REPORT ON EBIS STUDIES FOR A RHIC PREINJECTOR *

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Abstract

At Brookhaven, an Electron Beam Ion Source (EBIS) is now operational. This source is being used as a test bed to answer questions relevant to the eventual design of an EBIS-based heavy ion injector for RHIC. Such a source can easily produce ions such as Au^{43+}, but the challenge lies in reaching intensities of interest for RHIC (3 x 10^9 particles/pulse). The source studies are planned to address issues such as scaling of the electron beam to 10 A, possible onset (and control) of instabilities, ion injection, and parametric studies of output emittance.

I. INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is scheduled to be commissioned in 1999. The Tandem Van de Graaff accelerator presently supplies ions for the fixed target heavy ion program at the Alternating Gradient Synchrotron (AGS), and will initially serve as the preinjector for RHIC as well. We are now considering an alternative approach, where high charge state heavy ions would be produced in a source, accelerated in an RFQ followed by a short linac, and then injected into the AGS Booster. In principle such a preinjector should be simpler than a Tandem, more flexible in that it will offer a full spectrum of ion species, and allow for future increases in RHIC luminosity. Unfortunately, a high charge state heavy ion source that would satisfy the RHIC requirements still does not exist, but may be developed by scaling up of a device now available. The rest of the preinjector, an RFQ and linac, is a technology already adopted by industry.

From the point of view of the RFQ and linac, it is preferable to get from the source ions in charge states as high as possible, to make the preinjector more compact and efficient. We have considered several possible approaches to develop such an ion source, and have concluded that scaling-up of an Electron Beam Ion Source (EBIS) should be the most straightforward. EBISs deliver highly charged ions of virtually any species which are injected into the ion trap either as neutral gas or as low-charged ions. An EBIS operates best as a pulsed device, and can be well matched to a synchrotron with respect to pulse length. (Since the total charge per pulse is essentially independent of the extracted pulse width, short pulses can be extracted for efficient single-turn injection into a synchrotron). The evolution of charge states depends on the electron beam energy E and the product of the electron beam density and the ion confinement time, so that the charge state is easily optimized by variation of these parameters. While existing EBIS yields are lower than that required for RHIC by at least an order of magnitude, this can at least in part be attributed to the fact that before the advent of large colliders there was little need for high intensities of high charge state heavy ions.

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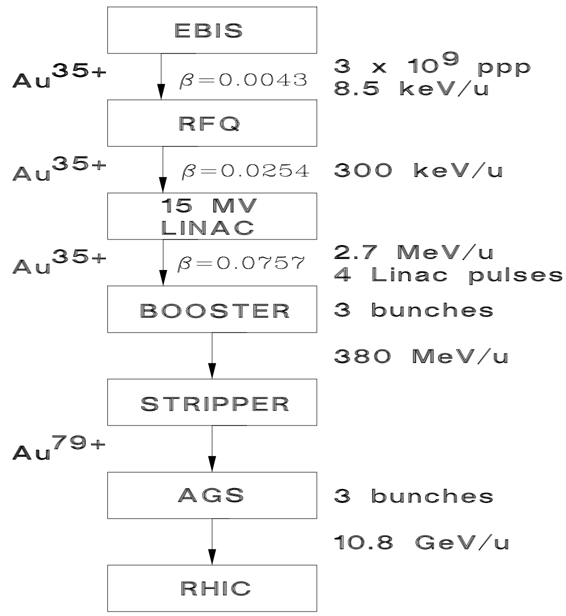

Figure 1. Stages for the EBIS-based injector for RHIC

Electron beam current	10 A
Electron beam voltage	20 kV
Length	1.5 m
Trap capacity	1.1 x 10^{12} charges
Yield, positive charges	5.25 x 10^{11}
Yield, Au^{35+}, design value	3 x 10^9 ions/pulse
Yield, Pb^{53+}, design value	2 x 10^9 ions/pulse

Table I
Parameters for an EBIS meeting RHIC requirments.

II. EBIS INJECTOR TO MEET RHIC REQUIREMENTS

The proposed acceleration stages for the EBIS-based injector are shown in Fig. 1. Starting with an estimate of 3x10^9 Au^{35+} ions per pulse of source output necessary to yield 1x10^9 ions per bunch in the 57 RHIC bunches, Prelec et. al.[1] have worked out the main operating parameters of the source, based on the experience of existing EBISs. These parameters are summarized in Table I. The 10 A electron beam current is much higher than existing EBISs produce (0.5 A). However, the requirement on the ion charge state is modest, thus allowing a relaxation of other parameters which have made EBISs technically difficult.

