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MAGNETIC FREEZE-OUT ON THE SUBSIDIARY MINIMA ASSOCIATED LEVELS IN n-InSb UNDER PRESSURE

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The Hall coefficient R_H in pure InSb was studied as a function of magnetic field up to 18T, at pressures up to 10 kbar and at temperatures 4.2-170K. The magnetic freeze-out on the two subsidiary minima associated donor levels was observed. The shift of both levels in magnetic field with respect to the Γ conduction band was found to be 1.8 meV/T.

I. Introduction

In pure n-InSb with extrinsic concentration below 10^{15} cm^{-3}, at pressures above 7 kbar the deionization of the two donor levels of the same impurity / probably oxygen / was observed Fig.(1) [1,2,3,4]. The levels are associated with the subsidiary conduction band minima L and X. At ambient pressure the levels lie above the bottom of the Γ band, but their energies E_{dL} and E_{dX} relative to the Γ band decrease linearly with pressure Fig.2. The observed pressure coefficients are close to those of the subsidiary minima L and X. The transfer of electrons between the Γ band and the E_{dX} level is controlled by the energy barrier /E_B=0.3eV/ due to the large lattice relaxation around the impurity. At temperatures 90-115K after a change of thermodynamical conditions, the equilibrium electron population of this level is attained through the slow relaxation process. At temperatures below 90K the relaxation process becomes so slow that the transfer of electrons between the Γ band and E_{dX} is practically unobservable.

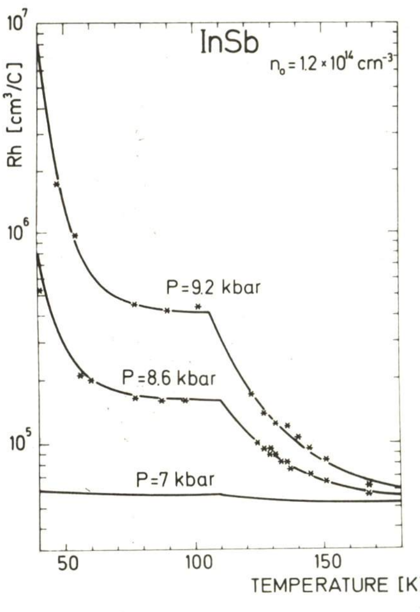

Fig.1. Deionization of E_{dL} and E_{dX} levels at high pressure

II. R_H (H) measurements

The Hall coefficient R_H was measured as a function of magnetic field up to 18T at temperatures 4.2-170K, for pressures which are marked at Fig.(2) with arrows. The CuBe clamped pressure cell was used.

The cell with the cryostat was placed inside the 10 MWatt Bitter-type solenoid /SNCI-Grenoble/ which allowed the magnetic field to be changed continuously up to 18T. For 7 kbar at the lowest temperatures the increase of R_H with magnetic field due to classical freeze-out into the hydrogenic impurities is observed, in a higher temperature range /above 40K/ R_H does not change with magnetic field. For pressures of 8.6 and 9.2 kbar the increase of R_H with H becomes much stronger and is observed in temperature range up to 170K. Fig.(3) and (4) give the typical R_H(H) dependence for n-InSb with initial extrinsic concentration $n_{o77K}=1.2\ 10^{14}\ cm^{-3}$.

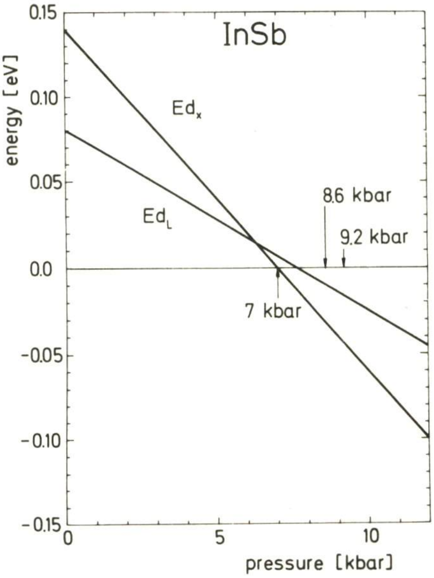

Fig.2. Energies of E_{dL} and E_{dX} levels, relative to the Γ minimum versus pressure

