LASER SOURCE OF HIGHLY CHARGED IONS FOR ITEP TERAWATT ACCUMULATOR FACILITY

S. Kondrashev, A. Balabaev, V. Balanutsa, D. Ermakov, N. Mescheryakov, V. Nikolaev, B. Sharkov, A. Shumshurov, R. Sydykov, ITEP, Moscow, Russia

Abstract

Nowadays, Laser Ion Source (LIS) is the most intense source of highly charged ions for pulse length about 5-10 μs [1]. Therefore it is so attractive to fill the synchrotron rings in a single turn injection mode. By these reasons LIS is using for ITEP TeraWatt Accumulator (TWAC) facility aiming at the production of TeraWatt power level (100 kJ/100 ns) of intense ion beams [2]. The absolute number of carbon and aluminum ions with different charge states generated by 5 J/0,5 Hz rep-rate CO_2-laser has been measured. Low Energy Beam Transport Line (LEBT) consisting of Einzellenses and a buncher have been used to match the source to 2 MV/2,5 MHz injector I-3. The first results of the transmission of C^{+4} ion beam through the LEBT and the results of acceleration in I-3 are presented. The next steps of LIS upgrading for TWAC facility are under discussion.

1 INTRODUCTION

Modification and upgrade of the existing heavy ion accelerator chain aiming at the production of TeraWatt power level (100 kJ/ 100 ns) of intense ion beams, is in a progress at ITEP now (ITEP-TWAC project).

The main idea of the project is the accumulation of the nuclei of the element as heavy as possible using non-Liouvilleian injection into the accumulator ring. Foil stripper will be used to strip highly charged ions to nuclei. Ions with very high charge states (close to He-like ions) have to be used to minimise losses of ions during non-Liouvilleian injection into the accumulator ring. As the accumulation time is restricted, the current of ions with desirable charge state at the exit of the source should be as high as 10 mA and more.

At the present status of ion sources only Laser Ion Source (LIS) can meet this requirement to intensity for so high charge states. By this reason it was decided to use LIS for ITEP-TWAC project.

According to ITEP-TWAC acceleration-accumulation scenario the required parameters of LIS are the following:

- Element – as heavy as possible,
- Ion charge state – close to He-like ions,
- Ion pulse length (for 95% of ions with desirable charge state) - 10-15 μs,
- The number of ions with desirable charge state – about $5 \cdot 10^{10}$ ions/pulse,
- The emittance of extracted beam – below 500 π mm-mrad,
- Repetition rate – ~ 1 Hz,
- The number of source operation cycles between interventions – about 10^5.

LIS is planned to use for the ITEP accelerator - accumulator complex in two stages. At the first stage the existing 5 J/ 0,5 Hz rep-rate CO_2-laser will be used to put in operation all accelerators and to prove the project principals. At the second stage, 100 J/ 1 Hz rep-rate CO_2-laser will be constructed and employed as a driver for LIS.

2 GENERATION OF IONS OF DIFFERENT ELEMENTS BY 5 J AND 75 J CO_2-LASERS

Nowadays, CO_2-laser seems to be the best one for LIS as it is possible to build 1 Hz rep-rate CO_2-laser with output energy of about 100 J required for generation of significant amount of, for example, Ti^{16+} and the number of shorts without interventions more than 10^6.

The generation of highly charged ions of different elements were investigated by using CO_2-lasers with output energies of 5 J and 75 J to specify LIS parameters for the ITEP-TWAC project. The absolute numbers of carbon and aluminum ions for different charge states generated by 5 J CO_2-laser are presented in Table 1 [1]. From Table 1 one can see that beams of highly charged ions such as C^{+4} and Al^{+7-+9} with the total number of particles of a certain charge state more than 10^{10} ions/pulse were obtained by using 5 J CO_2-laser.

The results of ion generation by 75 J CO_2-laser can be found in [1] where it was shown the possibility to extract from LIS ion beams of F^{+7-+9}, Mg^{+8-+10}, Al^{+9-+11}, $Ca^{+12-+15}$ and $Ti^{+14-+16}$ with the total number of particles of a certain charge state 10^{10}-10^{11} ions/pulse by using 75 J CO_2-laser.

