

Slow field fluctuations of the Stokes wave due to SMBS with a wide-band pumping

O. M. Vokhnik and V. I. Odintsov

M. V. Lomonosov Moscow State University

(Submitted 3 March 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 9, 437–441 (5 May 1981)

It was observed experimentally that as a result of generation and amplification of SMBS in the field of a wide-band pumping the Stokes wave, in addition to experiencing rapid fluctuations associated with its spectrum width, also experiences slow fluctuations with a characteristic time determined by the spectrum width of the phonon wave.

PACS numbers: 42.65.Cq

SMBS fluctuations produced as a result of excitation by a narrow-band laser were observed experimentally in Refs. 1–3. The observed fluctuations, which are determined by the spectrum width of the Stokes component $\Delta\omega_S$, have a characteristic scale $2\pi/\Delta\omega_S$. A wide-band pumping produces short fluctuations $2\pi/\Delta\omega_S \ll 1/\Delta\Omega$ because of the large spectrum width of the Stokes wave $\Delta\omega_S \approx \Delta\omega_L \gg \Delta\Omega$ ($\Delta\omega_L$ is the width of the pump spectrum and $\Delta\Omega$ is the width of the thermal-scattering line). We have established experimentally in this letter that, in addition to these fast fluctuations, the SMBS envelope experiences slow fluctuations in the coherent-scattering mode with a characteristic time $\tau > 2\pi/\Delta\Omega$, which is determined by the spectrum width of the phonon wave. The same kind of slow fluctuations of the envelope occur as a result of amplification of the Stokes pulse in an amplifier with a wide-band pumping.

Inverse SMBS was excited in CCl_4 , in benzene and in acetone by radiation from a single-mode ruby laser with a spectrum width of $\sim 0.15 \text{ cm}^{-1}$. The duration of the smooth laser pulse was 30 nsec. The pump radiation was focused by a lens ($f = 15 \text{ cm}$) on a cell of length $l = 22 \text{ cm}$. The diameter of the light spot on the lens was $\sim 3 \text{ mm}$. A 6-meter-long optical delay line was used to decouple the laser from the cell. The work was conducted at a slightly elevated SMBS threshold when the conversion factor to the Stokes component was $\sim 10\%$. The pump intensity in the focal region greatly exceeded the critical intensity I_f . There was no dielectric breakdown in the liquid. The SMBS in CCl_4 was close to a single-mode scattering and consisted of many transverse modes in benzene and acetone. A typical oscillogram of an SMBS pulse in CCl_4 , which was obtained at a pump power $P_L \sim 120 \text{ kW}$, is shown in Fig. 1a. Diaphragming of the light beam in front of the photocell did not increase the modulation depth. Since the decrease in the pulse intensity with increasing distance from the center displaces the peaks, the average spacing τ between them was determined from the "straightened" oscillograms. To do this, their ordinates had to be multiplied by appropriate factors which were determined from the average variation

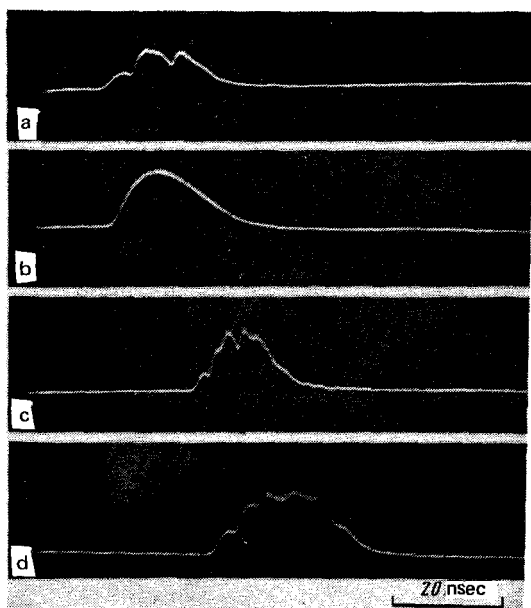


FIG. 1. Oscillograms of the SMBS pulses. (a) Lasing in CCl_4 , (b) lasing in acetone, (c) and (d) amplification in CCl_4 .

of the envelope. We have obtained $\tau = 8.5 \pm 1$ nsec for CCl_4 . The modulation depth for benzene was increased by inserting a small diaphragm in front of the photocell. The interval τ was 15 ± 2 nsec. As a rule, the SMBS pulse in acetone was smooth (Fig. 1b). A weak, second peak occurred rarely on its wings.

