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Status of the BNL High Current EBIS Test Stand*

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Abstract

As part of a new, compact heavy ion injector for AGS/RHIC complex at Brookhaven National Laboratory we are developing an Electron Beam Ion Source (EBIS) that would satisfy present and future requirements. Such a source should be capable of producing intensities of e.g. Au^{35+} ions of about $3x10^9$ particles/pulse or U^{45+} of about $2x10^9$ particles/pulse. To achieve this, the required e-beam intensity is 10A, at a pulse length of 100ms. An EBIS test stand has been constructed, designed for the full electron beam power and having close to 1/2 of the trap length of an EBIS for RHIC. Initial electron beam tests have resulted in a 50μs, 13A electron beam. Ion production and extraction has been shown with a 3.1 A, 50 ms electron beam, achieving an ion yield of 19 nC/pulse (neutralization degree of 61%); fast extraction trials have yielded extracted ion pulses of 1mA peak current and 18μs at FWHM. Details of the test stand construction, results of the electron beam studies, and properties of the extracted ion pulse are presented.

I. INTRODUCTION

The objective of the EBIS program at BNL is to develop a heavy ion source of the EBIS type, to serve as part of a future ion injector for the AGS/RHIC complex. The properties of the ion beam (intensity, ion species, etc.) extracted from the source should satisfy the present and possible future requirements of RHIC. Implementation of such an EBIS in high energy colliders has been described elsewhere [1] and the summary of pertinent parameters is given in Table 1. The required electron beam power, as well as the ion output, are an order of magnitude higher than in any existing ion source of this type. During the first phase of our program experiments were done on the upgraded SuperEBIS, obtained from Sandia National Laboratories [2]. Electron beam currents of 0.5A d.c. and 1.1A in the pulsed mode were achieved at BNL with this device. Narrow charge spectra were produced for ions such as sodium (peak 7+), argon (peak 14+), and thallium (peak 41+). Ion spectra of xenon were produced with a peak charge state of 27+, using an electron beam current above 0.4 A d.c., with a neutralization degree above 50% [3].

Encouraging results from these experiments led to a decision to proceed with the next phase of the program, the construction of a new EBIS Test Stand (EBTS), to be used to develop technologies and study the physics of a high power, high ion yield EBIS. This test stand is shown schematically in Fig. 1, and design parameters are also given in Table 1. (We have increased the nominal trap length to 70cm, compared with 50cm reported previously [4]). We have designed EBTS for the full electron beam power. The commissioning of the test stand is in progress, with simultaneous studies of electron beam formation and ion production and extraction. As described in the following sections, propagation of a 13 A electron beam through the superconducting solenoid magnet has been shown for 50 μs pulses, long pulse operation of the electron beam has been achieved (3.1 A, 50 ms pulse length), with simultaneous production and extraction of ions produced from the background gas. The program will continue with studies of long pulse and d.c. electron beams up to 10 A and ion production and extraction at the full electron beam power. Also of interest is the development of primary ion injection into the trap, the study of ion formation in, and the loss from, a high current electron beam and, finally, the study of fast ion extraction desired for a simpler injection into the AGS Booster. The ultimate objective of this part of the program is to show the production of ion beams with intensities close to1/2 of that in the final RHIC EBIS. The successful operation of this device will be followed by the design of the full scale EBIS, as well as of other elements of the injector.

II. EBIS TEST STAND SETUP

In an EBIS there is a certain flexibility when selecting its nominal parameters. To reach the desired charge state of a selected ion species, it is the product of the electron beam current density and the confinement time that is relevant. For the RHIC EBIS one would like to be able to produce the required charge state in intervals synchronized with the AGS Booster operation, making it desirable to limit the confinement time to about 100 ms. From this it follows that an electron current density of 400A/cm^2 will be needed for Au^{35+} ions, or for the heaviest species, U^{45+}, up to 600 A/cm^2. Our electron gun

(LaB_6 cathode, 8.2 mm diameter), designed and fabricated at Novosibirsk, perform in this range of parameters [5] by adjusting the electron beam launching parameters.

Initial tests described previously [6] were done with two long electrodes replacing the nine central drift tubes. Since then the full drift tube system has been installed, together with the water-cooled collector, gun magnet coil, collector correcting coils, transverse coils, ion extractor, and a number of diagnostics and controls. To date, the test stand has operated only with ionization of background gases (mostly coming from a tiny vacuum leak). Equipment for primary ion injection will be installed in the near future.

