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PROPERTIES OF THE TEXAS A&M ELECTRON BEAM ION SOURCE

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Summary

An EBIS (Electron Beam Ion Source) is presently being constructed for use on the Texas A&M cyclotron as an external heavy ion source. This description of the source, which is nearing completion, includes the essential elements, the operating conditions, expected output, and results of initial tests on some of the components.

Introduction

The upper limit to the heavy ion energy available from the cyclotron at Texas A&M University is given by

$$E_{max} = 147\ Q^2/A \text{ MeV},$$

where Q is the charge state and A is the atomic mass of the ion. Thus, the acceleration of heavy ions to high energies requires high charge states. Production of charge states in the range +10 to +25 is difficult with conventional discharge sources. A different source concept is therefore required to obtain the highly charged heavy ions necessary for achieving the first harmonic energies available from this cyclotron. The electron beam ion source (EBIS) which is being constructed is one such possibility. This configuration was introduced at Dubna,[1] and is also being developed by groups at Orsay,[2] Frankfurt,[3] and Giessen.[4] It consists of a very dense energetic electron beam magnetically confined within a series of cylindrical electrodes placed along the axis of a solenoid. The space charge of the dense electron beam creates a radial potential well within which ions are trapped as they are created by the electron beam. The ions are further confined axially by positive potentials applied to the electrodes at each end of the ionization region. Successive electron impact ionizations of the confined ions by the energetic electrons then create high charge states. After a confinement time which is optimized for production of the desired charge state, the ions are extracted from the ionization region by lowering the positive electrode potential on the output end of the source.

The achievement of an EBIS which produces sufficiently intense beams to serve as the injector for an accelerator has not yet been realized, although these sources have produced measurable currents[2,5] of highly charged ions such as Ar^{+14}, Kr^{+17}, and Xe^{+29}. The confinement time of the ions in the electron beam is limited by the space charge neutralization of the electron beam by these ions, which allows them to escape radially to the electrodes. This neutralization time is a function of the residual pressure in the ionization chamber and the maintenance of very long containment times (up to 1 sec) necessary for the production of very highly charged ions requires an ultra-high residual vacuum ($\sim 10^{-11}$ torr) in this rather inaccessible region.[5] The production of a given charge state within this neutralization time is then proportional to the electron beam current density. Thus, the production of an ultra-high vacuum within the ionization chamber and the formation and focusing of a very dense (>100 A/cm^2) electron beam through this region are the key requirements for usable currents of highly charged heavy ions.

Description

A cutaway view of the EBIS presently under construction at Texas A&M is shown in Fig. 1. The magnet

