THE EBIT CHARGE STATE BOOSTER FOR EXOTIC BEAM REACCELERATION AT MSU*

O. Kester#, S. Schwarz, G. Bollen, M. Johnson, M. Kostin, M. Portillo, J. Ottarson, C. Wilson, NSCL / MSU, East Lansing, MI 48824, USA

Abstract

The National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is implementing a system to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u. The reacceleration of stopped radioactive beams from projectile fragmentation at the NSCL/MSU makes use of charge state breeding in an Electron Beam Ion Trap (EBIT) to provide a compact and cost efficient system layout of MSU's ReA3. The MSU EBIT breeder device will provide a high electron beam current density of about 10^4 A/cm^2 making it well suited to rapidly increase the charge state of short-lived isotopes within tens of milliseconds or less. In addition, the breeder is optimized to provide a high storage capacity, a high beam acceptance and uses a continuous injection and beam accumulation scheme explicitly, which makes it unique. The electron beam system and the magnet configuration are unique to guarantee a high acceptance of the EBIT as well as rapid and efficient charge state breeding. The present paper will present an overview and the status of the ReA3 EBIT.

INTRODUCTION

Experiments with reaccelerated beams of rare isotopes are at the foremost frontier of nuclear physics research. Radioactive rare isotope beams in the energy range from a few hundreds of keV/nucleon to more than several MeV/nucleon allow the study of key reactions for nuclear astrophysics, investigating nuclear structure far from stability or at high excitations via Coulomb excitation and transfer reactions, and contribute to a better understanding of the synthesis of super heavy elements. With the development of the gas stopping, low energy beams of rare isotopes will be available from fragmentation facilities.

The key element of the re-acceleration approach is a fast and efficient charge state boosting [1] of the singly charged radioactive ions delivered by the gas stopper. The N+ reacceleration scheme has been recognized as the most promising option for the reacceleration of rare isotopes at present and future second generation RIB-facilities [2]. Charge breeding eliminates conventional electron stripping and its losses in efficiency. Furthermore it allows for a much simpler accelerator structure and makes the accelerator more compact and therefore more cost effective. The EBIS/T charge state breeder has been identified as the most promising breeder type with respect to efficiency, breeding time, beam quality and purity. For the ReA3 re-accelerator project [3] at the NSCL/MSU this option is being realized based on a high current EBIT.

*Work supported by MSU

#Kester@nscl.msu.edu

THE MSU-EBIT FOR REA3

The MSU breeder is mounted on a high-voltage platform (fig.1) with variable potential up to 60 kV to retard the ions extracted from the gas cell. Singly-charged rare isotope ions with 60 keV beam energy from the NSCL gas stopper are supplied by a vertical beam line and sent towards the EBIT via an electrostatic switchyard.

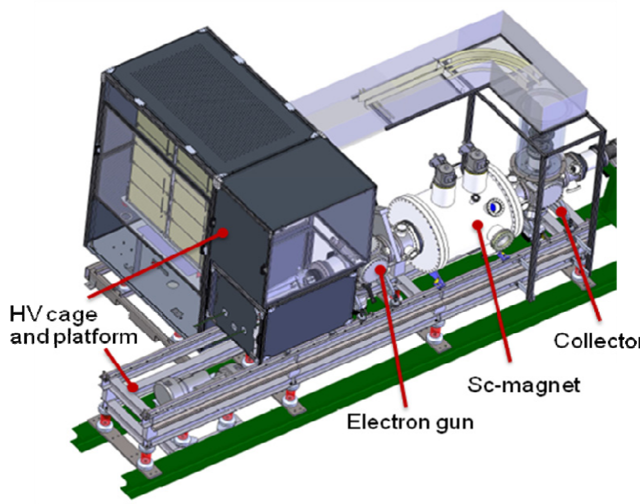

Figure 1: Layout of the MSU-EBIT

The EBIT is operated in the so called accumulation mode. The ions are continuously injected over the collector barrier, captured and then charge-bred to the desired charges state. The platform potential is changed prior to extraction to deliver the ions with the correct injection energy (20 – 60 keV·Q). A double-focusing charge-over-mass separator delivers the highly-charged ions to the linear accelerator [4]. The parameters of the MSU EBIT are listed in Table 1.

Table 1: MSU EBIT Parameter

Electron beam energy	< 30 keV
Electron beam current (upgrade)	< 1.4 A (2.5 A)
Length of trapping region	0.8 m
Maximum magnetic field	6 T
Electron beam current density	up to 10^4 A/cm^2

With an electron beam current of about 2.5A available from the electron gun, the NSCL EBIT will be able to hold about 10^{10} positive charges inside the trap while only partially compensating the charge from the electron beam. With repetition rates of 10-100 Hz, beam rate capabilities of the order of 10^{10} ion/s and possibly above are expected.

