

Infrared Absorption in *n*-Type Aluminum Antimonide

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The optical absorption constants of tellurium and selenium doped *n*-type AlSb have been determined in the spectral region 0.7–38 microns at 300 and 78°K. A 4.3-micron band exists at 300°K for which the absorption constant varies linearly with electron concentration. This band may be explained by a 0.3-ev spin-orbit split off conduction band or alternatively by a multivalleyed conduction band with a central minimum 0.3 ev above the lowest minima. A transition from the highest valence bands to the lowest conduction level could account for the observed absorption starting at 1.33 ev. At wavelengths greater than 8–10 microns free carrier absorption exists with a λ^2 dependence and a calculated effective mass of 0.3 *m*. Lattice bands are present at 11.2, 13.5, 16.5, 22.9, 27.8, and 29.8 microns.

THE absorption constants of several single crystal-line samples of tellurium and selenium doped *n*-type AlSb have been determined as a function of wavelength and temperature. The transmission and reflection coefficients for an optically polished plane parallel sample of thickness x and absorption constant K are given by Eqs. (1) and (2).¹ These equations include multiple reflections, but neglect interference effects.

$$T = (1 - R)^2 e^{-Kx} / (1 - R^2 e^{-2Kx}), \quad (1)$$

$$R' = R + TR e^{-Kx}. \quad (2)$$

Transmission and reflection measurements were made on samples of various electron concentrations in the spectral range of 0.7–38 microns at 300 and 78°K. From these data and the above equations, absorption constants were calculated using the IBM 704.

Figure 1(a) shows plots of log absorption constant versus log wavelength for the typical results obtained at room temperature. Samples 71-1, 11, and 12 are tellurium doped with room-temperature electron concentrations of $4 \times 10^{17} \text{ cm}^{-3}$, $2 \times 10^{17} \text{ cm}^{-3}$, and $4 \times 10^{16} \text{ cm}^{-3}$, respectively. Sample 87-6 is selenium doped with an electron concentration of $1 \times 10^{16} \text{ cm}^{-3}$. The 0°K Hall activation energy of the Te in AlSb is 0.068 ev while Se is 0.16 ev. All Hall and resistivity data on the materials studied were provided by Battelle Memorial Institute. From the curves in Fig. 1(a), one sees a 4.3-micron band which is linearly dependent on carrier concentration. The intrinsic edge of the material shows structure at about 1.33 ev or 0.93 micron. This edge detail has been substantiated by measurements at high resolution. Lattice absorptions are present in both *n*- and *p*-type AlSb at 11.2, 13.5, 16.5, 22.9, 27.8, and 29.8 microns. These absorptions are most apparent in Fig. 1(a) for sample 12; however, they can be easily identified in larger plots of the other samples. At wavelengths beyond 8–10 microns free carrier absorption exists at 300°K with λ^2 dependence as is expected from simple theory.² Equation (3) gives the expression for the absorption constant K due to N free carriers

of charge e , mobility μ , and effective mass m^* in a medium of index n .

$$K = (N e^3 / n c^3 \pi \mu) (\lambda^2 / m^{*2}). \quad (3)$$

Using this expression an electron effective mass of 0.3 *m* was calculated.

Blunt *et al.*³ observed the 4.3-micron band in more impure AlSb, but did not explain its origin. This band has the following characteristics which indicate that it is an interconduction band transition from the lowest conduction band to a band approximately 0.3

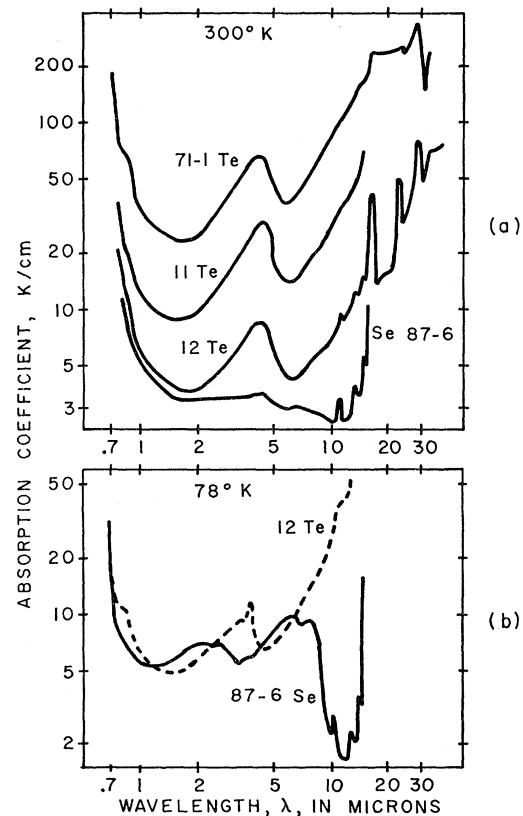


FIG. 1. Log of absorption constant versus log of wavelength for *n*-type AlSb at (a) 300°K (b) 78°K.

¹ L. C. Martin, *Geometrical Optics* (Philosophical Library, Incorporated, New York, 1956), p. 160.

