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Multiply charged ion spectra of a laser plasma produced on both sides of the target

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***Abstract*. Multiply charged ion spectra in plasmas produced on both sides of Al and W targets by laser radiation with an intensity of 0.1 — 500 GW cm^{-2} were investigated simultaneously. The charge-state and energy ion spectra of the laser plasmas were studied on both sides of the target with the aid of a double-channel mass spectrometer. The maximum ion multiplicity and energy on the rear side of the target were found to lower relative to the front side owing to a variation in the ionisation kinetics in the plasma.**

Keywords: *multiply charged ions, laser plasma, rear side of the target*.

1. Introduction

Laser-driven plasma production and heating is a topical problem of laser physics. The interest in this problem stems from the prospect of achieving controlled nuclear fusion, producing efficient X-ray, neutron, and multiply charged ion sources, obtaining lasing on the transitions of multiply charged ions and nonlinear-optical media [1 – 4]. The studies of physical processes in a multiply charged laser plasma are also of interest in the design of efficient heavy-ion injectors for accelerators and the mass analysers of solids with a complex elemental composition [5 – 8]. In this case, it is particularly important to investigate the mass-charge and energy spectra of plasma ions not only on the front side of the target [1 – 9], but on both its sides simultaneously, which is the aim of our paper.

2. Experimental setup

We performed experiments on the setup shown schematically in Fig. 1. The setup consisted of a laser system, a laser plasma ion source, a double-channel mass spectrometer including time-of-flight analysers combined with electrostatic separators, and also vacuum systems and detection equipment. For a simultaneous investigation of ions on the front [4] and rear sides of the target, one more mass spectrometer having similar parameters and comprising a time-of-flight analyser combined with an electrostatic separator was assembled on the basis of the setup used in Ref. [4].

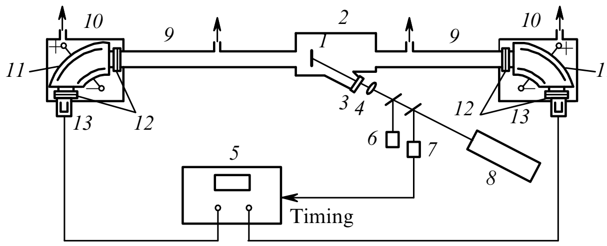

Figure 1. Schematic of a double-channel mass spectrometer for a simultaneous study of laser plasma ions on both sides of the target: (*1*) target under study with a target displacement device; (*2*) laser-plasma chamber; (*3*) optical window; (*4*) focusing lens; (*5*) double beam oscilloscope; (*6*) calorimeter; (*7*) coaxial photocell; (*8*) laser; (*9*) time-of-flight separator; (*10*) chamber of the electrostatic analyser; (*11*) electrostatic analyser; (*12*) entrance and exit analyser slits; (13) VEU-1A ion detector.

The overall ion-flight distance in each mass spectrometer was 150 cm, the laser radiation was incident at $\sim 18°$, the widths of the entrance and exit slits of the electrostatic analyser (~ 0.5 mm) provided a resolution $R_{\rm m} \sim 100$ in mass. The residual pressure in the chamber was $\sim 10^{-6}$ Torr.

Experiments were carried out with Al and W targets 10 – 50 μm in thickness. A special device was used to renew the irradiation spot on a target after every laser shot. The radiation intensity from a neodymium laser ($\lambda = 1.06$ μm, the pulse duration ~ 50 ns) was varied in the range $q = 0.1 - 500$ GW cm^{-2}. Note that every experimental value is the average of five laser shots.

3. Results of investigation

We obtained the mass-charge and energy spectra of multiply charged ions of the laser plasma on both sides of Al and W targets as functions of the laser radiation intensity and the target thickness. Comparison of these spectra allowed us to determine several features of the plasma ions on the rear side of the target relative to those on its front side in a broad range of charge multiplicities and ion energies. The observed characteristics of the multiply charged plasma

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ions produced on both sides of the target reveal themselves in the maximum ion charge multiplicities and energies, in the form of the energy spectrum, and also in their dependence on the laser radiation intensity and the thickness of Al and W targets.

An analysis of the multiply charged ion spectra of the laser plasma generated on both sides of the target allowed us to determine the following features: (i) multiply charged plasma ions of different multiplicity occur on both sides of the target simultaneously; (ii) the mass spectra of plasma ions consist of the peaks of ionised Al (W) atoms; (iii) the maximum charge multiplicities of plasma ions on the rear side of the target are in general lower than those recorded on the front side of the target (for instance, the maximum multiplicities Z_{max} of Al ions on the rear and front sides for $q = 500$ GW cm^{-2} are 3 and 7, respectively (for the W target, $Z_{max} = 2$ and 6); (iv) the maximum charge multiplicities of plasma ions generated simultaneously from both sides of the target are observed for the Al target thickness of about 13 μm and for the W target thickness of about 10 μm (for $q = 500$ GW cm^{-2}); (v) it was found that multiply charged ions are generated simultaneously on both sides of Al and W targets in the range $q = 50 - 500$ GW cm^{-2}, whereas for $q < 50$ GW cm^{-2} the ions are produced only on the front side of the target.

