# PROGRESS IN THE BNL PROGRAM FOR A RHIC EBIS*

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*Abstract*

The objective of the program is to develop a compact preinjector, based on a high charge state heavy ion source and state-of-the-art linac technology, to serve as a cost-effective alternative to the BNL Tandem. By the time of RHIC commissioning, we expect to have demonstrated operation of the BNL test EBIS at a yield of about 25% of the RHIC requirements and this will serve as the basis for the design of the final RHIC device. This paper reports on the studies done since the initial operation of the test EBIS in 1994. The electron gun of the source has delivered a low loss, dc electron beam of 350 mA and a low duty factor beam above 0.6 A, which is the limit of the cathode presently used. The near future objective is to raise the electron beam current to the level of 1 A by using a larger cathode; this is at least twice the typical current of any operating EBIS. Charge spectra of several ion species have been measured; for nitrogen we were able to obtain up to 75% of ions in the fully stripped state, while for argon the peak was in the charge state 14+. The heaviest species was thallium, with the peak in state 41+. We shall report on measurements of charge spectra and abundances for nitrogen, sodium, argon and thallium.

## 1 INTRODUCTION

In the present scenario for the commissioning and initial operation of the BNL's Relativistic Heavy Ion Collider (RHIC), the BNL Tandem Van de Graaff will supply ions of a number of species up to gold. From the tandem, ions will be injected into the Booster, accelerated, transferred into the Alternating Gradient Synchrotron (AGS), accelerated further, and finally injected into RHIC. There will be several stripping foils in this chain of accelerators to produce fully stripped ions needed for injection into RHIC. Although each stripping foil serves to increase the average charge of the beam, it also results in a substantial loss of the beam intensity, especially at lower energies.

We have been considering for quite some time a cost-effective alternative to the BNL Tandem. It is based on a high charge state, heavy ion source, followed by an RFQ and a short linac [1]. There are several possible candidates for such a source, but we have selected an electron beam ion source (EBIS) for our studies. From the point of view of further acceleration of ions produced in the source, a charge state as high as possible would be preferable to make the preinjector more compact and efficient. It is, however, a fact that the yield of ions most often goes down with higher charge states and so a compromise is needed. Our design is based on a charge state 35+ for gold or 45+ for uranium, with required source intensities of $3 \times 10^9$ particles per pulse (ppp) for gold or $2 \times 10^9$ ppp for uranium. At present there are no heavy ion sources capable of satisfying these requirements, so we have extrapolated from the performance of existing EBIS devices to the parameters of a device for RHIC. The preliminary design for the RHIC EBIS calls for an electron beam current of 10 A at a trap voltage of 20 kV, with a trap length of about 1.5 m [1]. It is expected that the solenoid will be superconducting because of a required magnetic field of several Tesla. The design of the next element, RFQ, is standard; the energy of the short linac, the last element of the preinjector, is a parameter still to be determined, but even a voltage as low as 10 MV (equivalent for protons) would already surpass the energy presently available from the Tandem.

Our initial goal, to be accomplished in about three years, is to upgrade our test EBIS, first to an electron beam current of 1 A and then, in the second stage, to 3 A. A successful operation at the 3 A level should result in a yield of gold ions above $10^9$ ppp and this would justify the design of the final, 10 A device. The present cathode in the electron gun is a 2 mm dia. single crystal $LaB_6$ , capable of emitting currents up to 0.6 A; for currents up to 1 A we intend to use a 3 mm $LaB_6$ cathode. A further increase of the electron beam current will require a redesign of the gun itself and use of a different cathode. We plan to construct a separate electron gun test stand for studies of cathodes, electron guns, launching of beams into the magnetic field, and designing electron collectors.

## 2 THE TEST EBIS

The test EBIS has been described elsewhere [2]; it has a cold vertical bore 120 cm long, an unshielded superconducting solenoid designed for fields above 3 T but presently operating at 1.7 T, and a drift tube system with 6.25 mm i.d. and about 80 cm long. The potentials to the drift electrodes are supplied by custom built HV power supplies with a dynamic range of 1 kV and 10 µs risetimes. A dc bias up to 5 kV with respect to ground can be applied to the electrodes. The power supplies controlling the electron beam launch and collection are

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mounted on a high voltage platform which has been designed to operate up to 20 kV with respect to ground. The advantage of this scheme is that only the collector power supply must provide high power, while other power supplies serve to determine electrode potentials and monitor beam losses between the cathode and the collector. An IBM compatible computer on the high-voltage platform contains DAC and ADC boards for controlling and monitoring the power supplies. A computer at laboratory potential provides a graphical user interface and performs the conversions and other necessary calculations. Data are transferred between the two computers over a serial fiber optic link.

