PROGRESS ON AN EBIS FOR RHIC*

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Abstract

Work is continuing on the development of an Electron Beam Ion Source (EBIS) which could be used as part of a new heavy ion injector for RHIC. On a test EBIS, we have operated with an electron beam current of up to 1.14A, and have extracted ions such as Tl^{41+}, Xe^{26+}, Ar^{14+}, N^{7+}, and Na^{7+}. Recent experimental results are reported. In addition, we discuss plans for a new electron beam test stand that is now being built. This will allow operation with electron currents of 10 A, as well as testing of a warm-bore superconducting magnet system, methods for fast extraction of ions, and possible off-axis collection of the electron beam.

1 INTRODUCTION

Present performance of the BNL tandem Van de Graaff accelerator should be adequate to fulfill RHIC requirements. Disadvantages of this approach are limitation of the ion species to those that can be produced as a negative ion, an 840 m long transport line from the tandem to the Booster, and a fairly large staff required to operate and maintain the accelerator. In looking at alternatives to the tandem as a RHIC injector, it becomes clear that a major consideration is the choice of ion source. Low charge state heavy ion sources exist which could fulfill the RHIC requirements, but the accelerators in such a scheme are large and costly. Although higher charge state ion sources produce fewer extracted particles, we feel that it is appropriate to put some effort now into the development of a source which produces sufficient intensity of intermediate charge state heavy ions, in order to greatly simplify the initial acceleration stages. Starting with higher charge state heavy ions, the accelerator can become quite compact. For example, an ion source producing U^{45+} could be followed by a 3 m RFQ and a ~4m superconducting linac, both available technologies. This would give a Booster injection energy at least equal to the present tandem injection energy of 1.1 MeV/amu.

Several candidate ion sources have been considered, and while no source can presently produce sufficient quantities of intermediate charge states, we feel that the EBIS source shows the greatest promise of fulfilling our needs. The Electron Cyclotron Resonance (ECR) source, while very widely used and clearly the best choice for steady state applications, seems more difficult to scale up in current. For our pulsed operation the EBIS has the very nice feature of providing essentially a fixed charge per pulse, almost independent of pulse width, allowing extraction of very high currents (mA's) in very short pulses (10 μS). This is a big advantage in that it would allow single turn injection into the Booster - a large simplification that will improve injection efficiency and reduce the emittance of the beam in Booster. Other features of the EBIS are the fact that high charge state ions can be produced of any species that can be injected either as a gas or a low charge state ion, and the extracted charge state can be selected, optimized to the application.

In order to meet the requirement of 10^9 ions/bunch in RHIC, an EBIS with parameters as shown in Table I is required. These parameters are based on present performance of other EBIS sources (neutralization efficiency, charge state distribution), and conservative estimates for accelerator efficiencies. While the electron current is an order of magnitude higher than present EBIS sources, it is not high compared to currents achieved in devices such as travelling wave tubes. Due to the low duty-factor required for RHIC injection, we also have the advantage of being able to pulse the electron beam, which can lead to an order of magnitude reduction in electron beam power.

Table I
Tentative parameters for EBIS meeting RHIC requirements

Electron beam	10 A, 20 kV
Trap length	1.5 m
Trap capacity	1.1×10^{12} charges
Yield, positive charges	5.3×10^{11}
Yield, Au^{35+}	3×10^9 ions/pulse

2 EBIS SOURCE R&D PROGRAM

We were fortunate to have received on long term loan from Sandia National Laboratory major parts of a near state-of-the-art EBIS. Additional necessary components (stand, electron gun, two sources for ion injection, time-of-flight spectrometer, control system) were fabricated, and the source is operational at BNL. We have operated with gas injection and external ion injection, and produced nitrogen (peaked at N^{7+}), argon (peaked at Ar^{14+}), sodium (peaked at Na^{7+}), thallium (peaked at Tl^{41+}), and xenon (peaked at Xe^{26+}).

Some of the specific goals for fiscal year 1997 on this EBIS are to use a 3mm diameter LaB_6 cathode to produce a 1A electron beam, and to obtain ion yields of at least 50% of the theoretical trap capacity (full neutralization of the electron beam space charge) at up to a 1A electron beam. Other goals are to study ion injection with heavy ions including uranium, and to develop and improve the control system. To date, we have met or made significant progress towards all these goals.

The projected design parameters of a RHIC EBIS injector are based on the possibility of compensating the

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electron beam with ion charge to 50% neutralization and also producing a narrow charge state distribution with at least 20% of the charge in the desired charge state. In past runs it has been demonstrated that the EBIS is capable of producing the charge states of interest in narrow charge state distributions [1]. The main challenge is to maintain neutralizations of 50% or greater while raising the electron beam current to sufficient levels, in our case 10A. In recent runs we have produced neutralizations above 50% for electron beams up to 0.5A. This was demonstrated for various ions including residual helium, and nitrogen and xenon injected via a neutral gas injection system, as shown in Fig. 1. The focus of these particular experiments was to demonstrate high electron neutralization, and in general the confinement times were short and the charge states were low. We are now studying the loss of ion charge with increasing confinement time. For some of the nitrogen trials the source operated very ideally, and both high charge state and high neutralization (above 50%) were achieved. A xenon charge state spectrum centered about 26+ and with neutralization at 41% is shown in Fig. 2.