Monitoring electron beam losses is important for preventing damage to the source components and for optimizing the source performance. We have provided for current measurements sensitive at the milliampere level on all electrodes in the electron beam path, from the anode to the collector structure. Any current which strikes electrodes not associated with the electron gun platform is considered to be fault current and is used as a signal to shut off the electron beam within a few microseconds should its value exceed a preset threshold, typically several milliamperes. In Fig.2, the setup for this electrode current measurement is shown.

Special care must be given to the electron collector, which must accept up to 100kW of power during a 100ms pulse. The power loading in the electron beam collector, if sufficiently localized, could cause melting. This could occur if a symmetric electron beam were collected over a short axial extent of the collector or, even worse, if the beam were deflected from the axis. In order to monitor the temperature of the collector wall, we have developed a heat sensitive detector with a response time on the order of 10μs. This consists of four infrared diodes which view the interior of the collector; their signals can be used to generate a fault condition.

In order to decrease electron beam losses we have small coils to give transverse magnetic fields of about 10-20 G [3], but this steering could also substantially increase the local power loading. To compensate for this we have incorporated the capability of rotating the electron beam about the collector surface using two orthogonal sets of transverse coils with sinusoidal currents 90 degrees out of phase [7]. Figure 3 shows the signals from the diode temperature monitor for two rotation frequencies, 15 Hz and 600 Hz.

To pulse the electron beam, we are using a 50 kV anode power supply together with 65 kV Behlke transistor switches to operate with very fast (~10μs) rise and fall times. Such a power supply allows both short electron beam pulses and a very rapid response to a detected fault condition.

Ions extracted from the source are detected on a segmented Faraday cup immediately downstream from the extractor. The detector has a 2.5cm diameter and is divided into five segments: a central circular segment of 0.9 cm diameter surrounded by four symmetric quadrant plates. Secondary electron emission is suppressed by the extractor mesh, which is several kilovolts negative with respect to the detector.

III. RESULTS

As reported previously [6], a 13A, 50μs electron beam was obtained with a 45kV anode voltage pulse, at the full main solenoid field of 5T. The ionization region energy, i.e., the potential difference between the cathode and trap region electrodes, was 36kV. For a 70cm ion trap region this gives a capacity of 5.1 x 10^{11} charges, which is the goal for the EBTS. The electron beam current density calculated from the ratio of the main field and the entrance field was ~500A/cm^2.

A base vacuum of 4 x 10^{-11} mbar was obtained in the ionization region before installation of the pre-collector coil and collector. A small water leak in the pre-collector coil has since limited the base vacuum to ~1 x 10^{-9} mbar and has precluded baking the system. The differential pumping between the gun, ionization, and collector regions of the source is good; a pressure bump of greater than 10^{-7} mbar in the collector region, due to 30kW, 50ms beam loading, leaves the ionization region in the 10^{-8} mbar range and the gun in the 10^{-9} mbar range. We expect that baking of the system and proper training of the collector will result in 10^{-10} range operating pressures in the ionization region, which will be sufficient for ionization and trapping of heavy ions.

In initial tests of ion production, the ion trap was formed by applying barrier voltages 2-3kV more positive than the trap region drift tubes. We have observed that by ramping the anode voltage of the electron gun (and therefore the beam current) to the final peak value during 10-20ms, essentially lossless electron beams could be transmitted (>99.9% efficiency) at a lower ionization region energy than for a beam with an abrupt rise time. This effect is due to the reduction of the space charge depression inside the drift tube due to partial compensation by ions. Using this method, a 50ms long electron beam pulse of current 3.1A and ionization region energy 14 kV was reached. (The space charge depression within the 32mm trap region diameter drift tube is 3kV for a "bare" 3.1A, 14kV electron beam). In this case, the trap capacity was 1.9x10^{11} charges, for the trap length of 70 cm. A total ion charge of 19 nC was extracted, corresponding to a 61% neutralization.

In more recent studies, a Behlke switch was used to apply a 3kV pulse with 20μs risetime to the trap region electrodes, causing ions to be expelled over the fixed extraction barrier. Fig.4 shows a 1mA peak, 18μs FWHM ion pulse produced by a 3A electron beam and 60ms confinement period. The total collected charge of 17.5nC gives a neutralization degree of 57%.