Electron Gun and Collector

Electron gun and collector design are based on the lay-out of the TITAN charge breeder EBIT [5] built in collaboration between TRIUMF and the MPIK Heidelberg. Significant effort went into simulations related to the analysis of the Pierce-type electron gun the TITAN system is using. The commercial TriComp code has been used in electron beam simulations to modify the electrode layout and boost the output current to 2.5A and later as an upgrade option to 5 A. The calculations have been cross checked with the code IGUN. As a result, two initial cathode and extraction electrode configurations have emerged, capable of producing electron currents between 1.5 and 2.5 A. The electron gun (fig.2) has been designed as a modular system. An outer shell houses a soft iron shield and a set of four water-cooled bucking coils that allow one to shape the magnetic field near the cathode for optimum beam formation and compression. The cathode and associated electrodes mount on a plug-type connector inside the shell and can easily be serviced or exchanged for future upgrades.

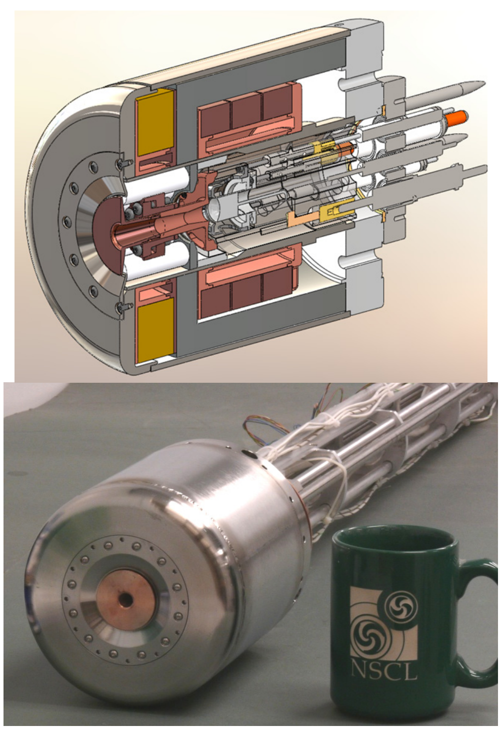

Figure 2: Electron gun of the MSU EBIT.

Commercially available Ba-dispenser cathodes with emission current density between 2-4 A/cm^2 of different sizes are used. Operation of the MSU breeder will start with a cathode of 6.25 mm diameter. In an upgrade scenario a 13 mm cathode is foreseen. The gun design is optimized to provide electron beams that can be highly compressed into the strong field of the superconducting (SC) magnet. The simulations on which the design has been based show that electron beam currents up to 1.4 A (2.5 A for the upgrade) for 11.5 kV extraction voltage. A concept has been developed for higher extraction voltages and for a modified electrode geometry to reach 5 A electron current in the future. The present gun design makes fully use of a Wehnelt-electrode which controls the emission current and the beam formation (fig.3).

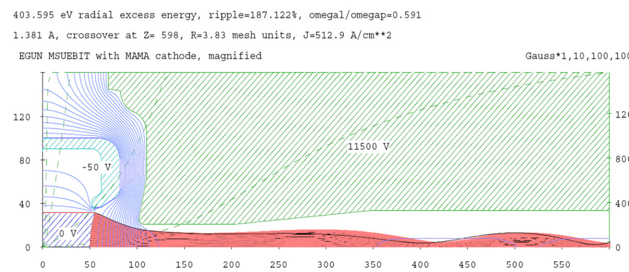

Figure 3: Electron gun simulation with the 6 mm cathode. The Wehnelt electrode is biased to -50 V for optimum beam formation.

The design of the electron collector allows for the absorption of up to 5A of continuous electron beam current at final energies of 4 keV. According to a thermal stress calculation, the resulting thermal load of 20kW uses only two third of the device's capabilities. The design has been optimized with respect to cooling water flow and heat transfer. Additionally the collector incorporates bucking coils, which shape the magnetic field such that electrons hit a large fraction of the collector surface to distribute the heat load.

Magnetic Field Configuration

The magnetic field, which compresses and guides the electron beam from the electron gun towards the collector is generated by a 6 T superconducting magnet. The magnet incorporates a pair of coils in Helmholtz arrangement, a solenoid and bucking coils at both ends of the magnet. This arrangement allows for a flexible magnetic field distribution (see fig. 3).

The Helmholtz coil section corresponds to a typical EBIT magnet setup that allows for radial access to the electron beam. The radial access to the trapping region is useful in terms of diagnostics of highly charged ions via X-ray spectroscopy and for atomic beam injection into the electron beam [6]. This field region will always be set to the highest field value and hence the highest current density is reached there. The extended region field region does increase the length of the trapping region and thus the storage capacity. In addition, different field values can be chosen for this region and therefore the electron beam diameter can be adjusted. As the acceptance of the EBIT for externally injected ions depends on the electron beam radius, it can be increased by lowering the magnetic field strength. Numerical simulations [7] support this approach. However, this has to be demonstrated in beam tests.

