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[1] Calculation by L. A. Vainshtein.

Note. Measurement accuracy: LP (laser plasma) ±0.0005, spark ±0.005, corona ±0.001.

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ACCELERATION OF LASER-PLASMA IONS WITH THE PREINJECTOR OF THE JINR LINEAR PROTON SYNCHROTRON

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We report the first instance of shaping and acceleration of a beam of multiply-charged ions of a laser plasma with the preinjector of the linear proton synchrotron accelerator. A procedure is considered for the formation of a beam of multiply charged ions, and data are given on the flux of carbon ions at the output of the preinjector. The feasibility of developing a laser source of nuclei is indicated.

1. We have effected, for the first time, the acceleration of multiply-charged ions of a laser plasma and the formation of an ion beam with the preinjector of a proton-synchrotron linear accelerator.

Experiments [1, 2] have shown that a laser plasma can serve as an effective source of ions in injectors of accelerators [3]. Acceleration of D^+ ions produced in a laser plasma was reported earlier [4]. The preceding studies of spatial and energy characteristics of the ion emission [5] have indicated, however, that the advantages of ion emission of a laser plasma can be utilized most effectively if the laser plasma is a source of ions in the preinjector of a linear accelerator. Indeed, the characteristics of the ion emission of a laser plasma make it possible to shape in a relatively simple manner an ion packet having the required characteristics.

2. For a linear accelerator that injects ions into a proton synchrotron, it is necessary to have packets of definite durations. Since the laser-plasma ions exhibit an appreciable velocity spread [5], the required ion packet was shaped in the course of the natural spreading of a plasmoid that had traversed an appreciable flight distance[1]. A narrow spatial distribution for ions with $Z = Z_{max}$ has made it possible to prevent appreciable losses incurred during the spread of the plasma and to use for the acceleration the greater part of ions with maximum ionization multiplicity. The energy spread $\Delta E(Z)$ of ions with specified Z, a spread used to control the beam duration Δt, does not prevent the ions from becoming captured in the

acceleration process by the linear accelerator, for if the preinjector voltage is 400 – 500 kV the ratio of the energy spread $\Delta E(Z)$ of the ions to the energy of injection into the linear accelerator amounts to a fraction of one per cent [7].

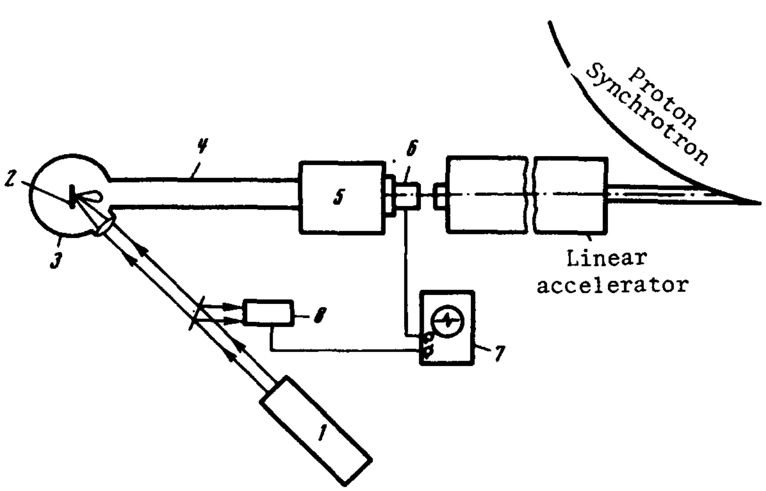

Fig. 1. Schematic diagram of experiment: 1 – neodymium laser, 2 – target, 3 – optical chamber, 4 – flight distance, 5 – preinjector, 6 – Faraday cylinder, 7 – oscilloscope, 8 – photocell.

3. A schematic diagram of the experiment is shown in Fig. 1. In this setup, the beam from a Q-switched neodymium laser (1) was focused on the surface of a target (2) placed in an optical chamber (3). The spreading laser plasma produced on the target surface by the laser beam, traverses a flight distance $\ell \simeq 2$ m (4). As a result of the energy spread $\Delta E(Z)$, the laser-plasma ions are shaped at the end of the distance ℓ into a packet of duration $\Delta t(\ell, Z)$. The plasma, which is restricted by the system geometry to a solid angle ψ ($\sim 4\times10^{-3}$ rad), then enters the acceleration tube of the preinjector (5) [8]. Inside this tube is located an ion-optical system in which the ions are picked off from the surface of the plasma, focused, and accelerated. The accelerated ion beam was registered with a Faraday cylinder (6), the signal from which was fed to an oscilloscope. The oscilloscope sweep was synchronized with the start of the laser pulse. The targets were carbon and ZrH_2 plates.