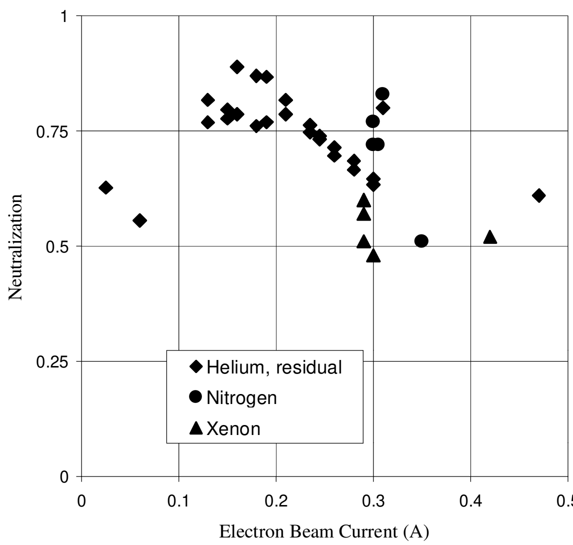

Figure 1 Neutralization vs. electron beam current, taken under various conditions.

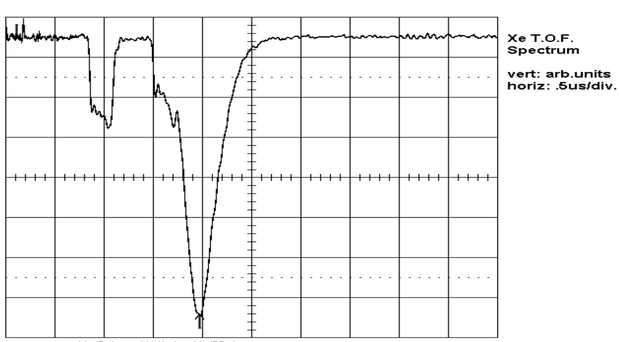

Figure 2 Xenon time-of-flight spectrum, with a peak at 26+.

Adjustable transverse magnetic fields (~10 Gauss) in the gun and collector regions of the unshielded main solenoid were installed [2]. In addition we developed the capability to produce pulsed electron beams, allowing us to operate at very low duty factors. These modifications were significant in reducing average electron beam loss during the optimization process so that we were able to increase the propagated electron beam to 1.14 A. Two rf pickups have been introduced within the ion trap region. Only limited observations have been made using a simple wide-band coaxial probe with a straight wire pickup, and the second, a quadrupolar pickup configured adjacent drift tubes, split along the beam direction, has not yet been monitored.

The gas injection system has been modified to allow the efficient introduction of gases such as xenon, which are condensable at temperatures higher than previously allowed by the system. Briefly, a gas cell was created over a 20 cm region and was isolated from the 4K surrounding structure. The cell can be heated to greater than 100 K using metal film resistors, and the temperature is monitored using Lakeshore TG-120 diodes. The use of a relatively long, low-pressure gas cell instead of a radial gas jet seems to provide superior gas injection at lower feed rates. This is important for avoiding long term contamination of the EBIS and subsequent degradation of performance.

Progress has been made both in control and monitoring, which has resulted in greatly improved operation of the EBIS. An EBIS voltage and timing controller has been developed to apply the time dependent potential distribution to the ion trap. The controller also coordinates the application of all time dependent voltages and timing references associated with the ion source, with a time resolution of 1 µs. The controller is operated through a graphical interface built using Labview and Labwindows programs.

During the balance of the year we will work on obtaining 50% neutralization for electron beams up to 1A. We are making preparations for injecting uranium from an external source (perhaps MEVVA). One of the main goals of this EBIS is to produce U^{45+} with a 1A electron beam and neutralization of 50%.

3 ELECTRON BEAM TEST STAND

The existing BNL EBIS has some disadvantages for R&D work, since its vacuum chamber includes the cold-bore of the superconducting solenoid, making turnaround times on modifications slow. The magnet also has an unusually high helium consumption, which, for practical reasons, limits the frequency of runs. Therefore, we are now in the process of building an Electron Beam Test Stand (EBTS). While the primary function of this test stand is the study of higher current electron beams, it is intended to be a versatile device to develop technologies that are relevant for a high intensity EBIS and to study the physics of ion confinement in a trap. The EBTS will have all the main attributes of EBIS: superconducting solenoid, electron gun, drift tube structure, electron collector, vacuum system, ion injection system, appropriate control and instrumentation. Thus, it can be considered a short prototype of an EBIS for RHIC. The test stand will be designed with a warm bore superconducting solenoid, with bakeable inner structure. We expect improved high-current performance with this type structure, and this will allow us to test the design with respect to vacuum technology. The concept of a warm EBIS has important advantages over a cold bore. The drift tubes do not condense gases and thus do not have a "memory effect", and all operations requiring exposure of EBIS to atmosphere can be done without warming up and cooling down the superconducting solenoid.

