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Formation of the characteristics of ion emission from a laser-produced plasma in the presence of a conducting diaphragm

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Abstract. The effect of electrical diaphragm-target coupling on the formation of ion component characteristics of a laser-produced plasma is considered. When the target and the diaphragm are insulated from each other and are under a floating potential, a high-energy ion peak is observed and the integral number of ions and their multiplicity increase compared to the case when the target and the diaphragm are connected and grounded.

1. Introduction

It is known that the ion energy spectrum is formed by an intricate combination of physical processes [1 – 4]. A laser-produced plasma is accelerated under the action of forces caused by the pressure gradient in a plasma bunch. Against the background of the hydrodynamic expansion, the ions experience additional acceleration in a self-consistent electric field induced at the periphery of the laser-produced plasma owing to a difference in the thermal velocities of the electron and ion components.

Given this, the search for techniques allowing us to control the electric field strength of this plasma capacitor and, hence, the characteristics of ion emission from a laser-produced plasma is critically important. In this work we study the effect of a plane conducting diaphragm, placed in the path of plasma expansion, on the laser-produced plasma for different electrical target-diaphragm couplings.

2. Experimental setup

A schematic layout of the experimental setup is given in Fig. 1. It comprises a CO_2 laser (*1*) with a maximum energy of 2 J and a pulse repetition rate of 1 Hz, a set of mirrors (*2*) for injecting and focusing the radiation along the normal to the target surface (to maximise the laser radiation intensity), a vacuum chamber (*3*), a collector recording system (*7*) located at a distance of 175 cm from the target (*4*), an electrostatic mass spectrometer (*8*), a secondary-emission multiplier (*9*), an amplifier (*10*), and a storage oscilloscope (*11*).

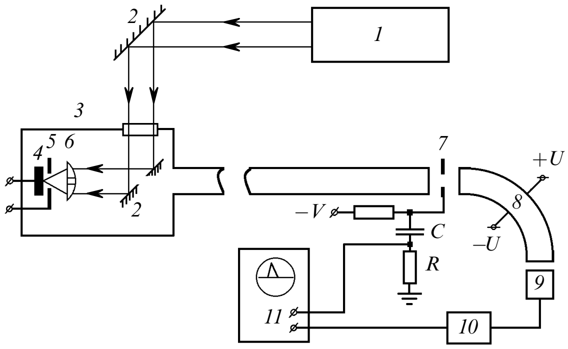

Figure 1. Schematic of the experimental setup: (*1*) CO_2 laser; (*2*) sets of mirrors; (*3*) vacuum chamber; (*4*) target; (*5*) diaphragm; (*6*) lens with a hole opening; (*7*) collector recording system; (*8*) electrostatic mass spectrometer; (*9*) VEU-2 secondary-emission multiplier; (*10*) fast-response amplifier; (*11*) storage oscilloscope.

A diaphragm, which was a plane metal plate (*5*) with a hole 2 mm in diameter, was placed between a carbon target (*4*) and a focusing lens (*6*). In this case, the target and the diaphragm were insulated from the chamber body (the ground). The target-electrode spacing was varied between 1 and 6 mm. Two holes with respective diameters of 2.5 and 3.5 mm were made in the lens and the mirror to extract ions from the plasma-producing unit. Considering that the laser beam was 25 mm in diameter, the losses of laser radiation due to the holes in the optical components did not exceed 5%.

The pressure in the system was $\sim 10^{-5}$ Torr. The laser radiation intensity determined experimentally from the threshold of laser-induced spark formation in the air was $\sim 10^9$ W cm^{-2}.

3. Experimental results

Two types of target-electrode coupling were studied in the experiments: (i) the target and the electrode were insulated from each other and were under a floating potential and (ii) the target and the electrode were connected to each other and grounded to the chamber body. It was assumed that the electric field strength could be enhanced by reducing the dimensions of the electron cloud (when the plasma capacitor plates are brought closer together) in the former case and, conversely, could be lowered owing to a sink of a part of the electrons to the target (plasma) in the latter case [5].

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Fig. 2 shows the typical signals from the collector in the cases when the target and the electrode were grounded (the lower curves) and when they were under a floating potential (the upper curves). The instant of the laser pulse production coincides with the origin of the horizontal graticule. One can see from the oscilloscope traces given in Fig. 2 that when the target and the diaphragm are decoupled from each other, the integral number of ions emitted from the plasma bunch is larger than that in the case when they are coupled and grounded. Also observed is the formation of a high-energy peak which builds up as the target-diaphragm separation is reduced (i.e., with an increase in the electric field strength of the plasma capacitor). This peak is clearly observed despite a strong initial radiation-induced signal from the collector.

