Long-wavelength optical absorption in *p*-GaSb

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(Submitted September 22, 1987)

Pis'ma Zh. Tekh. Fiz. **14**, 64–68 (January 12, 1988)

Gallium antimonide is becoming increasingly important as the basis of a family of solid solutions. Although research in this are a dates back quite far, we have only extremely limited information on the energy spectrum of impurity states and defects in GaSb (Ref. 1). The data which are available have been obtained primarily from electrical measurements and from studies of the luminescence spectra near the fundamental absorption edge. The only study which has been carried out on the long-wavelength optical absorption involving impurity levels has been in the part of the spectrum with a photon energy above 50 meV (λ < 25 μm).[2,3]

In this letter we report a study of optical absorption in p-GaSb in the part of the spectrum with wavelengths 16-500 μm. This study was carried out in order to obtain information on the energy spectrum of shallow impurity levels. We studied samples of p-GaSb, not deliberately doped, of two types: samples grown by the Czochralski method and epitaxial layers grown from stochiometric molten solutions of GaSb in lead.

The optical transmission spectra were measured on an LFS-1000 long-wavelength Fourier spectrometer. Samples in the form of plane-parallel plates with a thickness of 50-150 μm were prepared by grinding and were then treated in a polishing etchant. In the measurements we used an R-118 vacuum helium optical cryostat. The samples were cemented with a conducting silver adhesive to the heat sink of the cryostat.

Figure 1 shows the absorption spectra of an undoped sample grown by the Czochralski method. At room temperature we see absorption by free charge carriers and also lattice absorption: a one-phonon band peaking at about 230 cm^{-1} and two-phonon bands near 250 and 270 cm^{-1}. In addition, we see some fainter two-phonon structures in the regions 320-360 cm^{-1} and 390-450 cm^{-1}. The behavior of the absorption by the free charge carriers can be described approximately by $\alpha \sim \lambda^{1,0}$.

As the temperature is lowered to liquid nitrogen temperature, the spectrum changes markedly. A broad luminescence band with a threshold of about 210 cm^{-1} emerges. At liquid-helium temperatures the edge becomes sharper and the absorption in the band increases by a factor of 1.5-2. The sharp increase in the absorption with decreasing temperature and also the characteristic shape of the band indicate that this band is a consequence of the photoionization and photoexcitation of acceptor levels.

To determine the ionization energy of the observed level, we make use of the results of the theory of Ref. 4. The maximum in the photoexcitation spectrum is at 260 cm^{-1} (Fig. 1) and corresponds to $\hbar\omega \approx 32$ meV. The most intense photoexcitation lines correspond to the transitions $1S_{3/2} \to 2P_{5/2}(\Gamma_8)$ and $1S_{3/2} \to 2P_{5/2}(\Gamma_7)$ (Ref. 4, for example). According to the theory of Ref. 4, the binding energies of the $2P_{5/2}(\Gamma_8)$ and $2P_{5/2}(\Gamma_7)$ levels are 3.59 and 2.61 meV, respectively. In the spectra which we recorded we cannot see the individual photoexcitation lines, so we take the binding energy of the 2p levels to be the average of these values: 3.1 meV with an uncertainty of 0.5 meV. The ionization energy of the observed acceptor is thus E_A = 35 ± 1 mev.

Figure 2 shows absorption spectra of a p-GaSb sample synthesized by liquid-phase epitaxy. The most important structural feature in these spectra is the appearance at liquid-helium temperature of an absorption band in the long-wavelength region with a threshold near 80 cm^{-1}. This band has a strong temperature dependence; even at liquid-nitrogen temperature (Fig. 2) this band is essentially unseen. The characteristic shape of the band and also the increase in the absorption with decreasing temperature are evidence that this band stems from photoexcitation and photoionization of acceptors. The ionization energy of the level responsible for the band is found by the same arguments as were used for the level at 35 meV. Since the maximum of the photoexcitation band is at 105 cm^{-1}, we find the ionization energy to be E_A = 16 ± 1 meV, within the splitting of the $2P_{5/2}(\Gamma_8)$ and $2P_{5/2}(\Gamma_7)$ levels.

In the spectra in Fig. 2 we also see an absorption associated with the level at 35 mev, which we discussed above. A comparison of the spectra in Figs. 1 and 2 shows that the concentration of optically active centers with the 35-meV level in the epitaxial samples is about an order of magnitude lower than in the samples synthesized by the Czochralski method.

