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THE TEMPERATURE DEPENDENCE OF MAGNETOPHONON EFFECT IN n-InSb BELOW 90 K

D.Kusterle, Research and Development Institute, "Sava" Kranj
Z.Trontelj, Department of Physics, University of Ljubljana

The oscillating behaviour of the magnetoresistance of some semiconducting materials - the magnetophonon effect[1,2] - is due to inelastic resonant scattering of conducting electrons by longitudinal optical phonons from the centre of the Brillouin zone. Peaks of the oscillations as a consequence of the resonant scattering occur when the condition

$$\hbar\omega_o = M\hbar\omega_c \qquad M = 1,2,3,\ldots \qquad 1)$$

is fulfilled. ω_o is the frequency of the optical phonons and $\omega_c = eB/m^*$ is the cyclotron frequency, while B is the applied DC magnetic field, m^* is the cyclotron effective mass, and e is the unit charge.

There are two conditions which must be satisfied for the observation of magnetophonon effect: a) There must be enough excited phonons. b) The separation of the Landau levels must be much greater than the natural width:

$$\hbar\omega_c \gg \Delta E = \frac{\hbar}{\tau} \implies \omega_c\tau \gg 1 \quad \text{or} \quad \mu B \gg 1$$

where $\mu = e\tau/m^*$ is the mobility of the electrons and τ is the momentum relaxation time. The number of the phonons and the mobility of the electrons are temperature dependent; therefore also the amplitude of the magnetophonon effect has to depend on temperature. At high temperatures, there is a great number of excited phonons but the mobility is so small that the relation $\mu B \gg 1$ holds only for the values of B not in agreement with (1) and so the magnetophonon effect is not observable. As the temperature decreases the mobility increases and the magnetophonon effect appears. At lower temperatures the magnetophonon effect disappears because the number of excited phonons becomes very small.

The magnetophonon effect appears again at much lower temperatures but in stronger electric fields while being in the domain of "hot electrons". Due to stronger electric field the energy of the electron system increases. In equilibrium at a nonresonant magnetic fields the energy that electron system gains from the electric field is equal to the energy that system of electrons gives to the crystal lattice by the emission of the acoustical phonons. But at the resonant magnetic fields, when (1) holds, the energy of the system of electrons decreases because of the resonant scattering of electrons by creation of the longitudinal optical phonons. The resistivity at low temperatures depends on the scattering of electrons by the ionized impurities. Scattering is stronger as the energy of the electron system becomes smaller. Then the magnetophonon peaks appear.

The measurements on which we report here are a continuation of our previous measurements on the n-type InSb single crystal[3]. The experimental details are described in the reference 3. The peaks of the second derivative of the resistivity with respect to magnetic field were observed at the following values of the magnetic field: 1.14, 0.85, 0.67, 0.55, 0.47, 0.42 T which correspond to peaks with $M = 3,4,5,6,7,8$. When these values are put into (1) and when the known value of m^* (0.0138 m_e) is used, a good agreement with the measured frequency of optical phonons in n-InSb[4] is obtained, the accurancy of the measurements being considered.

Figure 1 shows temperature dependence of the amplitude of the magnetophonon peaks (maxima in the second derivative of the resistivity with respect to B) for M = 3 and M = 5. As the temperature decreases the amplitude becomes smaller and smaller until it is unobservable at temperatures below about 45 K.

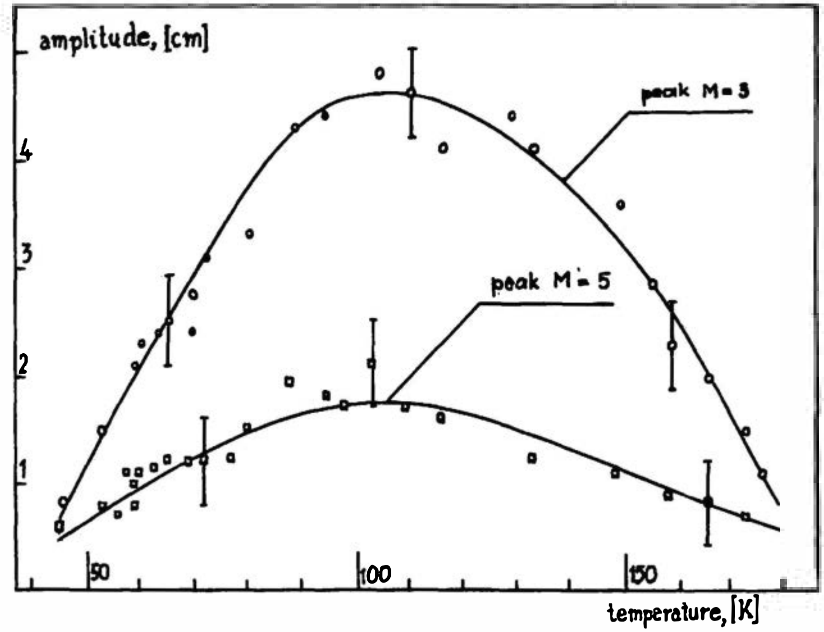

Figure 1 - Temperature dependence of the amplitude of the magnetophonon effect for peaks M = 3 and M = 5.

Further measurements were done at temperatures between 25 and 10 K and in a stronger electric field from about 100 mV/cm to about 400 mV/cm when "hot electrons" are present. Transversal as well as longitudinal orientation of magnetic field regarding direction of the current were used during the measurements. Under these conditions the second derivative minima appeared at the following values of the magnetic field: 1.06, 0.79, 0.63, 0.50, 0.44, 0.38 T for M = 3,4,5,6,7,8. Comparing these values with the previous ones, obtained at temperatures higher than 45 K it can be seen that the positions of all peaks are shifted towards lower fields, when measurements were performed at temperatures below 25 K. The shift is between 7 and 9 % for different values of M, which is comparable with the results obtained by Stradling and Wood[5] and by Akselrod at al.[6]

The shift of the resistivity peaks could be explained by the influence of the donor impurities which are scattering centers at low temperatures, as was mentioned already by Stradling and Wood.[5] Scattering is connected with the emission of optical phonons and the energy conservation can be written as

$$\hbar\omega_0 = E + M\hbar\omega_c \qquad 2)$$

where E is the activation energy of the donor impurity. Since the shifts are usually different for different peaks it follows that the activation energy depends probably on the magnetic field also. From (2) it is clear too that the electrons involved in this process have to be heated by the electric field only by the temperature difference $(\hbar\omega_0 - E)/k_B$, which is less than in the case when (1) is valid.

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