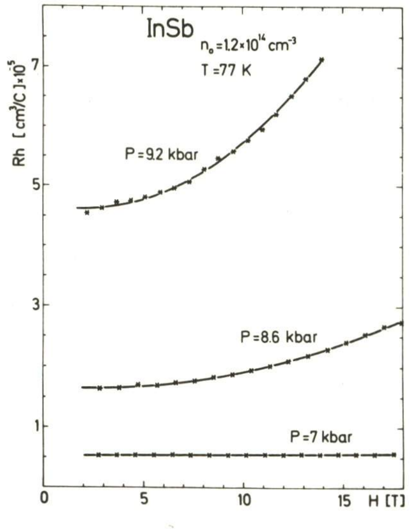

Fig.3. Magnetic field induced deionization of E_{dL} level at 77K.

III. Interpretation of R_H(H) measurements

The analysis of the R_H(H) data is based on the model of the donor center with two nonequivalent lattice positions and respectively with two thermal ionization energies E_{dL} and E_{dX} [2,3]. The observed increase of R_H with H is due to the transfer of electrons into the levels E_{dL} and E_{dX}. This transfer is due to the magnetic field-induced shift of the bottom of the Γ condution band in respect to these levels. At temperatures below 90K the population of E_{dX} is metastable, therefore at this range of temperature only the transfer of electrons into E_{dL} is observed. At the higher temperatures deionization of the both levels can be observed. However, for pressures 8,6 kbar and 9,2 kbar the observed changes of R_H are only due to the deionization of E_{dX} since its energy is lower than E_{dL}. In the analysis of R_H[H] dependence it was assumed that concentration of the free electrons $n=1/eR_H$. For each experimental point R_H(p,T,H) the Fermi energy was calculated and then energies E_{dX} and E_{dL} were found. The magnetic field and pressure induced change of the density of states in the conduction band was taken into account following the 3-band Kane model [5,6]. As an example, figure 5 presents the dependences of E_{dL} and E_{dX} vs magnetic field H at temperatures 77 K / E_{dL} / and 122 K /E_{dX}/. Within the experimental error these dependences are linear $E_{d(L,X)}=E^o_{d(L,X)}+\gamma_{(L,X)}H$ with the slope $\gamma_{(L,X)}=-1.8\pm0.2$ meV/T which is independent of pressure and temperature

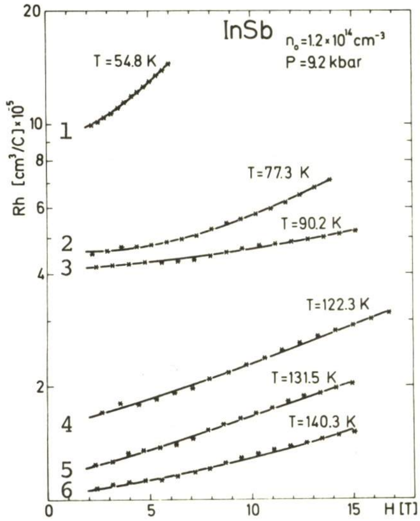

Fig.4. Curves 1,2,3-deionization of E_{dL} level /population of E_{dX} is metastable at the corresponding temperatures/ Curves 4,5,6 -deionization of E_{dX}

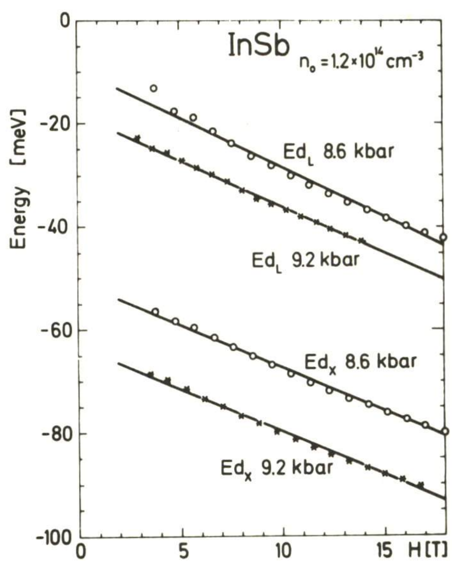

Fig.5. Calculated values of E_{dL} and E_{dX} versus pressure at temperatures 77K and 122K, respectively.

and the same for both levels. The theoretical value of the coefficient γ_Γ which describes the shift of the Γ minium with magnetic field at 9 kbar is γ_Γ = 1.9 meV/T. Within the experimental error the values of $\gamma_{(L,X)}$ and $-\gamma_\Gamma$ coincide, it means that the magnetic freez-out into E_{dL} and E_{dX} levels is due to the shift of the bottom of the Γ band with magnetic field.