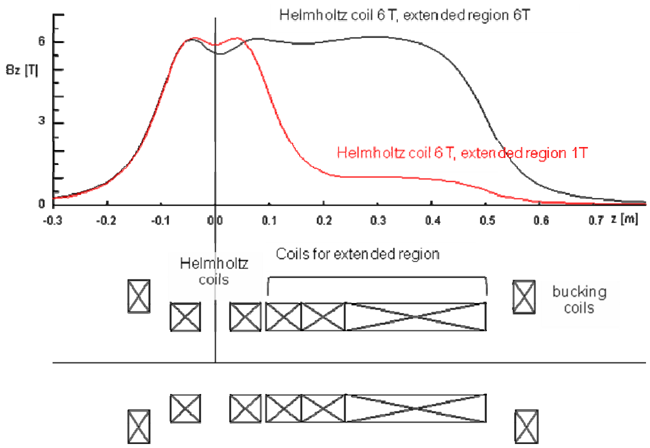

Figure 4: Magnetic field distribution the MSU EBIT.

The bucking coils extend the magnetic field to support the electron beam transport between the magnet and electron gun or collector respectively. Electron beam transport calculations based on the paraxial ray equation show that a loss free transport towards the collector requires the additional field.

Trap Electrode Structure

The electrode system of the charge state breeder that surrounds the electron beam establishes the trapping potential for the injected ions. The electrode system comprises 25 electrodes with 10mm inner diameter. Two kinds of electrodes shape the potential. The shorter electrodes (20 mm long) create the barrier potentials, longer electrodes (50mm long) shape the trapping potential. Fast switching of the barrier electrode potentials within a few 10 µs is required. In operation, the electrode structure will be on the 4 K temperature level. Therefore the insulating spacers between the electrodes will be made from sapphire to provide sufficient heat conductance to remove the heat stored in the structure. The electrodes have a significant overlap to protect the insulators from being charged by secondary electrons and to avoid rf-excitation of the electron beam due to feedback with the electrode structure.

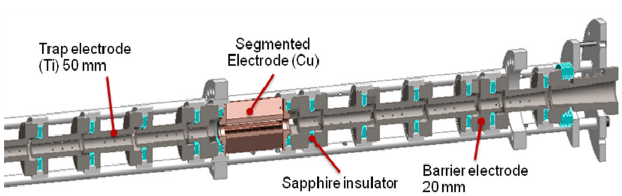

Figure 5: EBIT electrode system. The copper electrode in the centre of the Helmholtz arrangement is four fold segmented and allows direct view to the electron beam region.

The centre electrode has slots that enable the radial access to the electron beam region. This centre electrode will be made out of copper; the other electrodes are composed of Titanium. The electrode stack will be kept under mechanical tension and several Ti-rods support the complete structure, which has an overall length of about 1m. The support structure will be attached to the inner bore.

STATUS OF THE MSU-EBIT

The electron gun and collector have been manufactured, assembled and currently installed in a corresponding vacuum vessels. Both are integrated in a temporary test setup, which uses a pair of normal conducting coils for initial tests of both electron gun and collector. The purpose of this test setup is a complete performance test of electron gun and collector, prior to its assembly to the SC magnet. Together with electron gun characteristics and determination of the gun perveance in dependence on the Wehnelt potential the electron beam diameter will be determined in the transport section of the test setup. Therefore a carbon foil is mounted on a movable feedthrough and will intersect the electron beam path. The beam will burn holes into the foil and imprint its diameter, which will be determined with respect to the gun settings. Realistic performance tests do not require the SC magnet because the magnetic field at the gun and collector can be adjusted and shaped with the coils integrated in both components independent on the source of the main magnetic field.

The design of the drift tube structure has been completed and the SC-magnet is under construction. Delivery of the magnet is foreseen in Summer 2009. HV platform, racks and power supplies are installed to serve for the test setup. The remote control of the devices are available. The required HV-amplifier for fast switching of the barrier electrode potentials and adjustment of the potential distributions inside the trap region are ordered.

REFERENCES

[1] O. Kester, "Charge breeding application of EBIS/T devices", AIP conference proceedings 1099, 2008, p.7.

[2] S. Schwarz et al., Nucl. Instrum and Meth. B266 (2008) 4466.

[3] X. Wu et al., "Beam Dynamics Studies for the Reacceleration of low Energy RIBS at the NSCL", Proceedings PAC2007, TUPAS053, p. 1769 (2007); http://www.JACoW.org.

[4] M. Portillo et al., “An achromatic mass separator design for ions from the EBIT charge breeder at the NSCL”, these proceedings.

[5] G. Sikler et al., Eur. Phys. J. A 25 (2005) 63.

[6] M.W. Froese, “The TITAN Electron Beam Ion Trap: Assembly, Characterization, and First Tests”, Master thesis, University of Manitoba, 2006.

[7] E. Garvartin, "Acceptance Calculations for a Charge Breeder Based on an Electron Beam Ion Trap", master thesis, Michigan State University, 2008.