Change in the scattering spectrum of laser radiation in a plasma in the transition from spontaneous to stimulated Mandel'shtam-Brillouin scattering

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(Submitted June 17, 1975)
Zh. Eksp. Teor. Fiz. 69, 2056–2058 (December 1975)

The spectrum of radiation scattered by ion-sound plasma oscillations is obtained under conditions when the power density of the laser radiation is close to the threshold value for stimulated Mandel'shtam-Brillouin scattering. An additional maximum arises in the longwave range of the scattering spectrum when the laser power exceeds the threshold value. The width of the additional maximum indicates that the damping of the stimulated oscillations is weak. When the threshold power is exceeded severalfold, the intensity of the scattered radiation exceeds that of scattering by thermal oscillations by 15–20%.

PACS numbers: 52.25.Ps, 42.60.Nj

We have observed earlier [1] that when the threshold conditions for stimulated Mandel'shtam-Brillouin scattering (SMBS) are satisfied an increase is observed in the intensity of the light scattered by a plasma in comparison with the level corresponding to scattering from thermal fluctuations. Changes in the spectrum of the scattered radiation were recorded in the present work in the transition from spontaneous to stimulated scattering, i.e., under such conditions when the power density of the pump wave is close to threshold. We observed the scattering of light of a ruby laser $\lambda = 6943$ Å with a power of about 30 MW, the radiation of which was focused in the plasma to a spot of diameter 0.2 mm. The construction of the resonator enabled us to select the longitudinal oscillations modes of the plasma radiation. The wave vectors of the incident and scattered radiation were mutually perpendicular. The spectrum of the scattered radiation was recorded by means of an instrument of high resolving power, consisting of a monochromator, Fabry-Perot interferometer and an electron-optical converter. As in the previous work, [1] we recorded the scattering spectra from the plasma of a laser spark in air at different instants of time after the plasma production. The scattering spectrum was obtained by averaging the spectral contours corresponding to the different orders of the interference picture.

Figures 1 and 2 show the radiation spectra (by the dashed curves) scattered by the ion-sound oscillations of the plasma. In these drawings, the solid curves 1 indicate the theoretical contours corresponding to the thermal ion-sound oscillations in an isothermal plasma. [2] In the construction of the contours 1, instrumental broadening due to the recording apparatus is taken into account. The width and shape of the instrumental contour were determined experimentally. The excellent agreement of the experimental and theoretical contours in Fig. 1 indicates that spontaneous scattering takes place in the given case. In Figs. 2a and 2b the experimental and theoretical contours agree within the limit of error of the experiment only in the shortwave region of the spectrum. In the longwave region, an increase is observed in the intensity of the scattered light in comparison with the thermal level, exceeding the error of experiment. This increase in intensity is due to the appearance of an additional maximum in the longwave region of the spectrum under the influence of the field of the light wave. The additional maximum, obtained as the difference between the experimental and the theoretical curve 1, is shown by the dashed curves in Figs. 2a and 2b. The results of calculations, given below, show that the density of the power of the laser radiation, at which the additional maximum is observed, is in excellent agreement with the threshold value for the SMBS process. The plasma parameters which characterize the conditions under which the spectra shown in Figs. 1 and 2 are obtained are given in the table.

The values of the electron concentration n_e and of the temperature T of the charged particles are obtained from measurement of the areas and widths of the scattering contours shown by the curves 1 in Figs. 1 and 2.

The threshold power density, calculated from the measured values of n_e and T according to the formula

$$P_{\text{thr}}\,(\text{W/cm}^2) = 6.75\cdot 10^{-7}\, n_e(\text{cm}^{-3})/T\,(\text{eV}), \qquad (1)$$

is given in the fourth column of the table. Formula (1) is obtained from the following expression, which holds on the boundary of instability: [3]

$$r_E^2/r_D^2 = 16\,\gamma\gamma_s/\omega_0\omega_s, \qquad (2)$$

where r_E is the amplitude of the vibrations of the electron in the field of the light wave, r_D is the Debye radius

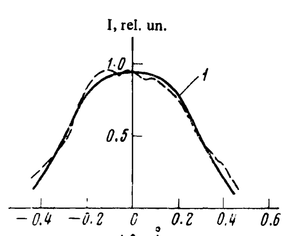

FIG. 1. Scattering spectrum: 1—calculated contour of spontaneous scattering. The parameters of the curves are given in the Table.