Neutral gas injection and ion injection are the methods we use to introduce ion species into the EBIS. Neutral gas injection is most commonly used on EBIS devices; low charge state ions formed in the gas injection region are allowed to reach the main trap region during a specified injection period (this is called "electronic injection" and was described in ref.3). We have used this method for nitrogen and argon. Ion injection into an EBIS is somewhat more difficult to implement because it requires a separate, external source of low charge state ions, but it offers a full spectrum of ions up to uranium with intensities as needed for RHIC. An impregnated zeolite (thermionic emitter) ion source [4] and a microMEVVA [5] ion source have been configured to be interchangeable modular units to serve as test EBIS injectors. The zeolite sources are useful for producing ions such as Na, Cs, and Tl, whereas the microMEVVA source can produce a broader range of metallic ions (on a separate test stand, we have operated our source with Ti, Ta, and U).

The development of controls and diagnostics has been an important part of our program. A simple controller is used to specify events at the microsecond level. A timeline is generated which multiplexes preset analog reference potentials to control the EBIS trap electrode voltages. In addition, pulses are generated to control the external ion source (if used), ion optics, and diagnostics. Our beam diagnostics consists of a target to measure the total extracted current and a time-of-flight (TOF) spectrometer to analyze the charge spectra in the extracted ion beam. We plan to introduce a harp-like beam profile monitor and a compact retractable emittance head between the EBIS exit and the existing TOF analyzer. Both devices were constructed at BNL and successfully tested at the Manne Siegbahn Laboratory in Stockholm, using the ion beam from their electron beam ion source, CRYSIS.

## 3 RESULTS

### *3.1 Electron Beam Studies*

Initial tests were made with the electron gun geometry as designed at Sandia National Laboratories. A 1 mm dia. $LaB_6$ cathode was used to produce electron beam currents up to its limit of about 110 mA; corresponding electron beam current densities ranged from 100 to 400 $A/cm^2$ in the trap. Subsequently the electron gun apertures were increased from 2 mm to 4 mm and a 2 mm dia. $LaB_6$ cathode installed. A fine tuning of the shape of the magnetic field has been achieved by adding coils to produce small transverse magnetic fields. With these modifications a low loss dc electron beam of 350 mA was propagated through the system; we were able to raise the dc current up to 420 mA with several percent beam loss. In a pulsed, low duty factor mode of operation, accompanied by higher losses, we have raised the current to 0.6 A, which is the limit for this cathode. We felt that further increases of the electron beam current, especially above the 1 A level, would necessitate a redesign of the collector structure so as to eliminate possible backstreaming of electrons into the drift tube system; this modification has been implemented and is now being tested. Computer simulations done for a high emission current density cathode (such as IrCe) show that it should be possible to produce and launch a 3 A electron beam from a 3 mm dia. cathode (Fig.1), with only minor modifications of the present electron gun.

### *3.2 TOF Spectra*

*a) Argon*

This spectrum was obtained by using the gas injection method; it was one of the first runs of the test EBIS, at a low electron beam current of 76 mA. After a confinement time of 300 ms the spectrum showed a peak in the charge state $Ar^{14+}$ (Fig.2a); the two helium peaks are caused by a leak which since then has been substantially reduced.

*b) Nitrogen*

Fig.3 shows the evolution of the spectrum with the confinement time. At 50 ms the peak was in the charge state $N^{5+}$, with a small contribution from the fully stripped state. At 100 ms the peak has already moved to $N^{7+}$, while at 200 ms the fully stripped state is dominant. This mode of operation is of interest for medical accelerators where it is preferable to produce fully stripped ions in the source itself, avoiding stripping foils and thus making the accelerator more compact and less expensive.

*c) Sodium*

For this species we have used an external ion source, with an impregnated thermionic emitter, and located at the collector end of the EBIS. Fig.2b shows the spectrum obtained after a 50 ms confinement time; the peak charge state was $Na^{7+}$.

*d) Thallium*

Thallium is the heaviest element we have tried so far; again, a thermionic emission external ion source was used to inject low charge state ions from the collector end. Due to the short distance in the TOF system, we were not able to resolve individual peaks in the thallium spectrum, although it is clear that the peak was around 40+ (Fig.2c). For this run the confinement time was 500 ms.

An encouraging characteristic of all the runs has been a neutralization degree of the electron beam approaching 50%. This parameter is of course very important for future scaling-up of the source because the ion yield will directly depend on it.