Table 1. Numbers of carbon (N_c) and aluminum (N_{al}) ions with different charge states (z) (CO_2-laser output energy – 3,6 J, first peak laser pulse duration – 70 ns, estimated focal spot diameter and maximum power density of laser radiation on the target surface are about of 40 μm and about of $2\cdot10^{11}$ W/cm^2 respectivly, the distance from the target to the extraction system – 125 cm, extraction aperture – 3 cm)

Z	1	2	3	4	5	6	7	8	9	10	11
N_C, 10^{10}	15	10	12	18	0.76	-					
N_{Al}, 10^{10}	4.3	3.2	5.3	2.9	2.2	2.0	1.6	1.7	1.0	0.6	0.01

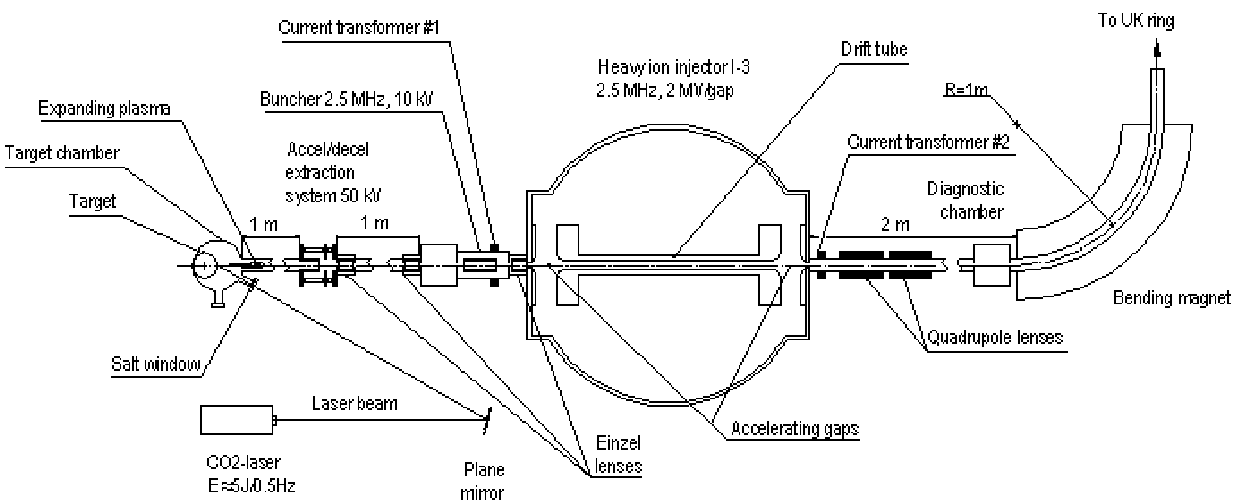

Figure 1: Lay-out of Laser Ion Source in line with heavy ion injector I-3.

3 LASER SOURCE OF C^{+4} IONS IN LINE WITH HEAVY ION INJECTOR

Low Energy Beam Transport Line (LEBT) consisting of three Einzellenses and 2,5 MHz, 10 kV buncher have been used to match Laser Source of C^{+4} ions to heavy ion injector I-3 (2.5 MHz, 2 MV/gap) (Fig. 1). C^{+4} ion beam was chosen at the first step as the most intense and stable one generated by LIS with 5 J CO_2-laser. Three aperture accel/decel system is used to extract ion beam under the potential of 50 kV. Grids with transparency about 95% are installed inside the middle electrode for all Einzellenses to reduce the aberrations. The buncher consists of two grounded apertures and middle tube under the potential with the same frequency as for injector I-3. The total length of LEBT is equal to 225 cm. It is clear that so long LEBT is not optimal to match intense ion source with total current about 50-100 mA to the first accelerator. However, as far as the main purpose at this stage is the test of accelerator-accumulator complex in new configuration, it was decided to use already existed LEBT.

The detailed description of three electrodes heavy ion injector I-3 (2,5 MHz, 2 MV/gap) can be found in [3, 4]. Four current transformers were installed along the channel from the source up to booster synchrotron ring: transformers # 1 and # 2 – at the entrance and at the exit of injector I-3, transformer # 3 – behind bending magnet (Fig.1) and transformer # 4 at the entrance of booster synchrotron ring.

LIS was operated with 0,25 Hz repetition rate. The results of averaging over 50 shots of currents measured by these transformers are presented in Figs. 2 (a, b, c, d) (solid lines). The dashed lines in these figures show standard deviations from average values in time.

