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GALVANOMAGNETIC PROPERTIES OF PLASTICALLY DEFORMED InSb

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Résumé - Des monocristaux d'antimoniure d'indium de type n ou p, ayant une densité de dislocations de croissance et une concentration de porteurs libres aussi faibles que possible ont été déformés en compression uniaxiale ou en torsion. Lorsque la densité de dislocations est élevée, relativement à la concentration des porteurs libres, les mesures d'effet Hall et de conductivité montrent, pour les dislocations coin, une décroissance importante du nombre des porteurs et de leur mobilité. Dans InSb de type n, les dislocations vis ont, à basse température, pour effet d'inverser le signe des porteurs libres majoritaires. Les résultats sont discutés en termes de position, taux d'occupation et localisation des niveaux d'énergie introduits dans la bande d'énergie interdite.

Abstract - n and p type InSb single crystals with as low as available initial carrier concentrations and dislocation densities were deformed by torsion or uniaxial compression. Hall effect and conductivity measurements exhibit a large decrease of the free carrier concentration and their mobilities for edge dislocations when the ratio between the carrier concentration and the dislocation density is not too high. Screw dislocations have been seen to inverse the type of the as-grown material for n-type InSb. Results are discussed in terms of position, occupation rate and localization of energy states introduced in the band gap.

I - INTRODUCTION

Dislocations in semiconductors are known to introduce electronic levels in the band gap and to affect both the free carrier concentration and their mobility. The particular interest of III-V compounds is twofold, when compared to covalent semiconductors :

- the piezoelectrical character of these materials leads to a specific diffusion potential which can widely modify the electrical properties of a sample containing edge dislocations,
- the two possible kinds of 60° dislocations -depending of the nature of the atoms in the core- should affect differently the electrical properties of the material.

This second point was at the origin of many investigations of the Hall effect and conductivity on deformed III-V compounds but the experimental results and their interpretation are quite different [1] [2] [3].

Our previous work on the plasticity of III-V compounds lead to an interesting result: plastic deformation have been carried out by uniaxial compression parallel to the $\langle 123 \rangle$ direction, complexe array of dislocations with edge and screw components were then controlled by direct observations. These observations (by X ray topography of deformed samples) at different stages of the deformation well established that only one type of 60° dislocations can develop in these samples [4].

This paper presents some results of Hall effect and d.c conductivity measurements for plastically deformed n and p type InSb in compression or torsion in order to investigate separately the case of " 60° " and screw dislocations. Comparison between experi-

mental results and theoretical analysis will lead to information about the position and occupation rate of energy levels to be associated with different types of dislocations.

II - EXPERIMENTAL RESULTS

D.c conductivity and Hall effect measurements have been performed for as grown, and deformed specimens with current flow parallel to the compression or torsion axis at temperatures between 300 K and 77 K. Contamination during deformation was controlled by specimens which remained undeformed while heated.

As there was no significant difference between the as-grown specimen and the heated one, the deformed specimen have been compared with the as-grown (reference) specimen.

II-1. Case of 60° dislocations

An excess of 60° dislocations was introduced by uniaxial compression in n-InSb samples (having an original carrier concentration of about 10^{14} cm^{-3} and in p-InSb samples with 10^{16} cm^{-3} carriers).

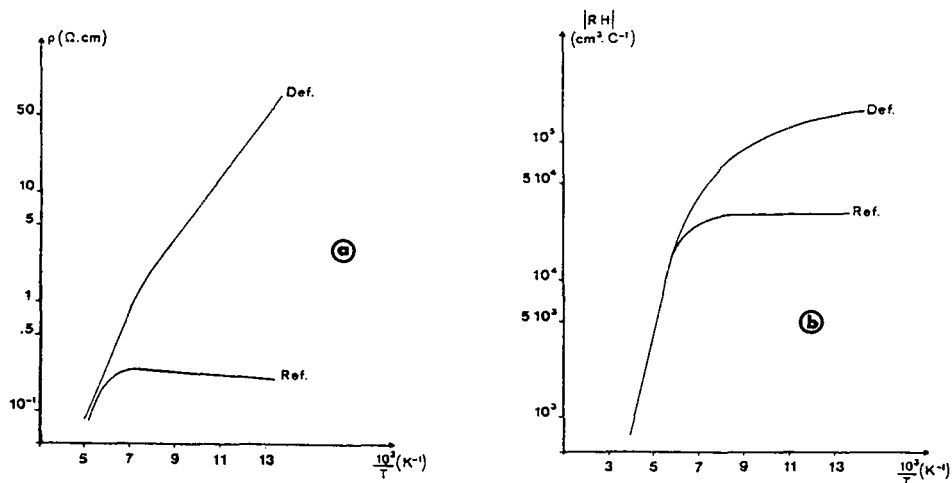


Fig. 1 : Typical resistivity (a) and Hall effect (b) versus $1/T$ for n-InSb samples ($N_D \sim 10^{14} \text{ cm}^{-3}$)

