Characteristics of a heavy ion injector Z/A≥1/3 based on laser-plasma ion source

Cite as: AIP Conference Proceedings **2011**, 040015 (2018); https://doi.org/10.1063/1.5053289
Published Online: 21 September 2018

T. Kulevoy, N. Alekseev, A. Balabaev, S. Barabin, A. Kantsyrev, I. Khrisanov, A. Losev, Yu. Orlov, I. Rudskoy, Yu. Satov, A. Shumshurov, and A. Vasilyev

Characteristics of a Heavy Ion Injector Z/A≥1/3 Based on Laser-Plasma Ion Source

T. Kulevoy[1,a], N. Alekseev[1], A. Balabaev[1], S. Barabin[1], A. Kantsyrev[1], I. Khrisanov[1], A. Losev[1], Yu. Orlov[1], I. Rudskoy[1], Yu. Satov[1,2, b], A. Shumshurov[1,c], A. Vasilyev[1]

[1]*Alikhanov Institute of Theoretical and Experimental Physics, National Research Center Kurchatov Institute, Moscow, 117218 Russia.*
[2]*National Research Center Kurchatov Institute, Moscow, 123098 Russia..*

[a)]Corresponding author: Kulevoy@itep.ru
[b)] satov@itep.ru
[c)] Alexander.Shumshurov@itep.ru

Abstract. Design of the high-current ion injector for ions with z/A≥1/3 is described. The system consists of a laser-plasma generator based on a repetition rate CO_2 laser, a vacuum target chamber with optical focusing lens, a beam extraction and transport system, and RFQ accelerator with z/A≥1/3. The goal of the work is to optimize parameters of all of the above components for maximum ion beam current at the output. Carbon ion energy spectra of CO_2 laser produced plasma at radiation power density of $8{\bullet}10^{11}$ W/cm^2 were studied. Conditions for generating C^{4+}÷C^{6+} ions in the vacuum chamber in use were found. The C^{4+} ion beam produced by the source was matched into the RFQ and measurements of its emittance and current are being performed.

SCHEMATIC DIAGRAM OF THE HIGH CURRENT ION INJECTOR

Schematic diagram of the high current heavy ion I-4 (ITEP) is shown on Fig. 1. It consists of two-modules CO_2 pulsed laser generator *1* which radiation is transported by copper mirrors *2* to the entrance tube of the vacuum chamber *3* that has the internal diameter of 350 mm. Then the laser beam is focused to the cylinder target *4* with the spherical lens. The target with the diameter of 130 mm rotates around the geometrical axis and shifts up and down during operation to avoid a crater formation in the target material. The laser beam falls on the target angularly (30º) but the surface normal coincides with the time of flight tube axis and laser plasma expansion direction. The extraction system consists of three electrodes: positive *5*, negative *6* and grounded (interelectrodes distances are 40 and 20 mm, accordingly). Positive extraction electrode is situated at the distance 1680 mm from the target. Its passage opening of 40 mm is closed by the grid. Gridded lens *7* is used to match the ion beam with the RFQ section *8* entrance. The RFQ section main characteristics are frequency–81.36 MHz, z/A≥1/3, injection energy–0.02 MeV/u, output energy–1.6 MeV/u, maximum ion current–100 mA, input emittance – 270 π mm mrad,output emittance - 23 π mm mrad [1]. The system operates in repetition rate mode up to 0.2 Hz.

CHARACTERISTICS OF LASER AND ION BEAMS

CO_2 laser oscillator [2] operates at a high level of the specific energy deposition into a self-sustained discharge . It provides laser beam with high quality of spatial and temporal characteristics:

- pulse energy – 7 J,
- peak power – 105 MW,
- FWHM duration – 30 ns, beam spatial profile – close to Gaussian

Proceedings of the 17th International Conference on Ion Sources
AIP Conf. Proc. 2011, 040015-1–040015-3; https://doi.org/10.1063/1.5053289
Published by AIP Publishing. 978-0-7354-1727-4/$30.00

