance of a 1.7 mA extracted beam from EBIS, with Au injection. ε (n, rms)= 0.1 π mm mrad.

4 CONCLUSION

Experimental results with extracted beams of gold ions from EBTS demonstrate that the initial goals of the RHIC EBIS prototype are reached for the charge state, intensity and emittance of the ion beam. The operation of EBTS with electron beam up to 10 A is stable and confinement of injected ions is efficient. By improving the vacuum in the ionization region in the future, the fraction of gold ions in the extracted beam can be increased. The methods of forming the electron beam and building the ion trap have proven to be justified for the electron current up to 10 A and current density up to 600 A/cm^2. This approach can be used for the further development of EBTS for the purpose of increasing the intensity of the ion beam and the charge states of the extracted ions.

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