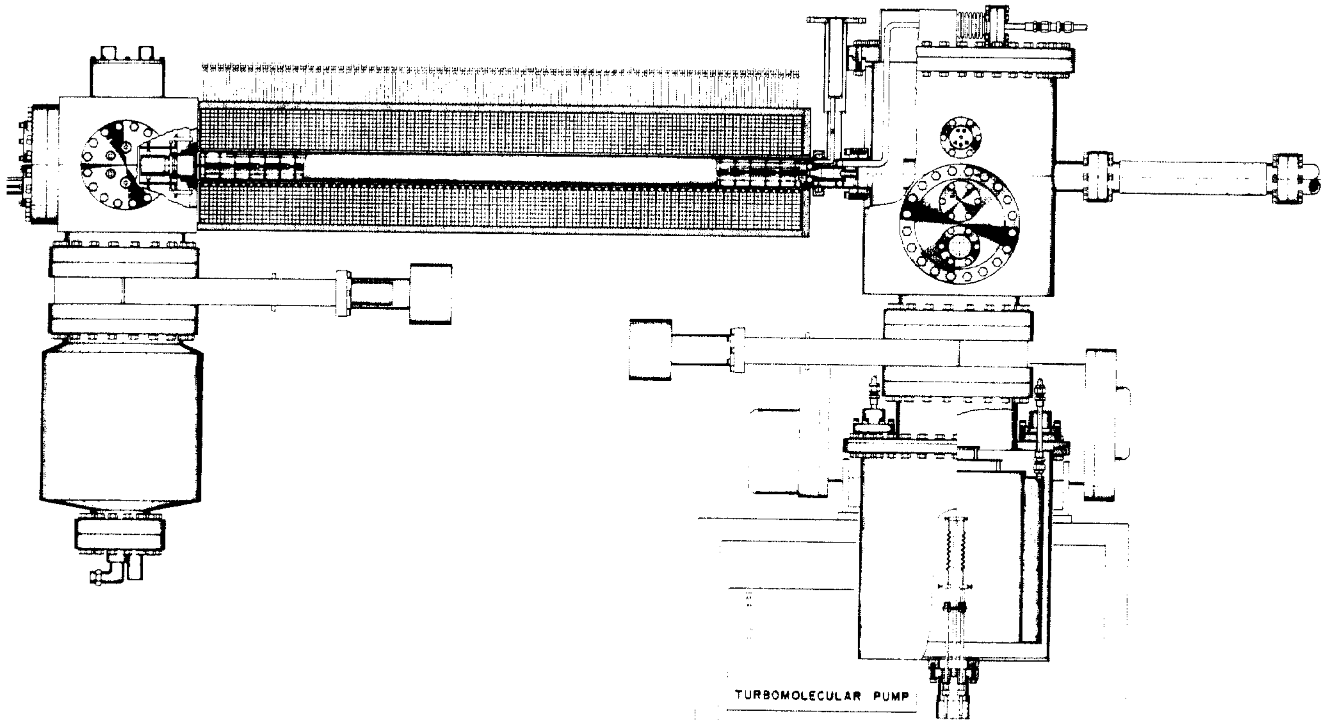

Fig. 1 Cutaway view of the electron beam ion source.

used for focusing the electron beam within the ionization chamber is an air core, water-cooled solenoid one meter in length and capable of producing an axial magnetic field of 9 kG within the 2-1/4 in. bore at a current of 500 A. The entrance vacuum chamber contains only the electron gun and is pumped by an 8-in. Granville-Phillips Electro-Ion pump (pumping speed - 1400 ℓ/s for air). The exit vacuum chamber contains the electron collector-ion extractor assembly, an einzel lens, and the feedthroughs to the ionization chamber. The vacuum in this chamber is produced by a liquid nitrogen-cooled titanium sublimation pump (pumping speed - 5000 ℓ/s) in parallel with a 260 ℓ/s turbomolecular pump. Both chambers are isolated from the hot filament pumps by large stainless steel gate valves which allow pump cleaning and filament replacement without letting the vacuum chambers up to atmosphere while keeping the conductance to the pumps very high. The ionization chamber, located within the bore of the solenoid, contains the cylindrical electrode system. This system of electrodes (drift tubes) is located within a cylindrical liquid-nitrogen dewar that also contains a liquid helium cryopumping surface (pumping speed - 2,000 ℓ/s). The 20 drift tubes are each mounted independently on two insulators to allow precise alignment of the assembly along the axis of the solenoid, and they are gapped to allow pumping of the region within the drift tubes by the cryosurface. The insulators are also used to support the voltage leads necessary for application of the axial potentials to the electrodes.

The electron gun chosen for the EBIS is a modified Pierce-type convergent gun which is operated externally to the bore of the solenoid. This model 112-B[6] electron gun has a microperveance of 2.0, a cathode to minimum beam diameter ratio of 8, and an operating range from one to ten kV. It can initiate a Brillouin-focused[7] electron beam of 1 mm diameter and current density greater than 100 A/cm^2 within the bore of the solenoid. Experimental development of the EBIS will be conducted with the ion source chambers electrically grounded and connected to a magnetic analysis system consisting of a C-magnet with an isolated floating vacuum chamber that contains current measuring and time-of-flight instrumentation coupled to a grounded recording system. The axial potentials of the EBIS are shown in Fig. 2. Initially, a differentially-pumped gas injection system will be used for introducing ~10^{-6} torr-ℓ/s of gas atoms into the ionization region, with pulsed ion or atomic beam injection left as possible later developments.