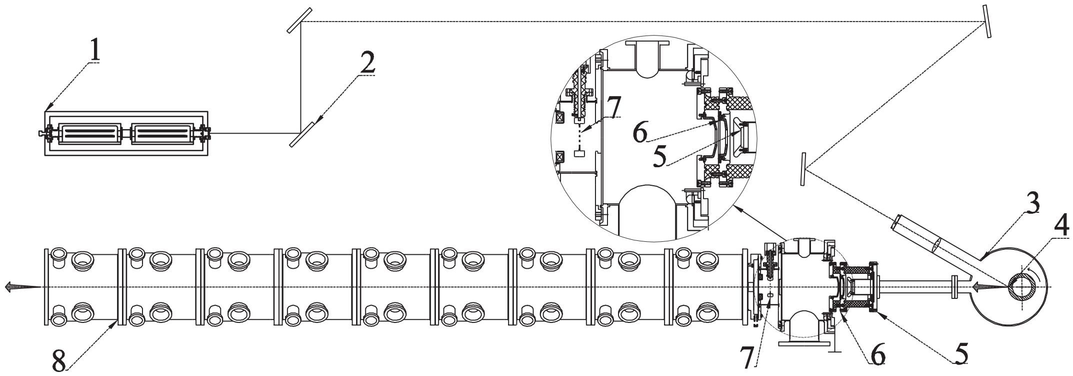
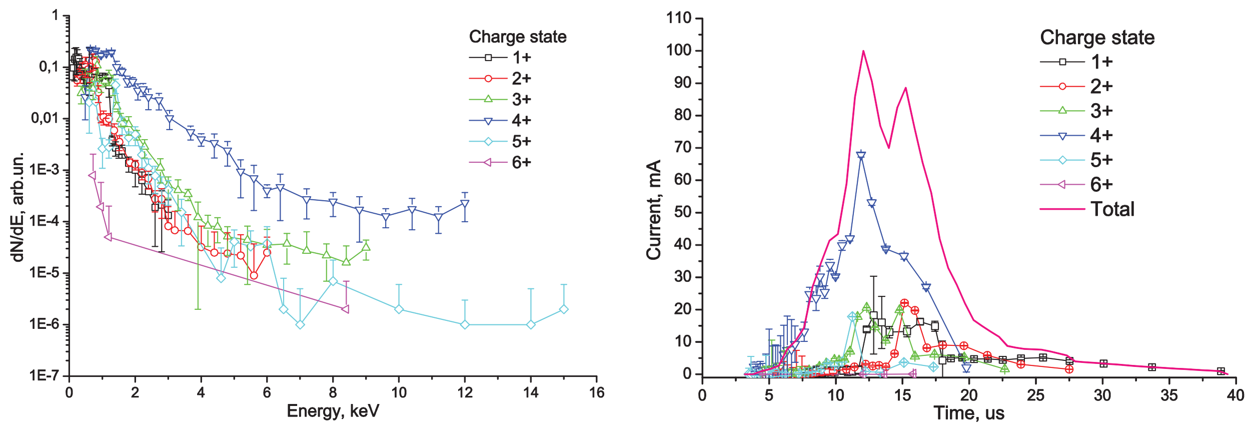


Figure 1. Schematic diagram of ion infector I-4.

These parameters have good reproducibility in long term operation.

Flat mirrors allow transporting the laser beam up to the input window of the vacuum chamber. Then laser radiation is focused on the target surface by spherical lenses with different focal length to vary power density in the range of $8\cdot10^{10}\div8\cdot10^{11}$ W/cm^2. A typical shape of the spatial distribution of the energy density in the focal spot is close to Gaussian with the characteristics widths of 200 μm.

The time-of-flight technique is used in investigations of a laser-plasma ion component. Registration of the parameters of a plasma stream using an electrostatic analyzer allows reconstructing the charge composition, the energy spectrum of ions, and their partial currents. The energy resolution $\Delta E/E$ of the instrument achieved is estimated as $\Delta E/E \approx 8 \times 10^{-4}$ [3]. The results are shown on Fig. 2 a, b.



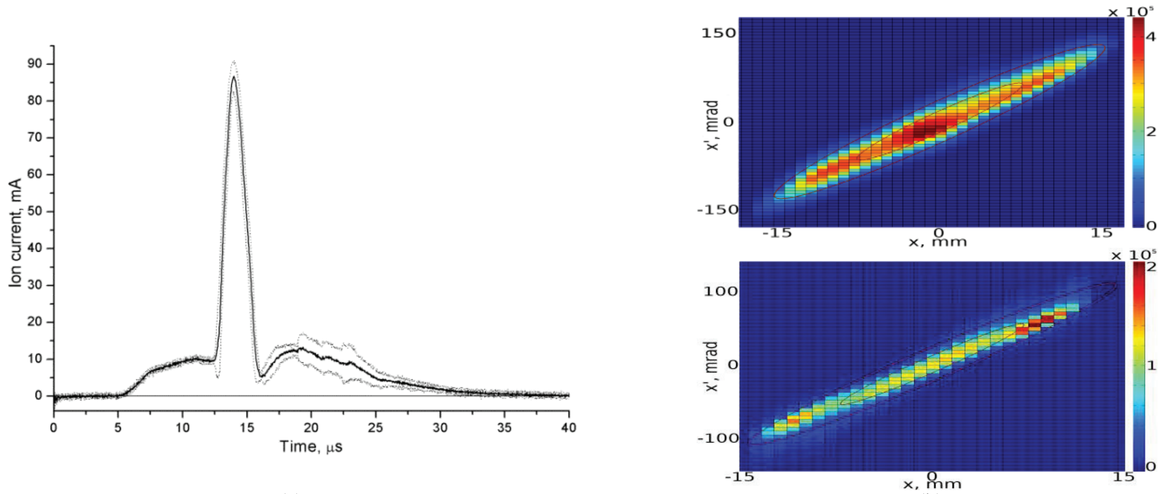
(a) (b)

