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THE TEMPERATURE DEPENDENCES OF THE CHANGES OF THE TRANSVERSE ACOUSTIC WAVES ATTENUATION IN n-InSb DUE TO THE MAGNETIC FIELD

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The changes of the attenuation of the piezoelectrically active shear ultrasonic wave of 428 MHz in the ⟨110⟩ direction of n-InSb single crystals due to the nearly transverse magnetic field of 0.1 – 0.5 T were investigated in the temperature range from 77 to 220 K. The results are in good agreement with the simplified Steele formula. The temperature dependences of the electron concentration and mobility in the absence of the magnetic field are gained from the measured changes of the attenuation and electrical conductivity.

I. INTRODUCTION

The ultrasonic wave in a semiconductor can be accompanied by an electric field which affects the current carriers. On the other hand the carriers contribute in such a case to the attenuation of the ultrasonic wave. The attenuation due to the carriers depends on the electromechanical coupling coefficient and on the concentration and mobility of the carriers, and thus can be influenced by the external fields. This enables in some cases to separate the attenuation on carriers by measuring the attenuation changes due to the external fields, and by comparing the results with the theory it is possible to determine the electromechanical coupling coefficient, or the mobility and concentration of the carriers.

For not too high frequencies of ultrasonic waves in InSb the interaction of electrons with an piezoelectrically active shear ultrasonic wave in the ⟨110⟩ direction is most significant. The influence of the transverse magnetic field on the attenuation of such waves was investigated by Nill and Mc Worther [1] in the temperature range 4 – 20 K for the frequency of 9 GHz, by Drichko et al. [2] at 77 K for the frequencies of 400 – 800 MHz, and by Smith et al. [3] at 296 K for the frequencies of 10 – 200 MHz. On the basis of their ultrasonic measurements these authors determined the following values of the component e_{14} of the piezoelectric tensor: 0.060 ± 0.005 Cm^{-2} [1]: 0.08 Cm^{-2} [2]: 0.076 ± 0.010 Cm^{-2} [3]. By other methods Arlt and Quadelflieg [4] got $e_{14} = 0.071 \pm 0.007$ Cm^{-2}, and Arnaud and Quentin [5] obtained the value of 0.079 ± 0.008 Cm^{-2}.

The present paper deals with the investigation of the attenuation changes caused by the magnetic field of 0.1 – 0.5 T in the temperature range 77 – 220 K and the experimental results together with the measured electrical conductivity are used for the determination of the mobility and concentration temperature dependences in the above mentioned temperature range, taking $e_{14} = 0.076$ Cm^{-2}.

II. EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

The changes of the attenuation of the 428 MHz piezoelectrically active shear wave in the ⟨110⟩ direction due to the magnetic field were measured from the amplitude change of the second acoustic echo by the "Matec ultrasonic comparator, model 9000". Sample I had the length 1.71 cm in the ⟨110⟩ direction and a cross section area of 0.797 cm^2 in the (110) plane. Its electrical conductivity at 77 K was $2 \times 10^3\ \Omega^{-1}\mathrm{m}^{-1}$. Sample II had the length of 1.25 cm, a cross section area of 0.879 cm^2 and an electrical conductivity of $3.9 \times 10^3\ \Omega^{-1}\mathrm{m}^{-1}$. The opposite (110) faces of each sample were ground and polished flat to $< 1\ \mu$m.

The measured attenuation changes $\Delta\alpha$ at 77 K versus the magnetic induction B are plotted in Fig. 1. The full lines are computed according to the formula

$$\Delta\alpha = \frac{e_{14}^2\omega^2}{2v_s^3\sigma_0}\,\frac{\mu_0^2B^2}{1 + \mu_0^2B^2\cos^2\vartheta}, \qquad (1)$$

where ω and v_s are the angular frequency and the velocity of the ultrasonic wave, respectively, $\sigma_0 = en_0\mu_0$ is the electrical conductivity, n_0 and μ_0 are the electron concentration and mobility in the absence of the magnetic field, ϱ is the crystal density, and ϑ is an angle between the vector $\boldsymbol{B}$ and the direction of ultrasonic wave propagation. The relation (1) comes from the formula derived by Steele [6] under the conditions

$$\cos^2\vartheta \ll 1,\quad \omega^2 \ll \omega_R\omega_D,\quad \omega_R \gg \omega\,\frac{1 + \mu_0^2B^2}{1 + \mu_0^2B^2\cos^2\vartheta}, \qquad (2)$$

where $\omega_R = \sigma_0/\varepsilon$, $\omega_D = ev_s^2/\mu_0kT$.

We used the following values of quantities in (1): $\omega = 2\pi \times 4.28 \times 10^8$ sec^{-1}, $v_s = 2.28 \times 10^3$ msec^{-1}, $\varrho = 5.8 \times 10^3$ kgm^{-3}, $e_{14} = 0.076$ Cm^{-2} [3]. Using the experimental value $\sigma_0 = 2 \times 10^3\ \Omega^{-1}\mathrm{m}^{-1}$ we have determined $\mu_0 = 52.7$ m^2/Vsec, $n_0 = 2.37 \times 10^2{}_1m^{-3}$, $\vartheta = 88^0 32'$ for sample I to fit the expe-

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rimental magnetic field dependence at 77 K, and similarly for sample II we have found: $\mu_0 = 27.2\ \mathrm{m^2/Vsec}$, $n_0 = 8.96 \times 10^{20} m^{-3}$, $\vartheta = 88^\circ$.

