Electrical and Optical Properties of Intermetallic Compounds. II. Gallium Antimonide*

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(Received July 19, 1954)

The Hall effect and resistivity of GaSb have been investigated over the temperature range 78° to 750°K. Hole mobilities as high as 400 cm²/volt-sec and a forbidden energy gap of 0.775 ev at absolute zero were found. Optical absorption studies at temperatures between 10° and 300°K confirm this value of the band separation.

INTRODUCTION

GALLIUM antimonide is a semiconductor of the group of IIIB–VB compounds with properties similar to those of Ge and Si. Its lattice has the zinc-blende structure; the melting point of the compound is 702°C.[1]

We report here on measurements of resistivity and Hall effect as well as optical absorption. Results are in general agreement with data reported by others.[1–3]

EXPERIMENTAL PROCEDURE AND RESULTS

Procedures for crystal growing and sample preparation are identical to those used for InSb.[4] The antimony was obtained from the Bradley Mining Company. The first shipment had a purity of 99.957 percent and contained Al, Cu, Fe, Mg, and Si as impurities; later on antimony of 99.994 percent purity was received, the major impurities being As, Cu, Fe, and Pb. Gallium was procured both from the Eagle Picher Company and the Aluminum Company of America. The purity of this metal was about 99.95 percent and the material contained the following impurities: Ag, Al, Ca, Cu, Ni, Pb, and traces of Fe, Mg, and Si. Zone melting improves the purity of the compound considerably. The grain structure of grown ingots can be made visible by etching with HF and HNO_3.

X-ray analysis showed the lattice to be of the zinc-blende type; the lattice constant is 6.1347 A at 26°C,[5] from which the nearest neighbor distance is calculated to be 2.65 A.

The equipment for measuring Hall coefficient and resistivity has been described elsewhere.[6] Measurements cover the temperature range from 78°K to 750°K. Results are given in Figs. 1 and 2.

Sample X-111 (p type) has been cut from an ingot containing excess Ga. This ingot was annealed at 500°C for 24 hours and then slowly cooled to room temperature.

Sample X-117 is a single crystal showing p-type conductivity.

Sample VI-170 is taken from the pure end of an ingot which has been zone-melted 7 times; this specimen is p type.

Sample VI-185 has been prepared from an ingot doped with tellurium and shows electron conduction at all temperatures.

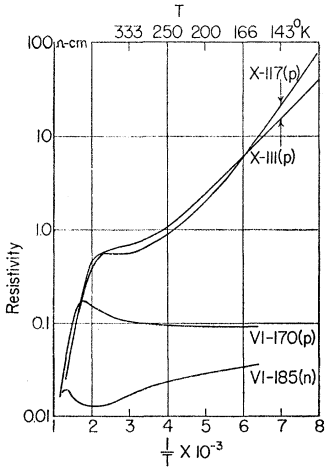

FIG. 1. Resistivity of n- and p-type GaSb.

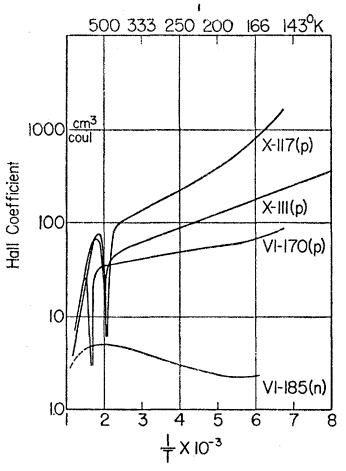

FIG. 2. Hall coefficient of n- and p-type GaSb.

* Supported in part by the Office of Ordnance Research.

[1] H. Welker, Z. Naturforsch. **7a**, 744 (1952); **8a**, 248 (1953).
[2] D. P. Detwiler, Phys. Rev. **94**, 1431 (1954).
[3] H. N. Leifer and W. C. Dunlap, Phys. Rev. **94**, 1431 (1954).
[4] Breckenridge, Blunt, Hosler, Frederikse, Becker, and Ashinsky, preceding paper [Phys. Rev. **96**, 571 (1954)].
[5] These measurements were carried out by the Microstructure Section of the National Bureau of Standards.
[6] R. G. Breckenridge and W. R. Hosler, Phys. Rev. **91**, 793 (1953).

