

DURATION OF THE STOKES SIGNAL AT STIMULATED MANDELSHTAM BRILLOUIN SCATTERING OF A XeCl LASER BEAM

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The possibility of SMBS appearance during a pulse of a pumping beam was studied experimentally for a XeCl laser ($\tau_{1/2} = 80$ ns). Duration of the Stokes signal depends on absorption of non-linear medium. Duration of the Stokes signal is $\tau_{1/2} \sim 15$ ns with heptane, $\tau_{1/2} \sim 70$ ns with SF₆. Disturbances in phase synchronism of SMBS process seem to be the most probable cause of small duration of the Stokes signal.

Development of laser systems using wave front inversion due to SMBS is one of the ways to obtain high beaming for eximer lasers. It is well-known that pulse duration of eximer lasers can vary from tens to hundreds nanoseconds. However, all the investigations devoted to SMBS of eximer laser beams and corresponding WFI realizations were mainly performed for radiation pulse duration at the amplitude half-height not more than $\tau_{1/2} \sim 15$ ns.¹⁻⁵ Wave front inversion of a XeCl laser beam with pulse duration $\tau_{1/2} = 35$ ns was studied in Ref. 6. Here, duration of the Stokes signal also did not exceed 15 ns. Shorter duration of the pulse scattered by non-linear medium was explained⁶ by threshold conditions of the SMBS process. In all the papers mentioned above, liquids (heptane, hexane, ethanol, etc.) were used as non-linear media.

In this paper, SMBS possibility during the pulse of the pumping beam is studied experimentally for a XeCl laser with duration at the amplitude half height $\tau_{1/2} = 80$ ns.

Figure 1 presents the optical systems used in our experiments. A laser system consisting of three electric discharge XeCl lasers was studied in the case presented in Fig. 1a. One of the lasers acted as a controlling generator, the second one operated in the regime of injective synchronization, the active volume of the third laser served as an amplifier. The controlling generator formed a diffraction beam with spectral line width of $(0.01 - 25)$ cm⁻¹.⁷ The beam was injected into the unstable generator of the second laser through a convex mirror with reflection factor $R = 80\%$ and radius of curvature $r = 134$ cm. A plane mirror with super-Gaussian profile of reflection factor⁸ was used as the second mirror of the resonator. Resonator magnification was $M = 7$. The laser guaranteed a radiation pulse of duration $\tau_{1/2} = 80$ ns with energy of 80 mJ and width of spectral line corresponding to the injected signal. About a 60% of laser radiation energy was contained in the diffraction angle. The output laser radiation was collimated by lens 9 and then

passed through the polarization diplexer into the active medium of the amplifier with active volume of $3.5 \times 2.5 \times 70$ cm³. Duration of the excitation pulse of the amplifier was 140 ns. After passing the amplifier, the beam was focused to the cuvette with non-linear medium 14 (heptane or gaseous SF₆ under pressure of 9 atm). Beam intensity inside the cuvette varied from $5 \cdot 10^7$ W/cm² to 10^{10} W/cm² due to variation of the focal length of the lens 13.

In the case presented in Fig. 1b, we used only the last laser with a plane-parallel resonator formed by a quartz plate and semitransparent mirror ($R = 20-50\%$). From the side of the quartz plate, laser radiation was focused into the non-linear medium (heptane). The experiment aimed to study radiation characteristics in the optical path between the cuvette and laser, and after the semitransparent mirror, depending on the degree of feedback between the non-linear medium and semitransparent mirror. The feedback was varied by disadjustment of the quartz plate.

The shape of the radiation pulses was displayed by the photodiode FEK22-SPU and oscillograph 6LOR. Radiation energy was measured by the measurer IMO-2N, spectral line width by the interferometer IT28-30 and spectrograph STE-1. Radiation divergence was determined by energy that passed through gauged diaphragms in the focal spot of the lens 15 with focal length 8 m.

Figure 2a demonstrates the shape of radiation pulses of pumping beam, Stokes signal, and radiation passed through the non-linear medium for experiments with heptane according to the optical system of Fig. 1a. Amplitude modulation of the pumping beam is caused by concurrence of transverse modes in the unstable resonator of the second laser.⁹ For the whole interval of intensities of pumping beam in the region of its amplitude maximum, intensity of the Stokes signal sharply decreased (approximately by a factor of 10^2), and pulse duration did not exceed 15 ns at the half-height of its amplitude. Variation of the spectral line width in fact did not influence on the temporal shape of the Stokes signal. Since the pumping beam has a fast

leading edge of the pulse ~ 5 ns, the delay time of the Stokes signal only insignificantly reduces the duration of its leading edge.