Ref.: reference sample

Def.: sample deformed by uniaxial compression at $T=500\text{K}$ ($\frac{\delta l}{l} \sim 2\%$)

One notices first that in n type InSb (fig. 1), the resistivity is relatively large even for lightly deformed specimens (i.e. for low dislocation densities); when the deformation rate increases, the resistivity becomes larger. The temperature dependence of the Hall coefficient shows a significant decrease of the number of free carriers. In the highly deformed specimen, Hall coefficient measurements could not be performed because of high resistivities.

On p type specimens, the deformation does not lead to remarkable variations of the resistivity and the Hall effect (fig. 2).

It is also important to remark that the Hall coefficient curve does not cross the Hall effect curve obtained for undislocated case.

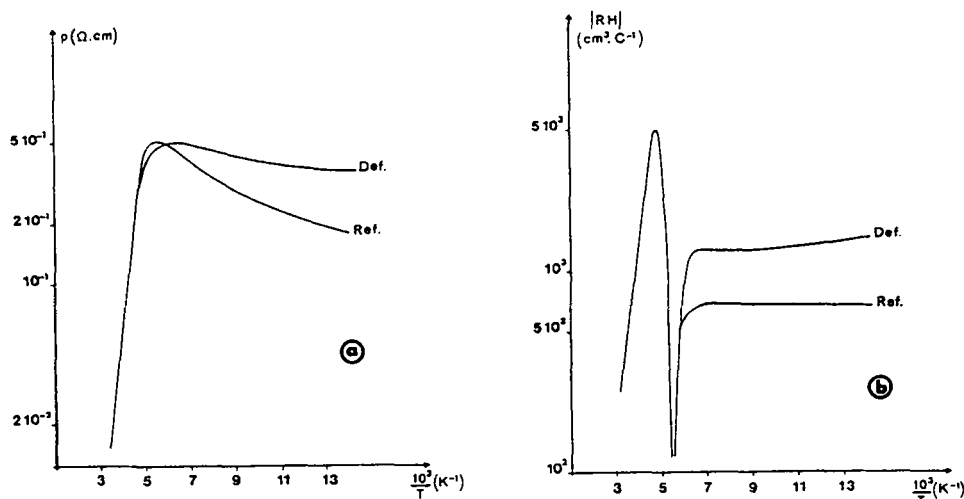


Fig. 2 : Typical resistivity (a) and Hall effect (b) versus $1/T$ for p-InSb samples ($N_A = 10^{16} \text{ cm}^{-3}$)
 Ref. : reference sample
 Def. : sample deformed by uniaxial compression at $T=500\text{K}$ ($\frac{\delta l}{l} \sim 2\%$)

II-2. Case of screw dislocations

Dislocation substructures with an upper density of screw segments than of edge parts were introduced by torsion around a $[111]$ axis in an n type InSb sample ($N_D \sim 10^{14} \text{ cm}^{-3}$); as there is no piezoelectrical effect associated with screw dislocations, this case is a good one to test the core effects of dislocations.

We did not anneal the samples after the deformation test since this kind of experiment only lead to a poorer density of the wanted dislocations but is, in fact, accompanied by a contamination by unwanted dopant impurities.

