DEVELOPMENT OF INJECTOR FOR ITEP HEAVY ION SINCHROTRON BASED ON LASER PLASMA GENERATOR

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Abstract

A schematic diagram of heavy ion injector based on laser ion sources is described. Two different basic laser configurations used in ITEP synchrotron. First laser excels in simplicity and consists of CO_2 free-running laser that is applied for carbon target plasma heating and ionization at laser power density $q=3\cdot10^{12}$W/cm^2 to create high current C^{4+} ion beam. Second master oscillator-amplifier laser configuration intends for production super high laser intensity at a target to provide considerable charge state in a plasma of heavy elements (Al, Fe, Ag etc). This laser configuration is founded on original physical principle* that simplifies the installation and ensures high reliability for long term operation.

Laser characteristics for the different laser scheme and ion current for injector outlet beam of C^{4+} and Ag^{+19} are shown in this paper. The latter was accelerated in synchrotron for energy up to 100 MeV/u.

* K. N. Makarov et al. Quantum Electronics (Russian), 2001, 31 (1), pp. 23÷29

INTRODUCTION

The fundamental knowledge of the high charge state ion generation with lasers was obtained in the frame of laser-plasma interaction researches. In Russia such investigations were carried out in leading physical institutes with different types of laser. In particular, it was shown that high intensity laser radiation focused on the material allows creation of high temperature powerful stream of plasma having small phase volume. The following separation of electron and ion components produces a pulsed ion source with superior luminosity. Basing on known in literature laser-plasma investigation publications one might say that there are no crucial distinctions for laser-plasma ion generators using different types (different wavelength) of lasers. Nevertheless, CO_2 lasers are mainly used in the practice due to their high output energy with comparative technical simplicity for the repetition rate operation, cheapness of the installation and ecological compatibility. These preferences of CO_2 lasers ensure adapting them in a laser-plasma ion source for an ion accelerator injector. The use of such injectors in a heavy ion synchrotron simplifies the accelerator scheme due to momentary (by a single pulse) ring filling by the particles of proper mass and charge state number.

The investigations of the ion generation from plasma produced by CO_2 laser pulses with a target power density q up to $q\leq5\cdot10^{13}$ W/cm^2 and the laser-plasma generators (LPG) development were realized by ITEP-CERN-TRINITI collaboration [1-9]. In the frame of lead ion generation measurements it was shown that, in particular:

1. The total ion current is proportional to the laser pulse energy while the other parameters remain unchanged.
2. The average ion charge state number is proportional to logarithm of the laser flux at a the target, at least, for the case of ionization of external atomic shells.
3. For an effective laser-plasma heating it is necessary to use the laser pulse duration τ_p less than the characteristic plasma expansion time τ_{exp} ($\tau_p < \tau_{exp}$). The latter is defined by the ion velocity and the characteristic plasma thickness which depend finally on the target laser pulse density. Otherwise, the process of laser-plasma interaction for long high power density pulses is complicated due to the refraction of the laser beam in the plasma corona, self-focusing of laser radiation and generation of shock waves distorting the expanding plasma flow. As a result, the laser heating efficiency drops and useful part of ions near expansion axis is decreased.

The experimental data allow choosing the laser driver scheme with such general considerations. It is known, for example, that the free-running CO_2 generator provides the laser pulses with duration $\tau_p \leq$ 40ns. That allows to use efficiently such a laser for ion generation up to $q\leq10^{11}\div10^{12}$W/cm^2 and, correspondingly, for the plasma expansion velocity $V_{exp}<10^6$cm/s. In these conditions the plasma extension is not to be significant during the laser heating $V_{exp}\cdot\tau_p <$ 0.4mm. The ion generation for a higher laser flux requires using more complicate optical laser scheme such as master-oscillator power amplifier (MOPA) configuration. The shortest pulse duration is to be $\tau_p \approx$150 ps correspondingly the amplification line width of 7GHz for the typical gas mixture of an atmospheric pressure CO_2 laser [10]. The ITEP heavy ion accelerator injector is based on both the free-running and the MOPA CO_2 lasers (LPG-1,2) to carry out scientific program devoted to fundamental researches and medical applications. Now the heavy ion acceleration program is basically founded on two laser systems: effective free-running generator “Malish” and wide aperture laser L-100 that operates in two modes, either a free-running generator [11] or a master oscillator-power amplifier configuration. The laser-plasma ion source with the MOPA scheme is directed to generate extremely ionized heavy particles, similar to Al, Fe, Ag, Pb, etc. The free-running CO_2 laser is used in the injector of carbon ions.

