Stimulated Mandel'shtam-Brillouin scattering in CdS crystals due to buildup of acoustic phonons

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Stimulated Mandel'shtam-Brillouin scattering in CdS crystals of a piezosemiconductor under conditions of acoustic-phonon buildup is investigated. It is shown that for sufficiently large amplification factors the stimulated scattering threshold decreases by several orders of magnitude.

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Stimulated Mandel'shtam-Brillouin scattering (SMBS) was investigated in many crystals and liquids.[1–6] The threshold intensity of light, necessary for development of

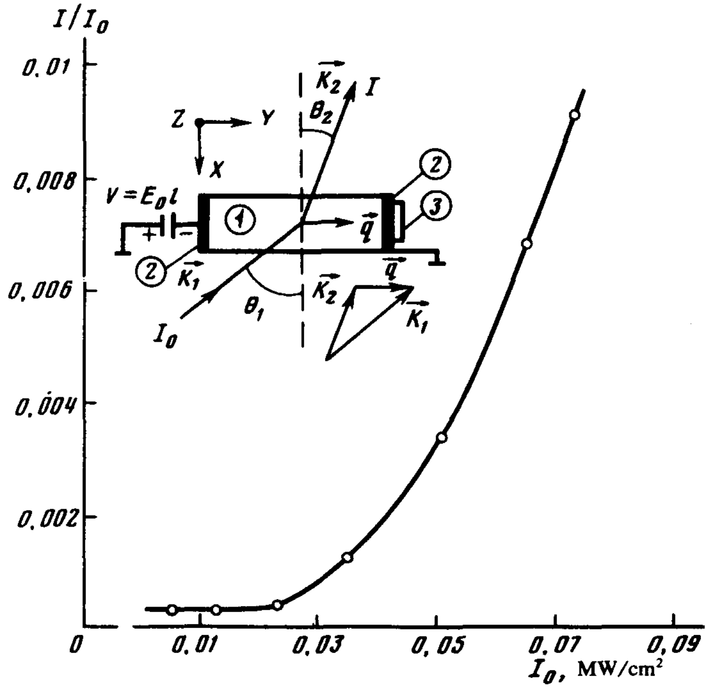

FIG. 1. Dependence of the relative intensity of scattered light on the intensity of incident light. Experimental arrangement: 1, cadmium sulfide sample 5 mm in length; 2, indium electrodes; 3, piezoelectric converter; $\mathbf{k}_1$, $\mathbf{k}_2$, $\mathbf{q}$ are the wave vectors of incident and scattered light and of the acoustic waves, respectively. The frequency of acoustic waves is 250 MHz.

the time instability of the SMBS process in the running-wave mode, can be estimated from the formula[1,2]

$$I_0^* = A \frac{\lambda_0 c (\alpha_a + \alpha_c)^2}{M_2 \nu} . \tag{1}$$

Here λ_0 is the wavelength of light, c is the velocity of light, ν is the frequency of acoustic phonons that participate in the scattering, α_a and α_c are the absorption coefficients of the acoustic and light waves, respectively, and M_2 is the acousto-optical Q factor expressed as $M_2 = p^2 n^6/\rho v^3$, where p is the photoelastic constant, n is the refractive index, ρ is the density, and v is the velocity of the elastic waves. The coefficient A in order of magnitude is $A \approx 0.1$ and its exact value depends on the manner in which the threshold is determined (we shall use the value $A = 0.1$ in our subsequent estimates). It follows from Eq. (1) that for the usual acoustic phonon frequencies ($\nu \approx 10^{10}$ Hz) for the SMBS and for the usual absorption coefficients of the crystals ($\alpha_a \approx 100$ cm^{-1}, $\alpha_c \lesssim 1$ cm^{-1}) the threshold, $I_0^* \approx 10^3$ MW/cm^2, is determined primarily by absorption of the acoustic phonons. When the acoustic losses are compensated for and even replaced by a buildup, as is the case, for example, in piezosemiconductors, due to hypersonic carrier drift in the external electric field E_0, the SMBS thresh-

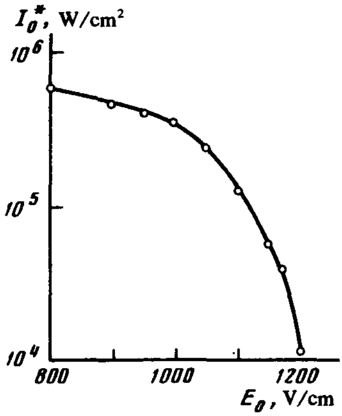

FIG. 2. Dependence of the SMBS threshold on the electric field of the drift E_0.