When the amplifier was used, the laser beam 1 (Fig. 2) was divided into two beams by a semitransparent mirror 3 after it was transmitted through the delay line 2. One beam was directed to the cell-amplifier 5 with CCl_4 ($l = 22$ cm) and the other was directed to the cell-generator 7 with acetone, which produced almost the same SMBS shift as CCl_4 . The smooth SMBS pulse in acetone (Fig. 1b) was directed to the cell-amplifier 5 in the opposite direction to the pump pulse. The pump power P_L in the amplifier was varied by means of a light filter 4. The pump intensity in the focal region exceeded I_L substantially. The SMBS input signal was attenuated by the light filter 6 in such a way that the power of the amplified signal was much smaller than P_L . The SMBS pulses at the input and output of the amplifier were recorded by the photocells PC.

The oscillograms of the SMBS pulses displayed slow fluctuations after amplification. The interval τ was smaller than that during lasing and it decreased as the pump power was reduced in the amplifier. Typical oscillograms of the amplified SMBS pulses are shown in Fig. 1c ($P_L \sim 20$ kW, amplification factor ~ 10) and in Fig. 1d ($P_L \sim 40$ kW, amplification factor ~ 300).

For a theoretical interpretation of the effect, we shall analyze SMBS in the field

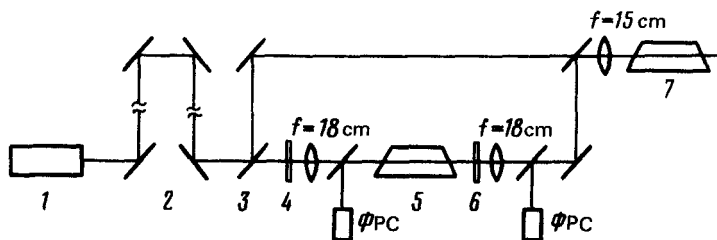


FIG. 2. Schematic of the device for observation of SMBS fluctuations in the amplifier.

of a plane pump wave $E_L(t, z)$. Assuming that SMBS is recorded at a small solid angle θ during lasing, we shall represent the field of the Stokes component in the form $E_S = \int_{(\beta)} d^{(2)}\vec{\beta} \int_0^\infty d\omega_S E_S(\omega_S, \vec{\beta}, z) e^{i[\omega_S t - \mathbf{k}(\omega_S, \vec{\beta}) \cdot \mathbf{r}]}$, where $|\mathbf{k}(\omega_S, \vec{\beta})| = k(\omega_S) = \omega_S n(\omega_S)/c$, n is the refractive index, $\vec{\beta}$ is the $\mathbf{k}(\omega_S, \vec{\beta})$ component at right angles to the z axis; the region $(\vec{\beta})$ is defined by the solid angle θ . We introduce the envelopes A_L and A_S through the relations $E_L = A_L e^{i(\bar{\omega}_L t - k_L z)}$, $E_S = A_S e^{i(\bar{\omega}_S t + k_S z)}$, where $\bar{\omega}_S = \bar{\omega}_L - \bar{\Omega}$, $\bar{\omega}_L$ is the average pump frequency, $\bar{\Omega}$ is the resonance frequency of the phonon wave, and $k_{L,S} = k(\bar{\omega}_{L,S})$. Using the calculation method developed in Ref. 4, we can obtain $A_S(t, \mathbf{r}) = A_L(t - z/u_L) \Phi(t, \mathbf{r})$, at a much higher intensity I_L^c , where $u_L = u(\bar{\omega}_L)$ is the group velocity,

$$\Phi(t, \mathbf{r}) = \int_{(\beta)} F(\beta, t, z) e^{-i\vec{\beta} \cdot \mathbf{r}} e^{-i \frac{\vec{\beta}^2 z}{2k_S}} d^{(2)}\vec{\beta}, \quad (1)$$

$$F(\vec{\beta}, t, z) = C \int_0^\infty d\Omega e^{-i(\Omega - \bar{\Omega}) \left(t + \frac{z}{u_S} \right)} \int_{-\infty}^\infty dq_z p^*(\Omega, -\vec{\beta}, q_z) \frac{e^{-\kappa z} e^{i\Delta z}}{\kappa + i\Delta}. \quad (2)$$

In the last expression C is a constant, $u'_S = u_S/k_S \sqrt{k_S^2 - \vec{\beta}^2}$, $u_S = u(\bar{\omega}_S)$, $p(\Omega, -\vec{\beta}, q_z)$ is the Fourier pressure amplitude determined by thermal fluctuations, $\kappa = 1/2g + i\rho/1 + \rho^2$, $g = bI_L$, b is the specific gain at the frequency $\omega_L - \bar{\Omega}$ due to monochromatic pumping, and $\rho = 2(\Omega - \bar{\Omega})/\Delta\Omega$, $\Delta = q_z - k_L - \sqrt{k^2(\bar{\omega}_L - \Omega) - \vec{\beta}^2}$. The reference point $z=0$ is at the right-hand boundary of the medium.

