THE LASER ION SOURCE OF THE SYNCROPHASOTRON AND THE NUCLOTRON IN DUBNA

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Abstract

Since 1976 the Laser Ion Source (LIS) has been operated at the Laboratory of High Energies. At present, the LIS is used to perform experiments on relativistic beams of Li, B, C, N, O, F, Mg and Si nuclei.

Introduction

The Synchrophasotron and the Nuclotron are the major accelerator facilities at the Laboratory of High Energies, Joint Institute for Nuclear Research, Dubna. The both machines have a common injector - linac LU-20. For LU-20 output, the energy of protons is 20 MeV, ions and nuclei is 5 MeV per nucleon.

To produce a wide spectrum of ions, different types of ion sources are used at LU-20. One of them is the LIS. The accelerators Synchrophasotron and Nuclotron require a large pulse ion intensity from an ion source (up to 10^{13} ions/pp). The pulse duration depends on injection time into the ring (up to 500 μsec for the Synchrophasoron and up to 8 μsec for the Nuclotron). The operating frequency is $0,1 \div 1$ Hz. The LIS parameters correspond to these requirements.

Operating principle

The LIS (Fig.1) has been operating at the preinjector of the linac LU-20 since 1976 [1]. The main operating principle of the source is ion extraction from laser plasma produced in a vacuum chamber by focusing laser radiation on the solid target surface [2]. The created laser plasma extends into the vacuum perpendicular to the

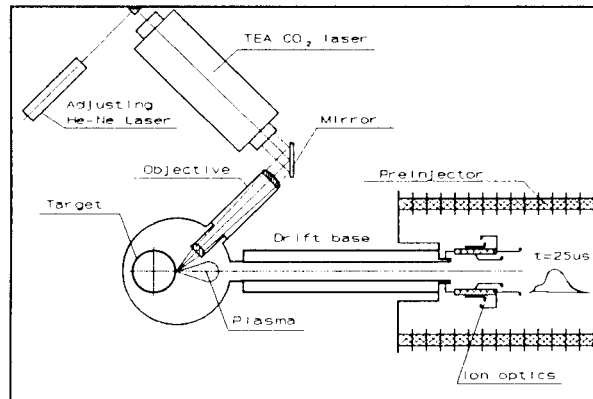target surface direction. A high electron temperature of the laser

Fig. 1 Functional scheme of the Laser Ion Source

plasma ($kT_e = 10^{-2} : 1$ keV) and a high value of the parameter $N_e \cdot \tau_i$ (up to 10^{13} cm$^{-3} \cdot$c), where N_e is the plasma electron density (usually $10^{19} \div 10^{21}$ cm^{-3}) and τ_i the ion containment time (as a rule, $10 \div 100$ ns), allow highly ionized ions to be produced. The number of these ions (more than 10^{12} ions/pp) satisfies the requirements of the accelerator facilities. A direct injection of plasma ions into the accelerators is not effective because the ion beam duration is less or equal to the laser pulse duration (about 10 ns for a Nd laser and up to 100 ns for a CO_2 one).The energy spread of extending laser plasma for each ion charge state Z is about $Z \cdot 10^3$ eV [2]. This property allows one to increase the beam duration by providing a distance for plasma drift. The plasma ions with a maximum charge fly within a small axial angle (less than 10^{-2} sr), and all these ions are extracted after the drift.

Recombination processes into the laser plasma slow down quickly with distance and the so-called "freezing" of ionization states [2] is achieved because N_e decreases with distance as L^{-3} and kT_e as L^{-2}. After the drift, ions are extracted out of the plasma, and the beam of ions is accelerated.

Design

The major LIS element is a laser. At first, a Nd laser with a peak power of 10^9 W was used in these experiments. But this type of lasers could only run with a frequency of less than 0,02 Hz. Therefore, since 1983 a CO_2 laser has been used for these experiments. At present the LIS has a CO_2 laser with a peak power of 10 MW, a beam divergence of $3 \cdot 10^{-3}$ rad and an operating frequency of up to 1 Hz.

The LIS is simple in operation. The laser beam is injected into a vacuum target chamber. The chamber is mounted on a high-voltage terminal. The laser beam is focused on the target through a NaCl two-lens objective. The maximum power density of a laser radiation flux on the target is about 10^{10} W·cm^{-2}. The ions extracted after a 150 cm drift of laser plasma are accelerated to 170 keV per nucleon and focused at the linac input by means of ion optics.

Experimental results

The ion beam at the LIS output has a wide charge and energy spectrum. The duration of a collector signal at the source output is $25 \div 30$ μsec for all charge states and $5 \div 10$ μsec for the highest ones. The total charge of ions obtained by collector signal integration is about $8 \cdot 10^{-6}$ Coulombs/pp within an axial solid angle of 10^{-3} sr for carbon. The mass-spectrometric measurements made with various elements for a flux density of 10^{10} W·cm^{-2} on a target allowed one to fix higher

charge states of $_{12}C^{6+}$, $_{27}Al^{11+}$, $_{64}Cu^{14+}$, and $_{184}W^{11+}$ ions at a distance of 200 cm from the target. The operating time without replacing the focusing point depends on target material, and it changes from about 250 laser pulses for magnesium up to about 3000 ones for carbon. The pulse to pulse instability of output current does not exceed 50%, and it changes monotonously with target destruction. Moreover, it has been found that after creating a crater in the target, the charge states of ions and their number at first increase, then remain invariable for some time and after that decrease [3].

TABLE 1

The pulse intensities of ions reached behind the linac LU-20 N_{LU} and the Synchrophasotron N_{SP}.[4,5].

Ion	Target material	N_{LU}	N_{SP}	
$_6Li^{3+}$	LiF	$3,5 \cdot 10^9$	$1 \cdot 10^8$	1
$_7Li^{3+}$	LiF	$5 \cdot 10^{10}$	$4 \cdot 10^9$	2
$_{12}C^{6+}$	Graphit	$1,5 \cdot 10^{10}$	$7,5 \cdot 10^8$	
$_{16}O^{8+}$	SiO_2	$3 \cdot 10^9$	$5 \cdot 10^7$	
$_{19}F^{9+}$	CaF_2, teflon	$2,5 \cdot 10^9$	$7 \cdot 10^6$	
$_{24}Mg^{12+}$	Mg	$1 \cdot 10^9$	$1,5 \cdot 10^7$ $1 \cdot 10^5$	3
$_{28}Si^{14+}$	Si,SiO_2	$1 \cdot 10^8$	$1 \cdot 10^3$ $5 \cdot 10^2$	4 5

where 1- natural isotope, 2- mixture, 3- with cryopumping, 4- $_{14}N^{7+}$ + 5% $_{28}Si^{14+}$, 5- with cryopumping 95% $_{28}Si^{14+}$

At present the LIS is used to perform experiments on relativistic beams of Li,B,C,N,O,F,Mg and Si nuclei (see Table 1). For increasing the beam intensity and improving

ion current stability, not only nuclear beams but also ion beams of these elements with a maximum charge state Z to mass A ratio of $Z/A=0,33$ are accelerated in the linac to an energy 5 MeV per nucleon. The stripper target is used for charge exchange after the linac.

Conclusions

The LIS demonstrates stable and reliable performances. The LIS is presently used for the Nuclotron. The carbon beams from the LIS injected into the Nuclotron were accelerated at the end of 1993.

References

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