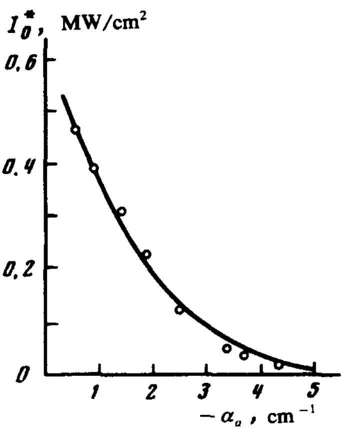

FIG. 3. Dependence of the SMBS threshold on the amplification factor of acoustic waves. The solid curve was plotted assuming an exponential dependence.

old must decrease substantially. This problem was examined in a number of papers,[7-10] but was not investigated experimentally.

In this paper we report the results of experiments on SMBS in a photoconductive CdS crystal (point group C_{6v}). Such crystals, which are almost insulators in darkness, must be irradiated in order to obtain in them an effective acousto-electron interaction. The samples used by us had a conductivity of $\sim 5\times 10^{-4}\ \Omega^{-1}\,\mathrm{cm}^{-1}$ and carrier mobility of $\sim 200\ \mathrm{cm}^2/\mathrm{sec\ V}$ after exposure. The scattering geometry was selected in such a way that the piezoactive, transverse, acoustic phonons propagating in the basal plane with polarization along the $C(Z)$ axis could participate during the scattering process. Investigations of SMBS were performed in a noncollinear geometry in which the acoustic phonon frequency did not exceed 1000 MHz. Note that a backward-scattering geometry is usually used in studying SMBS, but the efficiency of electron-phonon interaction decreases sharply in photoconductive cadmium sulfide crystals at the frequency of backward scattering ($\sim$13 GHz) and only a small part ($\sim$0.1%) of the lattice absorption of the acoustic phonons can be compensated for in the electric fields E_0. At the same time, at frequencies $\nu \lesssim 10^9$ Hz the lattice absorption can be fully compensated for and a pure buildup of the acoustic waves can be obtained.

In our experiments we used a Q-switched ruby laser ($\lambda_0 = 0.694\ \mu$m) with a pulse duration of $\sim 5\times 10^{-8}$ sec. The experimental arrangement is shown in Fig. 1. The investigations were performed at acoustic wave frequencies of 250 to 1000 MHz (the frequency was determined by the angles θ_1 and θ_2). The results obtained at different frequencies turned out to be qualitatively similar, and below we give data only for the frequency of 250 MHz.

The experiment showed that without a bias field E_0 (the field is applied in the form of pulses 10 μsec in duration) SMBS does not occur in the crystal up to $I_0 \sim 10$ MW/cm^2 with an irradiation and without it (at large I_0 there was local damage of the crystal apparently due to light absorption by the defects). SMBS was observed, however, in irradiated crystal when the field E_0 was applied simultaneously, although only in the Stokes scattering geometry. SMBS was recorded from a sharp increase in the intensity of the scattered light and from the acoustic pulse which was excited in the SMBS process and received by the piezoelectric converter (Fig. 1). The SMBS threshold is defined as the laser intensity at which the relative intensity of the scattered light increases by a factor of 5 as compared with that of the background due to elastic scattering processes (Fig. 1). The dependence of I_0^* on the bias field E_0 is shown in Fig. 2.

To determine the dependence of the threshold I_0^* on the amplification factor, we performed independent measurements of the amplification factors for the acoustic waves introduced into the crystal by means of the piezoelectric converter. These measurements were performed by using the acousto-optical method and a helium-neon laser. Special attention was given in this case to determining the possible influence of the ruby laser on the electric parameters of the sample and hence on the amplification factor. It is known that a high-power radiation of a ruby laser due to two-photon absorption processes may increase the carrier density; however, measurements of the amplification factor with a simultaneous action of the ruby laser showed that it does not change noticeably at laser intensities lower than ~ 1 MW/cm^2. The dependence of I_0^* on the amplification factor measured in this way is shown in Fig. 3 in which it can be seen that the threshold decreases exponentially with increasing amplification factor.

At $E_0 = 0$ the absorption of acoustic waves in an irradiated crystal is determined almost entirely by the electron-phonon interaction and for our frequencies amounts to $\alpha_a \approx 30$ cm^{-1}. If we use Eq. (1), the SMBS threshold turns out to be $I_0^* \approx 3\times 10^3$ MW/cm^2. Thus, the SMBS threshold decreases by several orders of magnitude in the electric field E_0 at which the absorption is replaced by a buildup.

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