FIGURE 2. Energy spectra (a) and partial currents (b) of carbon for drift length 1680 mm normalized to 100 mA of total current

Beam extraction system consists of three electrodes. The positive electrode has a grid (transparency: 90%, cell dimensions: 0.5x0.5 mm) and a diaphragm installed. To match C^{4+} ion beam energy into the RFQ the positive electrode has to be at +60 kV potential relative to ground. Extraction voltage is increased by the negative electrode. Ion beam current was measured by a Faraday cup placed behind the ground electrode of the extraction. Potential bias value of +1.5 kV was applied to the cup to suppress secondary electron emission influence.

Fig. 3 (a) shows the averaged ion current signal (a) and its deviation (b). Extraction voltage was 70 kV (+60 kV and -10 kV), aperture of the positive electrode was 15 mm. Zero time is the front of the laser pulse. For 10 mm aperture peak ion current was 30 mA.

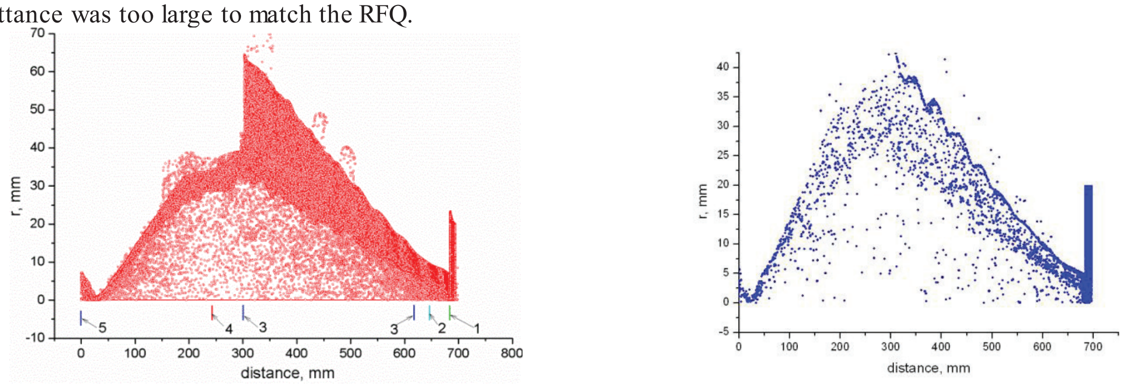
Measurements of phase parameters of extracted carbon ion beam were carried out. The "pepper-pot" technique with CCD-camera was used [4]. Measured 4 rms emittance values of 88 mA total ion current are 520 π mm mrad along y-axis and 560 π mm mrad along x-axis, for 30 mA total ion current – 346 π mm mrad and 341 π mm mrad correspondingly.



(a) (b)

FIGURE 3. Total (a) ion current with the related SD. X-axis emittance diagram of ion beam (b). 88 mA–upper, 30 mA–lower.

The code described in [5] was applied for simulation of low energy ion beam transporting through the gridded lens to the input of the RFQ. Calculations were based on experimental data and performed for 88 mA (Fig. 4(a)), 30 mA (Fig. 4(a)) beams, and hollow beam extracted from equal area. Transmission values are 15%, 97% and 80% respectively. Calculated emittance at the RFQ entrance for 30 mA beam is 420 π mm mrad. However hollow beam emittance was too large to match the RFQ.



(a) (b)

FIGURE 4. Numerical simulation of solid (a) and hollow (b) carbon ion beam transporting. 1 – positive electrode, 2 – negative electrode, 3 – ground electrode and flange, 4 – gridded lens, 5 – RFQ input.

Simulations using DYNAMION code package [6] were performed to calculate transmission through the RFQ. For beam with measured x-emittance of 341 π mm mrad and y-emittance 346 π mm mrad and beam current of 30 mA the simulated transmission is 96%.

REFERENCES

1. V. Andreev et al, "Progress work on high-current heavy ion linac for ITEP TWAC facility" in Proceedings of IPAC'10, edited by A. Noda et al. (IPAC'10 OC/ACFA, 2010)
2. Yu. A. Satov et al, Instrum. Exp. Tech. **59**, 3, 412-419 (2016)
3. Yu. A. Satov et al, Instrum. Exp. Tech. **60**, 4, 556-561 (2017)
4. D. Liakin et al, Rev. Sci. Instr. **81**, 02B719 (2010)
5. I. Roudskoy et al, Rev. Sci. Instr. **79**, 02B313 (2008)
6. A. Kolomiets et al, "DYNAMION – the code for beam dynamics simulations in high current ion linac" in EPAC'98 proceedings, edited by S. Myers et al. (Institute of Physics Publishing, Bristol, 1998) p.755-757