## 4 FUTURE PLANS

Studies of cathodes, electron guns and electron beam launching into the main magnetic field are of crucial importance for scaling of an EBIS. We plan to continue studies of ion yields and corresponding charge spectra for a number of ion species, at higher and higher values of the electron beam current. Our test EBIS is not very convenient for studies of electron beams themselves because of the long turnaround time involved in making changes to the cold bore, superconducting magnet EBIS. We plan to design and construct a separate electron gun test stand, with a ~5 T superconducting magnet, but having a warm bore. This will allow us to make changes in the system without having to warm up the magnet. In addition to electron beam launching studies, this electron gun test stand will be used to check collector designs, as well as to search for possible instabilities in high current/high current density electron beams. If instabilities occur, we can then also test possible methods of suppressing them.

## 5 REFERENCES


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3) E.D. Donets, in The Physics and Technology of Ion Sources, edited by I.G. Brown (Wiley, New York 1989), Chap. 12.

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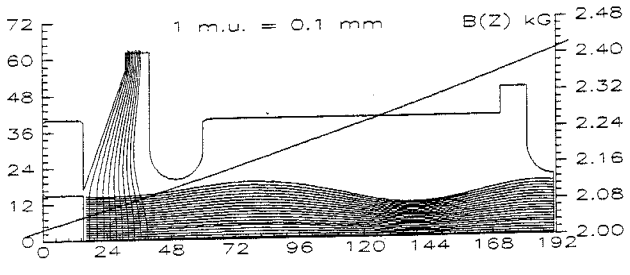


Figure 1. EGUN simulation of extraction of a 3 A electron beam from a 3 mm Ø CeIr cathode.

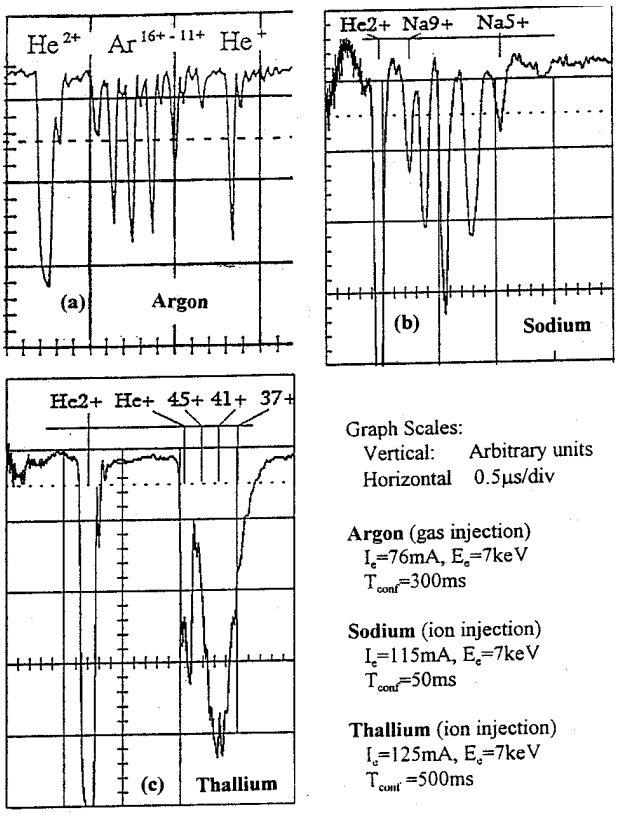


Figure 2. TOF spectra of multiply charged ions. (a) Argon (b) Sodium and (c) Thallium.

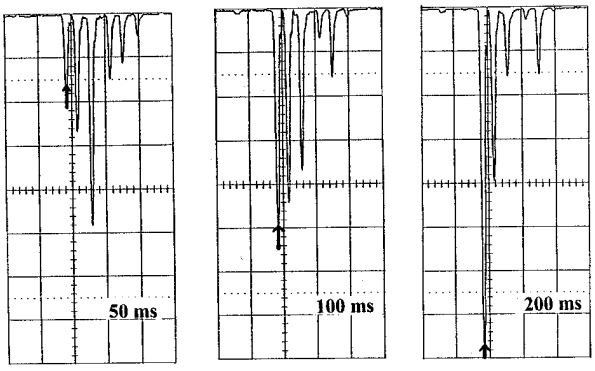


Figure 3. Evolution of the Nitrogen charge state distribution for confinement times of 50, 100 and 200 ms (left to right). The arrows point to the $N^{7+}$ peak.