EXPERIMENTAL RESULTS ON MULTI-CHARGE-STATE LEBT APPROACH*

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Abstract

A multi-charge-state injector for a high-intensity heavy-ion linac is being developed at ANL. The injector consists of an all-permanent magnet ECR ion source [1], a 100 kV platform and a Low Energy Beam Transport (LEBT). The latter comprises two 60-degree bending magnets, electrostatic triplets and beam diagnostics stations. At present the injector system allows us to accelerate all ion species up to q×100 keV total kinetic energy, where q is the charge state of an ion. In the current installation, the accelerating tube is followed by a 90º magnet and a beam measurement station [2].

Recently we studied the production of metal ion beams using an oven technique and high intensity light ion beams from the ECR ion. A pepper pot emittance meter based on a scintillator screen has been developed and tested with various CW ion beams. It was found that a CsI (Tl) crystal has a high sensitivity for a variety of ion species from protons to heavy ions with the current densities even below 1 μA/cm^2.

PRODUCTION OF ^{209}BI BEAM

During the past year the 700 W, 12.75-14.5 GHz TWT RF amplifier for the BIE-100 ECR ion source was repaired. When combined with the 2 kW, 14 GHz klystron, two frequency operation was restored. An easily replaceable commercial oven [3] for the production of metal ions was added to the source as well (Fig. 1).

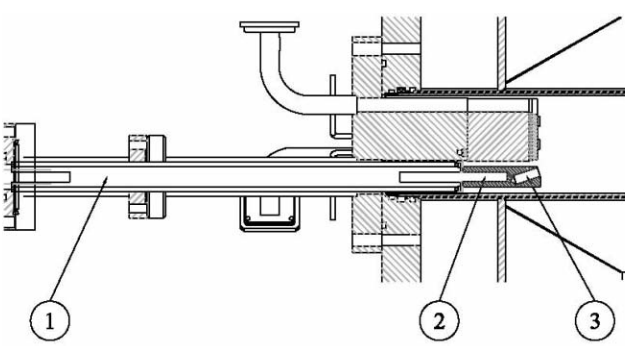

Figure 1: BIE-100 with (1) oven support assembly, (2) cartridge heater insertion point and (3) sample material.

The frequency of the TWT RF amplifier, biased disc potential and oven power are controllable from outside of the high voltage cage. The oven can be operated up to a temperature of 800°C which is enough to evaporate a wide range of metals. Bismuth with an operating temperature near 550°C was used for the tests. Only the bottom half of the crucible was filled with bismuth to minimize material heating by RF and sputtering by plasma ions. Oxygen was used as a support gas to enhance the charge states of ^{209}Bi ions.

The bismuth ion beam was first extracted by applying a 15 kV potential and then accelerated by the 60 kV potential of the HV platform. The 20 mm input aperture Faraday cup (FC) equipped with a suppression ring was installed downstream of the 90° magnet to record the currents of different charge states. The distribution of ^{209}Bi ion currents for different charge states obtained after a few days of the source conditioning and tuning is shown in Fig. 2. One can see that $^{209}Bi^{19+}$ and $^{209}Bi^{20+}$ ions are the most abundant in the distribution. Intensities of the $^{209}Bi^{20+}$ - $^{209}Bi^{24+}$ ions are in the range of 1-2.5 pμA. The source produces also O^{1+} and O^{2+} ions with the current up to 350 μA.

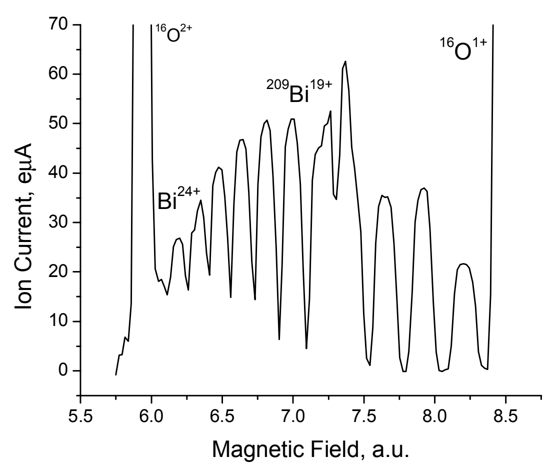

Figure 2: Bismuth beam intensities at different charge states.

The quality and intensity of bismuth ions are entirely adequate to verify multiple-charge state acceleration technique [4] using the new set-up of the multiple-charge state LEBT [2] being constructed.

HIGH CURRENT REGIME

Stability tests of the windowless liquid lithium stripper for AEBL [5] require 400 W bunched light ion beams in the energy range from 100 keV/u to 200 keV/u. The multiple-charge-state LEBT can be upgraded to obtain 150 keV/u beams by adding the second accelerating tube.