IV. Magnetic field-induced slow relaxation of R_H

In the temperature range 90-115K, for pressures at which the magnetic freeze-out is observed, after each change in the value of magnetic field slow relaxations of R_H are observed. Fig.(6) presents the typical process of the slow relaxation of the Hall coefficient after the rapid change of magnetic field at temperature of 111K and pressure of 8.6 kbar. The observed time dependence of Hall coefficient $R_H(t)$ is the same as the previously observed for the relaxations induced by rapid changes of pressure, temperature, or illumination [4]. The relaxations can be explained by the model of the donor center with two nonequivalent lattice positions [2,3]. Assuming $n=1/eR_H$, the time dependence of the free electron concentration $n(t)$ can be described by the expression

$$n(t) = n_\infty + [n(o) - n_\infty] \exp\left(-\frac{t}{\tau}\right),$$

where t stands for time; $n(o)$ and n_∞ are the initial and the equilibrium values of n, τ is the relaxation time of the observed process. Fig.(7) presents the temperature dependence of τ for pressure 8.6 kbar. Using the simple formula for thermally activated process

$$\tau = \tau_o \exp(E_B/kT),$$

activation erergy E_B was found to be E_B = 0,3eV. E_B corresponds to the value of the potential barrier between the two nonequivalent lattice positions of the donor center and its value 0,3eV is in good agreement with the previous results [4].

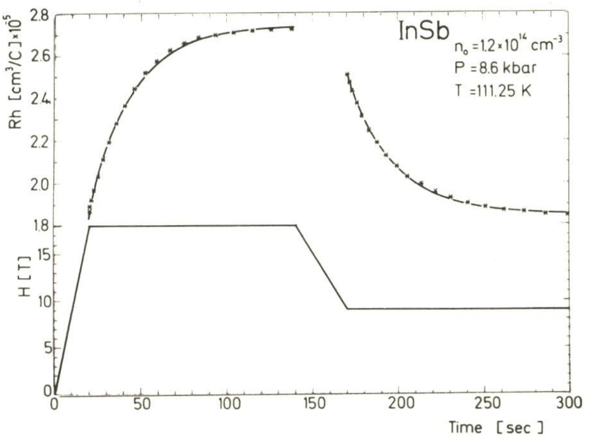

Fig. 6. Relaxation of the Hall coefficient after rapid change of magnetic field

V. Summary

Due to the magnetic field induced shift of Γ conduction band minima the freeze-out of the free carriers on two levels associeted with the subsidiary minima was observed. The magnetic field dependence of R_H and the time dependence of R_H in the temperature range 90-110K are well explained by previously proposed model of donor centers with two nonequivalent lattice positions separated by a potential barrier due to lattice distortion [2,3] .

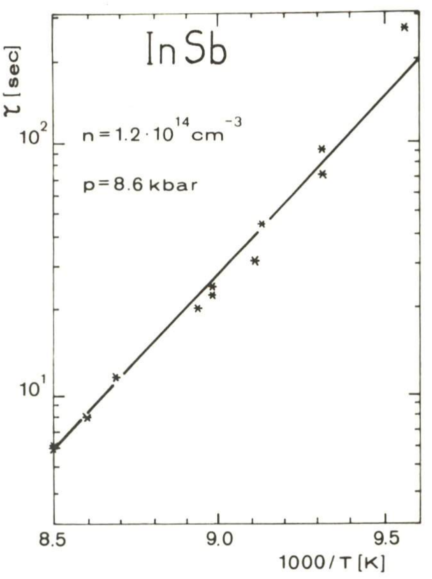

Fig. 7. Temperature dependence of τ for the relaxation of R_H induced by magnetic field for 8.6 kbar

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The experiments have been performed at SNCI CNRS Grenoble.