In order to reach our goals for the RHIC EBIS, it is important that we can maintain a linear increase in extracted charge with increasing electron beam current, since the present result for 3A is on target. The relationship between extracted charge and electron beam current is shown in Fig. 5 for the BNL EBTS. The trend is for the charge is clearly more than linear, giving much promise for future runs at higher electron current.

IV. SUMMARY

The commissioning of the Electron Beam Test Stand has proceeded well, with very encouraging initial results.

. A 13A, 50μs electron beam was produced and transmitted through the EBIS superconducting solenoid, operating at 5T; this current is well above the design parameters of the gun. Commissioning with long pulses is in progress, and a current of 3.1 A at a 50 ms pulse length has been reached so far. Simultaneously with raising the electron beam current and increasing its pulse length, extraction of ions produced from background gas has been studied. At this current level, an ion yield of $1.2\text{x}10^{11}$ charges per pulse was achieved, corresponding to a neutralization degree of 61%. In a simple, fast extraction mode, a 1 mA peak ion current pulse was observed, having a FWHM of only 18μs. This result shows that even without introducing a potential gradient inside the trap it is possible to achieve very short ion pulses, as desired for single turn injection mode into the AGS Booster.

Commissioning and tests will continue. A time-of-flight analyzer for measuring charge state distributions, and connecting chambers for primary ion sources, have been finished and will be installed shortly. While 100ms operation of the electron beam should be sufficient for production of even the heaviest ions, we are concerned that the present collector design may limit the electron beam power. The design of a new collector with more efficient cooling has begun, to be capable of operating with the full current d.c. electron beam.

ACKNOWLEDGEMENTS

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Table Captions

Table I Parameters for the RHIC EBIS and the EBTS.

Figure Captions

Fig. 1: Layout of the EBIS test stand.

Fig. 2: Electrode and current measuring schematic for electron and ion beam tests.

Fig. 3: Signals from the collector temperature monitor for rotation frequencies of 15 Hz (lower) and 600 Hz (upper).

Fig. 4: Trace of a 1 mA ion pulse, produced by a 3A electron beam. The total collected charge is 17.5 nC.

Fig. 5 Total charge extracted for electron beam currents up to 3A.

Parameter	**RHIC EBIS**	**EBTS**
e-beam current	10 A	10 A
e-beam energy	20 keV	20 keV
e-beam density	~575 A/cm^2	~575 A/cm^2
Ion trap length	1.5 m	0.7 m
Trap capacity (charges)	1.1 x 10^{12}	5.1 x 10^{11}
Yield positive charges	5.5 x 10^{11}	2.6 x 10^{11}
Yield Au^{35+}, design value	3 x 10^9 ions/pulse	
Yield U^{45+}, design value	2 x 10^9 ions/pulse	

Table I

Parameters for the RHIC EBIS and the EBTS.