4. Figure 2 shows a number of oscillograms of the currents of accelerated carbon ions, obtained at a number of laser-emission densities q.

The voltages at the drawing and focusing electrodes of the ion-optical system, as well as the accelerating voltage, are the same for all oscillograms. Each oscillogram of Fig. 2 shows the resultant current for accelerated ions of a definite charge group, from $Z = 1$ to $Z = Z_{max}$, corresponding to a definite value of q [5]. (Experiments with a magnetic analyzer have shown that $Z_{max} = 6$ at $q \simeq 10^{12}$ W/cm^2). The dependence of the growth of the ionization multiplicity Z_{max} and of the maximum kinetic energy of the ions on the flux density q [5] is revealed in Fig. 2 by a decrease of the time interval between the start of the oscilloscope sweep and the appearance of the signal. It follows from the oscillograms that the total current (for a group of ions of equal charge) of the accelerated beam of carbon ions reaches ∿140 mA at a duration ∿15 μsec. The experiments have shown that the accelerated ion-beam current signals exhibit satisfactory reproducibility and can be controlled at all the applied voltages. Figure 3 shows the current oscillograms for a beam of Zr and H^+ ions from a ZrH target. The gain of the recording systems is 10 times larger for curve a than for curve b.

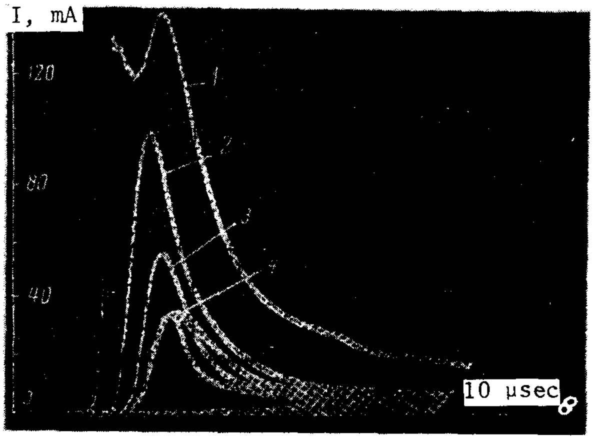

Fig. 2. Oscillograms of the currents of accelerated carbon ions at a number of radiation flux densities q (in W/cm^2): 1 – 10^{12}, 2 – 4×10^{11}, 3 – 2.5×10^{11}, 4 – 1.5×10^{11}. The preinjector voltages are: $U_{dr} = 41$ kV, $U_{foc} = 23$ kV, $U_{accel} = 440$ kV.

Using the data of [9] on the energy distributions of the H^+ and Zr ions, we were able to identify the H^+ and Zr ion current signals (Fig. 3a), which in this case were fully resolved in time. It follows therefore that if necessary a laser ion source can be used not only to inject multiply charged ions (e.g., C and Zr), but also to inject

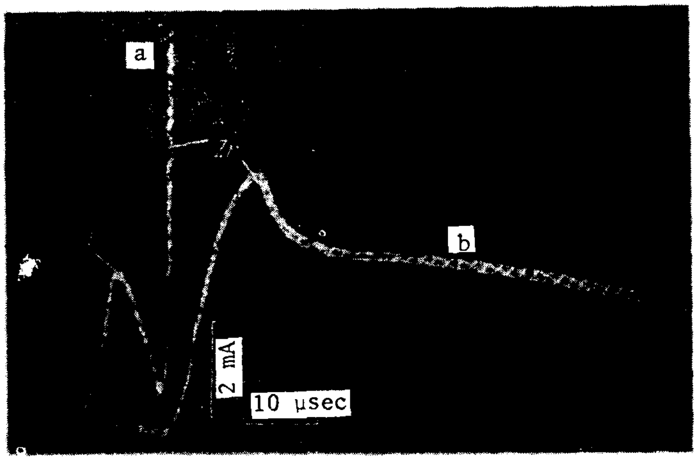

Fig. 3. Oscillograms of currents of accelerated H and Zr ions at a flux density $q = 10^{11}$ W/cm^2 and at preinjector voltages U_{dr} = 29 kV, U_{foc} = 23 kV, and U_{acc} = 440 kV. The gain of the recording system is 10 times larger for curve a than for curve b.

H^+ and D^+ ions.

5. The fact that C and Al nuclei had been obtained in a laser plasma [10], together with the present results, make a laser ion source quite promising, since the acceleration of deuterium nuclei and α particles in a proton synchrotron [11] has demonstrated the need for developing a source of ionized atoms from D to Ca, with A/Z = 2 [12]. It should also be noted that a laser source of nuclei can be used also in the development of the "Nuclotron" accelerator system [13].

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