AMPLIFICATION OF SOUND IN n-InSb IN A TRANSVERSE MAGNETIC FIELD

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The coefficient of sound absorption by carriers moving under the influence of an external electric field in a piezoelectric semiconductor is determined, in accordance with the linear theory [1, 2], by the following expression (one-dimensional case):

$$\alpha_{el} = \alpha_0 \frac{\gamma\omega\tau_M}{(1+\omega^2\tau_L^2)^2 + \gamma^2\omega^2\tau_M^2}, \qquad (1)$$

where

$$\alpha_0 = 4{,}34\,\frac{4\pi\beta^2}{\epsilon\rho v_{ac}^2}\,\frac{\omega}{v_{ac}} = 8{,}68\,\frac{k^2}{2}\,\frac{\omega}{v_{ac}}\ (\text{dB/cm})$$

β - effective piezoelectric coefficient in the propagation direction, ε - dielectric constant, $\tau_M = \varepsilon/4\pi\sigma$ - Maxwellian relaxation time, σ - conductivity, ρ - density, $\rho_L = R_{scr}/v_{ac}$, R_{scr} - screening radius, v_{ac} - speed of sound, ω - sound frequency, $\gamma = 1 - (v_{dr}/v_{ac})$, v_{dr} - drift velocity, and K- coefficient of electromechanical coupling.

It is seen from [1] that when $v_{dr} > v_{ac}$ the absorption of sound gives way to amplification. In CdS, CdSe, GaAs and in other materials, the mobility is $u \approx 10^2 - 10$ cm^2/V-sec and the threshold field is $E \approx 10^2 - 10^3$ V/cm. In n-InSb with electron density $n = 10^{14}$ cm^{-3} we have $u \approx 6 \times 10^5$ cm^2/V-sec (at T = 78° K), and therefore sound amplification should take place already in a field E = 0.5 V/cm. However, owing to the small value of the electromechanical coupling coefficient ($K^2/2 \approx 7 \times 10^{-4}$ in InSb compared with 1.8×10^{-2} in CdS), α_{el} in n-InSb is a small fraction of the lattice absorption of sound α_{lat}, and has no effect.

Placing the sample in a transverse magnetic field changes the ratio of α_{el} and α_{lat} [3, 4]. In a strong transverse magnetic field ($uH/c^2 \gg 1$) we have $\sigma \sim \sigma_0/(uH/c)^2$, and therefore the quantity τ_M, and consequently also α_{el}, increases strongly. We know of no experimental observation of this effect, in spite of its undisputed interest.

We investigated the dependence of α_{el} in n-InSb on the electric and magnetic fields. We used for the measurements a piezoelectrically active shear wave propagating in the [110] direction with polarization along [001] ($v_{ac} = 2.26 \times 10^5$ cm/sec). Samples of suitable orientation were cut from n-InSb single crystals with $n = 1.1 \times 10^{14}$ cm^{-3} and $u = 6 \times 10^5$ cm^2/V-sec (T = 78° K) in the form of right parallelepipeds measuring 6 x 6 x 15 mm. Lithium niobate piezoelectric converters were glued to the plane-parallel and optically-polished bases of the samples. To excite the sound, radio pulses with frequency f = 400 -- 800 MHz, approximate duration 2 μsec, and repetition frequency 25 Hz were applied to one of the bases. After passing through the sample and reconversion, the sound pulses were amplified and detected with a superheterodyne receiver and observed on an oscilloscope screen. A drift-voltage pulse with amplitude V up to 20 V, duration 10 μsec, and repetition frequency 250 Hz was applied to the sample in the [110] direction.

The radio-pulse generator was triggered by a controlled-dealy circuit, so that the delay