Table I., Beebe, Rev. Sci. Instrum

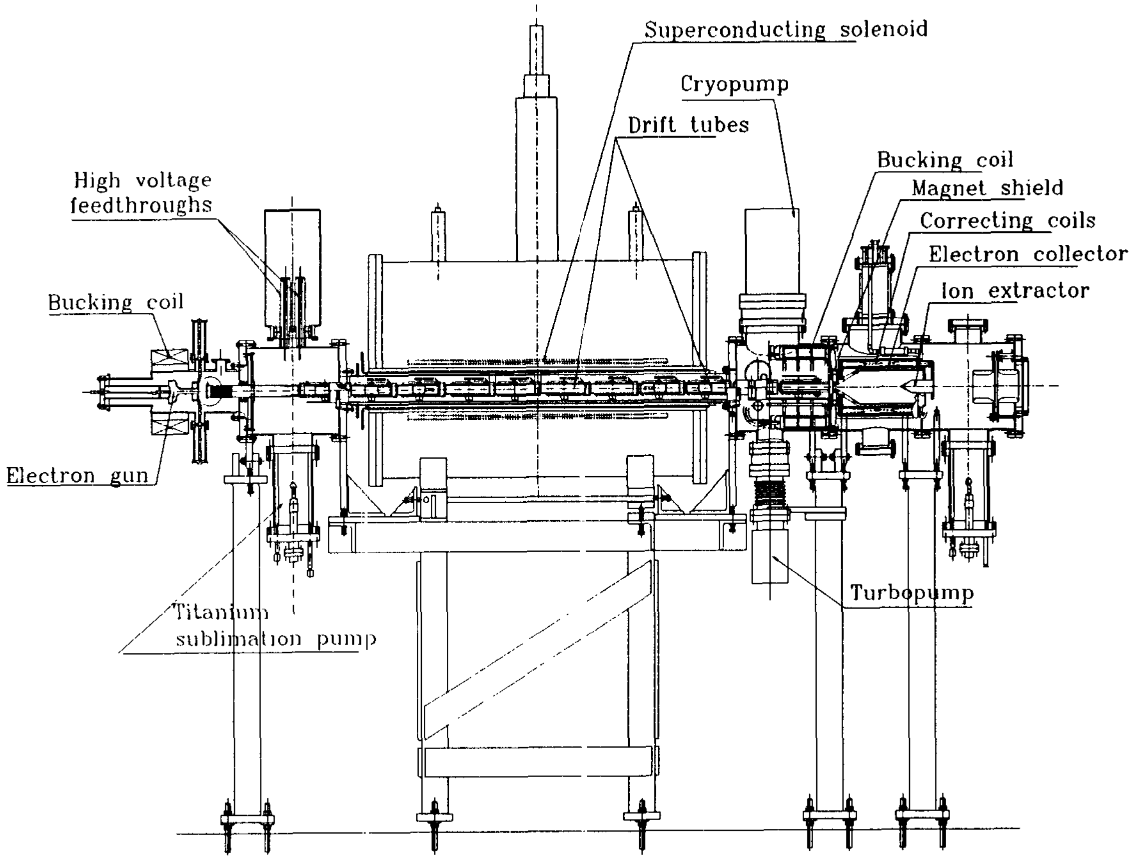

Figure 1: Layout of the electron beam test stand

Figure 2, Beebe, Rev. Sci. Instrum.

