Mechanism of contraction of the light pulse duration in stimulated Mandel'shtam-Brillouin scattering and the generation of nanosecond pulses

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The time and energy characteristics of light pulses in stimulated Mandel'shtam-Brillouin scattering (SMBS) are sutdied under specific conditions when scattering is induced in the solution of a saturable dye and the SMBS generator and amplifier are decoupled by a saturable filter. Under these conditions a series of short pulses with varying repetition times is obtained; under certain conditions single high-intensity pulses with a duration of less than 2 nsec may be obtained. A qualitative physical explanation of the observed phenomena is presented.

1. INTRODUCTION

Stimulated Mandel'shtam Brillouin scattering (SMBS) has been investigated many times in liquids under various conditions, including in liquids and solutions having more or less strong linear absorption[1-3]. The questions mainly studied were the competition between SMBS processes and temperature (entropy) scattering of light, and also the character of the influence of these processes on each other[4,5].

In the present paper we investigate the physical nature of the influence of a saturable dye and feedback on the SMBS characteristics. A pulsed structure is obtained, and also an appreciable shortening of the SMBS pulse duration.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 1. A Q-switched ruby laser radiates pulses with power up to 20 MW, duration ~25 nsec, divergence $\sim 2 \times 10^{-2}$ rad, and spectrum width $\sim 10^{-2}$ cm^{-1}.

The temporal characteristics of the radiation were registered with an I-2-7 oscilloscope (time resolution 1.5 nsec), the energy was measured with a calorimeter. The radiation spectrum was registered with a Fabry-Perot interferometer with a dispersion 0.4 cm^{-1}. The SMBS was excited in the following three systems:

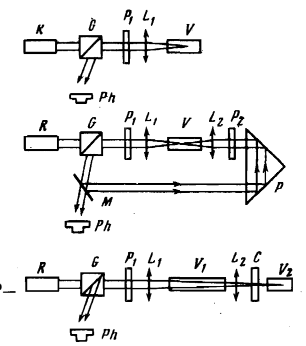

FIG. 1. Systems in which SMBS was excited. R—ruby laser, G—Glan prism, P_1 and P_2—Fresnel rhombs, Ph—oscilloscope input. The elements G and P_1 comprise a polarization shutter that decouples the ruby laser from the scattering volume V. a) Excitation of SMBS in a saturable-dye shutter. Lens focus L_1 = 10 cm. b) System using feedback. The focal length of lenses L_1 and L_2 is 10 cm, the length of vessel V is 14 cm, P—rectangular glass prism, M—semitransparent mirror. c) System with tandem amplification. The focal lengths of lenses L_1 and L_2 are respectively 100 and 8 cm. The lengths of vessels V_1 and V_2 are respectively 45 and 10 cm, the thickness of the cell C is equal to 1 mm.

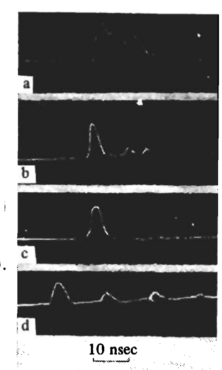

FIG. 2. Oscillograms of the SMBS pulse in a saturable-dye solution; the sequence a→b→c corresponds to increasing dye concentration; d—SMBS pulse in system with feedback (Fig. 1b).

1. Excitation of SMBS in a solution of a saturable dye

The optical system is shown in Fig. 1a. The light of laser R passes through a polarization shutter (G, P_1) and is focused into a vessel V containing a solution of cryptocyanine in methyl alcohol. At light absorption up to 0.1 cm^{-1}, the SMBS pulse is shortened in comparison with the pulse produced when the light is scattered in the pure liquid, but the peak power remains practically the same. When the absorption is increased to 0.15 cm^{-1}, the generation becomes unstable, and modulation appears in the SMBS pulse (Fig. 2a), and 100% amplitude modulation of the SMBS pulse takes place at an absorption ~0.20 cm^{-1} (Fig. 2b). At absorptions ~0.25 cm^{-1}, a single pulse is observed (Fig. 2c), of duration ~2.5 nsec. The conversion coefficient in this case reaches ~0.1 of the laser pulse intensity and ~0.5 of the intensity of the SMBS pulse without an absorber. With further increase of the absorption, the SMBS intensity decreases sharply.

2. System using positive feedback (Fig. 1b)

In this system, part of the SMBS radiation produced in vessel V and emerging through the lateral face of the Glan prism (G) is redirected by semitransparent mirror M and rectangular prism P into the nonlinear-interaction region. At absorptions ~0.25 cm^{-1}, an SMBS pulse is produced in the form of a sequence of short pulses (Fig. 2d). The pulse repetition interval is determined by the length of the optical path in the feedback circuit. In this regime, when the solution in vessel V saturates, an SMBS pulse is produced and passes then several times through the region of nonlinear interaction, becoming amplified in the pump field.

