Far-infrared lattice absorption in gallium phosphide

B. Pödör, V.P. Izvekov

► To cite this version:

B. Pödör, V.P. Izvekov. Far-infrared lattice absorption in gallium phosphide. *Revue de Physique Appliquée*, 1983, 18 (11), pp.737-739. 10.1051/rphysap:019830018011073700 . jpa-00245139

HAL Id: jpa-00245139

<https://hal.science/jpa-00245139>

Submitted on 1 Jan 1983

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification
 Physics Abstracts
 78.30 — 63.20

Far-infrared lattice absorption in gallium phosphide

B. Pödör (*)

Research Laboratory for Inorganic Chemistry of the Hungarian Academy of Sciences, Budapest, Hungary

and V. P. Izvekov

Department of General and Analytical Chemistry, Technical University, Budapest, Hungary

(Reçu le 15 mars 1983, révisé le 28 juin, accepté le 8 juillet 1983)

Résumé. — L'absorption en infrarouge lointain dans le réseau de phosphure de gallium a été mesurée en utilisant un spectromètre à transformée de Fourier à 300 et 100 K. Des combinaisons à 2 phonons (soustraction et addition) ont été observées dans la bande spectrale 30-300 cm^{-1} . Les caractéristiques observées sont attribuées, sur la base de paires de phonons proches des limites de la zone de Brillouin, aux points X, L, W et K.

Abstract. — The far-infrared lattice absorption in gallium phosphide was measured using a Fourier-transform spectrometer at 300 and 100 K. Two-phonon combination (difference) and overtone bands were identified in the spectral range 30-300 cm^{-1} . The observed features were assigned on the basis of zone-edge phonon pairs at X, L, W and K points.

1. Introduction.

In the recent years considerable experimental work has been done to obtain zone edge critical point phonons in GaP while using inelastic neutron scattering [1, 2], second order Raman scattering [3-5], and infrared absorption [6-10]. Most of the infrared absorption measurements published so far [7-10] were restricted to the spectral range above about 400 cm^{-1} , i.e. above the Reststrahlen band, where two-phonon summation and overtone bands appear. As far as the present authors know, only one work dealt with the infrared lattice absorption below the Reststrahlen band, in the far-infrared range [6]. In the work of Koteles and Datars [6] the lowest frequency feature recorded in the two-phonon far-infrared absorption spectrum of GaP at 20 K was found at 180 cm^{-1} . In this work most of the prominent features of the absorption spectrum were assigned to pairs of phonons on the hexagonal face of the Brillouin zone while phonon pairs at X and L generally were thought to contribute only minor features in the spectrum. The two-phonon features in the spectral range below the Reststrahlen band have mainly been investigated by second order Raman scattering experiments [3-5].

In the present paper we report the results of far-infrared lattice absorption spectra measurements on GaP. The observed spectral features were interpreted invoking difference combinations and overtones of zone-edge phonons.

2. Experimental procedure.

Far-infrared spectra were measured on thin GaP single crystals with average thickness of 200-400 μm at room temperature and at about 100 K. The spectra were taken in the 10-130 cm^{-1} and 200-310 cm^{-1} range with a Grubb-Parsons IS-3 interferometer using the Fourier transform technique. Above about 310 cm^{-1} our samples were totally absorbing, due to the tail of the Reststrahlen absorption. Between 130 and 200 cm^{-1} the spectra were too noisy to be meaningful. Spectral resolution was about 5 cm^{-1} and wave number reproducibility was $\pm 0.5 \text{ cm}^{-1}$. The spectrometer was calibrated using the lines of water vapour. The samples were supported on polyethylene strip.

3. Results and discussion.

The far-infrared absorption spectrum of GaP at room temperature in the spectral range of 20-130 cm^{-1} and 200-310 cm^{-1} is presented in figure 1. The spectrum contains various features (peaks and shoulders) which

(*) Present address : Department of Electronic and Electrical Engineering, University of Ife, Ile-Ife, Oyo State, Nigeria.

Table I. — Assignment of the features observed in the two-phonon far-infrared absorption spectrum of gallium phosphide.

Feature No	Energy cm ⁻¹		Assignment		Shape		IR ^(a) 20 K cm ⁻¹	Raman ^(b) cm ⁻¹	Neutron ^(c,d) cm ⁻¹
	300 K	100 K	Branch	CP	Observed	Predicted			
1	31	37	A _{II} - A _I	W	Peak	P ₂ P ₃		30	30 ± 5
2	38		A _I - TA	K	Peak			43 ?	50 ± 9
3	62		A _{III} - A _{II}	W	Peak	P ₀ P ₁ P ₂		62 ?	60 ± 17
4	74 ^(e)								
5	106	105	TO - LA	X	Peak	P ₀	213	104	104 ± 9
6	112	113							
7	219		2 TA	X - K	Peak	P ₁		210	213 ± 4
8	228				P ₁				
9	238		O _I - A _I	W ^(f)	Peak	P ₀ P ₁	234		237 ± 17
10	249		2 A _I	W	Peak	P ₂			247 ± 5
11	261		LO - TA	X	Peak	P ₂	258	257	260 ± 12
12	292		LO - TA	L	Peak	P ₂	294	288	288 ± 8

^(a) Reference 6.
^(b) Reference 3, the lines at 43 and 62 cm⁻¹ are marked there with ?
^(c) Reference 1 for the phonons at X and L.
^(d) Reference 2 for the phonons at W and K.
^(e) Probably absorption band of polyethylene.
^(f) At W approximately O_I = O_{II}.

