Amplitude-spatial effects of high-intensity radiation conversion in a laser plasma

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We investigated experimentally the transformation of the spectrum and the amplitudes of neodymium-laser radiation reflected from a plasma at intensities 10^{15}–3×10^{16} W/cm^2. Rather narrow regions of plasma luminosity were observed at the frequencies $2\omega_0$ and $3\omega_0/2$. Various mechanisms that can be responsible for the observed effects are considered.

At high intensities ($I > 10^{14}$ W/cm^2), the principal role in the interaction of radiation with a plasma is played by nonlinear processes. They cause an anomalously high absorption of the pump wave, a conversion of its frequency, and distortion of the spectrum of the light reflected from the plasma. We have investigated experimentally certain effects that lead to spatial, amplitude, and frequency changes in high-intensity incident radiation interacting with a dense plasma.

1. The experimental setup and the diagnostic apparatus, which are described in detail in[1], were supplemented with systems for the measurement of the angular distribution of the reflected radiation in the near zone at frequencies ω_0 and $2\omega_0$, and also with apparatus that made it possible to localize the region of the maximum luminosity of plasma regions at the frequencies ω_0, $3\omega_0/2$, and $2\omega_0$. In each experiment, simultaneously with determining the spatial characteristics (the angular distribution and the zones of conversion of the incident radiation) at one of the harmonics, we made a spectrographic analysis of this section of the spectrum using a MDR-3 monochromator, and also registered the spectra of the radiation incident on and reflected from the aperture of the focusing lens in the region of ω_0, using a spectrograph with dispersion 30.4 Å/mm. In addition, we monitored in each flash the contrast, the incident and reflected energy, and the electron temperature of the plasma.

2. We observed certain singularities in the spectral conversion of a high-intensity pump wave.[2] It turns out that at intensities 10^{15} to 3×10^{16} W/cm^2 the radiation passing through the aperture of the focusing lens contains the frequencies $3\omega_0/2$, $2\omega_0$, and ω_0, where ω_0 is the pump-wave frequency. The second harmonic $2\omega_0$ consists of a narrow and a broad component, the energy ratio of which reaches 2×10^{-3}. An interesting feature of the narrow component is its weak dependence on the incident-radiation intensity, whereas the broad component satisfies the relation $I(2\omega_0) = I^\alpha(\omega_0)$, where $\alpha > 2$. Figure 1 shows density plots of the radiation of frequency near $\lambda/2$ leaving the aperture of the focusing optical system. Curves 1, 2, 3, and 4 correspond to the
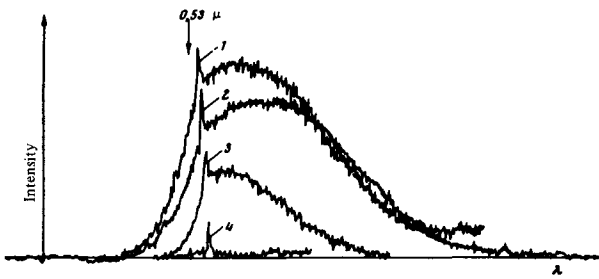
FIG. 1.

FIG. 3.

incident-wave intensities $I_1 = 2\times10^{16}$, $I_2 = 1.5\times10^{16}$, $I_3 = 8\times10^{15}$, and $I_4 = 3\times10^{15}$ W/cm^2. The width of the spectrum (1) at the 0.1 level is $\Delta\lambda \approx 380$ Å. In addition, in contrast to[3], all spectrograms reveal a tendency to a splitting of the narrow components into a doublet, with a spacing $\Delta\lambda \approx 3-5$ Å between the lines. Special notice should be taken of the fact that the second harmonic is shifted 10—12 Å in the red direction.

The spectra of the incident and reflected radiation in the region $\lambda \approx \lambda_0$ are shown in Fig. 2. The pump-wave intensity is $I(\omega_0) = 1.5\times10^{16}$ W/cm^2. Attention is called to the fact that the reflected radiation has relative to the incident radiation, a red shift ~ 5 Å, and a broadening ~ 7.5 Å. A distortion of the shape of the reflected-radiation spectrum, compared with the incident spectrum, is also clearly seen.

In the experiments we localized the regions of maximum luminosity at the frequencies $3\omega_0/2$ and $2\omega_0$, but we were unable to observe such a region at the frequency ω_0. It appears that reradiation at the fundamental frequency comes from rather extensive regions of the plasma.

A characteristic feature of the angular distribution of the second harmonic is the presence of a rather narrow maximum at an angle $\sim 18°$ to the optical axis. Since the energy of the broad component is much larger than the energy of the narrow component, it must be assumed that it is precisely the broad component that has the angular distribution represented in Fig. 2. In this figure, the abscissas are the angles between the optical axis and the registration direction, and the ordinates are the relative intensities of the radiation at the given angle. The aperture of the lens corresponds to an angle of 26.7°.

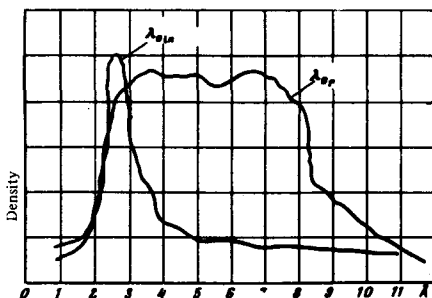3. The incident radiation spectrum, as seen from Fig. 2, is appreciably broadened in the red direction.

FIG. 2.
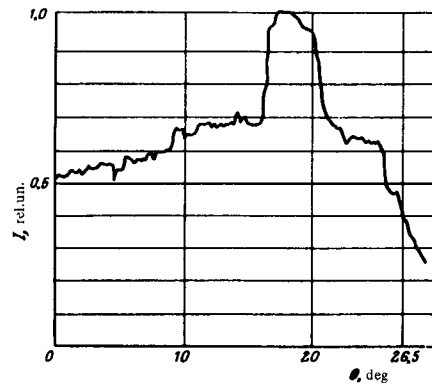
The character of this broadening, however, and its dependence on the intensity of the laser pulse, differ strongly from the character and the dependence of the second harmonic. Moreover, although the shift of the second harmonic is about double the shift at the fundamental frequency, the broadening of the narrow component of the second harmonic is much less than expected. It turns out here that the "red" line of the doublet, which is always less intense than its "blue" neighbor, is located at an approximate distance corresponding to double the broadening of the fundamental line. The intensity difference between the second-harmonic doublet lines may be connected with a difference between their polarizations. On the other hand, a similar picture can be observed if there are two second-harmonic generation zones. The shift of the spectrum of the fundamental-frequency reflected radiation can be due to SMBS, but so large a broadening of the spectral line is then possible if the scattering is sufficiently effective in an extended range of plasma parameters. This assumption is confirmed by the absence of a clearly pronounced zone from which the fundamental-frequency radiation is reflected. The presence of sharply pronounced regions of conversion into the second harmonic, and particularly into the fractional harmonic, may offer evidence in favor of parametric instabilities.[4] It appears in this case that the ($\omega_0 \to 2\omega_0$) zone is located near $n_e \approx n_{cr}$, while the ($\omega_0 \to 3\omega_0/2$) zone is located near $n_e \approx n_{cr}/4$. From this, knowing the distance between these zones, we can determine the gradient $\nabla n_c \approx 10^{24}$ cm^{-4} and the characteristic dimension $a \sim 10^{-3}$ cm.

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