DEVELOPMENTS OF LPG-1 AND LPG-2

Laser plasma generator LPG-1 including the free-running laser “Malish” was developed to increase output laser intensity as a main parameter. The improvement consists of modernization of an electrical scheme for formation of volume discharge basing on the techniques described in [12]. The concept is to try to separate the stages of the discharge volume ionization and the energy input to the discharge similar to the non-self-maintained discharge techniques. To do this a specially profiled voltage pulse is generated to apply on the discharge electrodes simultaneously with UV-preionization of gas volume. This is provided by introduction of additional `shock' LC-circuit to the HV pulse generator. Finally, it results in a growth of the energy input to the uniform discharge and to raise the molecular gas content in the active mixture of the laser. As a result, it was obtained superior laser specific output laser power of 105 MW/l that corresponds to peak laser pulse of about 60 MW [13] as shown in Fig.1.

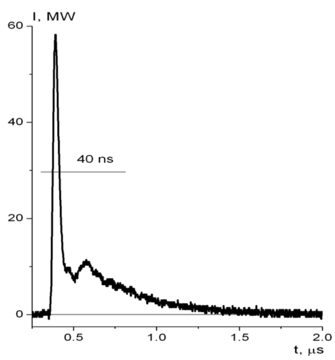

Figure 1: Oscilloscope trace of pulse intensity for laser driver in LPG-1.

A numerical calculations shows that laser target power density reach for focal spot center value of $5 \cdot 10^{11}$ W/cm^2. This laser beam intensity level allows reliable creation of C^{4+} particles in plasma and production about 100mA of total ion current after extraction system.
MOPA laser driver produces now laser pulse with duration of ~30ns (see Fig.3) that corresponds to peak power density q=10^{13}W/cm^2 in the focal spot.

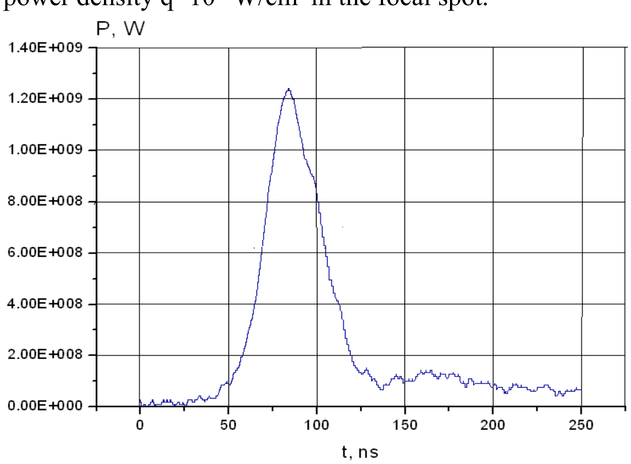

Figure 2: Oscilloscope trace of pulse intensity for laser driver in LPG-2.

In the frame of heavy ion injector development it is intended to improve the laser driver for LPG-2 to reach for higher laser target flux. The main modification of the MOPA scheme is including of two-module preamplifier that allows proper formation of the laser special form and the temporal shape of the MO beam at the power amplifier entrance. At present, the preamplifier with active volume of 3 liters has been manufactured and is under testing (see Fig.3). Second modification of the ion injector concerning both LPG-1 and LPG-2 generators is a perfection of focusing mirror. The idea is to install off-axis parabolic mirror instead of present spherical one.
As a result of modifications, the laser target power density might reach for value of $5 \cdot 10^{14}$ W/cm^2 in accordance with estimations that could ensure more wide investigations of heavy ion production, acceleration and application.

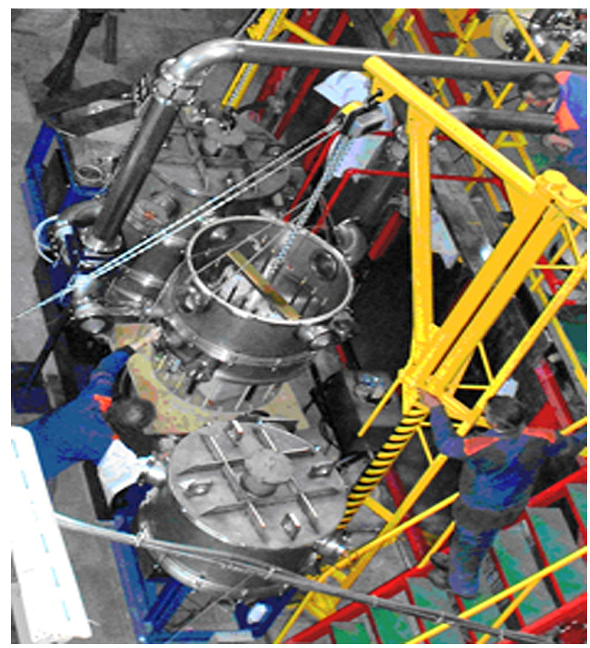

Figure 3: The view of two-module preamplifier.