The following average values of ion currents were found: the total current of the different charge states of carbon ions are equal to 17 mA and 5 mA at the entrance and at the exit of injector I-3. Current of C^{+4} ions behind bending magnet is equal to 1.2 mA and current of C^{+4} ions at the entrance of booster synchrotron ring is equal to 0,6 mA. The currents measured by transformers should be considered with usual care as far as secondary electrons from walls of vacuum chamber can influence on the result of measurements. Shot to shot stability of ion currents along the whole channel is in the range ± 7%. Ion pulse length defined at the level 0.1 from the amplitude along the channel is in the range of 20-25 μs.

The number of accelerated C^{+4} ions is equal to $3\bullet10^{10}$ behind bending magnet and $1.4\bullet10^{10}$ at the entrance of booster synchrotron ring.

LIS was operated during two months with repetition rate of 0,25 Hz. After this period the focussing mirror

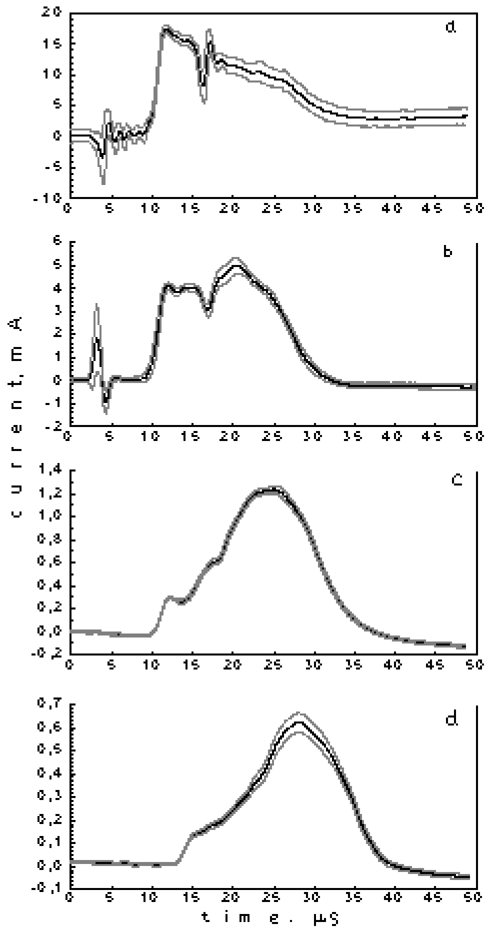

Figure 2: (a, b, c, d) Average currents (solid lines) and standart deviations (dashed lines) measured by current transformers along the channel from LIS to synchrotron.

with focal length of 130 mm should be replaced because of carbon film formation on mirror surface with resulting degradation of its optical quality.

4 FUTURE STEPS OF LIS UPGRADING AND DEVELOPMENT

At the first stage existing 5 J CO_2-laser will be used as a driver for LIS. The following technical improvements will be done to stabilise its operation:

1) additional support for laser resonator separated from discharge chamber, will be installed,
2) gas mixture regenerator will be inserted in circulation circuit.

New LEBT with much shorter length similar to one designed and tested for CERN LIS [5] is planning to be installed.

At the second stage 100 J/1 Hz rep-rate CO_2-laser similar to one which is presently under design and manufacturing for CERN LIS [5] will be constructed and used with new target illumination chamber. Two gaps injector I-3 is planning to be replaced by especially designed high current and high acceptance RFQ. Different elements up to Ti will be used for highly charged ion beam generation with 100 J CO_2-laser.

5 CONCLUSIONS.

Laser Source of C^{+4} ions driven by 5 J CO_2-laser was operated during two months with repetition rate of 0,25 Hz. After this period only the replacement of focussing mirror was required. Low Energy Beam Transport line consisting of three Einzellenses and 2,5 MHz, 10 kV buncher have been used to match LIS to heavy ion injector I-3 (2,5 MHz, 2 MV/gap). 1.2 mA of C^{+4} ion beam accelerated by injector I-3 was measured by current transformer behind bending magnet. Ion pulse length is in the range of 20-25 µs. The number of accelerated C^{+4} ions is equal to $3 \bullet 10^{10}$ behind bending magnet placed at the exit of injector I-3. Shot to shot stability of ion current along the whole channel is in the range of $\pm$7%.

100 J/1 Hz rep-rate CO_2-laser and new high current and high acceptance RFQ are planning to be used for ITEP-TWAC project at the second stage.

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