The experimental values of $\Delta\alpha$ for $B = 0.476$ T versus temperature are plotted in Fig. 2. The experimental temperature dependences of the electrical conductivity of samples I and II are shown in Fig. 3, and in Fig. 4 there are the temperature dependences of μ_0 and n_0 computed from formula (1) by the use of experimental values of $\Delta\alpha$, σ_0 and the angles ϑ determined from the magnetic field dependences of $\Delta\alpha$ at 77 K.

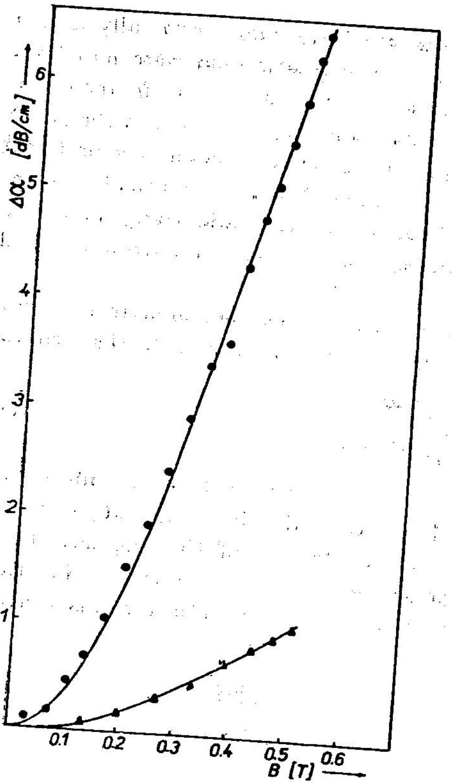

Fig. 1. The magnetic field dependences of the attenuation changes at 77 K for sample I (●), and sample II (▲).

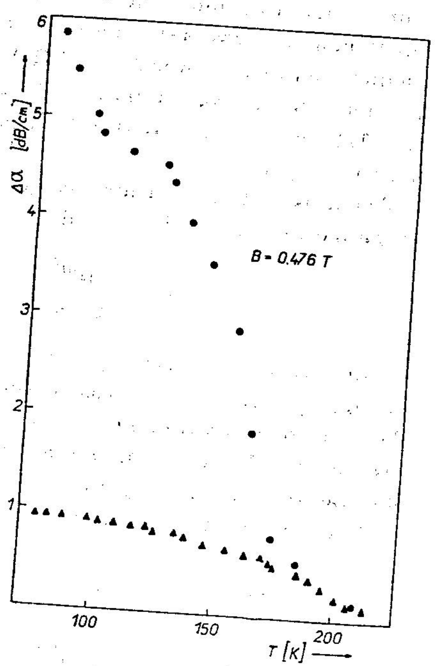

Fig. 2. The temperature dependences of the attenuation changes due to the transverse magnetic field $B = 0.476$ T for sample I (●), and sample II (▲).

III. CONCLUSION

We have shown that for the change of the piezoelectrically active shear ultrasonic wave attenuation due to the magnetic field in n-InSb the simple formula (1) of Steele's theory can be used if the conditions (2) are fulfilled. From the magnetic field dependence of $\Delta\alpha$ at 77 K a comparatively accurate determination of the angle between the vector $\boldsymbol{B}$ and the direction of the ultrasonic wave propagation can be done. Then from the measured values of $\Delta\alpha$ and σ_0 the electron concentration and mobility can be determined without the Hall measurements being necessary. This may be an advantage if we are interested in the mean values of these quantities in rather large samples of an arbitrary cylindrical shape with an axis in the $\langle 110 \rangle$ direction (or the $\langle 111 \rangle$ direction for a longitudinal wave), where the measurement of the Hall voltage would be difficult.

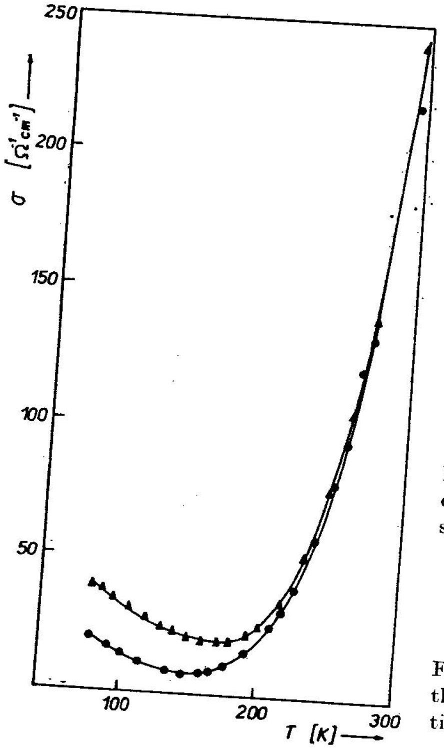

Fig. 3. The temperature dependences of the electrical conductivities at zero magnetic field for sample I (●), and sample II (▲).

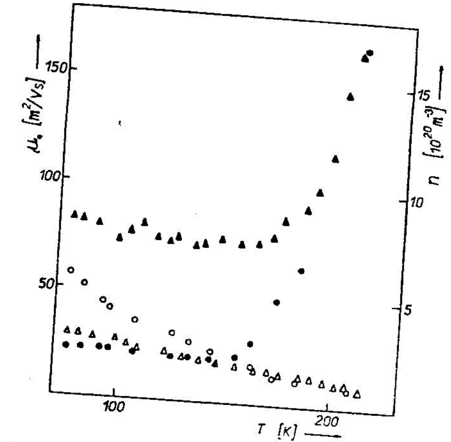

Fig. 4. The temperature dependences of electron concentration and mobility, respectively, for sample I (●), (○), and for sample II (▲), (△).

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