SCHEMATIC DIAGRAM OF ITEP HEAVY ION INJECTOR

The synchrotron injector scheme based on the laser-plasma ion generator is shown in Fig.4. The laser beams created by different systems are converted in the optical scheme to adjust with a common focusing objective with aperture F/10 (diameter of the laser beam is 160mm). The plasma jet expanded after the target heating comes up to the HV extraction system where separation of charged particles occurs and the ion beam is created. The ion beam comes into a buncher operated at frequency of 2.5~MHz after low energy transport line consisted of three electrostatic lenses and then goes to the resonance two-gap (2MeV per gap) accelerator I-3.

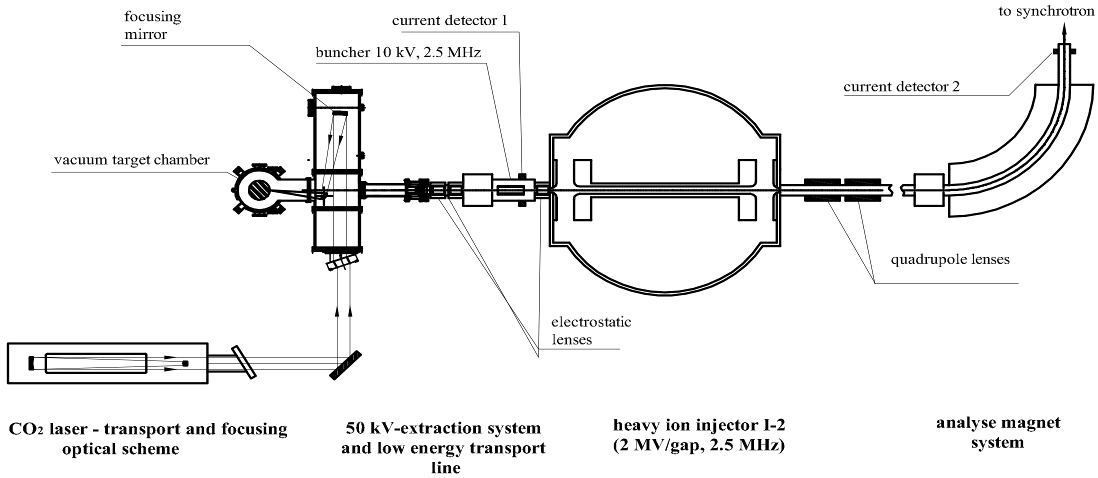

Figure 4: ITEP heavy ion injector scheme based on laser-plasma generator.

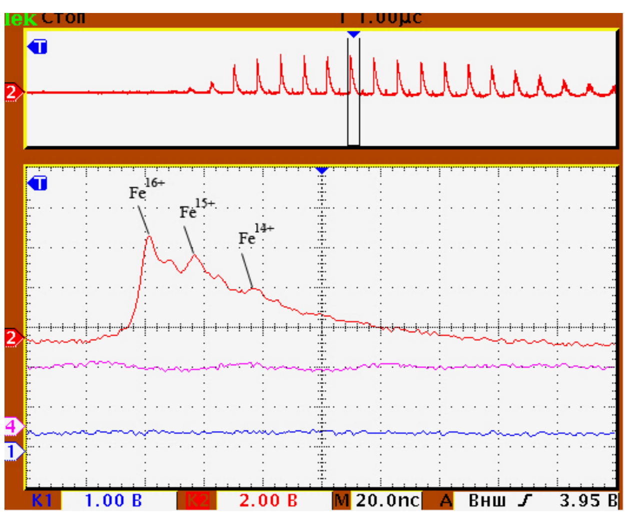

Figure 5: Bunched structure of iron ion beam at the outlet of I-3 (upper trace) and charge state content (lower trace).

The oscilloscope trace of bunched iron ion beam at the outlet of I-3 and charge state structure is shown in Fig. 5. The magnet analyzer is situated at the injector output so, finally, the ion beam is separated for one charge state number as shown, for example, in Fig. 6 for the beam of C^{4+}.

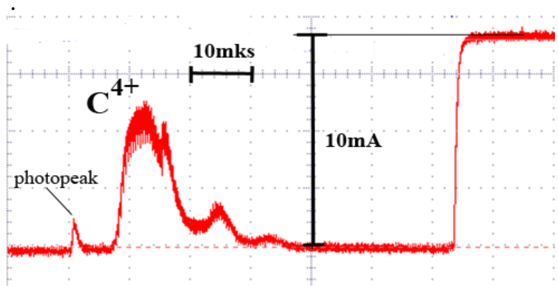

Figure 6: C^{4+} ion current signal at outlet of injector.

ITEP acceleration complex operated this year 630 hours in accumulation mode of carbon nuclei for energy of 200-300 MeV/u, 480 hours in acceleration mode up to energy of 4GeV/u, 60 hours for acceleration of silver nuclei with energy 100 MeV/u and 228 hours for iron nuclei acceleration for energy up to 230 MeV/u. During these periods experiments devoted to high energy density physics, radiation biology, fundamental nuclear physics and their applications were carried out.

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