² H. Y. Fan and M. Becker, *Proceedings of the Reading Conference on Semiconducting Materials*, edited by H. K. Henisch (Butterworths Scientific Publications, London, 1951), pp. 132–147.

³ R. F. Blunt, H. P. R. Frederikse, J. H. Becker, and W. R. Hosler, *Phys. Rev.* **96**, 578 (1954).

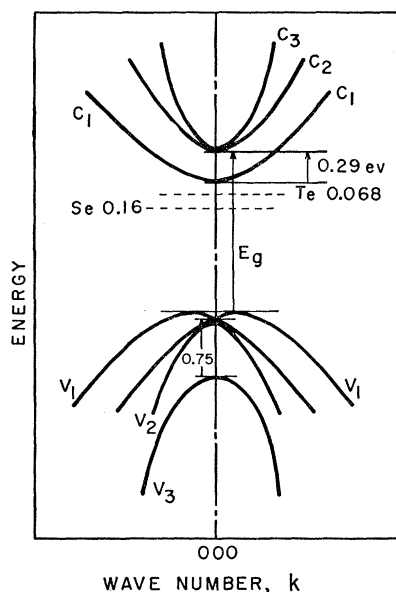


FIG. 2. One possible band picture for AlSb.

ev higher in energy: (1) the magnitude of the absorption constant; (2) the linear dependence of the absorption constant on electron concentration independent of the donor impurity; (3) the shape and the temperature dependence of the band [see Fig. 1(b)].

Figure 2 shows one possible band picture for *n*-type AlSb. The valence band structure was first suggested by Braunstein⁴ and measurements at IBM on *p*-type material confirm this type of picture.

A transition from the highest valence bands V_1 to the lowest conduction band C_1 would give rise to the observed edge structure at 1.33 eV or 0.93 micron for 300°K and 1.40 eV or 0.89 micron for 78°K. This structure has been observed in both *p*- and *n*-type material. Similarly a transition from conduction band C_1 at $k=0$ to the higher conduction bands C_2 and C_3 , could account for the 0.29 eV or 4.3-micron room-temperature band. At 78°K this band shifts to 0.32 eV or 3.9 microns for Te-doped samples. The optical gap corresponds to a transition from the valence bands V_1 to the upper conduction bands C_2 and C_3 . The values obtained for the gap are 1.62 eV at 300°K and 1.70 eV at 78°K. It should be noted that the energy difference between the gap transition, V_1 to C_2 and C_3 , and the transition from V_1 to C_1 is just equal to the inter-conduction band transition from C_1 to C_2 and C_3 at $k=0$.

From electrical data Te provides a level 0.068 eV below the lowest conduction band while Se provides a level 0.16 eV below it. Direct optical confirmation of the Te level is not present in our data as free carrier and lattice absorption dominate in the expected spectral region. However, at 78°K the Se sample, 87-6, [Fig. 1(b)] shows a freezing out of free carrier absorption;

⁴ R. Braunstein, Bull. Am. Phys. Soc. 4, 133 (1959).

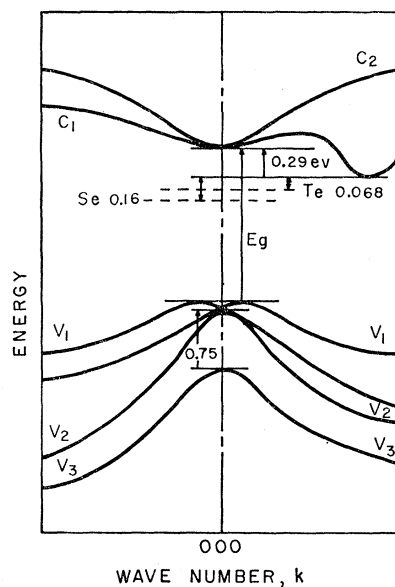


FIG. 3. An alternative band picture for AlSb.

a loss of the 4.3-micron band and the appearance of two new bands at approximately 2.5 microns and 7 microns. The 2.5-micron band is due to transitions from the Se level to the upper conduction bands, C_2 and C_3 , while the 7-micron band results from transitions from the Se level to the lower conduction band, C_1 . Therefore, the absorption spectra of selenium doped AlSb demonstrates that a 0.3-eV transition exists which is intrinsic to *n*-type AlSb.

Although the band structure shown in Fig. 2 seems to explain the characteristics of the 4.3-micron band, it does not explain why the nearly direct transitions from V_1 to C_1 result in such a weak 0.93-micron or 1.33-eV band. This fact suggests that the conduction band of AlSb may be many valleyed with a minimum at $k=0$ which is 0.29 eV above the lowest minima as shown in Fig. 3. Since the lowest minima would not be at $k=0$ they would provide for an indirect transition at 1.33 eV. This transition would be weaker than the more direct transition to the $k=0$ minimum. The central minimum should have a large density of states to make transitions from the lowest minima to the central minimum sufficiently probable to account for the 4.3-micron band. This could be provided by degeneracies at $k=0$ as is the case for *n*-type silicon.

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