For electron beam focusing and confinement in the region of the ion trap, we have on order an unshielded superconducting solenoid with maximum magnetic field 5T and warm bore. The requirement to modify the axial distribution of magnetic field for various types of electron guns determined our choice of an unshielded solenoid. The longitudinal axis of the solenoid will be oriented horizontally. The length of the solenoid coil will be 1 m and the inner diameter of the warm bore will be 155 mm. The period between refilling of the cryostat with liquid helium will be not less than 30 days in the persistent mode.

The drift tube structure will be mounted in a vacuum tube inside the warm bore of the superconducting solenoid. It will be at room temperature, and its design will employ UHV technology. In the drift tube region, we will be able to test various schemes for fast extraction of ions, in order to determine the optimum method. We will also test the use of "lossy" ceramics to suppress oscillations in the drift tube structure. (Any sort of excitation of the electron beam is highly undesirable because it can cause heating of ions in the trap). The system of drift tubes should allow us to have as low as possible radial potential and as low as possible ion losses during confinement in the trap. These requirements are contradictory, and the optimum ratio of drift tube diameter to diameter of electron beam is to be found experimentally. The initial inner diameter of the drift tubes is planned to be 32 mm, and the electron beam diameter $\approx$2 mm.

Several alternative cathode types, and various electron gun launching conditions will be tested, eventually operating with a 10 A electron beam through the solenoid and drift tube structure. A collaboration has been set up with the group of G. Kuznetsov at Novosibirsk for the design and construction of a 10 A gun, using a partially immersed LaB_6 cathode.

The energy of the electron beam in the ion trap region should be as low as possible for increased trap capacity, and will be limited by stability of the electron beam and formation of a virtual cathode. For electron current I_{el}=10 A and energy of the electron beam in the ion trap E_{el}=20 keV (microperveance of ion beam P_{μ}=3.5) the total charge of the electron beam in the volume of the ion trap with length L_{trap}=0.6 m will be $Q_{el}=4.5\cdot10^{11}$ el.ch. If $\phi_{drift\ tube}/\phi_{beam}=16$, the total radial potential well inside the drift tube will be ΔU_{rad}=7.1 kV. This is a substantial fraction of the electron energy. Tests will be made of ways to minimize the energy of the electron beam while maintaining stability, such as increasing the current of the electron beam during ion injection, so the electron space charge is considerably compensated, or injecting ions into an initially high energy electron beam with subsequent deceleration.

The construction of the electron collector must be such that the temperature of the inner wall is well below the melting point of copper under a wide range of operating conditions, and the outgassing of the electron collector must be low. The total inner area of the electron collector is ~1000 cm^2. For a power of 50 kW the calculated temperature difference between the cooling water and the wall of electron collector is ~30^{0}C. The electron collector has bucking and transverse magnet correcting coils, a heater, and a thermocouple mounted in a separate chamber above the water-cooled shield. This assembly is installed inside an iron magnet shield and mounted on a high voltage (40 kV) insulator such that only the entrance aperture in the electron collector connects the inner volume of the electron collector to the central part of EBTS. The construction of the electron collector and materials used for its manufacture allow baking to 450°C. We are also considering tests of an electron collector which is off-axis, so the electron beam can be dumped far from the trap region, eliminating reflected and backscattered particles, and collector gas load, from the trap region.

A primary consideration in EBTS construction is the vacuum system. The pressure of residual gas in the ion trap region must be $P\leq1\cdot10^{-10}$ Torr with an electron beam of 10 A passing through it. This is a challenging requirement, considering the expected power dissipation in the electron collector is up to 50 kW. There have, however, been encouraging results from Saclay on vacuum technology of a warm EBIS [3]. To satisfy the high vacuum requirements, it is planned to do a preliminary high temperature vacuum firing of almost all components of the central drift tube region before installation, and to bake this part of the EBTS to 300°C after each exposure to atmosphere. The electron collector will be baked to 450°C after each exposure to atmosphere. The vacuum conductance will be restricted between the central part, containing the ion trap, and heavy outgassing regions such as the electron collector and the electron gun, while at the same time providing high pumping speed for these systems with separate vacuum pumps. The central part of the EBTS will be pumped by the combination of cryopump, titanium sublimation pump, and turbopump. This combination, with a total pumping speed $F\geq2000$ l/sec for H_2 (the main expected component of residual gas), is capable of providing the required pressure $P=1x10^{-10}$ Torr if the total gas load does not exceed $Q\leq2x10^{-7}$ Torr·l/sec.

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