

Laser-plasma diagnostics near one-quarter of the critical density

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Results are presented of experimental measurements of the generation of the harmonic $3\omega_0/2$ in spherical heating of hollow glass microspheres by intense neodymium-laser radiation. It is shown, on the basis of parametric-turbulence theory, that it is possible to determine the electron temperature and the characteristic dimension of the plasma inhomogeneity of the plasma in the region of one-quarter of the critical density from the spectrum and intensity of the $3\omega_0/2$ harmonic.

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Experimental investigations of the generation of the $3\omega_0/2$ harmonic by a laser plasma were carried out by spherically heating hollow microsphere of SiO_2 glass (sphere diameter $\approx 70\text{--}95\ \mu$, wall thickness $\Delta \approx 1.2\text{--}3.6\ \mu$) using the "Calmar" neodymium-glass nine-channel laser installation.^{[1] [1]} The active element of the master generator was yttrium aluminum garnet. The half-width of the emission line at the entrance to the laser setup was $\approx 10\ \text{\AA}$ ($\lambda \approx 10640\ \text{\AA}$). The laser radiation was focused with nine two-lens systems ($f=20\ \text{cm}$) into the vacuum chamber.

The light-pulse duration was $\approx 2.5\ \text{nsec}$ at the base, the rise time was $\lesssim 0.5\ \text{nsec}$, and the energy contrast of the radiation was $\sim 10^6$. The light energy in the region of the target was $100\text{--}120\ \text{J}$. The diameter of the light beam in the

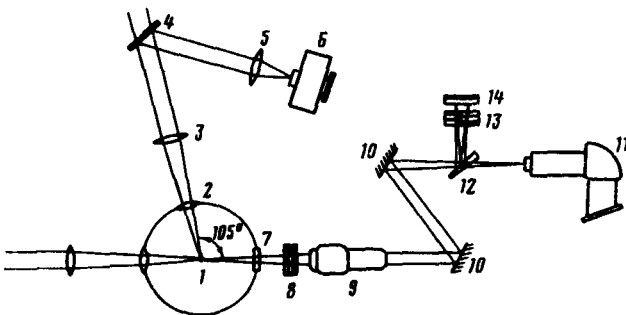


FIG. 1. Arrangement of the spectral diagnostic apparatus: 1—target, 2 and 3—one of the focusing systems, 4—plane-parallel plate, 5—lens, 6—MDR-2 spectrograph, 7—diagnostic window, 8—light filters, 9—long-focus objective, 10—mirrors, 11—ISP-51 spectrograph, 12—one-degree wedge, 13—light filters, 14—cassette.

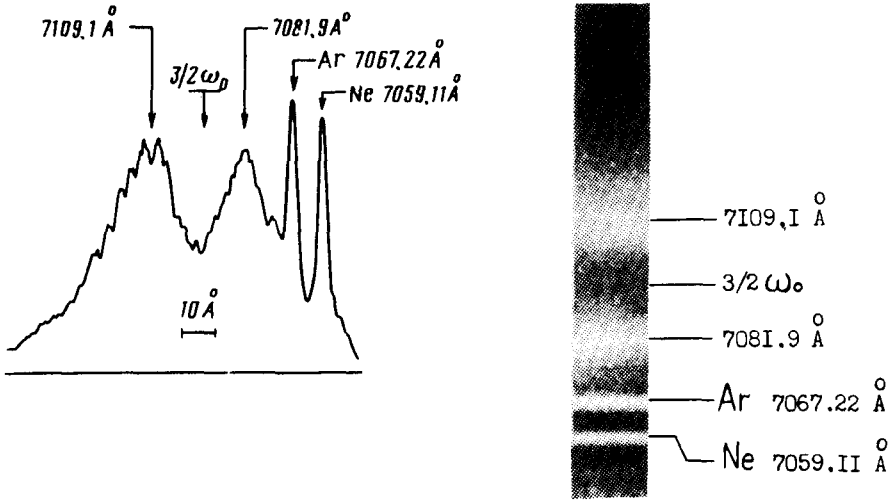


FIG. 2. Spectrogram and microgram of the frequency region near $3\omega_0/2$, obtained in the first registration direction following irradiation of a hollow glass microsphere of $\approx 83 \mu$ diameter and wall thickness $\approx 3.6 \mu$, with Ar 7067.22 Å, and Ne 7059.11 Å as the reference lines.

target plane was $\sim 150 \mu$. The average flux density on the target surface was $q \approx 10^{14} \text{ W/cm}^2$.

The generation of the $3\omega_0/2$ harmonic was investigated in two directions, (Fig. 1), the angle between which was $\approx 105^\circ$. In the first direction, the target image (1) was projected on the slit of the MDR-2 diffraction spectrometer (6) through one of the focusing systems (2 and 3) and the lens (5), i. e., the observation was backwards relative to one of the heating beams in a solid angle $3 \times 10^{-2} \text{ sr}$. In the second direction, the image was projected through the diagnostic window (7) via an objective (9) ($f=300 \text{ mm}$) with eightfold magnification unto the slit of an ISP-51 prism spectrograph.^[11] The observation direction coincided with the direction of one of the heating beams. The observation solid angle was $\approx 3 \times 10^{-3} \text{ sr}$.