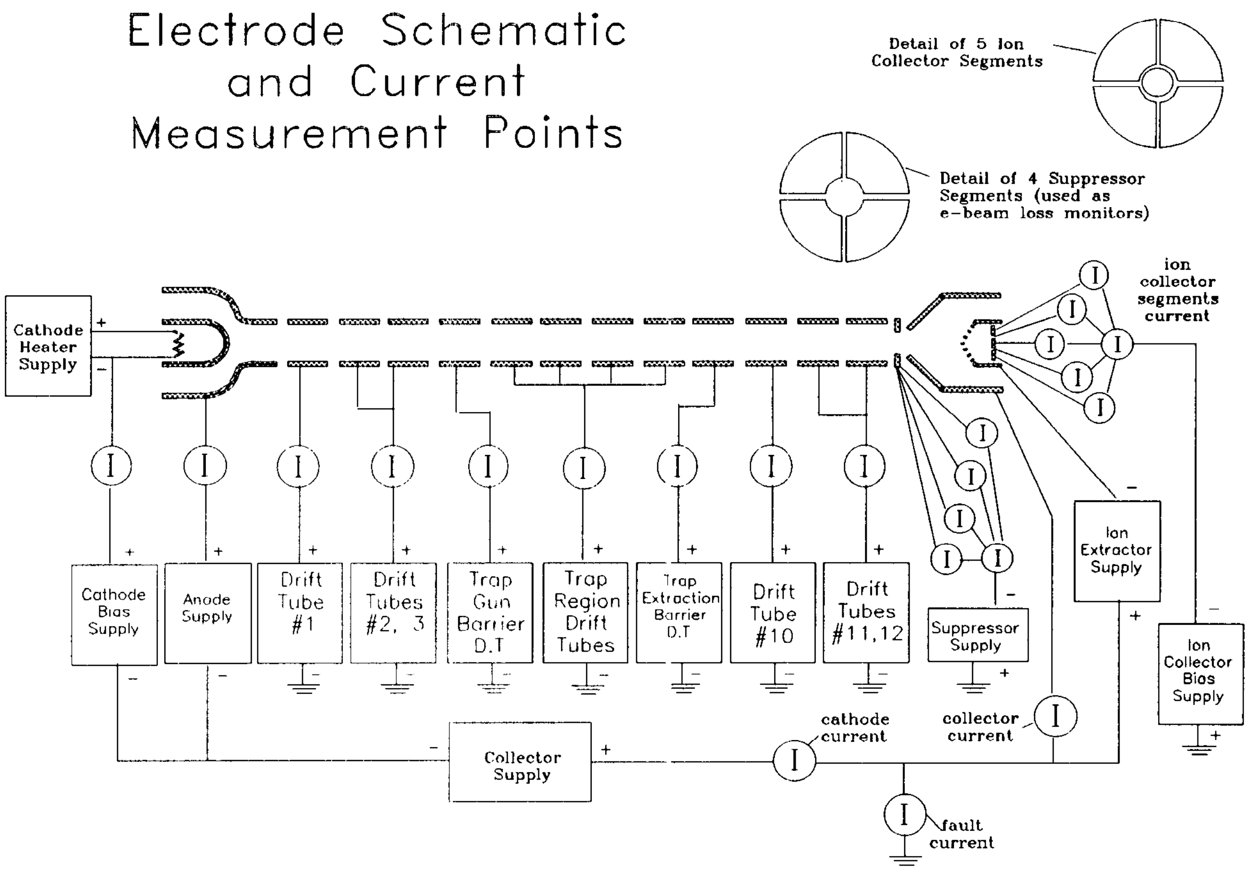

Figure 2: Electrode and current measuring schematic for electron and ion beam tests.

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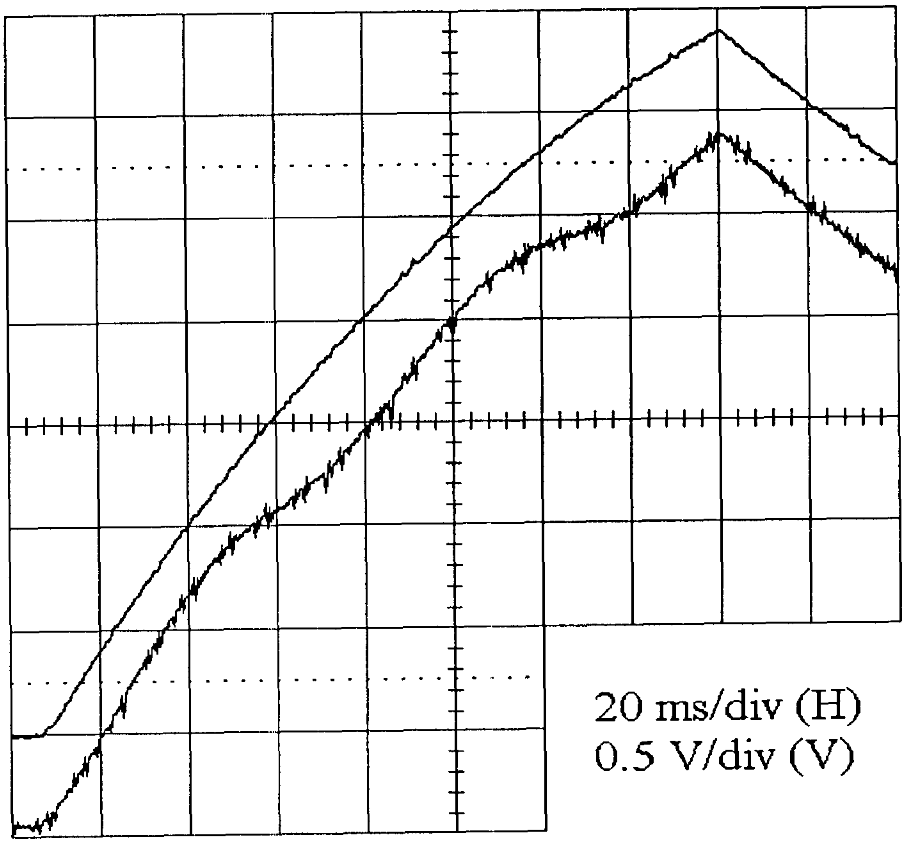

Figure 3 . Signals from the collector temperature monitor for rotation frequencies of 15 Hz (lower) and 600 Hz (upper).

Figure 3, Beebe, Rev. Sci. Instrum.