3. System with tandem amplification

In this system (Fig. 1c), the pump-light pulse passes through vessel V_1 without producing SMBS in it. The light then passes through cell C with the saturable filter and is focused into the vessel V_2. Vessels V_1 and V_2 contain pure benzene. The character of the pulse produced in the driving SMBS generator (V_2) can vary, depending on the absorption in the cell C. The oscillograms (Figs. 3a, b, c) show how the waveform of the SMBS pulse varies with the absorption in cell C (the vessel V_1 is removed). In the complete system of Fig. 1c, the gain in the vessel V_1 was made optimal by moving the vessel relative to the lens L_1 (f = 100 cm). At a linear absorption on the order of $\sim 14\ cm^{-1}$ in the cell C, a regime sets in wherein a train of pulses is radiated (Fig. 4a). The interval between individual pulses is determined by the length of the amplifier and is approximately equal to $\tau = 2ln/c$, where l is the length of the vessel V_1 and c/n is the speed of light in the amplifier medium. With increasing absorption, the pulses become narrower (Fig. 4b), and a single-pulse regime is realized at an absorption $\sim 21\ cm^{-1}$ in cell C (Fig. 4c). The duration of the pulse shown in Fig. 4c is ~ 1.5 nsec (i.e., it coincides with the apparatus function of the oscilloscope) at a power ~ 1 MW.

The measurements show that the divergence of the short SMBS pulses decreases by approximately one order of magnitude, reaching 2×10^{-3} rad (the ruby-laser divergence is 2×10^{-2} rad). A typical value of the SMBS-radiation divergence is 5×10^{-3} rad.

Comparison of the SMBS spectra with the ruby-laser pulse shows that one Stokes SMBS component is excited in all the systems described above, and the weak modes that are sometimes present in the spectrum of the exciting radiation do not appear in the scattering. A narrowing of the spectral line of the scattered light in comparison with the spectral half-width of the exciting radiation is observed and is typical of stimulated scattering processes.

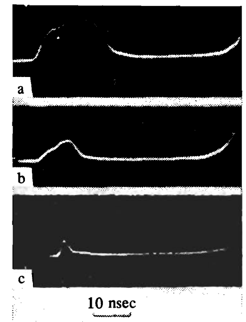

FIG. 3.

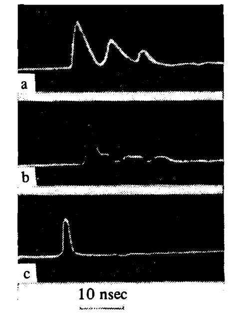

FIG. 4.

FIG. 3. Oscillograms of SMBS pulse in driving generator (Fig. 1c, vessel V_2) as a function of the absorption in the cell C. The sequence a→b→c corresponds to increasing absorption.

FIG. 4. Oscillograms of SMBS pulse in tandem-amplification system (Fig. 1c). The sequence a→b→c corresponds to increasing absorption.

3. DISCUSSION OF RESULTS

The use of a medium with a saturable absorber in this study has made it possible to obtain a tenfold reduction in the duration of the SMBS light pulse in comparison with the duration of this pulse in a transparent medium. A train of SMBS pulses was also obtained at pump intensities lower by one order of magnitude than needed under conditions of a pure liquid[6,7]. The fact that no analytic solution of the nonlinear stationary problem of stimulated scattering in a medium with nonlinear absorber exists also for the case of other experimentally realized conditions does not permit a quantitative comparison of the experimental results with the theoretical deductions.

It is relatively easy to analyze the observed results qualitatively. The kinetics of generation of a train of SMBS pulses (Figs. 4a, b) in the system with tandem amplification (Fig. 1c) can be explained in the following manner.

The pump-light pulse passes through vessel V_1 and, at a definite intensity, bleaches the absorber in cell C. SMBS is then produced in V_2 and propagates in a direction opposite to that of the pump pulse. The SMBS light is amplified in vessel V_1, and the pump light is weakened to such an extent that absorption is restored in the cell C and this stops the SMBS generation in vessel V_2. However, as soon as the SMBS pulse leaves the amplifier V_1, the pump light again bleaches the cell C and again excites SMBS in V_2, which then, as in the preceding case, is amplified in V_1 and a new cycle is thus started. The observed interval between the pulses in the train is approximately equal to $\tau = 2ln/c$, where l is the length of vessel V_1 and c/n is the speed of light in the amplifying medium. The regime in which one SMBS pulse is observed corresponds to single bleaching of the cell C.

When SMBS is excited in a saturable-absorber solution (Figs. 2a, b, c) the mechanism of the modulation of the SMBS pulse is similar to a considerable degree to the mechanism described above. In this case, as the pump light is attenuated in the SMBS process, the bleached part of the region of nonlinear interaction becomes shorter and can diminish to such an extent that the SMBS process is in fact stopped. The pump light that continues to enter bleaches the medium, produces SMBS again, and a new cycle begins. Here, however, no regular sequence of pulses in the train is observed. This qualitative examination shows that an analytic description of the process calls for allowance for the nonlinearity and nonstationarity of the SMBS process, and of the dependence of the absorption on the intensity.

The relatively small value of the coefficient of conversion of pump light into SMBS light is due to the construction of the described experimental installation[1)] and is determined by the losses on the surfaces of the Glan prism ($\sim 30\%$), of the Fresnel rhomb, and others.

In the described method, the pulse duration is limited by the time of establishment of the SMBS process, which for most substances amounts to several nanoseconds. Further nonlinear amplification of the SMBS pulses should lead to a still further shortening of the pulse duration. To obtain much shorter pulses by the described method it is necessary to use stimulated Raman scattering[8] or stimulated Rayleigh line wing scattering[7], the transient times in which are such that attainment of single pulses of picosecond duration becomes realistic.

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[1)] The conversion coefficient can be increased by using a magnetic polarization shutter or the second harmonic, in which case there is no need for the shutter at all.

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