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SPECTROSCOPY OF THE L BAND OF Ga-Sb STUDIED BY SHUBNIKOV-DE-HAAS EFFECT IN HIGH MAGNETIC FIELD, UNDER UNIAXIAL STRESS

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We report the study of Shubnikov-de-Haas effect in the L conduction band of Ga-Sb, under uniaxial stress in pulsed magnetic field higher than 30 Tesla. From the temperature dependance of the oscillations amplitude of longitudinal magnetoresistance we deduce the conduction effective mass and the anisotropy of L band. Such results have also been obtained from the Hall voltage analysis. (m_t^{*L} = 0.285 m_0 and K = 10).

I. Introduction

There has been considerable interest in the study of the transport parameters and the band structure of gallium antimonide. It has been established for a long time that the conduction band of Ga-Sb possesses a minimum at the center of the Brillouin zone and satellite minima in both directions <111> and <100> [1]. The energy difference between the Γ and L minima is sufficiently small so that both are occupied at room temperature. It is thus important to know the transport parameters of the L band. There is considerable confusion over the value of the density of states effective mass m^*_{dL}, and the anisotropy of the transport effective mass $K = m^*_\ell / m^*_t$, where m^*_ℓ and m^*_t are the longitudinal and transverse effective mass of the L band. Hall effect [2], piezoresistance [3], Faraday rotation [4] and reflectivity measurements have been used for the determination of these parameters, giving values varying from 8 to 13 for K coefficient. This was the situation before it was possible to use resonant experiments : for example Shubnikov-de-Haas effect (S.d.H.) for measuring these parameters. The reasons for this are on one hand due to the mixture of the two series of oscillations arising from the Γ and L bands, on the other hand due to the fact that these oscillations occur in the range of very high magnetic fields (higher than 20 Tesla).

The present study reports the first measurements of the transport effective mass parameters (m^*_t and K) in the L band from S.d.H. oscillations. The determination of these parameters has been obtained by use of magnetic field higher than 30 T, and by the application of a uniaxial stress up to 5 kB, which allow the two series of oscillations to be decoupled.

We have, also, obtained for the first time such results by the analysis of the Hall voltage. The oscillations in this voltage occur with an amplitude larger than predicted and show, in the case of high carrier concentrations an opposite phase with respect to the oscillations in the transverse magnetoresistance.

II. Experimental Method

The observation of S.d.H; oscillations in the L band of Ga-Sb requires the use of highly doped samples with a carrier concentration much more greater than the critical density n_c [5]. Previous observations in the direct magnetoresistance [6] show that these oscillations are too low in amplitude to allow a direct measurement of the effective mass. To overcome this difficulty we have used the technique of double differentiation.

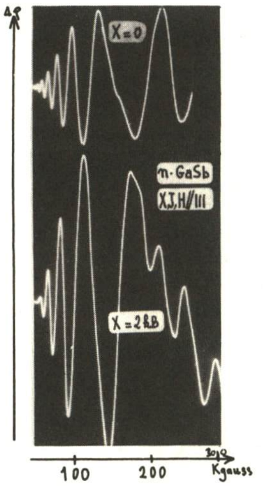


Fig.(1) Influence of stress on the S.d.H. oscillations

An accurate measurement of the mass parameters of the <111> band, needs the separation of the oscillatory series associated with the Landau levels of the Γ and L bands. This separation of the two series is achieved by the application of the uniaxial stress in the <111> direction. The stress reduces the energy gap between the Γ and L minima, thus causing a transfer of electrons from Γ to L.

This transfer is analysed by the change in periodicity of the oscillations associated with Γ band. Fig. (1) shows the decrease of density $n \sim (\Delta(1/B))^{-3/2}$ in the central band versus the stress.

This relative depopulation of the central band favours the appearance of the oscillations associated with the Landau levels of the L band as shown in figure (1).

III. Measurement of the Effective Mass and Anisotropy of the L Band

The samples of high homogeneity n-Ga-Sb were cut in the form of rectangular bars (4 x 0.6 x 0.6 mm3), with the long axis oriented along <111>, <100> and <11$\bar{2}$> crystal axes.

The transport effective mass of the carriers at the Fermi level is obtained by measurements of the temperature dependance of the oscillations amplitude of longitudinal magnetoresistance. As the Dingle temperature may be considered constant at low temperature [7], the amplitude of an oscillation may be simply described by the expression

$$A \sim \frac{U}{\text{sh}U} \quad \text{where } U = 2\pi^2 kT/\hbar\omega_c .$$