Although it would be convenient for us to design both systems for the 201.25 MHz frequency of the present 200 MeV Linac for H^- ions at BNL, we have made our preliminary designs of the RFQ and linac using 80 and 160 MHz, respectively

[2]. The focusing strength of an RFQ is related to its phase advance/focusing period, the optimum value of which is approximately 60 degrees. For the range of q/m we are dealing with, the frequency at which optimum phase advance occurs is approximately 80 MHz. On the other hand, a high frequency is necessary for the linac if the cavities are to have reasonable dimensions comparable to, say, the cavities in the ATLAS Positive-Ion Injector Linac at Argonne [3], since the starting β is 0.0254 (see Fig. 1), compared with 0.009 in the ATLAS.

We were very mindful of the successful experience of the ATLAS project at Argonne National Laboratory [4] with constructing and operating an independently phased superconducting resonant cavity linac. For now, we have chosen this approach for further study. The key features of this type of linac are: one gets maximum use of the available voltage from all the cavities for essentially any mass ion, and every cavity can be operated at its full potential. These provide the highest energy beam for injection into the synchrotron which is always important for overcoming losses due to stripping and space charge.

III. BNL EBIS R&D PROGRAM

Many of the issues which need to be addressed prior to the design of an EBIS for the new AGS Booster injector require an operating Test EBIS. Fortunately, we have obtained on a long term loan the Sandia National Laboratory “SuperEBIS” [5], and put it into operation in our ion source laboratory. So far, we have operated this source with electron beam currents up to 110 mA and have extracted helium-like argon ions (Ar^{16+}). Over the next two years our plans for this Test EBIS are the following:

a) Increase the electron beam current in steps up to 1 A, exceeding the current of any operating device of this type. With a 1 mm dia. LaB_6 cathode in the electron gun, we have obtained an electron beam current of 110 mA. A 2 mm dia. cathode, which we are now testing, should allow operation at currents up to 500 mA. We may then test a 3 mm dia., which should raise the current to the 1 A level. If our experiments on an electron gun test stand show that other cathode types are promising, they too may be tried on the Test EBIS.

b) External ion injection will be studied in order to provide the variety of ions (especially metallic) required for RHIC. There are several candidates for the primary ion source and they will be tested first on a separate stand to determine the yield and charge state distribution. We presently have a pulsed MEVVA [6] source of metallic ions (up to uranium) and several steady state sources using zeolite cathodes (Na, Cs, Tl) but other types may be investigated as well.

c) Possible sources of instabilities will be investigated to see whether they might develop in an EBIS as the electron beam current is increased above the levels presently achieved in similar devices.

d) Simultaneously with an increase of the electron beam current, we shall do parametric studies of the yield and charge state distributions to verify EBIS scaling laws.

e) Fast extraction of ions will be studied because the single turn injection of ions into the Booster would greatly simplify the process and lead to a high capture efficiency. In order to achieve this, ions must be extracted in a pulse of less than 10 microsecond duration. There are several methods for a fast extraction (ramping the axial electric field in the trap, pulsing schemes for trap electrodes) and we have to develop and select the one which gives the best combination of extraction efficiency and beam emittance.

f) Cooling of ions in the trap will be studied and applied to improve the performance of the test EBIS.

g) Measurements of the output beam emittance will be performed in order to characterize beam parameters and design the matching section to the next element, the RFQ. Parametric studies will be made of the emittance of the extracted beam vs. ion extraction method, magnetic field strength, ion confinement time, ion charge state, ion beam intensity, etc.

IV. PROGRAM STATUS

Initial operation of the source has been made using continuous (d.c.) electron beams of 5-110 mA and current densities of 100-400 A/cm^2. The 1 mm diameter LaB_6 cathode is immersed on axis in the solenoidal field of an unshielded superconducting solenoid to a level of 400-800 Gauss. The beam is then compressed by the increasing axial field which is currently operated at about 1.2 Telsla. Modifications are underway to increase the electron gun apertures to accomodate a 2 mm LaB_6 cathode which should allow the propagation of electron beams on the order of 500 mA.

