LASER ION SOURCE FOR HIGH CURRENT INJECTION INTO SYNHROTRONS

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1 INTRODUCTION

Laser ion source (LIS) is suitable to fill synchrotron rings with highly-charged ions in a single turn injection mode. Intense ion beams (I ~ 5 - 10 mA) of highly-charged ions (Z = 5 - 30) of practically any elements can be obtained from LIS with ion pulse length of about 5 - 10 μs [1, 2].

Modification and up-grade of the existing heavy ion accelerator chain, aiming at the production of Terra Watt power lever (100 kJ/100 ns) of intense heavy ion beams, is in progress at ITEP now (ITEP-TWAC project) [3]. Such beams will be used for research into the physics of high energy density in matter, relativistic nuclear physics and for hadron tumour therapy. As a matter of fact LIS with a very high pulse current (in comparison with other highly-charged ion sources: ECR, EBIS) and ion pulse length close to TWAC booster synchrotron UK filling time in single turn injection mode is the best candidate to be used in this scheme. The important requirement to the ion source is the generation of the ion beam with very high charge states (closed to He-like ions) to minimize losses of ions during non-Liouvillean injection into the accumulator ring. Since the total energy of stored beam is proportional to ion mass it is reasonable to use as heavy ions as possible.

Recently the possibility to build a 1 Hz rep-rate CO_2-laser with output energy of about 100 J and the number of shots without interventions about $2{\cdot}10^6$ has been demonstrated. Such CO_2-laser seems to be close to the present technical limit. It is designed and has been constructed for CERN LIS in 1999-2001 in Russia. The simulations show that highly charged ions (C-like – He like) of Ti can be obtained in laser-produced plasma by using of 100 J CO_2-laser.

2 DEVELOPMENT AND OPERATION OF LASER SOURCE OF HIGHLY CHARGED IONS FOR ITEP TERRA WATT ACCUMULATOR FACILITY

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

- Element - as heavy as possible,
- Ion charge state - in the range C-like - 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 more than 10^6.

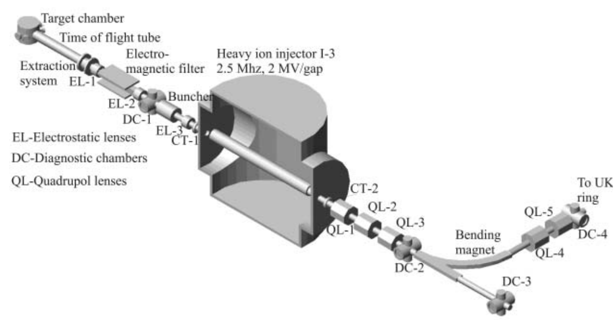

Figure 1. Experimental setup.

Transport line (see figure 1) consisting of three Einzel lenses and buncher (2.5 MHz/10 kV) was used to match LIS to heavy ion injector I–3. LIS was routinely operated with rep-rate of 0.25 Hz to inject C^{+4} ion beam to ITEP–TWAC ion accumulator facility during more than one year. Three months of intervention free period of LIS operation was achieved by using of Palladium catalyst for CO_2–laser gas mixture regeneration.

LIS is planning to be used 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 is used to generate the intense beam of C^{+4} ions to prove the project principals. The total ion current of carbon beam from LIS and emittance are sown on figure 2-3.accumulator complex in two stages. At the first stage the existing 5 J/0,5 Hz rep–rate CO_2–laser is used to generate the intense beam of C^{+4} ions to prove the project principals. The total ion current of carbon beam from LIS and emittance are sown on figure 2-3.

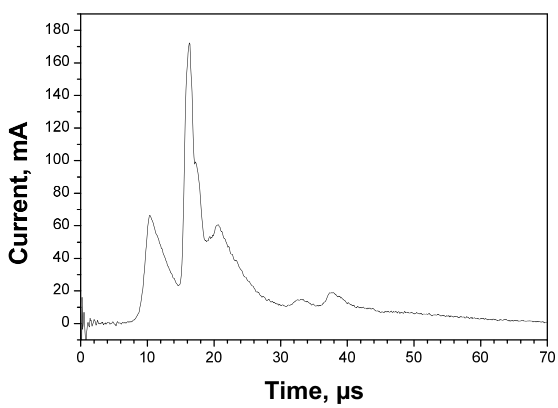

Figure 2. Total carbon ion beam current.

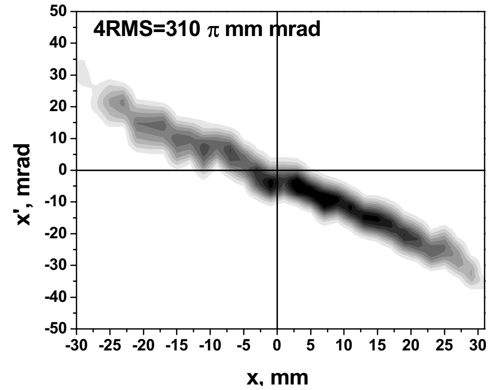

Figure 3. Total carbon ion beam emittance.

