Stimulated Mandel'shtam-Brillouin scattering in an external transverse cavity

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We present the results of an experimental investigation of the spectral and time characteristics of stimulated Mandel'shtam-Brillouin scattering (SMBS) in an external transverse cavity, which indicate that the SMBS components are self-synchronized.

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In this paper we report the results of our experiments which show that self-synchronization of the components of stimulated Mandel'shtam-Brillouin scattering (SMBS)[1] is possible in an external trasverse cavity which is a laser emitting a train of picosecond light pulses.

1. SMBS was excited by a light of ~ 30 nsec duration from a 100-MW ruby laser. A container made from a section of a tube with an outside diameter of 3 cm and 5.5 cm in length and filled with a dispersive nonlinear medium was placed inside the cavity formed by a flat and a spherical (radius of curvature 15 cm) mirrors with reflection coefficients of 100% and $\sim 90\%$, respectively. Acetone and ethyl ether were used as scatterers. The exciting light, which was linearly polarized in a perpendicular plane to the scattering plane, was focused by a cylindrical lens ($f \sim 6$ cm) into the container; the generator of lenses was oriented parallel to the axis of the cavity. The spectrum of light of the SMBS emitted by the cavity was analyed by a Fabry-Perot interferometer with a dispersion region of 2.5 cm^{-1}, and the time-dependent characteristics were investigated by using a coaxial photoelectric cell connected to a I2-7 oscillograph or a ÉOK-2 electron-optical camera with a time resolution of ~ 10 psec.[2]

2. Under the described conditions of the experiment, we observed up to 13 components of the SMBS in the spectrum of light emitted by a SMBS laser (Fig. 1a). The time scanning of this spectrum (Fig. 1b), obtained with ÉOK-2 electron-optical camera, shows that each successive SMBS component appears 1–2 nsec after the preceding one. The intensity of each SMBS component increases rapidly (in 0.5 nsec) to a maximum, then decreases slightly and during the remaining times of development of the process remains approximately constant, differing little from the intensity of the other components (Fig. 1c). The oscillogram of spectrally undecomposed light shows a barely resolved, equidistant time structure with a scattering between the maxima of 200–300 psec. The time scanning of this radiation using the ÉOK-2 electron-optical camera showed (Fig. 2) that it is a regular sequence of pulses of duration $\leqslant 40$ psec with a spacing of ~ 220 psec between them. This distance coincides with the period of the hypersonic wave in acetone, which is generated at an angle of $\theta = 180°$ as a result of SMBS.[1]