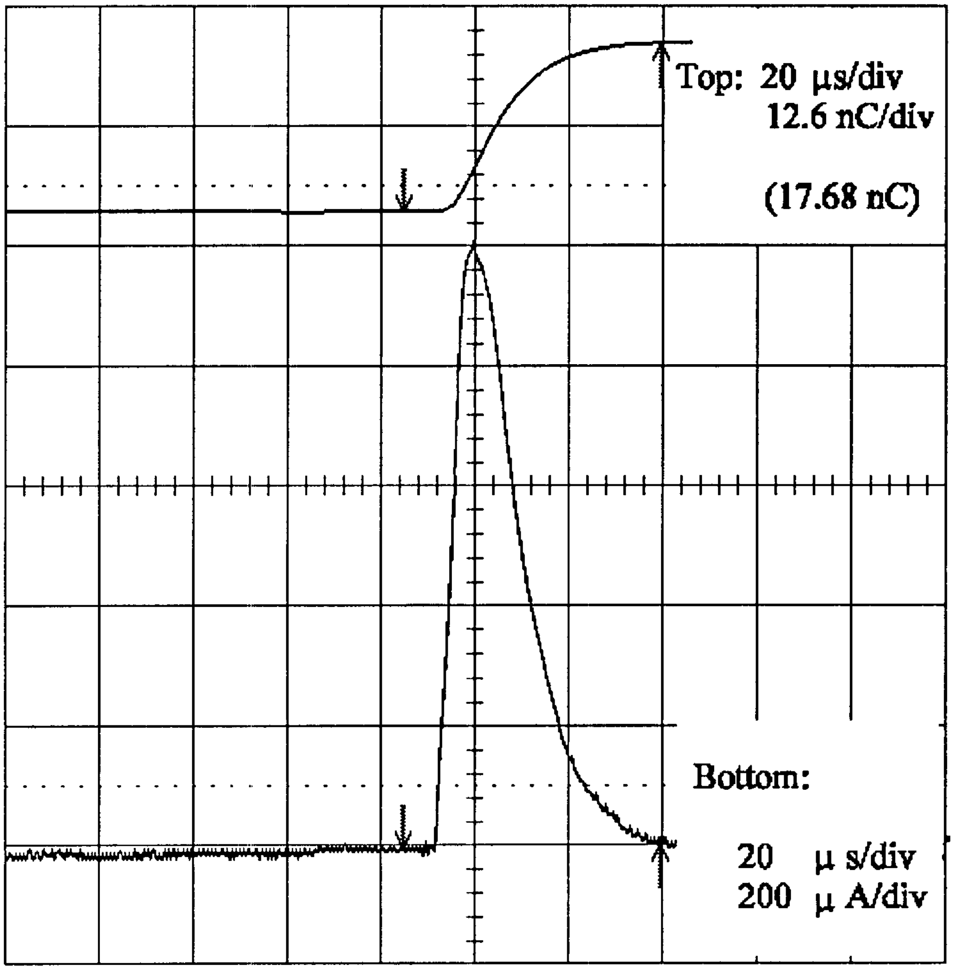

Figure 4 Trace of 1 mA ion pulse, produced bya 3A electron beam. The Total collected charge is about 17.5 nC

Figure 4, Beebe, Rev. Sci. Instrum.

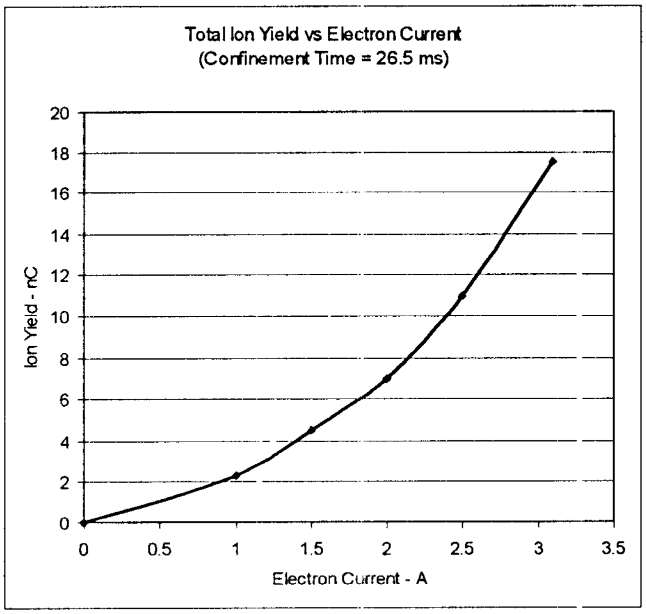

Figure 5 Total charge extracted for electron beam currents up to 3A.

Figure 5, Beebe, Rev. Sci. Instrum.