The ion current for C^{+4} behind the bending magnet has maximum value of 3 mA. At the second stage, 100 J/1 Hz rep–rate CO_2–laser will be built and used as a driver for LIS, generating intense beams of highly charged ions (Z/A~0.33÷0.45) with atomic masses of up to 60. With this respect the generation of highly-charged ions of F^{+7-+9}, $Mg^{+8...+10}$, $Al^{+9...+11}$, $Ca^{+12...+15}$, $Ti^{+14...+16}$ with total number of particles of certain charge state 10^{10}-10^{11} ions/pulse has been tested by using CO_2 - laser with output energy 75 J [4]. Ion pulse durations of different charge states containing 95% of each charge state are in the range of 5-7,5 µs for highly-charged ions of Ti at the distance 308 cm, from the target (see Table 1). On the base of the results obtained it is possible to choose optimal species and charge state of highly charged ions to be used to get maximum power of accumulated beam in frame of ITEP Terra Watt Accumulator (TWAC) project.

Table 1. Main ion beam parameters for different materials.

Z	F (CaF_2-target)		Mg		Al		Ca (CaF_2-targ.)		Ti	
	N, 10^{10}	Δt,µs	N, 10^{10}	Δt,µs	N, 10^{10}	Δt,µs	N, 10^{10}	Δt, µs	N, 10^{10}	Δt, µs
4	0.1	5	0.2	3.6	-	-	-	-	-	-
5	0.3	5	0.4	4	-	-	-	-	0.15	23
6	1.1	4.5	1.4	4.8	-	-	-	-	0.25	12
7	3.7	4	3.5	6.7	0.15	6.5	-	-	0.3	19
8	-	-	7.0	6.6	0.8	8.5	0.05	4	0.75	16
9	-	-	14.	6.2	2.6	8	0.15	6	0.6	18
10	-	-	18	5.7	6.3	7.5	0.6	5.5	1.0	17
11	-	-	0.6	4.5	12	7	1.0	5	1.8	16
12	-	-	-	-	0.1	5	2.0	4.5	3.8	15
13	-	-	-	-	-	-	3.4	4	4.7	12
14	-	-	-	-	-	-	3.0	4	5.5	7.5
15	-	-	-	-	-	-	1.4	3.5	4.0	5.5
16	-	-	-	-	-	-	0.3	3	1.3	5
17	-	-	-	-	-	-	0.2	3	0.2	5.5

3 LONG PULSE GENERATION OF INTENCE BEAMS OF Pb^{+4}÷Pb^{+10} IONS IN LASER ION SOURCE

The goal of this work is the investigation of a possibility to generate the intense long-pulse beam of Pb^{+4}÷Pb^{+10} ions in LIS [5]. The experiments were carried out to optimize the yield of Pb^{+4} ions from plasma produced by 100 J CO_2-laser. Laser power density on

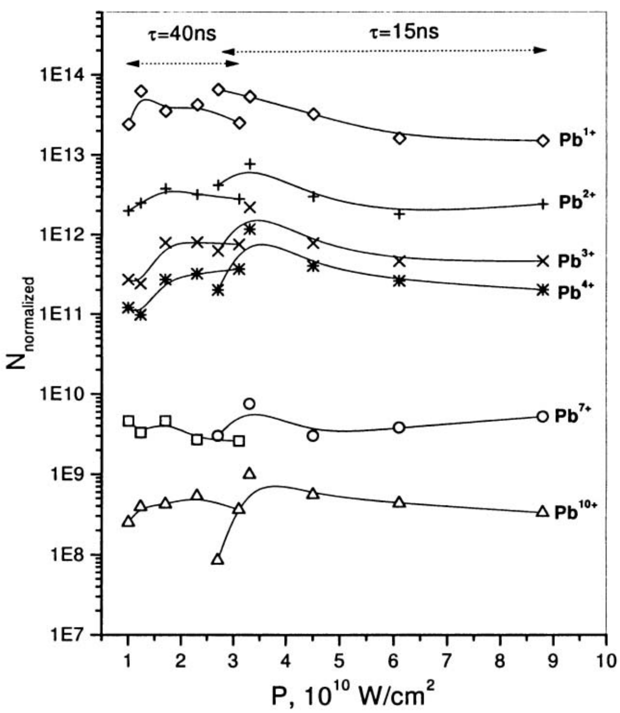

Figure 4. Total number of ions for different charge states of Pb.

the target surface was varied in the range (1 ÷ 9)×10^{10} W/cm^2 by changing of the focal spot size. Data on generation of Pb^{+1} ÷ Pb^{+10} ions are present for 15 ns and 40 ns laser pulse durations on figure 4. The 10 mA/80 μs pulses of Pb^{+4} ions (about 10^{12} ions per pulse) were obtained into extraction aperture of 3.4 cm in diameter for optimal irradiation conditions. This is comparable with parameters of MEVVA ion source. Laser Ion Source (LIS) can be especially attractive due to the absence of typical for MEVVA ion source "noise" problem and possibility of generation of higher charge states.

The emittance of lead ion beam extracted from laser-produced plasma was measured by using 5J laser providing plasma parameters (electron temperature, ion velocities and charge states distribution) close to that of plasma generated by 100 J CO_2-laser in optimized conditions for the yield of Pb^{+4} ions. The emittance was measured for 30 kV and 50 kV extraction voltages with 10 μs temporal resolution. The value of about 400 π mm•mrad was found for lead ion beam with total current of 10 mA and pulse length of 75 μs for about 75% of ions in the beam. The yield of Pb^{7+}÷Pb^{10+} ions is about one order less than the yield of Pb^{4+} ions and it is in the range 10^{10}÷10^{11} ions per pulse into the aperture of 3.4 cm in diameter at the distance 3 m from the target.

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