It can be seen from Eq. (1) that a coherence region must be isolated in order to observe the fluctuations Φ . The power spectrum of the random function Φ , which determines the characteristic fluctuation time, is given by

$$J_\Phi(\Omega, z) = \frac{k_B T \bar{\omega}_S}{2\pi \lambda_S^2 \Omega} \left(\exp \frac{G}{1 + \rho^2} - 1 \right) \theta, \quad (3)$$

where k_B is the Boltzmann constant, $G = -gz > 0$, and λ_S is the length of an SMBS wave in the medium. The J_Φ distribution in Ω repeats the spectrum of the excited

phonon wave and $I_{\Phi} = \int_0^{\infty} J_{\Phi}(\Omega, z) d\Omega$ determines the average intensity of the SMBS $I_S = n_S/n_L I_L I_{\Phi}$. At $G \gg 1$ the J_{Φ} dependence on Ω has the shape of a Gaussian curve with the width $\delta\Omega = \Delta\Omega\sqrt{\ln 2/G}$. It follows from the theory of random functions⁵ that $\tau = 5.54/\delta\Omega$. Thus τ is determined only by the spectrum width of a phonon wave $\delta\Omega$. The values of τ , which were calculated by using the known values of $\Delta\Omega$ at $G = 27$, are 9.3, 17.2, and 29.6 nsec for CCl_4 , benzene, and acetone, respectively. They are in good agreement with the experiment for CCl_4 and benzene. The value of τ for acetone is much larger than the width of the SMBS pulse, which accounts for the absence of ripples in the oscillograms if the small modulation depth is taken into account.

If an amplifier is used, assuming that $E_S = E_S^0 + \tilde{E}_S$, where E_S^0 is the field of the input signal, we can obtain $\tilde{A}_S = A_L \Phi$ for the \tilde{A}_S envelope at a much higher I_L^e , where the Φ function varies slowly with t . In the absence of a correlation between E_S^0 and E_L its power spectrum for $\exp(1/2 G) \gg 1$ has the form

$$J_{\Phi}(\Omega, z) = \frac{n_L}{n_S} \frac{I_S^0}{I_L} \left(\exp \frac{G}{2(1+\rho^2)} - 1 \right)^2 \int_0^{\infty} \eta_S^0(\omega_S) \eta_L(\omega_S + \Omega) d\omega_S,$$

where I_S^0 is the intensity of the input signal, and η_S^0 and η_L are the spectra of the input signal and pumping, which are normalized to unity. At $G \gg 1$ $\delta\Omega$ and τ are expressed the same way as in the case of lasing. As I_L increases τ increases by $\sim \sqrt{I_L}$, consistent with the experimental data.

1. V. I. Bespalov, A. A. Betin, G. A. Pasmanik, and A. A. Shilov, *Pis'ma Zh. Eksp. Teor. Fiz.* **31**, 668 (1980) [*JETP Lett.* **31**, 630 (1980)].
2. M. V. Vasil'ev, A. L. Gyulamiryan, A. A. Mamaev, V. V. Ragul'skiĭ, P. M. Semenov, and V. G. Sidorovich, *Pis'ma Zh. Eksp. Teor. Fiz.* **31**, 673 (1980) [*JETP Lett.* **31**, 634 (1980)].
3. N. G. Basov, I. G. Zubarev, A. B. Mironov, S. I. Mikhailov, and A. Yu. Okulov, *Pis'ma Zh. Eksp. Teor. Fiz.* **31**, 685 (1980) [*JETP Lett.* **31**, 645 (1980)].
4. V. I. Odintsov, *Optika i spektroskopiya* **50**, 374 (1981).
5. V. I. Tikhonov, "Vybroso sluchainykh protsessov," (Emissions of Random Processes), Nauka, Moscow, 1970.

Translated by S. J. Amoretty

Edited by Robert T. Beyer