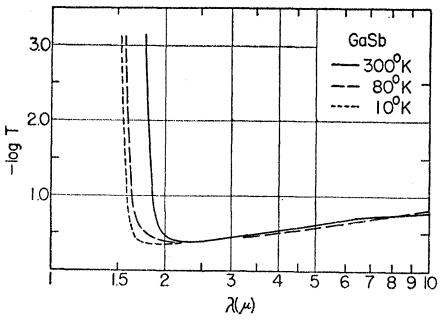

FIG. 3. Absorption spectrum of p-type GaSb at three different temperatures.

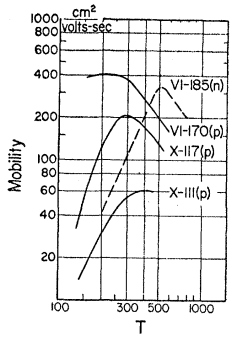

FIG. 4. Charge carrier mobilities of GaSb.

The absorption spectra of several GaSb samples were investigated with a Perkin-Elmer monochromator using procedures described previously.[4] Figure 3 shows the absorption spectrum (minus log transmission *vs* wavelength) of a specimen cut from the ingot labeled VI-170 (impure end); this specimen was ground and polished to a thickness of 0.13 mm. Other samples show similar results; the position of the absorption edge of p- and n-type samples is the same. Measurements taken at three different temperatures (300°K, 80°K, and 10°K) show clearly the shift of the absorption edge; the long-wavelength tail changes very little with temperature.

DISCUSSION

The carrier mobility has been calculated from the Hall coefficient R and the conductivity σ by using the expression

$$\mu = R\sigma/r. \tag{1}$$

r is a factor which depends on the scattering mechanism. At high temperature where lattice predominates $r=1.18$, while in the impurity region at low temperatures $r=1.93$.[7] Figure 4 shows the results for the four samples presented. Other investigators have reported values of 2000 cm²/volt-sec[2] and 800 cm²/volt-sec[3] for the mobility of holes at room temperature.

A comparison of the three p-type samples shows that specimen VI-170 has the highest mobility, but at the same time the lowest Hall coefficient; the mobility of this sample is even higher than that of the single crystal X-117. This suggests that the low mobility of most of our samples is due to two causes: (a) the polycrystalline structure of the samples, and (b) a large amount of impurities, both donors and acceptors, giving rise to a high concentration of ionized scattering centers, but very few carriers due to compensation. Zone melting of ingot VI-170 has apparently removed a larger number of donor impurities, resulting in a higher hole concentration and also higher mobility.

We have used the data of sample VI-170 to calculate the mobility ratio b at the temperature where the Hall coefficient reverses sign.[8]

The conductivity is given by

$$\sigma = e\mu_p(nb+p), \tag{2}$$

where n is the concentration of electrons and p is the concentration of holes. The expression for the Hall coefficient R is

$$R=(3\pi/8e)[(nb^2-p)/(nb+p)^2]. \tag{3}$$

The Hall coefficient reverses sign at $T=617$°K; hence at this temperature,

$$R=0, \quad \text{and} \quad nb^2=p=n+N, \tag{4}$$

where N is the effective concentration of impurities. Substituting n in Eq. (2) and using the values for σ and μ_p from Figs. 1 and 4, we obtain $b=5.5$ for the mobility ratio.

The width of the forbidden energy band can be derived from the relation

$$np=4(2\pi mkT/h^2)^3(m_nm_p/m^2)^{\frac{3}{2}}\exp-(E_0+\beta T)/kT \tag{5}$$

where

$$\beta=dE/dT,$$

and m_n, m_p=effective mass of electrons and holes, respectively. The slope of ln (np/T^3) against $1/T$ determines therefore the energy gap at absolute zero. Calculation yields a value of $E_0=0.77$ ev.

The band separation can also be identified with the optical absorption edge. From Fig. 3 we derive an energy gap $E=0.67$ ev at room temperature. The temperature dependence of E in the range 10–300°K appears to be -3.5×10^{-4} ev/deg. These values are in good agreement with the result from electrical data.

Beyond 2.5μ the absorption curve rises slowly with increasing wavelength; this absorption can be attributed to free carrier transitions. Several samples show at room temperature a slightly higher absorption in the region 4 to 8μ, suggesting a small but broad band.

[7] W. Shockley, *Electrons and Holes in Semiconductors* (D. van Nostrand Company, Inc., New York, 1950), pp. 278–279.

[8] The procedure used in the case of InSb is not applicable here due to the uncertainty of R_{ex} at the temperature of the Hall maximum.