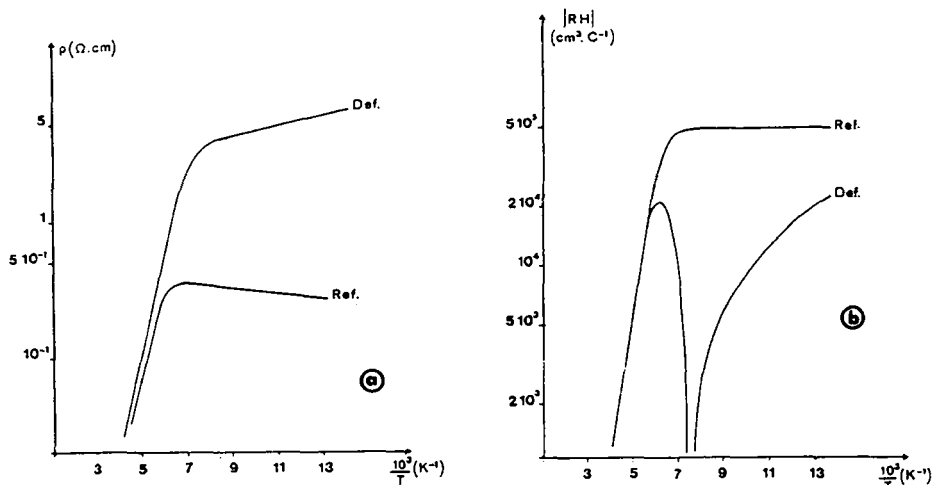


Fig. 3 : Typical resistivity (a) and Hall effect (b) versus $1/T$ for n-InSb samples ($N_D = 10^{14} \text{ cm}^{-3}$)
 Ref. : reference sample
 Def. : sample deformed by torsion at $T=500\text{K}$ ($\sim 10^\circ/\text{cm}$ twisted)

Resistivity and Hall effect measurements versus temperature are reported on figure 3 for an about $10^\circ/\text{cm}$ twisted sample. The noticeable point is now the change of sign of the Hall coefficient at $T = 130$ K.

III - DISCUSSION

The discussion developed here is based on the theoretical analysis drawn up earlier by Farvacque and al [5,6]. Hall effect and conductivity can be calculated self consistently when the position of the levels associated with the dislocations and their occupation, when neutral, are known.

Characteristics of deep states associated with dislocations are evidently dependent on their actual core structures ; this complex problem is far from being well solved and one has no other possibility, in the lack of experimental datas than choosing values which are as more realistic as possible but do remain formal ones.

For 60° dislocations in p type InSb, we have not observed the temperature neutrality point of the dislocations (i.e. the point where the Hall effect curve of the deformed material crosses the Hall effect curve of the as-grown material).

The extra charge on the dislocation is given by

$$n_t = \frac{2D}{b} \left\{ \frac{1}{1 + \exp \frac{E_D^* - E_F}{kT}} - \xi \right\}$$

$$\text{with } E_D^* = E_D + \frac{n_t e^2}{2\pi \epsilon_0 \epsilon_L D} \left\{ \log \frac{\lambda_G}{b} - \frac{1}{2} \right\}$$

E_D is the energy level associated with the dislocation, E_D^* the shift energy level due to electronic interactions of charges trapped along the dislocation line, D the density of dislocations of Burger's vector b , λ_G the generalized screening length.

The neutrality point $n_t = 0$ leads to

$$E_D = E_D^* = E_F + kT \log \frac{1-\xi}{\xi}$$

If this particular point is not observed, it may be because it occurs at temperature too high to be in the extrinsic conductivity range, that is as $T > \approx 160$ K.

Assuming $\xi = 5/8$ [7] implies $E_D > \approx 60$ meV ; this remark does not contradict optical datas obtained on the same specimens which lead to a dislocation level located at about 140 meV from the valence band [8].

The large experimental increase of the resistivity in n-type material results from the decrease of the number of free carriers and from the decrease of their mobility due to a very efficient piezoelectrical scattering.

In p type material, the dislocation effect is not so pronounced because of a higher ratio between free carrier and dislocation densities.

For screw dislocations, the temperature T_0 at which the Hall coefficient goes to zero allows to determine the Fermi level at this point

$$E_F = \frac{1}{2} \left[E_G + kT \log \frac{1}{\beta^2} \frac{m_p^*}{m_e^*} \right]^{1.5}$$

where β stands for the mobility ratio between electrons and holes. Knowing E_F determines the extra charges trapped on dislocation levels n_t .

Using the classical picture of two levels associated with screw dislocations -the lowest one being completely filled and the upper one completely empty- and inserting an effective level E_D^* at about 30 meV from the valence band as evaluated by optical absorption [8], the theoretical calculation of R_H exhibits for decreasing temperature a transition at T_0 from a p-type material to an n-type material but does not give the transition from a n-type to a p-type material as experimentally observed. To obtain such a transition it is necessary to introduce a single level very near the valence band with an occupation rate $> 0,7$ and to allow trapped carriers to be partially delocalized around this dislocation trap, in order to keep E_D^* at the proximity of the valence band.

IV - SUMMARY

Edge type dislocations look to introduce amphoteric deep levels, the location of which would be in the upper part of the band gap. These levels would shift with the electrostatic energy of trapped carriers, when considered to be strongly localized along the dislocation line.

On the other hand, screw dislocations are seen to introduce some kind of shallow energy states located very near the valence band. These levels do not experience, with their occupation rate a shift as strong as in the previous 60° dislocation case and have therefore to be seen as partially delocalized levels.

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