Study of a liquid metal ion source for external ion injection into electron-beam ion source

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A liquid metal ion source (LMIS) has several attractive features as an external injector of primary ions (mostly metallic ions) into electron-beam ion source (EBIS). It does not use a buffer gas and therefore it provides only a very small gas load to the system; its control and operation are simple, power consumption does not exceed 10 W, and beam pulses are very stable. A gold-silicon LMIS was supplied by FEI Company (http://www.feibeamtech.com/pages/liquid.html) and tested in a pulsed regime with an ion pulse width of 2 ms and frequency up to 5 Hz. Total extracted ion current reached 50 μA and the normalized emittance of the total ion beam was 0.05π mm mrad. The results of this test, as well as results of experiments in which this ion source is used for injection of Au ions into EBIS, are presented. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2166428]

I. INTRODUCTION

A few types of low-charged ion sources have been used for external ion injection into BNL electron-beam ion source (EBIS), an ion source based on impregnated zeolite (thermionic emitter),[1] a LEVA ion source,[2] and a hollow-cathode ion source (HCIS).[3] Both LEVA and HCIS were used successfully for the injection of different metallic ions into EBIS and proved to be reliable ion sources. The advantage of LEVA ion source is its ultrahigh vacuum (UHV) compatibility, but the stability and noise level could be improved. The HCIS is stable but requires a feed gas; therefore an efficient differential pumping system must be employed to maintain the low vacuum within the EBIS ionization region. Thermionic emitters, for which the species choice is limited mostly to alkali metals, have been used early in our program to provide modest ($\sim$1 μA) beams of Na, K, Cs, and Tl. This source has favorable properties in terms of emittance and stability, assuming its output could be scaled to meet $\sim$10–50 μA singly charged ion seed current requirement of the high current EBIS. The liquid metal ion source (LMIS) seems to be a good candidate for ion injection into EBIS, because it is capable of producing a variety of metallic ions with adequate intensity, has good stability, and is UHV compatible.

II. DESIGN AND SIMULATIONS OF THE LMIS

The design of LMIS optical electrodes is similar to the geometry of Ishikawa.[4] The goal of the LMIS optics design was accepting the entire cone of ions emitted from the needle, thus no provision for the collimating of the beam has been made at this time. The design of the optical structure of LMIS is presented in Fig. 1.

Ion beam transmission from the LMIS to a distance of 50 cm was simulated with the program TRAK[5] (Fig. 2).

Simulations demonstrated that the ion beam could be propagated through the optical structure without losses and focused to a spot with diameter less than 20 mm at a distance of 50 cm.

III. EXPERIMENTAL STUDY ON THE TEST BENCH

LMIS from FEI Company[6] loaded with Au–Si alloy having over 80% of Au was used. The ion optics of the experimental bench included a postdecelerator electrode with controllable positive voltage, which was located downstream of the LMIS second accelerating electrode followed by an *X-Y* deflector of the ion beam. The ion current on a Faraday cup (biased to +200 V to suppress the secondary electrons) was measured through a 100 kΩ resistor. With extractor voltage $U_{extr} \approx 13$ kV with the respect to the emitter, the observed total ion current on a Faraday cup was (30–50) μA. The LMIS was tested in a pulsed mode for a range of pulse lengths and frequencies: $\tau_{pulse}=(2-100)$ ms and frequency (0.5–5) Hz. Waveforms of ion pulses measured on a Faraday cup are presented in Fig. 3.

This experiment demonstrated very high stability of the extracted ion beam; the variations of amplitude did not exceed 1% over several hours.

The transverse (vertical) normalized RMS emittance of the total ion beam measured on a distance of 60 cm from the emitter was $\varepsilon_{\_rms\_norm}=0.05\pi$ mm mrad.

