Observation of transient field oscillations in the radiation of stimulated Mandel'shtam-Brillouin scattering

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The transient amplitude and phase oscillations of stimulated scattering due to the noise of this effect were observed.

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1. Stimulated scattering radiation is caused by the exponential buildup of the startup (spontaneous) noise in a frequency band and solid angle that are determined, respectively, by the relaxation time τ of the refractive index perturbations and by the geometric dimensions of the region of nonlinear interaction.[1,2] Because of this, the noise properties should appear in the stimulated scattering radiation. Nevertheless, despite a large number of spectral investigations,[3-5] no variation of the stimulated scattering field that is random in time has been observed experimentally. At the same time, the random oscillations of the scattered radiation associated with the noise of this effect, can exert a significant influence on the optical radiation based on stimulated scattering, which has been widely investigated recently (see, for example, Ref. 6).

We have established the conditions for observing and detecting the transient oscillations of the stimulated Mandel'shtam-Brillouin scattering (SMBS) field. Amplitude modulation of the field was recorded both in the absence of transverse modes of the amplified Stokes radiation and in their presence. By using a mixing of two independently scattered light beams we also observed phase modulation of the stimulated scattering radiation.

The second harmonic of the radiation of a single-frequency neodymium laser with diffraction-limited divergence was used for the pumping in all the experiments ($d_p = 2.5$ mm, $t_p = 25$ nsec). The oscillograms were recorded with an FEK-13 photocell and an I2-7 oscilloscope (resolution time ~1 nsec).

2. The noise of the scattered radiation can be easily detected in the absence of its transverse modes (Fig. 1a). In the field of a single-mode, collimated pumping beam the spontaneous noise builds up in a frequency bandwidth $\Delta\omega = 2/(\sqrt{M})\tau$ and a solid angle determined by the ratio of the diameter of the pumping beam to the length of the scattering medium ($M = 25$ is the total stimulated scattering increment). A spatially incoherent Stokes radiation can be produced if the scattering layer is sufficiently short.[7] However, the length of the ordinary giant laser pulses ($t_p \approx 20$–30 nsec) exceeds the correlation time $\tau_{\rm cor} = 2(\sqrt{M})\tau$ of the SMBS radiation by a comparatively small factor. This leads to the fact that the time-averaged transverse intensity distribution of the Stokes radiation has a rather sharply defined spatially nonuniform structure, rather than a smeared one.

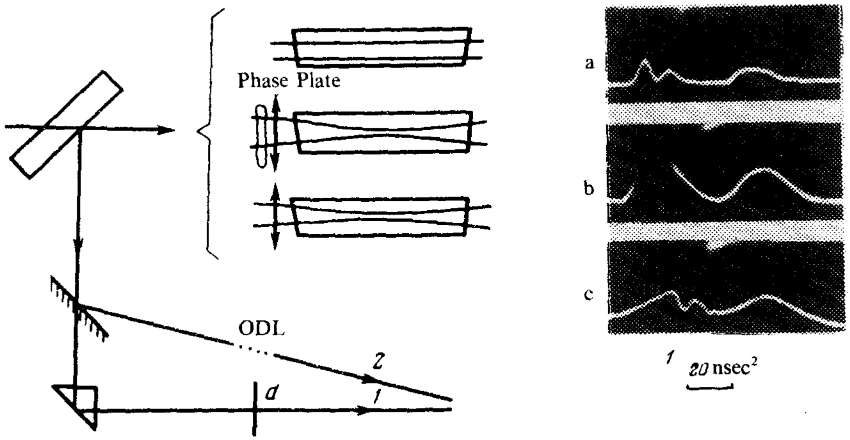

FIG. 1. The photodetector receives Stokes radiation that was transmitted through 0.5-mm-diam diaphragm *d* (1) and the power integrated over the beam cross section is supplied through the optical delay line (ODL) (2).

The statistical properties of the scattered wave can be evaluated from the variation of the transverse structure of the beam during the pulse.

To investigate the statistics of the Stokes radiation, the latter was fed to the photodetector through a diaphragm whose diameter approximately matched the transverse field inhomogeneity. Although the Stokes pulse integrated over the beam cross section was always smooth, we observed random oscillations in the radiation transmitted through the diaphragm (Fig. 1a). This indicates that there is a random variation of the transverse distribution of the scattered-wave field during the pulse. The number of oscillations is consistent with the estimate of the formula $t_p/\tau_{\rm cor}$. Thus, the Stokes radiation was spatially incoherent under the conditions of this experiment.

3. To investigate the influence of spatial selection on the transient characteristics of the Stokes radiation, we focused the laser beam on an acetone-filled cell and placed a phase plate (PP) in its path, which increased the divergence to $\sim 6\times 10^{-3}$ rad (Fig. 1b). Under these conditions we achieved an inversion of the Stokes radiation wavefront, and the oscillograms in beams 1 and 2 were always identical (Fig. 1b). This indicates that the scattered radiation is spatially coherent when the increments of the amplified Stokes modes are discriminated. In this experiment we could observe the amplitude modulation of the radiation near the stimulated scattering threshold, which is attributable to fluctuations of the spontaneous startup noise power (Fig. 2).