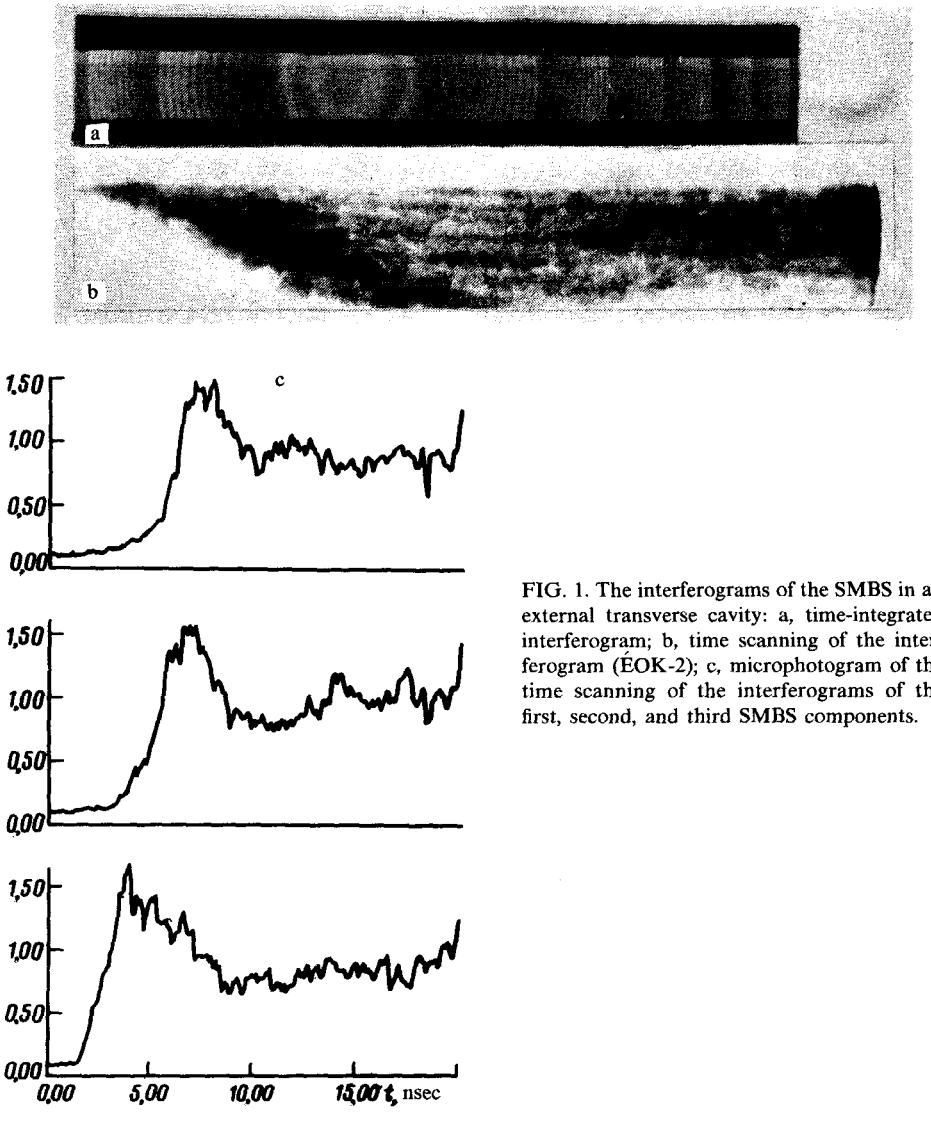

FIG. 1. The interferograms of the SMBS in an external transverse cavity: a, time-integrated interferogram; b, time scanning of the interferogram (ÉOK-2); c, microphotogram of the time scanning of the interferograms of the first, second, and third SMBS components.

The described results observed by us were frequently repeated in the experiments. The time and spectral characteristics of SMBS did not vary as a result of varying the distance between the mirrors of the cavity from 6 to 9.5 cm. We believe that the results cited above give us reason to assume that self-synchronization of the SMBS components occurs in the external transverse cavity. In this case the duration τ of the emitted pulses should be $\tau \sim 1/N\Omega_{\text{MB}}$, where N is the number of synchronized components and Ω_{MB} is the shift of the SMBS components.

3. The synchronization of the cavity modes was observed experimentally in the case of stimulated scattering of light of the wing of the Rayleigh line[3] and a result of

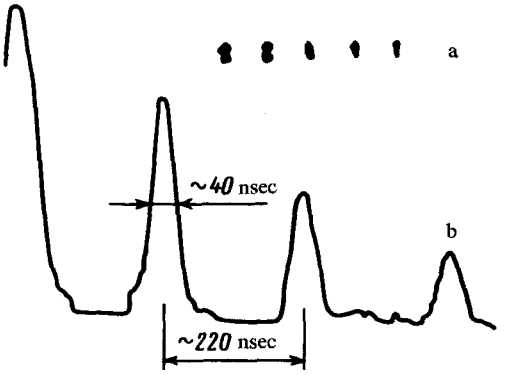

FIG. 2. (a) Time scanning of SMBS emission obtained by using ÉOK-2 and (b) its microphotogram (the difference in intensities of the pulses in the microphotogram is due to the nonuniform sensitivity of the ÉOK-2 screen.

SMBS in long light pipes.[4] In both cases the synchronization of modes occurred within the limits of the amplification band of each type of light scattering. The synchronization of the SMBS components and of the components of stimulated Raman scattering of light (SRS) was discussed theoretically many times in the literature.[5,6] It was shown in the theory developed by Lugovoĭ *et al.*[5] that synchronization of the SMBS components may occur if a nonlinear absorber is placed inside the cavity. In our experiments we observed for the first time a synchronization of the SMBS components in pure liquids in the absence of a nonlinear absorber and, in contrast to Ref. 4, when the distance between the cavity modes was greater than the amplification band width of the SMBS.

To explain purely qualitatively the conditions under which a synchronization of the SMBS components cannot occur and those under which it can occur, initially we shall assume that the dependence of the refractive index on the electric field of the light wave can be disregarded. In our experiments we observed a generation of successive SMBS components corresponding to the scattering angle $\theta = 180°$. It follows from the energy and momentum conservation laws that the frequency ω_l and the wave vector $\mathbf{k}_l$ of the lth component are related to the frequency and the wave vector of the $(l+1)$th SMBS component by the relations $\omega_l = \omega_{l+1} + \Omega_l$ and $\mathbf{k}_{l+1} + \mathbf{q}_l$, where Ω_l and $\mathbf{q}_l$ are the frequency and the wave vector of the lth hypersonic wave. If all the successive SMBS components are equidistant ($\Omega_l = \Omega_{\mathrm{MB}}$), then taking into account the preceding expressions we obtain

$$\Delta q_e = q_l - q_{l+1} = 2n\Omega_{\mathrm{MB}}/c, \tag{1}$$

where c is the velocity of light. The quantity $\Delta q_l(\mathrm{cm}^{-1})$ exceeds significantly the width of the Mandel'shtam-Brillouin components. The fact that Δq_l are nonvanishing means that each SMBS component is generated in the Debye heat wave whose phase is not connected in any way with the phases of the other heat waves in which the other SMBS components are produced. Because of this, the light of the different SMBS components has different random phases which cannot interfere effectively, and hence there is no synchronization of the SMBS components.

A synchronization of the SMBS components observed in our experiments prob-

ably indicates that there is a mechanism which produces a common hypersonic wave ($\Delta q_l = 0$) for all the SMBS components. The nonlinear dependence of the medium's refractive index on the electric field of the light wave, specifically due to electrostriction, is the only mechanism in our case that is capable of satisfying the condition $\Delta q_l = 0$ and hence $k_l = k_{l+2}$.

If this is true, then we can expect that a coherent cascade production of components can occur in one wave of the molecular vibrations in the case of SRS in a dispersive nonlinear medium. In the latter case, light pulses $< 10^{-13}$ sec in duration may appear as a result of synchronization of the SRS components.

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