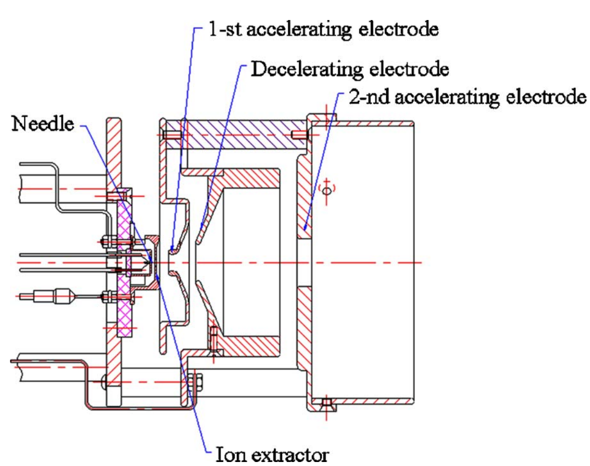

FIG. 1. LMIS assembly.

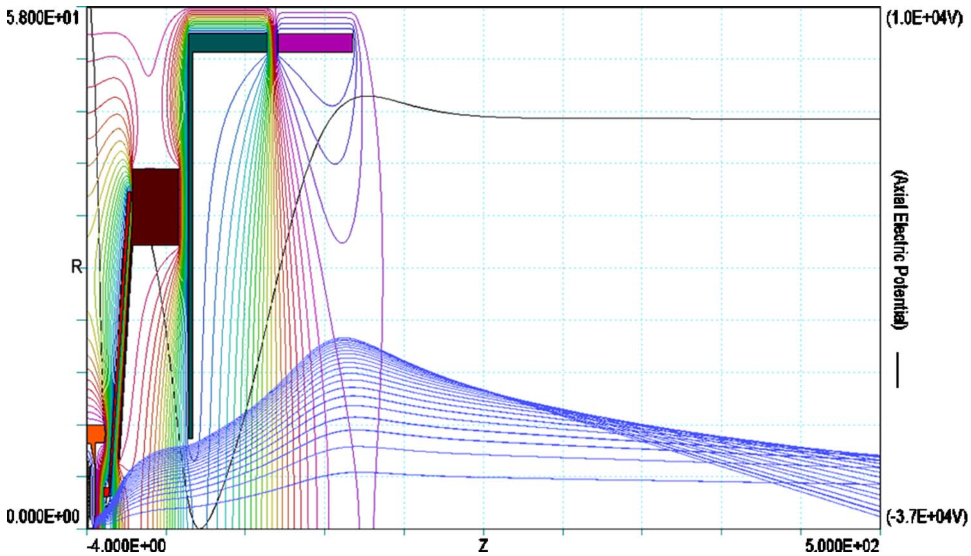

FIG. 2. Simulation of the ion beam extracted from the LMIS. Ion current 40 μA, emitter-extractor voltage, 6 kV, accelerator-emitter voltage, 32 kV, and emitter bias with respect to ground is +10 kV.