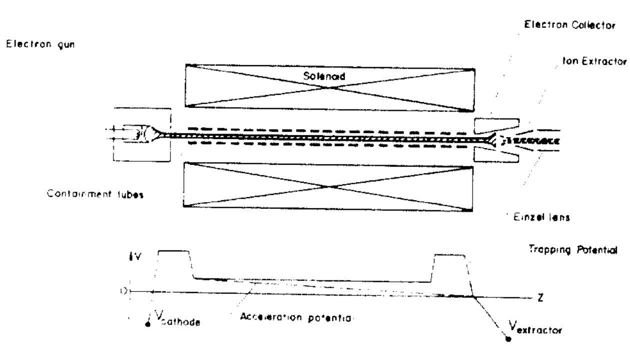

Fig. 2 Applied axial potential in the EBIS during containment and extraction

Calculations

Preliminary calculations have been concerned with the vacuum system design and the expected ion output of the source for realistic electron beam parameters and source operating conditions. We modeled the very intricate geometry of the vacuum system by several lumped conductances, and calculated the residual gas loads using the reported[8,9] outgassing rates for the vacuum materials. Using these residual gas loads, the speeds of the vacuum pumps and the values of the lumped conductances, this simplified model (shown in Fig. 3) gives the residual gas pressures:

$$P_1 = 6.5 \times 10^{-10} \text{torr } P_2 = 3.0 \times 10^{-11} \text{ torr}$$
$$P_3 = 9.0 \times 10^{-11} \text{ torr } P_4 = 7.5 \times 10^{-9} \text{ torr.}$$

Using reported values for the pumping speed as a function of the adsorbed gas layers on a cryopumping surface and a gas injection rate of 10^{-6} torr-ℓ/s in the ionization chamber, the cryosurface has a useful lifetime of ~400 hours. Using this gas adsorption, radiation heating, and heat conduction to the helium lines yield a helium consumption rate of ~0.5 ℓ/hr.

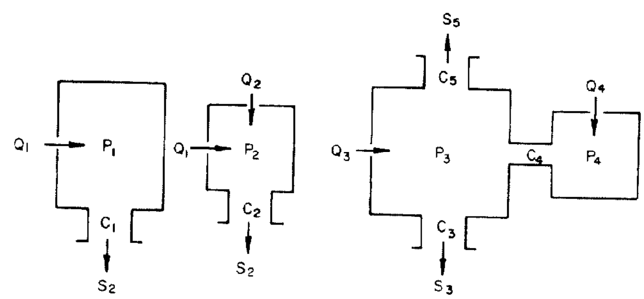

Fig. 3 Lumped conductance model used for pressure calculations.

We have estimated the maximum possible expected EBIS output by using the measured electron beam properties and reported experimental observations of the charge state distributions and successive ionization cross-sections. Figure 4 shows the results of these calculations.

Charge states were chosen such that the final energy of these ions accelerated on the Texas A&M cyclotron would be 10 MeV/nucleon. The electron gun extraction voltage was set at 7 kV and the ion extraction time was chosen to be 100 μs. Extraction of the ions from the ionization volume was assumed to be complete and the optimum containment time was assumed to yield a space charge neutralized electron beam with a negligible residual gas contribution. Recent experiments at Orsay have indicated that complete space charge neutralization of the fast electron beam has been achieved under their source operating conditions.[10]

Very little is presently known concerning the evolution of the slow electrons produced within the ionization volume by the fast electron impact ionization collisions. The concentration of these slow electrons in large numbers within the ionization volume will certainly reduce the ion yields from these calculated estimates due to ion-electron recombinations. The extraction efficiency would also be lowered by the presence of these slow electrons in the ion extraction region, but the local neutral gas pressure would probably have a much greater effect on the extraction efficiency because of the very low velocity of the ions in this region. The little that is known about the charge change cross sections for highly-charged heavy ions at such low velocities indicates they will be greater than 10^{-14} cm^2. However, a working pressure of 10^{-9} torr in this region would achieve a transmission of 99.9% for a charge change cross-section σ of 10^{-12} cm^2. Subsequent transport of the extracted ions at 10 keV/nucleon is subject to $\sigma \simeq 10^{-14}$ cm^2 and a vacuum requirement of 5×10^{-7} torr is required for 95% transmission over a 3-meter path. Because of the large acceleration per turn available within the cyclotron, vacuum requirements there are considerably more relaxed, due to the energy dependence of the charge change cross-sections.