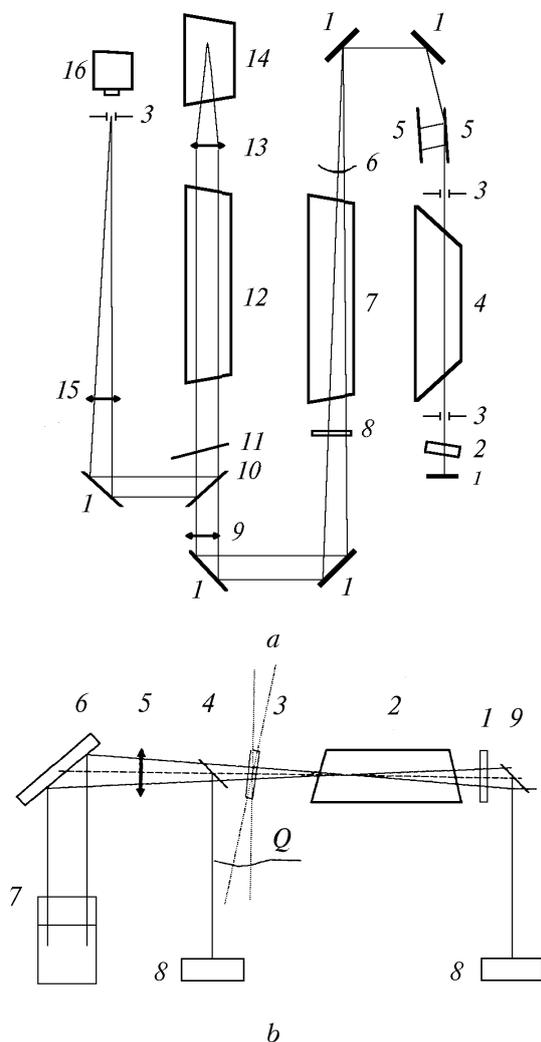


FIG. 1. Optical schemes of the experiment; a: aluminum mirror (1); Fabry-Perot etalon, $h = 10$ mm (2); diaphragm $\varnothing 1.5$ mm (3); active medium of XeCl lasers (4), (7), (12); diffraction grating 2400 slit/mm (5); meniscus with mirror plating (6); super-Gaussian mirror (8); lens, $F = 9$ m (9); pellicular polarizer (10); $\lambda/4$ -plate (11); lens, $F = 1$ m (13); cuvette with non-linear medium (14); lens, $F = 10$ m (15); photoreceiver (16); b: mirror, $R = 30\%$ (1); active medium of the XeCl laser (2); plane-parallel quartz plate (3); separating quartz plate (4), (9); lens, $F = 1$ m (5); aluminum mirror (6); cuvette with non-linear medium (7); photoreceiver (8).

Small duration of the SMBS pulse could be explained by appearance of another concurring type of stimulated scattering, e.g. STS. However, this type of scattering arises under intensities considerably higher than 0.1 GW/cm^2 see Refs. 4 and 5 and, as shown in Ref. 5, can exist parallel with SMBS and

does not disturb it but only reduces its share with the increase of pumping intensity.

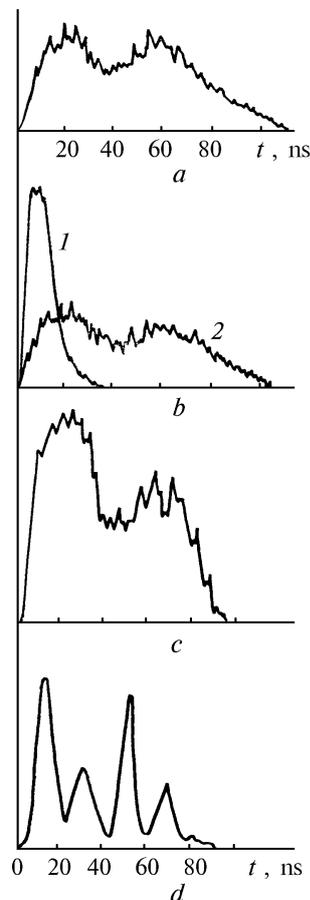


FIG. 2. Temporal behavior of pumping beam radiation pulses before the cuvette (a) and after passing the cuvette with heptane (b, curve 2), Stokes signal in use of a cuvette with heptane (b, curve 1) and SF_6 (c), and one of laser beams formed in the optical scheme of Fig. 1b (d).

