SS05: The Magnetophonon Effect

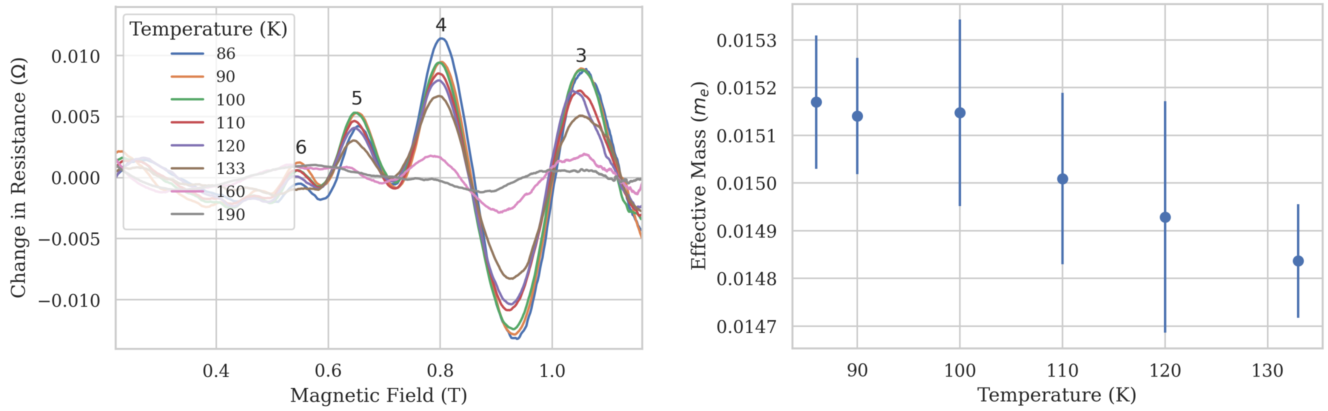
Abstract

A technique to observe the magnetophonon peaks in the electrical resistance of a Te-doped InSb crystal, for temperatures in the range of 86 K to 133 K, is presented. The technique uses the subtraction of the background polynomial fit and averaging to create sharp peaks for both the upward and downward sweep of the magnetic field, which is measured using a Hall probe. The average of the peak magnetic field from the sweeps is used to calculate the effective mass of the electrons, m^*, in the sample. The effective mass of the electrons decreased in the range of intermediate temperatures considered. In addition, at 86 K and 133 K, the resistivity of the n-InSb sample at zero field and the Hall voltage are measured. These measurements are used to calculate the charge carrier density and the mobility.

The magnetophonon effect arises from the resonant scattering of electrons by longitudinal optical (LO) phonons between the quantum states formed by the cyclotron motion of electrons. Electrons in n-InSb can be treated as free electrons with an effective mass, m^*, which takes into account the interaction of electrons and their surroundings. The application of a magnetic field, B, quantises the energy of the electrons into Landau levels, $E = (n + \frac{1}{2})\hbar\omega_c$, where the cyclotron frequency, $\omega_c = \frac{eB}{m^*}$. The scattering of electrons by LO phonons with angular frequency, ω_{LO}, impacts the electrical resistivity of the sample. Due to the conservation of energy and momentum, the condition for phonon emission/absorption is $\omega_{\mathrm{LO}} = p\omega_c$, where p is a positive integer. For a more detailed explanation of the effect, readers are referred to a review paper [1].

In the low magnetic field limit, at 86 K and 133 K, measurements of resistivity and Hall voltage are carried out. Using these measurements, the charge carrier density, N, is calculated to be $N_{86\,\mathrm{K}} = (1.76 \pm 0.05) \times 10^{20}$ carriers m^{-3} and $N_{133\,\mathrm{K}} = (2.89 \pm 0.09) \times 10^{20}$ carriers m^{-3}; the mobility, μ, is calculated to be $\mu_{86\,\mathrm{K}} = 42.8 \pm 1.7\,\mathrm{m}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$ and $\mu_{133\,\mathrm{K}} = 25.9 \pm 1.1\,\mathrm{m}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$.

In the high magnetic field limit, we can observe the magnetophonon effect within a range of intermediate temperatures. For a given temperature, a polynomial can be fit to the resistance as a function of magnetic field and then subtracted to observe magnetophonon resonances; the temperature must be high enough for a significant number of long wavelength LO phonons, but low enough for the Landau levels to be reasonably sharply defined. Using a fourth order polynomial and averaging over 8 values was found to be optimal for sharp magnetophonon resonances, as shown in Figure 1a. The average of the magnetophoton peak positions on the up and down traces is used to calculate the effective mass of the electron, as shown in Figure 1b. The electron effective mass tends to decrease in the range of intermediate temperatures considered, which is consistent with other work [2].



(a) The Magnetophonon Peaks for the Upward Sweep of the Magnetic Field over a Range of Temperatures

(b) The Temperature Dependence of Effective Mass of the Electrons

Figure 1: Figures created using the subtraction of the background polynomial fit and averaging method.

---

[1] Nicholas, R. (1985). The Magnetophonon Effect. *Progress in Quantum Electronics*, 10(1):1-75.

[2] Stradling, R. and Wood, R. (1970). The temperature dependence of the band-edge effective masses of InSb, InAs and GaAs as deduced from magnetophonon magnetoresistance measurements. *J. Phys. C: Solid State Phys*, 3(5):L94.