CHARACTERISTICS OF LASER-PLASMA ION SOURCE BASED ON A CO2-LASER FOR HEAVY ION ACCELERATORS AT ITEP

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Abstract

The design of laser-plasma heavy ion source is described. This ions source is supposed to operate at I-3 and I-4 accelerators at ITEP. Characteristics of ion component of plasma produced by pulses of the CO2 laser were studied, when irradiating a solid carbon target at power density of $10^{11} \div 10^{12}$ W/cm$^2$. Time-of-flight technique using a high-resolution electrostatic energy analyzer was applied to explore charge state and energy distribution as well as partial currents of carbon and tungsten ions. Some results of investigation of influence of cavern formation on charge state of generated ions are presented. This work is of considerable interest in a wide area of applications of accelerated particle beams, including fundamental studies of state of matter in particle colliders (NICA project at JINR), radiation damage simulation and hadron therapy for cancer treatment. The goal of this work is to investigate characteristics of ions in expanding laser plasma and find optimal conditions of target illumination and ion beam extraction. This research is valuable for adapting an intensive beam from laser ion source to the accelerator, improving acceleration efficiency and rising the amount of accelerated particles.

SCHEMATIC DIAGRAM OF THE HIGH CURRENT ION INJECTOR

Schematic diagram of the high current heavy ion I-4 (ITEP) is shown on Fig. 1.

![Figure 1: Schematic diagram of ion injector I-4.](image)

CHARACTERISTICS OF LASER BEAM

CO2 laser setup [1] 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 – up to 105 MW
- FWHM duration – 30 ns
- Beam divergence – close to diffraction limit

These parameters are reproduced during long term operation.

Flat mirrors transport the laser beam into the vacuum chamber. Then laser radiation is focused on the target surface by exchangeable spherical lenses with different focal length to vary power density in the range of $8 \times 10^{10} \div 8 \times 10^{11}$ W/cm$^2$. A typical shape of the spatial distribution of the energy density in the focal spot is close to Gaussian and its width is between 200 $\div$ 600 $\mu$m.
The time-of-flight technique is applied to study ion component of the laser plasma plume. Use of an electrostatic energy analyzer allows reconstructing charge state and energy distributions of ions, and their partial currents. Energy resolution $\Delta E/E$ of the instrument achieved is estimated as $\Delta E/E \approx 8 \times 10^{-4}$ [2]. The 143EM secondary electron multiplier with one-electron response time of 3 ns was used as the particle detector.

Energy distributions and partial currents of carbon ions emitted from laser produced plasma plume are presented on Figs. 2 and 3. These results were obtained when target was shifted by 500 $\mu$m after each laser pulse. The results presented on Figs. 4 and 5 were obtained with fixed target after 600 laser pulses.

Figure 2: Partial currents of carbon ions. Target was shifted after each laser pulse.

Figure 3: Energy distribution of carbon ions. Target was shifted after each laser pulse.

Figure 4: Partial currents of carbon ions. Target was fixed.

Figure 5: Energy distribution of carbon ions. Target was fixed.

Figure 6 shows the dependence of $C^{3+} + C^{5+}$ ion signal amplitude on time of operation with fixed target. Ion energy is set to $E = 600 \cdot Z$ eV. A 1.5 mm deep cavern was created on the surface of the target.

Figure 6: Dependence of ion signal amplitude on time of operation with fixed target.
Figure 7 shows the difference in charge state distribution for conditions with fixed and moving target. This effect can be explained by differences in distributions of plasma density and temperature along the plasma expansion axis.

Another target material for ion source was tungsten. Ions with charge states up to +20 were detected. Charge state distribution of tungsten ions is presented on Fig. 8.

Results of this measurement were used to calculate number of particles in single ion beam pulse: $7.3 \times 10^{11}$ particles in total, 46% of them are $C^{4+}$. The “pepper-pot” technique with a CCD-camera was used to measure beam emittance [3].

Temporal shape of total carbon ion beam current is presented on Fig. 9. Peak value is 25.8 mA.

Beam extraction system consists of three electrodes. The positive electrode has a grid (transparency: 90%, cell dimensions: $0.5 \times 0.5$ mm) and an exchangeable 10 mm 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. +1.5 kV potential was applied to the cup to suppress secondary electron emission.

Number of particles corresponds to 1 mA of extracted current, secondary emission coefficient is neglected.

REFERENCES