The investigation of the energy spectra of multiply charged ions of the laser plasma on both sides of the target also allowed us to determine several features of the formation of ion spectra. Fig. 2 shows typical energy spectra of multiply charged plasma ions produced on both sides of the 13-μm thick Al target for $q = 500$ GW cm^{-2}. Note that the ion energy spectra recorded on both sides of the target are rather close in character but differ in energy ranges. One can see that the multiply charged plasma ions that flew through the hole in the Al target to its rear side have lower energy than those recorded on the front side. The maximum energy of the ions that flew through the hole amounts to 1.0 keV, whereas the maximum ion energy on the front side is of the order of 5.0 keV. This energy decreases with target thickness, although the ion charge multiplicity did not change when the Al target thickness was varied from 13 to 50 μm (from 10 to 40 μm for the W target).

As the target thickness increases, the peaks in the ion energy spectra disappear, beginning with higher-multiplicity ions. For thicknesses corresponding to the threshold laser intensities required to produce holes, the energy spectrum of only singly charged ions is retained. These experimental facts show that the main part of laser radiation energy is absorbed in the material ejected and the subsequent course of the process is related to this absorption. In particular, the maximum multiplicity of the plasma ions detected on the rear side ($Z_{max} = 3$) is lower than that on the front side ($Z_{max} = 7$). This fact suggests that the high-charge plasma fraction is formed at the front of the expanding plasma, whereas the low-charge fraction resides in the interior of the plasma, closer to the target. Naturally, when the hole is burned through, it is primarily the nearby plasma layers that find their way to the rear side of the target.

The experiment shows that the forward plasma layers will be stronger heated by the still persisting laser beam, with the result that the maximum charge multiplicities and the energies of the ions that make up these layers will be higher than inside the plasma. This ion regrouping will also be favoured by the plasma expansion on the front side of the

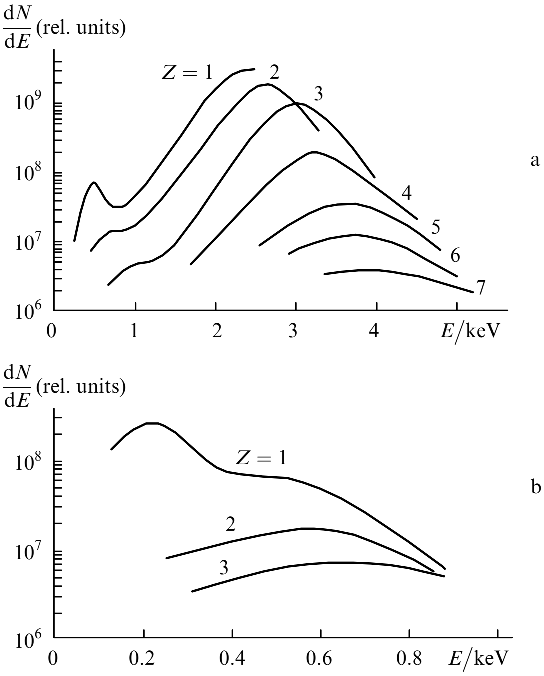

Figure 2. Typical energy spectra of multiply charged plasma ions with the charge multiplicity $Z = 1 - 7$ detected on the front side (a) and the charge multiplicity $Z = 1 - 3$ detected on the rear side (b) of a 13-μm thick Al target for a laser radiation intensity of 500 GW cm^{-2}.

target. In this case, the plasma electrons will be forces out of the plasma medium and be ahead of the ion component due to their small mass and high mobility. The resultant electric field will accelerate ions in accordance with their charges, so that the higher-charged ion component will find itself in the leading plasma layers.

Fig. 3 shows the maximum energy of Al ions that flew through the target as a function of the target thickness ($d = 10 - 50$ μm). One can see that the peak energy of Al ions (as well as of W ions) decreases asymptotically with target thickness. Physically, it is clear that a higher energy should be spent for producing a hole in a target of higher thickness. As a result, the energy of the ions that flew through the hole should become lower. The detection of ions on the front side in the case of hole formation showed that their energy also decreases compared to the energy of ions produced in the absence of the hole. As the target thickness is reduced, the energy and the multiplicity of the ions that fly to the rear side approach those of the ions flying to the front side.