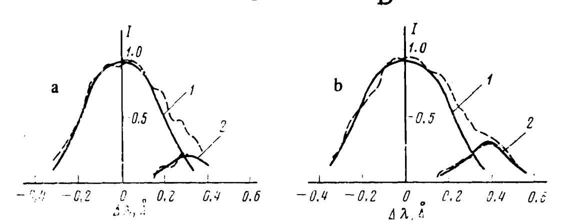

FIG. 2. Scattering spectra: 1—calculated contours of spontaneous scattering; 2—instrumental contours of the recording apparatus. The parameters of the curves of Figs. 2a and 2b are given in the table.

	n_e, cm^{-3}	T, eV	P_{thr}, W/cm^2	P/P_{thr}	$\Delta W/W_T$	ω, sec^{-1}	ω_s, sec^{-1}
Fig. 1	$2 \cdot 10^{17}$	2,3	$8.9 \cdot 10^{10}$	0.75	0	–	$5 \cdot 10^{10}$
Fig. 2, a	$5 \cdot 10^{16}$	1.0	$3.4 \cdot 10^{10}$	2.7	0.13	$12 \cdot 10^{10}$	$3.4 \cdot 10^{10}$
Fig. 2, b	$5 \cdot 10^{16}$	1.35	$2.9 \cdot 10^{10}$	4.5	0.2	$15 \cdot 10^{10}$	$3.9 \cdot 10^{10}$

of the electrons, $\tilde{\gamma}$ and ω are the damping decrement and the frequency of transverse waves, γ_s and ω_s are the damping decrement and the frequency of the ion-sound waves. It is assumed that $\gamma_s \sim \omega_s$ in an isothermal plasma.

The ratio of the power density of the laser radiation to the threshold value calculated from (1) is given in the fifth column of the table. It is seen from the table that the scattering contour shown in Fig. 1 is obtained at a pump-wave power density below threshold. For the curves shown in Figs. 2a and 2b, the power density of the pump wave is several times the threshold value. Here the increase in the intensity of the scattered radiation $\Delta W/W_T$ is equal to the ratio of areas of the additional maximum in the longwave region of the spectrum and the curve 1, and amounts to about 15–20%.

In the last two columns of the table, we have the frequency of the induced ion-sound oscillations, determined from the shift in the additional maxima in the scattering spectrum, and the frequency of the ion-sound vibrations $\omega_s = k\sqrt{T/M_i}$ (here $k = 1.28 \times 10^5$ cm^{-1} is the length of the wave vector, equal to the difference in the wave vectors of the incident and scattering radiation, M_i is the mass of the nitrogen ion).

It follows from the dispersion equation for perturbations in a plasma located in the field of the light wave[3] that the frequency of stimulated oscillations for the case of an isothermal plasma, near the SMBS threshold, exceeds the ion-sound frequency by a factor of about $1/kr_D$. For plasma with parameters $n_e = 5 \times 10^{16}$ cm^{-3} and $T = 1$ eV, we have $1/kr_D = 2.3$. According to the experimental data, an increase in the threshold value of the power by severalfold increased the frequency of the stimulated oscillations above the ion-sound frequency by a factor of 3.5–8.3.

The shapes of the additional maxima of the scattering spectra are in excellent agreement with the instrumental shape of the recording apparatus. (The instrumental contours are shown in Figs. 2a and 2b by the curves 2.) This indicates that the real width of the spectrum of the excited oscillations is small, as it should be in the case of weak damping of the stimulated oscillations.

In conclusion, the authors express their gratitude to Professor V. E. Golant for interest in the research, and to A. D. Piliya and V. I. Fedorov for discussion of the results of the experiment.

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Translated by R. T. Beyer
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