Generation of the $3\omega_0/2$ harmonic, with a clearly pronounced doublet structure, was registered in both direction. The doublet contained two components: red, shifted from the nominal value $2\omega_0/3=7093.3 \text{ Å}$ towards longer wavelengths by 15 to 32 Å, and a less intense blue component, shifted from the nominal value towards shorter wavelengths by 7 to 13 Å; the distance between components ranged from 27 to 42.5 Å in the different flashes. The position of the minimum between peaks corresponded, accurate to 2–3 Å, to the nominal value of $2\lambda_0/3$. The ratio of the intensities of the blue and red components ranged from 0.35 to 0.95. For the spectrogram shown in Fig. 2, the half-widths of the red and blue components were ~ 33 and $\sim 24 \text{ Å}$, respectively, and the total width of the entire distribution at the level of 1/10 the maximum intensity was $\sim 80 \text{ Å}$. Practically all the $3\omega_0/2$ spectrograms obtained in both observation directions revealed modulation of the spectral distribution of the radiation intensity, with distances from 3.5 to 11.5 Å between spikes.

Absolute measurements of the energy of the $3\omega_0/2$ harmonic, carried out along the second direction, have shown that it reaches 10^{-2} erg (for a target with 83μ diameter and $\Delta \approx 3.6 \mu$). Assuming isotropic radiation of the harmonic, this leads to a value $3.5 \times 10^{-6} \text{ J} \cdot 4\pi \text{ sr}$, and yields a harmonic-conversion coefficient $\sim 10^{-7}$.

The generation of the $3\omega_0/2$ harmonic is due to excitation in the plasma of a parametric instability of the type of decay of a light wave of frequency ω_0 into two plasmons of frequency $\omega_0/2$ in the region of one-fourth the critical density. The resultant parametric turbulence of the plasma leads to generation of a transverse wave of frequency $3\omega_0/2$, either as a result of the coalescence of the incident light wave with the parametrically-excited electron plasma oscillation (the process $l+t \rightarrow t$), or as a result of coalescence of three plasma waves (the process $3l \rightarrow t$). Although the second of these mechanisms is a nonlinear process of higher order of smallness, in a number of cases of practical interest it turns out to be more significant than the process $l+t \rightarrow t$, since the probability of the process $l+t \rightarrow t$ is low because it is impossible to satisfy the resonance conditions with respect to the wavelengths, inasmuch as the wave vector \mathbf{k}_l of the longitudinal plasma waves is much larger than the wave vector $\mathbf{k}_{3/2}$ of the $3\omega_0/2$ harmonic and the wave vector \mathbf{k}_0 of the pump wave, $\mathbf{k}_{3/2} \neq \mathbf{k}_l + \mathbf{k}_0$.

Using the equation for the nonlinear interaction of waves in a plasma^[5] and the expressions^[6] for the turbulence level of the waves in two-plasmon parametric decay, we can obtain the following expression for the energy flux density $q_{3/2}$ in the harmonic $3\omega_0/2$

$$q_{3/2} = 2.3 \cdot 10^{-17} q^{3/2} T_e^{3/2} A \frac{a}{\lambda_0} \left(1 - \frac{1}{p}\right)^2 \left(1 + 1.4 \cdot 10^6 \frac{\lambda_0^2 T_e^2}{za}\right)^{-1/2} \times \left[1 - 78.3 T_e^4 \frac{A^2}{z^3} \left(1 - \frac{1}{p}\right)^4 \left(1 + 1.4 \cdot 10^6 \frac{\lambda_0^2 T_e^2}{za}\right)^{-1}\right]. \quad (1)$$

Here $q_{3/2}$ and q are measured in W/cm^2 , the electron temperature T_e in keV, while the pump wavelength λ_0 and the characteristic dimension a of the plasma-density inhomogeneity at a quarter the critical density are measured in cm, A and z are the atomic weight and charge of the target material, $p^2 = q/q_{\text{thr}}$ is the excess of the pump-wave flux over the threshold of parametric two-plasmon instability.^[7] In^[8], the average flux density was less than the threshold value ($q \approx 10^{13} \text{ W}/\text{cm}^2$). This explains why the $3\omega_0/2$ harmonic was not generated under the conditions of^[8].

The first term of (1) is due to the process $l+t \rightarrow t$, and the second to $3l+t$. The spectrum of the $3\omega_0/2$ harmonic consists of two (red and blue) satellites shifted by

$$\delta\omega_{3/2} \approx 4.8 \cdot 10^{-3} T_e \omega_0 |\cos \theta|, \quad (2)$$

where θ is the angle between the vectors $\mathbf{k}_{3/2}$ and \mathbf{k}_0 , while T_e is in keV. Formula (2) enables us to determine T_e directly from the spectrum of the $3\omega_0/2$ harmonic. Bearing in mind the Doppler frequency shift due to the hydrodynamic expansion of the plasma, the shift of the satellites can be determined from the value of half the distance between the peaks. Since the mean value of the angle

is $\theta \approx 120^\circ$, we obtain according to (2) $T_e = 1$ keV. At this temperature, the average multiplicity of the ionization of the glass target ($A = 20$) is $z \approx 9.6$. Using the experimentally obtained transformation coefficient, we determine from (1) the characteristic dimension $a \approx 10^{-2}$ cm of the density inhomogeneity. At the obtained plasma parameters, the threshold of the two-plasmon decay is $q_{\text{thr}} \approx 5 \times 10^{13}$ W/cm² and $p^2 \approx 2$. We find then that the first and second terms of (1) are of the same order of magnitude, i. e., the processes $l+t \rightarrow t$ and $3l \rightarrow t$ are equally probable. At large pump fluxes, the process $2l \rightarrow t$ is the principal one.

¹Generation of the $3\omega/2$ harmonic was investigated in^[2-4] for the case of sharp focusing of the heating radiation on a flat target.

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