Axial ”drift tube” electrodes are used to control the ion production processes. The potentials to these electrodes are supplied by custom built HV power supplies with a dynamic range of 1 kV and risetimes on the order of 10 microsec. A d.c. bias can be imposed which allows the application of potentials of up to 5 kV to the trap region with respect to laboratory ground.

In EBIS sources the working species is typically introduced by radial injection of neutral gas into a special drift tube, or by injection of low charge state ions from an external source along the EBIS axis. At BNL we have been working on both methods. The gas injection method allows immediate verification of the EBIS performance. Ion injection is somewhat more difficult to implement but is expected to provide better performance for our long term goal of producing milliampere currents of moderate charged metallic ions.

Neutral gas injection is the most commonly used method for introducing the species to be ionized in an EBIS. Low charged ions formed in the gas injection region are allowed to reach the main trap region during a specified injection period according to the value of potential applied to an intervening electrode. Transfer of ions using this method is called ”electronic injection” following the early description of this process by Donets [7]. In Figure 2, a time of flight spectrum for neutral gas injection of argon is given. Present are contaminant peaks of H^+, He^{2+} and He^+ due to a helium leaks and residual hydrogen background. Argon charge states from Ar^{11+} through Ar^{16+} are observed after a injection period of 50 ms and confinement period of 300 ms. The total charge extracted in this case was 925 pC during an extraction pulse of duration 75 μs FWHM, corresponding to a beam neutralization of 77%.

Tests are currently being made using a sodium impregnated zeolite ion source for external ion injection. Typically, extraction from the auxillary source is made at 5 kV and the beam is retarded to 1-3 kV, i.e, the potential of the EBIS trap region electrodes. Na^+ beams of about 5 microamps are obtained at a Faraday cup just outside the EBIS electron collector. We have observed injected ions propagating through the EBIS to a point just in front of the electron gun cathode but we have not yet observed an extracted high charge state sodium ion spectrum. Nevertheless, ion injection into EBIS has been well demonstrated at Saclay [8] and Stockholm [9]. Improvements to the control system which will allow greater control of the ion optics, beam energies, and timing are expected to facilitate the ion injection procedure.

The development of a control system has been an important part of our program. A simple EBIS controller has been constructed around commercially available PC timing boards which can be used to specify events at the microsecond level. A timeline is generated which multiplexes preset analog reference potentials to control the EBIS trap electrode high voltage. In addition, pulses are generated to control the external ion source, ion optics, and diagnostics such as the time-of-flight spectrometer. The duration of a complete EBIS cycle is on the order of 100 ms with several distinct subperiods such as injection, confinement, and extraction. Eventually, the control system will facilitate setting and monitoring all potentials and intervals through a graphic oriented PC interface.

An ion source test stand has been constructed for developing the auxiliary ion sources and EBIS diagnostics. The impregnated zeolite and micro MEVVA ion sources have been configured to be interchangeable modular units. They have been adapted to include a deceleration stage which provides high extraction energies for increased beam current, while accomodating the rather low injection energies necessary for ion trapping in the EBIS. Compact, harp-type beam profile monitors have been constructed at BNL and tested at the Stockholm EBIS. They are 95% transparent and are especially useful for adjusting the focus and positions of the injected and extracted ion beams when external ion injection is used to load the EBIS. A compact emittance head suitable for measuring the EBIS extracted beam has been constructed and is currently under test using a Na^+ beam from the zeolite source in the auxiliary test stand.

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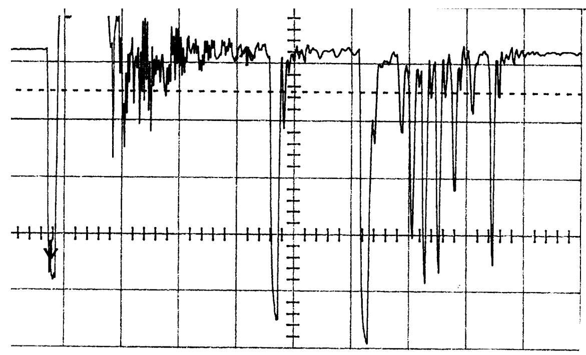

Figure 2. Argon TOF spectrum from the EBIS. Charge states 11+ through 16+ are observed.

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