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3 mA dc beam current in a single charge state is required to achieve 400 Watts on the target. Helium and hydrogen were used as working gases to verify the performance of the ECR ion source. The ion beams were extracted with a 15 kV potential and accelerated by the 60 kV potential of the HV platform. The distributions of helium and hydrogen ion beam intensities obtained after the source conditioning and tuning are shown in Fig. 3 and 4. The dc 3.3 mA proton beam was successfully generated which is entirely suitable to form a bunched and well focused beam on the target.

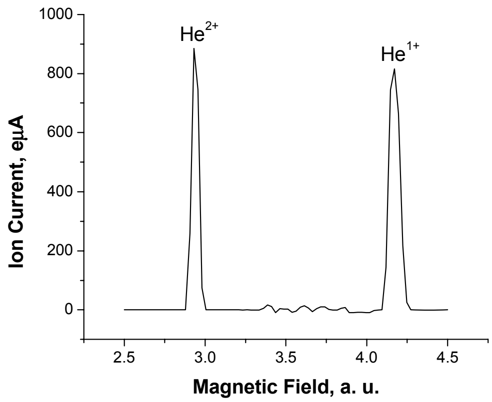

Figure 3: Helium beam intensities.

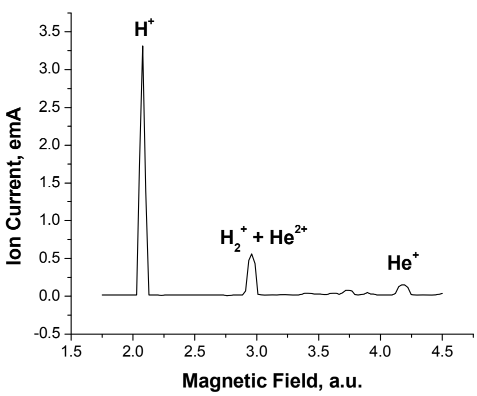

Figure 4: Hydrogen beam intensities.

SCINTILLATOR SCREEN BASED CW BEAM EMITTANCE MEASUREMENTS

Fast emittance measurements can be performed using a beam imaging system placed downstream of a "pepper pot" plate. The pepper pot method has the advantage of giving the possibility to extract emittances for both vertical and horizontal planes using the same single image. Micro channel plates (MCP) and scintillator screens are normally used as an imaging system. However, scintillator screens are preferable due to their simplicity and wider dynamic range. An approach based on scintillator screens was used to measure the emittances of ion beams [6] with energies higher than 100 keV/u or intense (above 10 mA) pulsed low energy (below 100 keV/u) ion beams [7]. There is no data on scintillator screen sensitivities for low intensity (0.1-10 eμA/cm^2) low energy (below 100 keV/u) CW beams typically generated by ECR ion sources.

The main goal of this study is to find whether the pepper pot - scintillator screen (PPSS) method can be used to measure emittances of CW beams generated by ECR ion sources. The BIE-100 ECR ion source was used to generate ion beams of various elements from hydrogen to bismuth. The PPSS assembly, shown in Fig. 5, was placed downstream of the 90º magnet and movable faraday cup (FC).

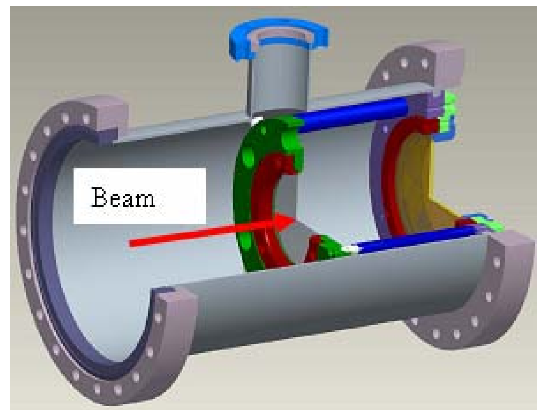

Figure 5: Cut-out view of the pepper pot – scintillator screen assembly.

The pepper pot plate has 100 pinholes each with a 200 μm diameter and a 4-mm spacing between the holes horizontally and vertically covering a working area of 36×36 mm^2. The CsI (Tl) crystal was chosen as a scintillator screen because it has shown the highest sensitivity for high energy proton beams [8]. The diameter and thickness of the crystal are 80 mm and 3 mm respectively. A grounded fine metal mesh with transparency above 50% is attached to the crystal surface irradiated by ions to prevent an increase in the potential caused by ion beam charge. The distance between the pepper pot and scintillator screen is 100 mm. COHU 2600 monochrome CCD camera connected to a PC was used to acquire and save beam images. The pepper pot plate is isolated from ground and its potential can be varied in the range of ±1 kV to study the effect of secondary electrons on the emittance. The FC was used as a shutter and detector of the ion beam current. In our measurements, the beam energy is 75 keV per unit charge for all elements used.