4. It is interesting to note that the intensity oscillations without a phase plate (Fig. 1c) were observed in the field of a single-mode, focused pumping beam of approximately the same power as the radiation transmitted through the diaphragm, although these oscillations were missing in the power integrated with respect to the beam cross section.[1] An increase of the stimulated scattering threshold, which was considerably greater in this case than in the previous one, was equal to a factor of 30 to 200. The

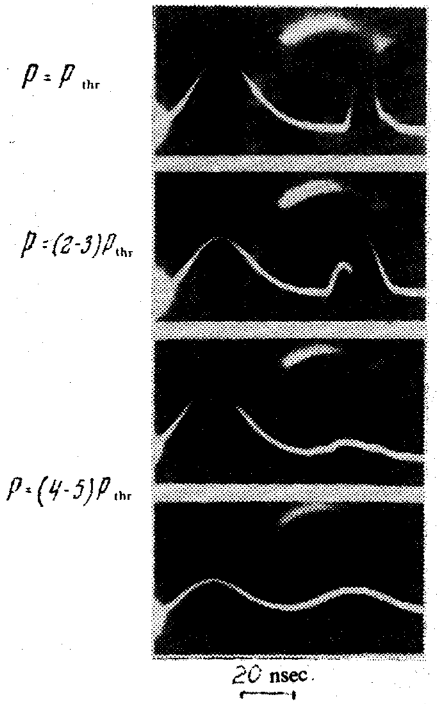

FIG. 2. Time dependences of the power integrated over the beam cross section of the incident (first pulse) and scattered (second pulse) radiation. After the stimulated scattering threshold is exceeded, we can see the amplitude oscillations of the Stokes radiation power, which gradually smooth out with further increase in the pumping level due to saturation effects.

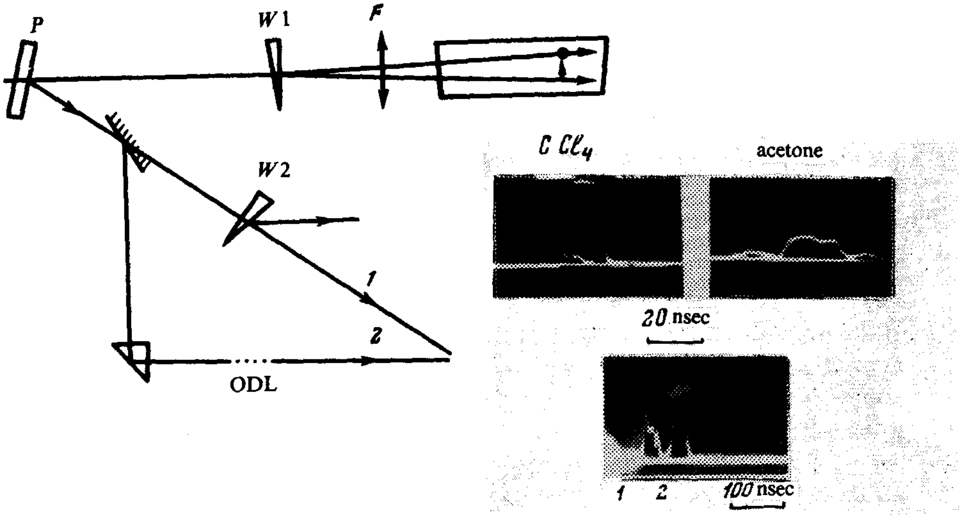

FIG. 3. The upper photographs show oscillograms of the polarized part of the Stokes radiation. The lower photograph is an oscillogram of the Stokes pulse in one (1) and both (2) polarizations for SMBS in acetone.

transverse distribution of this intensity of the Stokes radiation in the near and far zones was also different from that when the phase plate was used by the presence of a ring around the central core that contained (according to the photometry data) not more than 15% of the energy. The obtained results indicate that, in addition to the fundamental mode, there is at least one more transverse mode with independent transient field oscillations in the scattered radiation. The origin of this mode can be attributed to inadequate discrimination of the increments of the amplified Stokes modes in the neighborhood of the focal constriction of the lens, which may be due to a distortion of the spatial distribution of the pumping compared to the Gaussian distribution, because of the enhancement of the stimulated scattering threshold or aberrations introduced by the optical elements. The absence of oscillations in the integral power of the Stokes wave is apparently due to the averaging, which actually reduces to a summing of the powers of the two modes.

5. At the same time, the random phase modulation in the Stokes radiation is preserved under these conditions. To observe it, we split the laser beam into two beams by using the birefringent spar wedge *W* 1 (Fig. 3). After their focusing ($F = 66$ cm) in a cell ($L = 20$ cm) with acetone or carbon tetrachloride (the beams did not cross in the cell), two scattered Stokes waves with orthogonal polarizations were excited. Since the phases of these waves oscillated independently, the scattered waves, after combining in the spar wedge *W* 1, formed a light beam with a polarization state that varied randomly with time. A part of this beam, which was divided by a splitter plate *P* oriented almost normally to it, was fed to a photodetector through the second spar wedge *W* 2 (first pulse) and the optical delay line (ODL) (second pulse). As a result, the phase modulation of the scattered radiation was converted into an amplitude modulation. The corresponding oscillograms (Fig. 3) indicate that this modulation is random with respect to time, and, as comparative studies of the SMBS in carbon tetrachloride and acetone showed, the shorter is the hypersound relaxation time, the smaller is the modulation scale.

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[1)] Occasionally, a random modulation was observed near the stimulated scattering threshold in the integral, scattered radiation power, but this modulation was hardly ever observed when the threshold was exceeded, although the scattered pulse was lengthened to the pumping pulse.

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