Time dependence of x-ray spectrum of an aluminum laser plasma

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The time dependence of the spectral lines of hydrogenlike and heliumlike alumium ions in the x-ray emission spectrum of a laser plasma is investigated. The ratio of the line intensities in the spectrum is used to determine the temperature and density of the electrons with a time resolution not worse than 1.8 nsec.

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Laboratory x-ray sources such as laser plasmas uncover completely new possibilities in the study of the spectra of multiply charged ions. These spectra contain very abundant information on the elementary processes that occur in the plasma. Various spectroscopic methods of plasma diagnostics by means of the spectra of hydrogenlike and heliumlike ions have been extensively developed of late.[1,2] The study of the time dependence of the spectral lines of multiply charged ions has therefore become quite timely, since it may make possible the study of the dynamics of laser-plasma development and to determine the role played by the principal elementary processes at different instants of time.

We know of only one publication[3] dealing with the time dependences of two separate lines of multiply charged ions in a laser plasma. The use in that study of a photomultiplier with a scintillator as an x-ray receiver is not promising, because of the insufficient time resolution of the photomultiplier (~ 2—3 nsec) and because it is impossible to register the entire structure of the spectrum.

In the present study we investigated the time dependence of the spectrum of an aluminum laser plasma in the wavelength range 7—8 Å. The use of a radia-

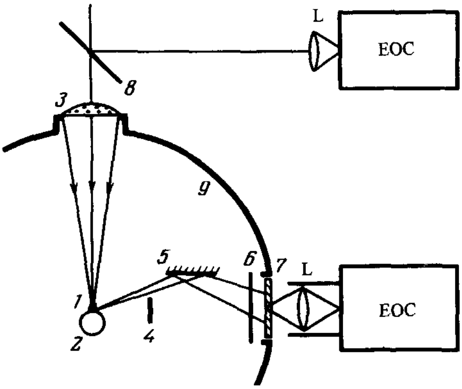

FIG. 1. Experimental setup: 1—laser plasma, 2—target, 3—focusing lens, 4—screen, 5—mica crystal, 6—x-ray filter (4 μm polypropylene + 0.4 μm aluminum), 7—scintillator, 8—plate, 9—vacuum chamber, L—lenses, EOC—electron-optical cameras.

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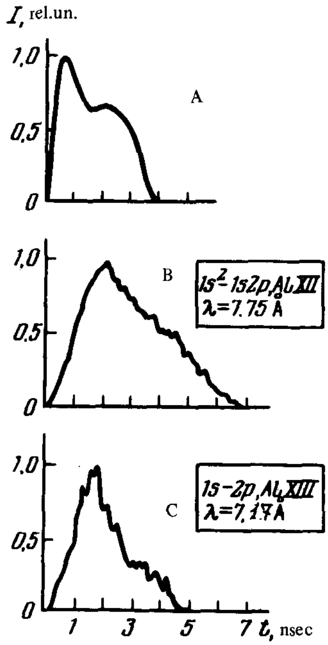

FIG. 2. Time scan of the emission of the resonance lines of heliumlike and hydrogenlike aluminum ions in a laser plasma: A—incident laser pulse, B—emission of the $1s^2$—$1s2p$ resonant line of the ion Al XII, C—emission of the resonance line $1s$—$2p$ of the ion Al XIII.

tion receiver consisting of a high-luminosity x-ray spectrograph[4] and of an electron-optical camera with a scintillator at its input[5] has made it possible to observe the entire structure: the resonance lines and their satellites of the hydrogenlike and heliumlike aluminum ion. The time resolution of the method is determined by the scintillator emission time τ, which amounted in the present study to $\tau \leq 1.8$ nsec. Simultaneously with investigating the x-ray spectrum, we registered the laser radiation incident on the target.

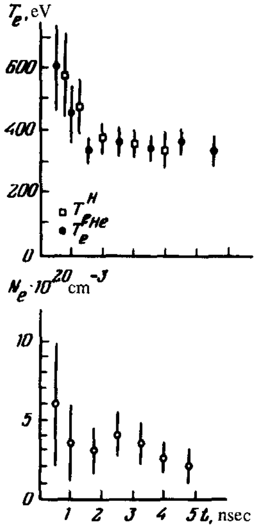

FIG. 3. Experimental values of the temperature T_e and the density N_e of the electrons at various instants of time.

The experimental setup is shown in Fig. 1. The plasma was heated with a neodymium-glass laser with pulses of 10 J energy and 4 nsec duration. The laser radiation was focused on the target with a lens of $f = 300$ mm, and the flux density at the target was $\sim 10^{14}$ W/cm^2.

The x-radiation was spectrally resolved with a focusing spectrograph of the Gamos type with bent mica crystal. The dispersion of the spectrograph in first order of the spectrum was 0.083 Å/mm. The x-ray observation angle was ~ 70° relative to the laser-beam axis. The spectrum was registered with an electron-optical camera operating in the slit-scan regime. The time scan of the spectrum was in a direction perpendicular to the spectrograph dispersion.

The results of the reduction of the temporal spectrogram are shown in Fig. 2. The emission duration of the resonant line of the heliumlike ion Al XII was ~ 4 nsec at half-height. The emission time of the hydrogenlike ion Al XIII, measured from the resonance line, was much shorter and varied from 1.8 to 3.5 nsec.

From the ratio of the line intensities in the spectrum we determined the time dependence of the electron temperature and density. The electron temperature T_e was determined from the intensity ratio of the dielectron satellites to the resonance lines of the corresponding ion.[6,7] The value of T_e^{H} was obtained from the ratio of the summary intensity of the dielectronic satellites to the intensity of the resonance line of the ion Al XIII. The main contribution to the satellite intensity is made by t the transitions $1s2p\,^1P_1-2p^2\,^1D_2$, $1s2s\,^1S_0-2s2p\,^1P_1$, and $1s2s\,^3S_1-2s2p\,^3P_2$. The value of T_e^{He} was obtained from the ratio of the intensity of the satellites $1s^22p\,^2P_{1/2,3/2}-1s\,2p^2\,^2D_{3/2,5/2}$ to the resonance line of the Al XII ion. The electron density N_e was determined from the intensity ratio of the intercombination and resonance lines of the Al XII ion on the basis of the data of[8].

The measured electron temperatures and densities at various instants of time are shown in Fig. 3. The values of T_e^{H} and T_e^{He} are the same within the limits of the measurement error. At the initial instant of time, corresponding to the leading front of the x-ray pulse, the electron temperature has a maximum $T_e \sim 600$ eV, which then falls off to a constant value $T_e \sim 350$ eV. The electron density has a value $(2-5) \times 10^{20}$ cm^{-3} during the pulse.

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