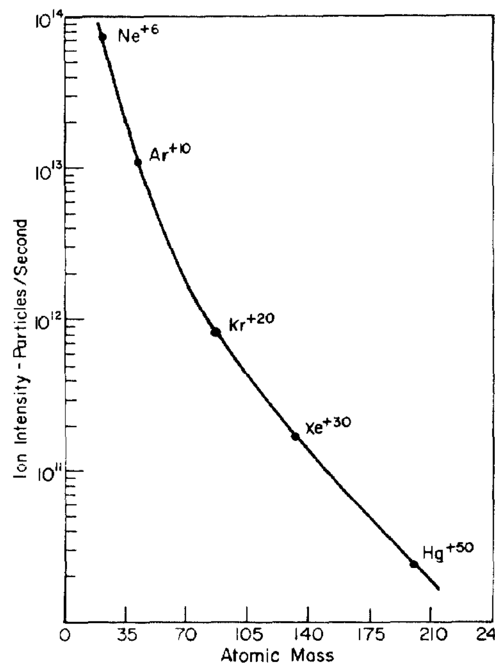

Fig. 4 Estimated upper limit currents assuming complete extraction and space-charge neutralization for an electron current at 1.17 A and current density of 100 A/cm^2, with no losses due to recombination.

Present Status

A recent photograph of the EBIS is shown in Fig. 5. The solenoid has been tested with an axial field of 8.8 kG at a current of 480 A. With a water flow of 18 gal/min, the temperature rise is only about 30°F. The field symmetry of the magnet has been mapped with Hall probes, and the magnetic axis has been located as a function of the axial distance through the bore.

The main vacuum chambers have been tested. In the initial pump-down, a pressure in the entrance chamber of 1.5×10^{-9} torr was attained and the pressure in the larger exit chamber reached 3.5×10^{-9} torr. The ionization chamber has been leak-tested at a vacuum of 10^{-7} torr, and the drift tube assembly is presently being installed and aligned within it. This chamber will be tested initially without the cryopumping surface. The cryopumping system and the ion extraction assembly are presently under construction.

A special 0.01-cm. dia. pin hole electron beam analyzer and test chamber has been built to study the entrance and stability properties of the electron beam injected into the solenoid. Testing with this apparatus will begin shortly. The pulsing circuit for the electron gun and the drift tube assembly is nearing completion, and will be used for the entrance condition testing of the electron beam.

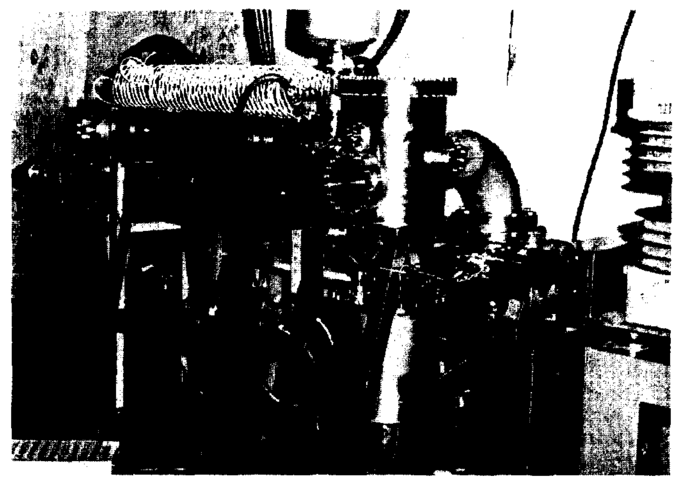

Fig. 5 A recent photograph of the EBIS.

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