Disturbance of phase synchronism of the SMBS process due to variation of the refractive index of the medium with its heating¹⁰ can be another cause. The heating can take place due to linear and two-photon absorption of pumping radiation by the non-linear medium. Estimation of the two-photon absorption coefficient at pumping intensity $I \leq 0.1 \text{ GW/cm}^2$ yields rather small value $\gamma = 0.03 \text{ cm}^{-1}$. According to our measurements, the coefficient of linear absorption of heptane is $\alpha = 0.053 \text{ cm}^{-1}$. The limiting absorption coefficient for $\lambda = 308 \text{ nm}$ at which phase synchronism can be disturbed was calculated in Ref. 4. Its value is $\alpha \sim 0.1 \text{ cm}^{-1}$.

Thus, disturbance of phase synchronism of the SMBS process due to absorption of pumping radiation by non-linear medium is the most probable cause of small duration of the Stokes signal.

In connection with this hypothesis, heptane was changed in our experiments by SF₆ whose linear coefficient is $\alpha = 0.0007 \text{ cm}^{-1}$. In this case SMBS threshold was reached at intensity $I_{\text{thr}} = 0.18 \text{ GW/cm}^2$, and intensity of 75 GW/cm^2 in the focal neck caused an optical breakdown in gas. As seen from Fig. 2, the situation changed significantly. Duration of the Stokes signal increased up to 70 ns at the amplitude half-height, and its shape was in fact similar to that of the pumping beam pulse. The scattered pulse has a stronger amplitude modulation connected, in our opinion, with threshold character of SMBS. The coefficient of SMBS reflection by the medium of the pumping beam is ~50%.

Using the non-linear medium of SF₆, we realized WFI of the beam with conservation of its almost whole pulse duration. WFI accuracy calculated as $K = K_s(\theta_d)/K(\theta_d)$, where $K_s(\theta_d) = E_s(\theta_d)/E_s$ and $K(\theta_d) = E(\theta_d)/E$ are the parts of energy of Stokes radiation and pumping beam in the diffraction angle θ_d , is 70%. In observing the mask image in radiation of the Stokes signal, the image was not very clear what indicates the presence of a non-inverted component in the Stokes signal.

In Ref. 11 we demonstrated the possibility of repeated scattering of a short pulse by heptane. In connection with this, we used heptane in experiments on obtaining a train of Stokes pulses during the whole duration of the pumping pulse. The optical system is presented in Fig. 1b. In the case of an adjusted laser resonator, the non-linear medium scattered one short pulse whose duration was $\tau_{1/2} \sim 15 \text{ ns}$. After disadjustment of the quartz plate by an angle $Q \sim 3 \text{ mrad}$, the feedback between the non-linear medium and semitransparent mirror begins to predominate in the concurrence between light flows. In heptane there begins an alternate operation of two spaced regions. An initially formed Stokes signal of spectral line width $\sim 0.3 \text{ cm}^{-1}$ (Ref. 12) by-passes the resonator and focuses itself already in an other place in heptane. Being scattered repeatedly and acquiring the Brillouin frequency displacement $\sim 0.3 \text{ cm}^{-1}$, it by-passes the resonator and returns into the initial region of heptane being reflected again and undergoing the frequency shift. Alternation of regions in the non-linear medium with continued variation of signal frequency makes it possible to reflect a train of short pulses from heptane

during the pumping pulse of duration about 100 ns. At the laser output, one can display two beams placed at angle Q with respect to each other. It is a train of pulses (Fig. 2d). With further disadjustment of the resonator, we come to the situation which was described in Ref. 11: a train of pulses which were formed initially from spontaneous noises of the active medium of the laser without the quartz plate is formed at the output of the laser. The total energy of the laser decreases here by several fold.

Thus, in this paper we demonstrate that duration of the Stokes signal at SMBS of a XeCl laser depends on absorption of the non-linear medium. Using media with small absorption coefficient ($\alpha \sim 0.0007 \text{ cm}^{-1}$), one can preserve the SMBS process during the whole pumping pulse ($\sim 80 \text{ ns}$). In absorbing media ($\alpha \sim 0.05$), it is possible to realize repeated scattering of a short Stokes pulse ($\tau_{1/2} \sim 15 \text{ ns}$) and form a train of these pulses during the whole pumping beam pulse.

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