It is well known that the hole conductivity of undoped GaSb is determined by the presence of a

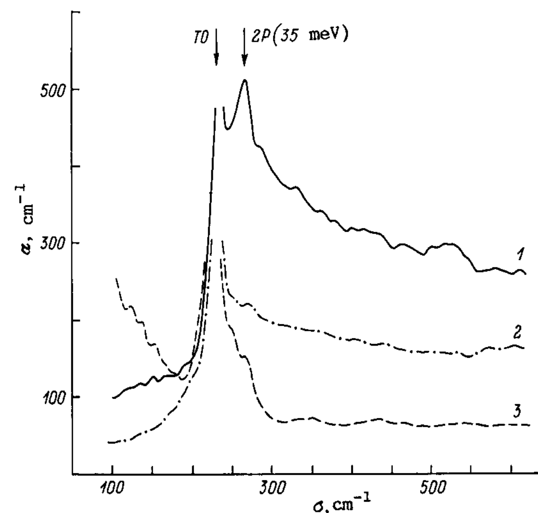

FIG. 1. Optical absorption spectra of GaSb synthesized by the Czochralski method. Temperature, K: 1) 10; 2) 80; 3) 295. The arrows show the position of the maximum in the photoexcitation spectrum of the acceptor (2P) and the position of the one-phonon band (TO).

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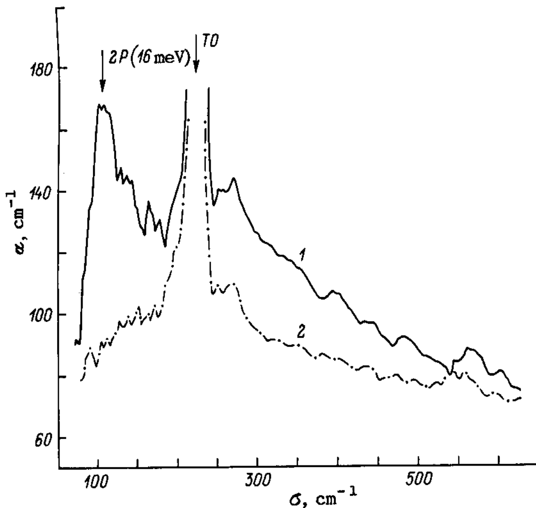

FIG. 2. Optical absorption spectra of GaSb synthesized by liquid-phase epitaxy. The notation is the same as in Fig. 1.

natural acceptor, which is, according to the data of Refs. 5 and 6, a stable vacancy center of the $V_{Ga}Ga_{Sb}$ type. For the energy of the first charge state of this acceptor, the values 34 meV (Ref. 2), 34.5 meV (Ref. 7), and 38 meV (Ref. 6) have been reported. The level at 35 ± 1 meV which we observe in the samples grown by the Czochralski method is close to the values just listed and can be identified with the first charge state of a natural acceptor.

The presence of a level at 16 ± 1 meV in the samples grown by liquid-phase epitaxy is evidence for the presence of a singly charged shallow acceptor in these samples. The nature of this acceptor has not previously been established. The existence of a shallow acceptor in p-GaSb has been mentioned previously in several papers. For example, Jakowetz et al. [8] report data on the photoluminescence of GaSb samples, both undoped and doped with Ge and Si. In all three cases, a peak (D^0, A^+) was observed and interpreted there as corresponding to radiative recombination at donor—acceptor pairs. The ionization energy found for the acceptor on the basis of these results is about 15.5 meV and close to the value which we observe. Bagraev et al. [6] report no manifestations of a shallow acceptor level in the ESR spectra of samples grown from gallium melts, while a peak observed in the spectra of samples grown from antimony melts corresponds to an ionization energy of 17 meV for the shallow acceptor. Th appearance of a shallow acceptor was linked with th presence of excess gallium vacancies. According to the data of Ref. 9, the photoluminescence spectra of compensated samples grown from a melt rich in Sl has a band which corresponds to a shallow acceptor with an ionization energy of about 13 meV. This acceptor was linked with the presence of Si. The information presently available on the level of the shallow acceptor has been found from photoluminescence data. Such data are frequenly difficult to interpret reliably. On the other hand, if the photo luminescence data are supplemented with data from a study of the long-wavelength optical absorption it becomes possible to make a completely definite case for the presence of a shallow acceptor level and to establish a fairly reliable value of the energ of this level: 16 ± 1 meV. The results presented here constitute the first direct observation of shallo acceptor levels in GaSb. This observation will mak possible an unambiguous determination of their ener positions.

We wish to thank Yu. P. Yakovlev for useful discussions.

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Translated by Dave Parsons