Features of the structure of the harmonics $2\omega_0$ and $3\omega_0/2$ generated in a laser plasma

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Results are presented of experimental investigations of the spectral structure, the angular dependences, and the temporal characteristics of the emission of the harmonics $2\omega_0$ and $3\omega_0/2$ generated in a plasma produced when flat targets are irradiated by a powerful light beam from a neodymium laser in the intensity range 2×10^{13}–2×10^{14} W/cm^2. The study of the nonlinear mechanisms of the interaction of the radiation with the plasma is of great interest for research on laser-ignited controlled thermonuclear fusion. Most papers devoted to this question deal with decay (parametric) instabilities and generation of the harmonics and subharmonics of the laser radiation. The situation here, however, is not perfectly clear, and the need for comprehensive experimental investigations in a wide range of conditions is perfectly obvious.

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We wish to report results obtained recently with the "Mishen' 1" installation at the I. V. Kurchatov Institute of Atomic Energy.[1] We investigated the spectral composition, the time characteristics, and the angular dependences of the radiation at the frequencies $2\omega_0$ and $3\omega_0/2$ (ω_0 is the working frequency of the laser), scattered by the plasma produced when flat targets of polyethylene and aluminum, is irradiated by a focused beam from a neodymium laser. The targets were placed in a vacuum chamber. At a laser-pulse duration 3.5 nsec, the light-flux density in the focal spot on the surface of the target varied in the interval $2\times10^{13}-2\times10^{14}$ W/cm^2. The spectrum of the radiation scattered by the plasma in directions making angles 180, 135, and 90° to the axis of the incident

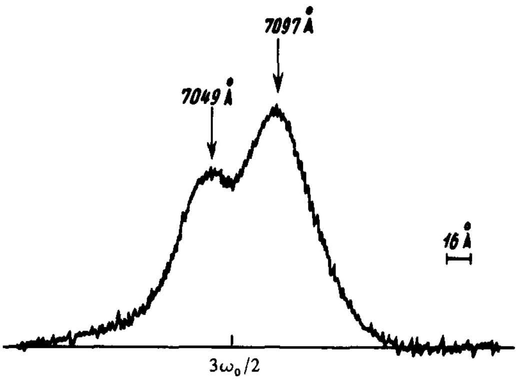

FIG. 1. Spectral contour of the radiation at the frequency $3\omega_0/2$.

laser beam was registered both for normal incidence of the beam on the surface of the target and for the case when the surface of the target was at an angle of 45° to the beam. The time variation of the intensity of the radiation at the frequencies ω_0, $2\omega_0$, and $3\omega_0/2$, scattered into the aperture of the focusing lens, was registered with an electron-optical converter of the UMI-93 type, operating in the streak regime. The resolution time of the recorder did not exceed 5×10^{-11} sec.

The principal results reduce to the following.

1. The contour of the $3\omega_0/2$ line, in the case of observation in a direction opposite to the direction of the incident laser beam, is split into two components the distance between which in the wavelength scale is 40—50 Å in the case of the aluminum target and 20—30 Å for the polyethylene target.[2,3]

Figure 1 shows a typical contour of the $3\omega_0/2$ line, obtained by irradiating an aluminum target at a light-flux density $\sim 8\times10^{13}$ W/cm^2. It is seen that besides the component whose maximum intensity corresponds approximately to exact position of the $3\omega_0/2$ line, there is a component shifted into the long-wave side.

2. In the case of normal incidence of the laser beam on the surface of the target, a rather sharp directivity of the radiation at the frequency $3\omega_0/2$ into the aperture of the focusing lens is observed. The $3\omega_0/2$ harmonic could not be registered in the case of observation at 90° to the laser beam. It must be noted, however, that the observed anisotropy can be attributed to the strong absorption of the radiation propagating along the surface of the target. Indeed, as shown by simple calculations, the characteristic absorption length of radiation with frequency $3\omega_0/2$ in a plasma of density[1)] $n_{cr}/4$ and at temperature ~ 400 eV amounts to ~ 150 μ. At the same time, in accordance with numerical two-dimensional calculations, the transverse dimensions of the plasma flare turn out to be much larger.

3. In observation at 135° to the laser-beam axis, the distance between the components of the $3\omega_0/2$ line is smaller by an approximate factor 1.5 than the distance registered in observation at 180°.

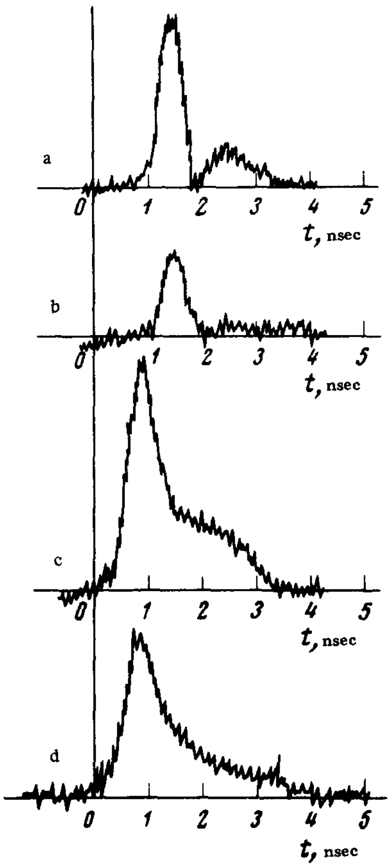

FIG. 2. Time scan of the incident (2) and reflected radiation at the frequencies ω_0 (c), $2\omega_0$ (b), and $3\omega_0/2$ (a).

4. If the target is mounted in such a way that its surface is inclined 45° to the laser beam, then a sufficiently bright $3\omega_0/2$ line is registered at all three observation angles, namely 180° (in the aperture of the lens), 135° (normal to the surface of the target), and 90° (in the direction of the specular reflection). In all cases, however, the line splittings are small. In experiments with oblique incidence of the laser beam on the target, the reflection of the light at the fundamental frequency into the aperture of the focusing lens decreases strongly, whereas the main fraction of the reflected radiation emerges in a direction corresponding to specular reflection.[4]

5. When the target is rotated 45° relative to the incident beam, the $2\omega_0$ line is practically not observed in any of the indicated three directions. The apparent reason is the reflection of the incident radiation from the region of the plasma with density lower than the critical value, and thus, the absence of electromagnetic waves in the resonant region, where $\omega_0 = \omega_p$.

6. Typical time scans of the incident and reflected pulses and of the plasma

radiation at the frequencies $2\omega_0$ and $3\omega_0/2$, obtained simultaneously in a single experiment, are shown in Fig. 2. Attention is called to the time delay $(0.5-1)\times10^{-9}$ sec between the pulse reflected at the frequency ω_0 and the radiation pulses at $2\omega_0$ and $3\omega_0/2$. The waveform of the $3\omega_0/2$ pulses is close in all experiments to the waveform of the reflected and radiation pulses. The appearance in a number of cases of spikes of the reflected signal at the fundamental frequency is accompanied by spikes in the $3\omega_0/2$ pulse (with the appropriate time delay $(0.5-1)\times10^{-9}$ sec).

The results can be compared with the theoretical models describing a decay instability of the type $\omega_0 \to \omega_p + \omega_p'$ and the mechanism of generation of the harmonic $3\omega_0/2$, and possibly will cast light on the question of the transformation of plasmons in the region of small k. In this connection, interest attaches to recently undertaken measurements, with high time resolution of the spectral distribution of the split $3\omega_0/2$.

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[1)] n_{cr} is the critical plasma density for the radiation with frequency ω_0.

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