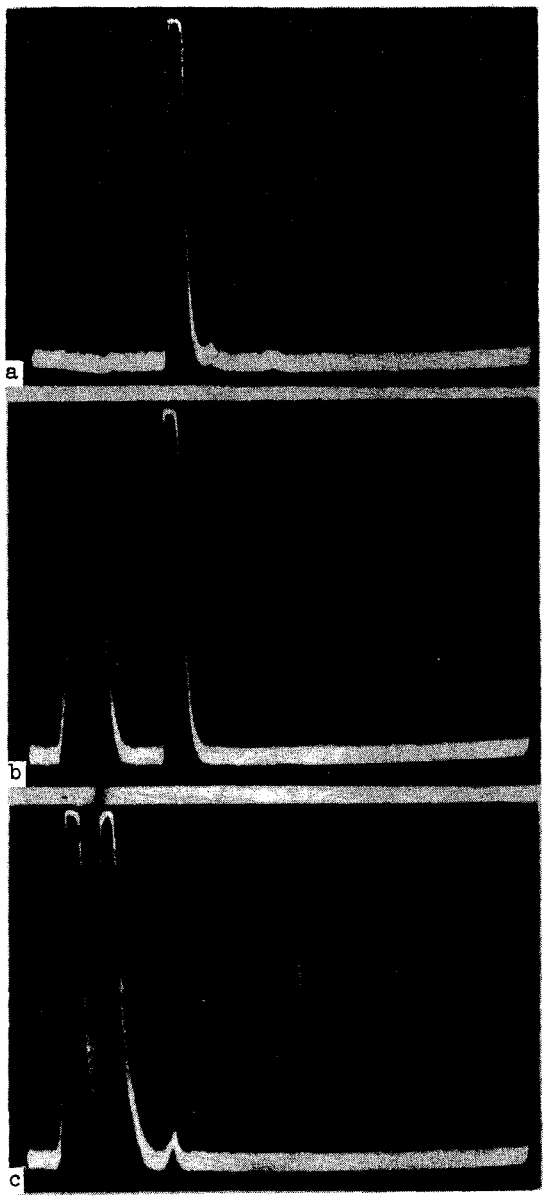

Fig. 1. a) The sound and drift-field (V = 20 V) pulses are fully separated in time, H = 0, there is no attenuation of sound or amplification of noise. b) Relative position of pulses the same, H = H_{opt} = 4000 Oe, a strong attenuation of the sound pulses and an intensification of the noise in the drift field is observed. c)H = H_{opt} = 4000 Oe, optimal coincidence of pulses in time. (The constant-amplitude pulse shown in all the photographs is a stray pulse.)

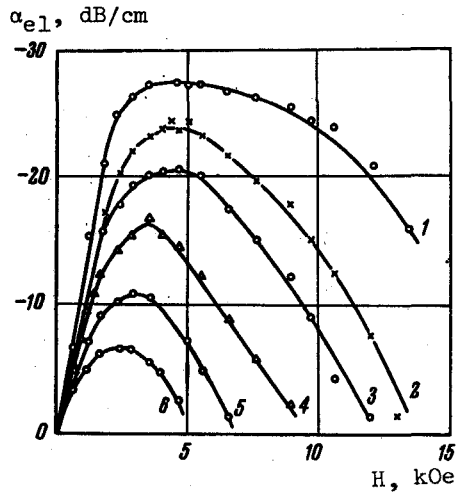

Fig. 2. Gain α_{el} vs. H at different values of V = 20 V(1), 15 V(2), 13 V(3), 10 V (4), 8 V(5), and 6 V(6).

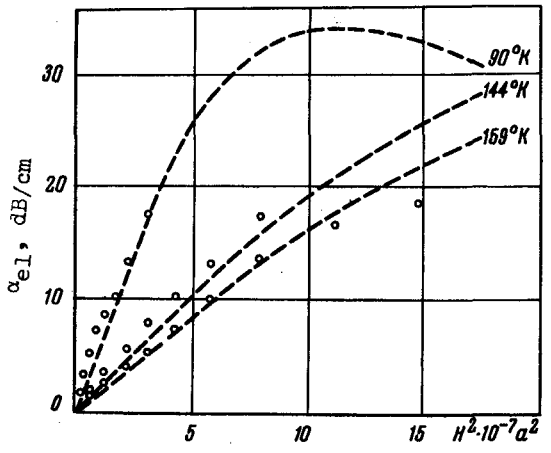

Fig. 3. Dependence of the absorption α_{el} on H^2 at different temperatures.

of the sound pulse relative to the drift pulse could be varied. The intensity of the magnetic field could be smoothly varied from 600 to 13500 Oe.

The dependence of α_L on H was measured in the temperature interval 78 -- 300° K, and the dependence of the amplification of the sound on E and H was investigated at 78° K.

Figure 1 shows oscillograms of the sound pulse (f = 620 MHz) passing through the sample under different conditions. An appreciable intensification of the sound (40 dB) is observed at H = 4000 Oe and V = 20 V (Fig. 1c).

The measured dependence of the sound amplification on H at different values of the external field is shown in Fig. 2 (α is given in decibels relative to the initial sound signal, f = 620 MHz). The curves for f = 420 and 520 MHz have a similar form. The maximum gain changes approximately in proportion to the frequency.

For a comparison with formula (1), these data have to be recalculated with allowance for the dependence of v_{dr} on H.

When H < 2500 Oe and the gain is small, such a recalculation leads to satisfactory agreement with theory. At larger H, when the gain is large, deviations appear, caused apparently by the reaction of the amplified sound signal on the amplification process.

Therefore, better agreement with formula (1) can be expected in an investigation of the dependence of α_{el} on H^2 in the absence of a drift field. The $\alpha_{el}(H^2)$ curves for a number of temperatures corresponding to the region of impurity conductivity are shown in Fig. 3. We see that the dashed curves, calculated using the value $K^2 = 1.4 \times 10^{-3}$, agree satisfactorily with experiment.

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STIMULATED SCATTERING IN RUBIDIUM VAPOR

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In [1] we reported observation of stimulated electronic Raman scattering and stimulated resonance-line emission in potassium vapor. In this paper we present the results of an investigation of the action of intense optical radiation on vapor of another alkali metal - rubidium.

We observed stimulated three-photon scattering under conditions close to resonance. A frequency $2\omega_{inc} - \omega_{at}$ appeared in this case in the spectrum, where ω_{inc} - frequency of incident radiation, and ω_{at} - frequency of the resonant transition $5S_{1/2} - 5P_{3/2}$ in rubidium vapor at the anti-Stokes frequency $\omega_{inc} + \Delta a_{at}$, where $\Delta\omega_{at}$ is the difference frequency between the levels $5P_{1/2}$ and $5P_{3/2}$.