Of considerable interest are the ion energy spectra for target thicknesses corresponding to the threshold intensity

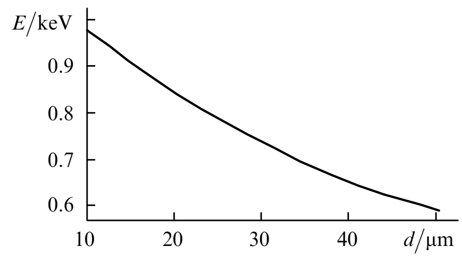

Figure 3. Maximum energy of plasma ions detected on the rear side of an Al target as a function of the target thickness.

of laser radiation, when the hole in the target just begins to emerge. The energy spectrum of only the singly charged ions is retained in this case, whereas the ions of higher multiplicity are not detected. Fig. 4 shows the energy spectra of Al ($d = 30$ μm, $q = 50$ GW cm^{-2}) and W ($d = 10$ μm, $q = 100$ GW cm^{-2}) ions plotted from the ion peaks, each of which was obtained at the third laser shot directed onto the same spot on the target (the hole in the target appears after the third laser shot). One can see from Fig. 4, that these spectra also correspond to the regime when only singly charged ions fly through the target.

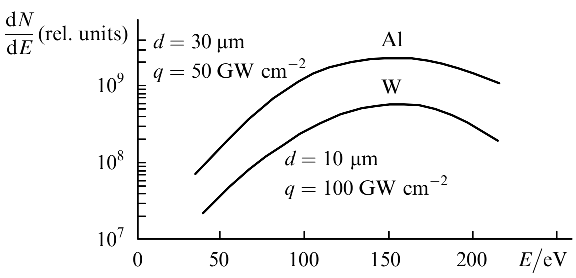

Figure 4. Energy spectra of singly charged Al and W ions recorded on the rear side of the target for different target thicknesses and laser radiation intensities.

4. Conclusions

The above experimental results suggests that the plasma expansion is accompanied by a redistribution of the mass of the expanding material, and, hence, of the energy carried away by its particles, towards the rear side of the target, the redistribution depending on the target thickness. For thin targets, shorter times and a lower consumption of energy are required to produce a hole. For this reason, the ions that fly to the rear side of the target still possess the features inherent in the ions on the front side of the target (without formation of a through hole), i.e., the existence of maxima in their energy spectra, the energy range for the ions of each multiplicity, etc. The thinner the target, the smaller the barrier it provides for the particles flying apart.

For thick targets, longer times and higher energies are required to produce a hole, so that only the ions which make up the 'tail' of the flying apart particles will find themselves on the rear side of the target. This means that the main part of the ions manage to recede so far from the target in a time taken to produce the hole that the particles which make up the mass bunch centre will not reach the rear side of the target. Therefore, the energy spectrum of the ions with multiplicities higher than unity is represented by a descending curve (without a maximum). For a specific relation between the target thickness and the light intensity this spectrum vanishes, and there remains the energy spectrum of only the singly charged ions.

References

1. Basov N G, Krokhin O N *Zh. Eksp. Teor. Fiz.* **46** 171 (1964)
2. Basov N G, Zakharenkov Yu A, Rupasov A A, et al. *Diagnostika Plotnoi Plazmy* (Diagnostics of Dense Plasmas) (Moscow: Nauka, 1989)
3. Krokhin O N, Mikhailov Yu A, Pustovalov V V, et al. *Pis'ma Zh. Eksp. Teor. Fiz.* **20** 239 (1964)
4. Bedilov M R, Kholbaev A *Fiz. Plazmy* **15** 114 (1989)
5. Bedilov M R, Khaidarov R T, Kunishev U S, et al. *Fiz. Plazmy* **24** 366 (1998)
6. Bedilov M R, Khaidarov R T, Davletov I Yu *Kvantovaya Elektron.* **22** 593 (1995) [*Quantum Electron.* **25** 567 (1995)]
7. Bedilov M R, Bykovskii Yu A, Kuramatov D et al. *Kvantovaya Elektron.* **14** 1675 (1987) [*Sov. J. Quantum Electron.* **17** 1068 (1987)]
8. 8. Bedilov M R, Bykovskii Yu A, Khaitbaev K Kvantovaya Elektron. **18** 79 (1991) [*Sov. J. Quantum Electron.* **21** 71 (1991)]
9. Abdupataev R, Bedilov M R *Kvantovaya Elektron.* **14** 2281 (1987) [*Sov. J. Quantum Electron.* **17** 1454 (1987)]
10. Bedilov M R, Khaidarov R T, et al. *Kvantovaya Elektron.* **23** 835 (1996) [*Quantum Electron.* **26** 814 (1996)]