It was found that CsI (Tl) has a high sensitivity for a variety of ion species from protons to heavy ions. Pepper pot images were at recordable level for proton and bismuth beams with current densities below 1 μA/cm^2. A typical image of $^{129}Xe^{14+}$ ion beam with current density of 7 μA/cm^2 is shown in Fig. 6.

The analysis of captured images was performed using software developed at BNL [9].

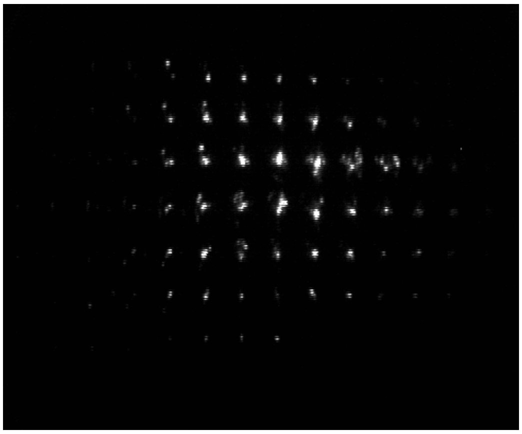

Figure 6: Pepper pot image of $^{129}Xe^{14+}$ ion beam.

Horizontal and vertical phase space plots for the $^{129}Xe^{14+}$ ion beam together with the results of the rms emittance calculations are presented in Figs. 7 and 8 respectively. The 4-rms emittance ellipses are plotted in red as well. The linearity of the CsI (Tl) crystal for different input current densities and its life-time under irradiation by CW ion beams will be studied in the near future. A new mask with 100 μm pinholes spaced by 3 mm in both directions is being developed to improve the resolution. Software for on-line emittance measurements is under development as well.

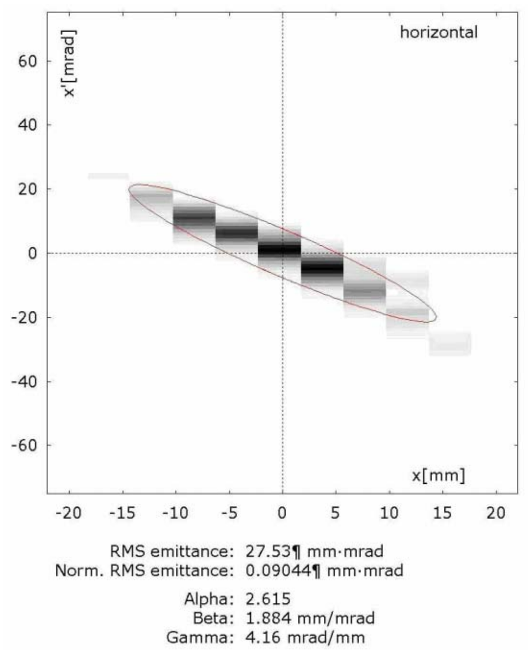

Figure 7: Horizontal phase space plot of the $^{129}Xe^{14+}$ ion beam.

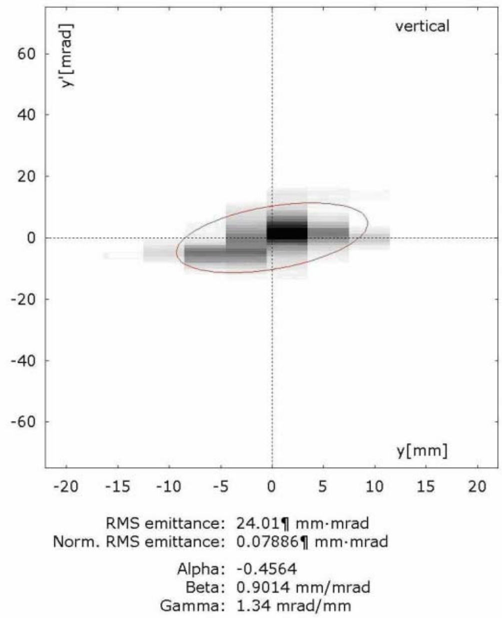

Figure 8: Vertical phase space plot for the $^{129}Xe^{14+}$ ion beam.

CONCLUSION

The current ECR-LEBT installation at ANL can produce an ~2.5 pμA bismuth beam in a single charge state which is sufficient for the future studies of transport and merging of multiple-charge-state ions. In addition, the ion source together with the HV platform can produce high power light ion beams for the study of liquid stripping films.

We have developed and tested a simple pepper pot - scintillator screen based emittance meter to measure emittances of CW beams generated by ECR ion sources.

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