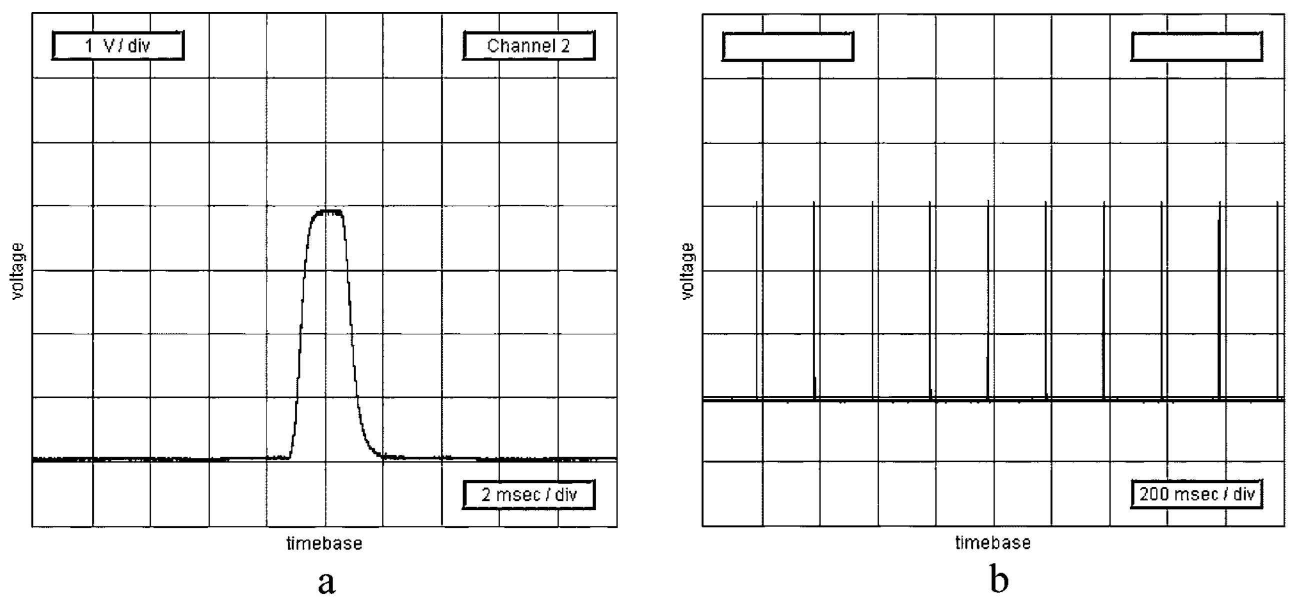

FIG. 3. Wave forms of LMIS total ion current: (a) single ion pulse (I_{ion}=38 μA, full width at half maximum (FWHM)=2 ms), (b) train of pulses (I_{ion}=32 μA, FWHM=2 ms, f=5 Hz).

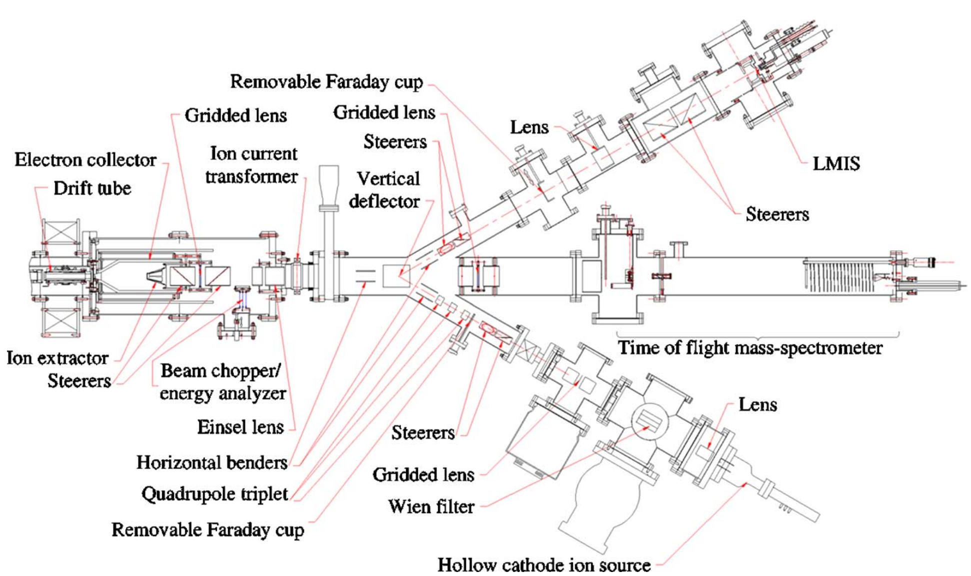

FIG. 4. Test EBIS low-energy beam transport line.