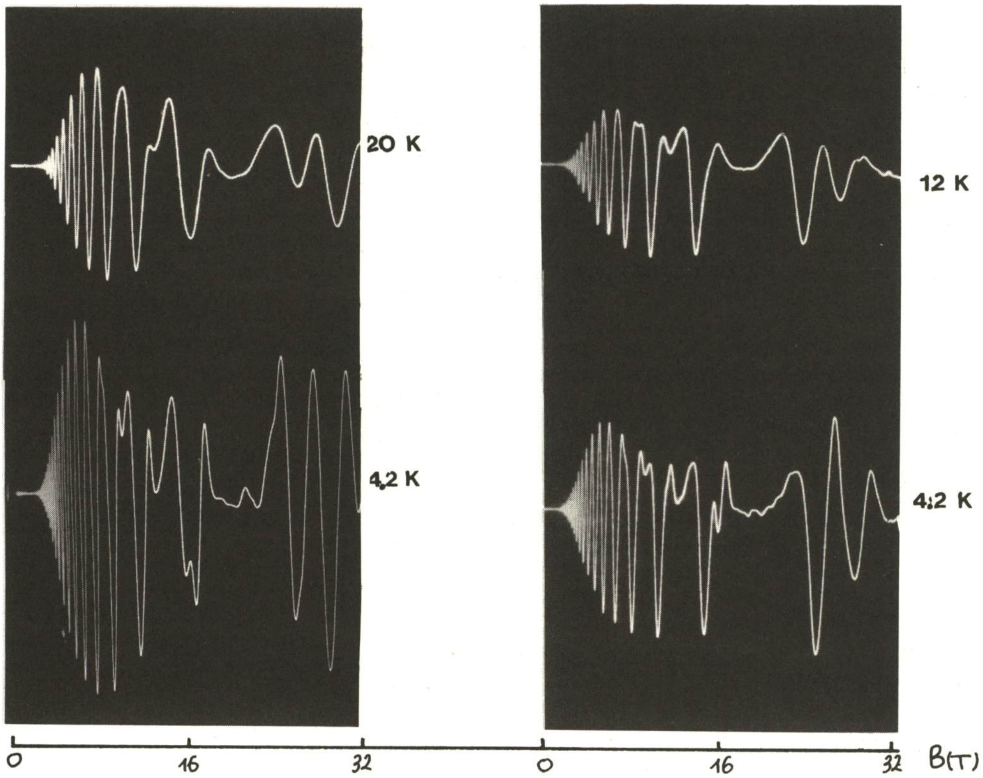
Fig. (2) shows typical recordings of such temperature dependance for two particular configurations.

Measurements were made at temperature between 1.8°K and 20°K.

The L band transverse effective mass is directly measured for B parallel to <111>. The anisotropy is obtained from measurements performed with B respectively parallel to the directions <111>,<100> and <11$\bar{2}$>. We obtained the following results :

- configuration B // <111> $m^* = m_t^* = 0.285 \pm 0.005\ m_o$,
- configuration B // <100> $m^* = 0.44 \pm 0.01\ m_o$,
- configuration B // <11$\bar{2}$> $m^* = 0.307 \pm 0.005\ m_o$.

From these values we get K = 10 ± 0.5.



a) B //<11$\bar{2}$>   b) B //<100>

Fig. (2) Longitudinal magnetoresistance

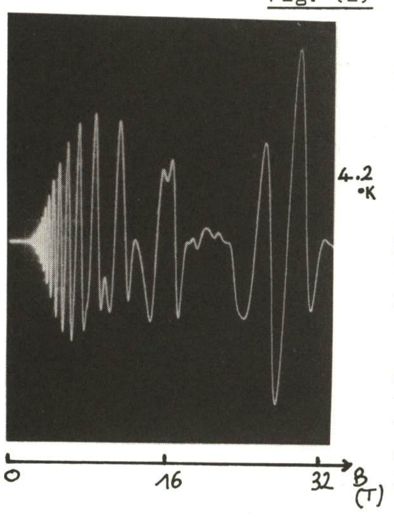


Fig.(3) Hall effect B//<11$\bar{2}$>

The values of the effectives masses reported here are larger than those obtained by macroscopic measurements of Hall effect, resistivity [8] or Faraday rotation [9]. The value of anisotropy of the L band determined above is in good agreement with those given by Mathur and al. [10] obtained from Faraday rotation. On the other hand, Mashovets [6] estimated m_t^* from S.d.H. effect to be 0.3 m_o, which agrees with our results.

We also deduce from the masses values and the positions of oscillations respectively in the Γ and L band the gap Δ = 63 meV between Γ and L at 4.2°K and the critical density $n_c \sim 7\times10^{17}$ cm^{-3}. Values which are lower than the previous determinations.

IV. Oscillations of the Hall Voltage

For highly doped samples we observe oscillations of the Hall voltage due to the Landau quantification of the L band. The comparison of these oscillations with those of the transverse magnetoresistance indicate that in this case the maxima of the magnetoresistance correspond to minima of the Hall voltage as shown in Fig.(3).

Yep et al. [11] has studied the phase shift in the Γ band between the Hall voltage oscillations and those of the magnetoresistance as a function of carrier concentration. This phase shift varies with the carrier concentration in such a way that it is not possible to obtain empirical law. It is at the moment not possible to explain it. The amplitude of the observed oscillations of the Hall voltage are larger than predicted. This can be attributed to the contribution of two phenomena. One is a resonant transfer of carriers from one band to the other, and the second is a S.d.H. type oscillations in the σ_{xy} conductivity term [12].

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