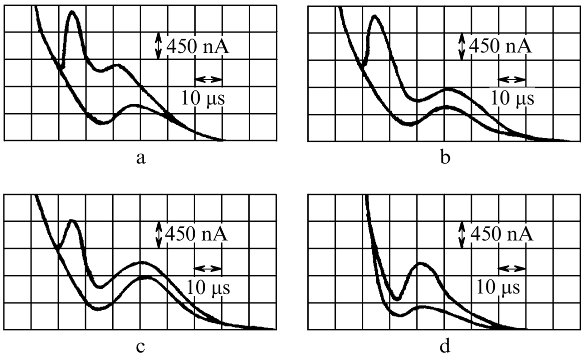

Figure 2. Oscilloscope traces of the ion current from a laser-produced plasma to the collector for a floating potential of the target and the diaphragm (the upper curves) and when they are connected to each other and grounded to the body of the vacuum chamber (the lower curves) for a target-diaphragm spacing $L = 1$ (a), 3 (b), and 6 mm (c) as well as without a diaphragm (d).

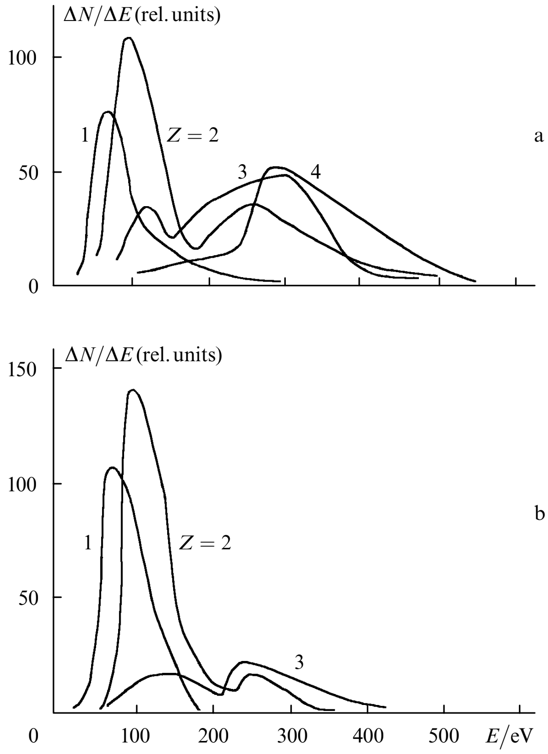

Figure 3. Energy spectrum of carbon ions when the target and the diaphragm were disconnected (a) and grounded (b) for Z specified by the curves.

The reduction in the integral number of ions and their energy in the case of a grounded diaphragm can be attributed to a recharge of the diaphragm-target system resulting in the efficient deceleration of the expanding plasma bunch and in the increase in the probability of recombination processes. For comparison, in Fig. 2d are given typical oscilloscope traces of the signal from the collector in the absence of the electrode when the target was grounded (the lower curve) and when it was under a floating potential (the upper curve), in which the high-energy peak is not observed.

The diaphragm also affects the ionic charge composition of the laser-produced plasma. Fig. 3 shows the energy spectra of carbon ions for the two above variants of connecting the target and the diaphragm. For the floating potential of the target and the diaphragm, in addition to the shift of the ion energy spectrum towards higher energies, we observed an increase of the maximum ion charge Z in comparison with the case when the target and the diaphragm were grounded. One can see from Fig. 3a that ions with $Z = 4$ are present in the case of a floating potential, whereas they are hardly observed in the case of grounding (Fig. 3b). This fact may be interpreted as follows. Since the diaphragm is used to strengthen the electric field at the periphery of the plasma bunch, the ion velocity also increases (Figs 2a – c) to exert an appreciable effect on the efficiency of recombination processes in the plasma [6, 7].

4. Conclusions

The above results suggest the fundamental possibility to affect, early in the plasma expansion, the formation of the spectra of ions as regards to their energy, multiplicity, and number. This is of prime interest from the standpoint of attainment of the requisite characteristics of the ion component of a laser-produced plasma, for instance, for the production of highly efficient laser sources of multiply charged ions for accelerators of different types.

This method also can be applied to laser mass spectrometry. One of its goals is to reduce the number of multiply charged ions, emitted from the plasma, in a fairly simple way and without reducing the fraction of singly charged ions.

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References

1. Bykovskii Yu A, Vasil'ev N M, Degtyarenko N N, Elesin V F, Laptev I D, Nevolin V N Pis'ma *Zh. Eksp. Teor. Fiz.* **15** 308 (1972)
2. Bykovskii Yu A, Degtyarenko N N, Elesin V F, Kozyrev Yu P, Sil'nov S M *Zh. Eksp. Teor. Fiz.* **60** 1306 (1971)
3. Goforth R R, Hammerling *Appl. Phys.* **47** 3918 (1976)
4. Tonon G F, Rabeau A *Plasma Phys.* **15** 871 (1973)
5. Bykovskii Yu A, Kozyrev Yu P, Konyukhov I Yu, Peklenkov V D, Suvorov K G, Sharenko O V *Preprint No. 089-88* (Moscow: Moscow State Engineering Physics Institute, 1988) p. 8
6. Plotkin M E, Ragozin E N *Kvantovaya Elektron. (Moscow)* **8** 1721 (1981) [*Sov. J. Quantum Electron.* **11(8)** 1039 (1981)]
7. Rumsby P T, Paul J W *Plasma Phys.* **16** 247 (1974)