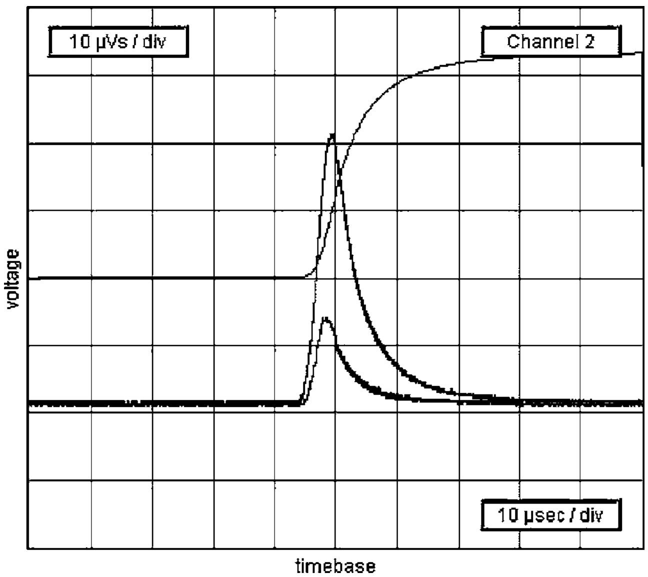

FIG. 5. Extracted ion beam for confinement time τ_{conf}=36 ms and electron current $I_{\_el}$=6.8 A. With ion injection, the total extracted ion charge was $Q_{\_ion}$=32 nC, with ion current I_{ion}=4.0 mA (top and middle traces). Without ion injection the extracted background charge was Q_{bckg}=4.0 nC (bottom trace).

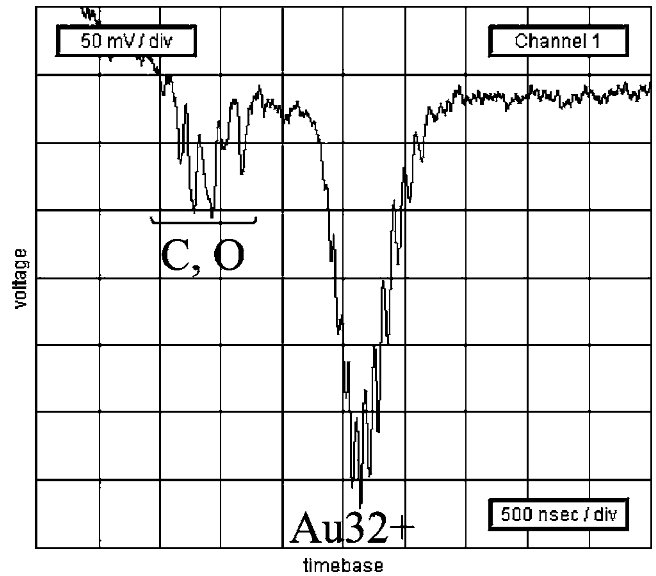

FIG. 6. Charge state spectrum of the ion beam extracted from EBIS with LMIS ion injection. τ_{conf}=36 ms and $I_{\_el}$=6.8 A. The background is C and O ions.

IV. ION INJECTION INTO EBIS

The LMIS was installed on one arm of the Test EBIS *Y*-chamber electrostatic switchyard, which is part of the EBIS low-energy beam transport line. The other arm is occupied by a hollow cathode ion source. This allows ions from either source to be selected for ion injection on a pulse-to-pulse basis. A schematic of the EBIS ion beam line is presented in Fig. 4.

An ion beam from the LMIS with a current of (40–60) μA containing both Au and Si ions was used for injection into EBIS, i.e., no species selection was made in the beamline. The total ion current extracted from the EBIS ion trap was measured using a current transformer located 50 cm from the ion extractor. During experiments with ion injection from the LMIS the electron current in EBIS was I_{el}=6.8 A. The wave form of the total ion current pulse extracted from EBIS with the LMIS ion injection is presented in Fig. 5.

The charge state spectra of the extracted ion beam were measured with a Mamyrin-type time-of-flight mass spectrometer. Fig. 6 presents an example of the ion spectra.

The contamination of the ion beam with the residual gas ions is relatively small. No visible traces of Si ions are present in this spectrum even though the expected abundance of Si ions in the LMIS beam is 14%. The possible reason for this can be loss of Si ions in a process of energy exchange with heavier Au ions during confinement in a trap.

V. SUMMARY

A LMIS with a Au–Si alloy was tested on a bench in a pulsed mode with output ion current up to 50 μA, and the measured normalized RMS emittance was 0.05π mm mrad. The ion source demonstrated very high stability, reproducibility and reliability on a test bench. The LMIS has been used successfully as an injector of Au^+ into the EBIS. The extracted beam of highly charged ions from EBIS had the same excellent stability as the primary ion beam from the LMIS.

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