Fig. 1. — Far-infrared absorption spectrum of gallium phosphide at room temperature. Sample thickness 200 μm.

are attributed to two-phonon interactions. Table I lists the frequencies of the observed features, the two-phonon combinations assigned to them and their Brillouin zone locations, and the observed and predicted shapes. Phonons at points W and K are labelled according to the scheme used by Borchers *et al.* [2]. For the sake of comparison positions of lines observed in infrared absorption at 20 K by Koteles and Datars [6] and in second order Raman scattering experiments by Hoff and Irwin [3] are also listed.

The assignments proposed in table I are based on the phonon dispersion curves obtained from inelastic neutron scattering experiments by Yarnell *et al.* [1], and more recently by Borchers *et al.* [2].

From the twelve features listed in table I four and three lines respectively were assigned to difference or overtone bands originating from the critical points W and X respectively, and one feature to difference band at point L and other one to point K. One feature is thought to originate from the absorption of polyethylene supporting strip. The remaining two features were left unaccounted for.

At 100 K temperature feature No 1 disappeared. At the same temperature features Nos 2, 5 and 6 were seen at 37, 105 and 113 cm⁻¹ respectively. Feature No 4 was present only as a shoulder.

To predict the shapes of relevant features, the experimental phonon dispersion curves obtained in inelastic neutron scattering [1, 2] were examined. Where it was possible the probable shape of the singularity in the two-phonon density of states was determined according to the sign of the second derivative of the experimental $\omega(\mathbf{k})$ curves [11]. Use was also made of the theoretical results of Birman [12] concerning the one-phonon critical points in the related diamond structure crystals.

Features Nos 7, 9, 11 and 12 were also observed by Koteles and Datars [6] in their spectra covering the spectral range down to about 180 cm⁻¹. We think that feature No 7 observed here is an unresolved composition of the otherwise well documented line at around 210-212 cm⁻¹ in the Raman spectra [3, 4], usually ascribed to 2 TA(X-K) in the literature [4-6, 13, 14], and an other peak at around 220 cm⁻¹, which we ascribe to optic and acoustic difference combinations at K and W. Feature No 9 is assigned in

[6] to an unspecified location on the hexagonal face of the Brillouin zone. Feature No 11 is generally assigned to a difference band $\text{TO}(\text{X or L}) - \text{TA}(\text{X or L})$ [3-6, 13, 14]. The feature at 292 cm^{-1} was assigned by Weinstein and Piermarini [13, 14], on the basis of pressure dependence of Raman intensities either to $2 \text{ TA}(\text{K})$ or $2 A_{\text{II}}(\text{W})$.

As far as the present authors know all the features below 120 cm^{-1} are reported here for the first time for absorption. Feature No 1 coincides with a major peak observed in second order Raman scattering experiments [3-5], assigned either to $\text{LO}(\text{X}) - \text{TO}(\text{X})$ [3, 4] or $\text{LO}(\text{L}) - \text{TO}(\text{L})$ [5]. Features Nos 2 and 3 probably correspond to two minor but unidentified peaks seen by Hoff and Irwin [3] in second order Raman spectra. The identification of features Nos 1 and 3 as difference bands arising from critical point W appears to be convincing in the light of the recently published inelastic neutron scattering dispersion curves [2]. The assignment of the feature at 104 cm^{-1} corresponds to that one of Hoff and Irwin [3]. Feature No 2 is tentatively assigned to an optical-acoustical difference band at symmetry point K.

Feature No 4 is probably an artifact, caused by the polyethylene strip used to support the sample. The far-infrared absorption spectrum of polyethylene

shows a weak absorption band near 71 cm^{-1} [14].

On the basis of the assignments listed in table I the following values for the characteristic phonon energies at the critical points W could be deduced: $A_{\text{I}}(\text{W}) = 122 \pm 3 \text{ cm}^{-1}$, $A_{\text{II}}(\text{W}) = 152 \pm 3 \text{ cm}^{-1}$, $A_{\text{III}}(\text{W}) = 212 \pm 3 \text{ cm}^{-1}$, and $O_{\text{I}}(\text{W}) = O_{\text{II}}(\text{W}) = 360 \pm 3 \text{ cm}^{-1}$. These values agree well with the corresponding ones deduced from inelastic neutron scattering experiments by Borchers *et al.* [2]. They represent an improvement over the data obtained from a theoretical fit of the second neighbour ionic model, due to Banerjee and Varshni [15] to the Raman data of Hoff and Irwin [3].

Finally it should be mentioned that infrared absorption measurements performed on the same crystals in the spectral range above 400 cm^{-1} by one of the present authors [17] are also consistently interpreted using among others the phonon energies for critical point W deduced here.

4. Acknowledgments.

Grateful acknowledgments are due to Mrs. Z. Laczkó and Dr. B. Zelei for their cooperation in the measurements referred to in [17] and also for fruitful discussions.

References

- [1] YARNELL, J. L., WARREN, J. L., WENZEL, R. G. and DEAN, P. J., *Proc. Symp. Neutron Inelastic Scattering*, IAEA, Vienna, 1968, Vol. 1, p. 301.
- [2] BORCHERDS, P. H., KUNC, K., ALFREY, G. F. and HALL, R. L., *J. Phys. C* **12** (1979) 4699.
- [3] HOFF, R. M. and IRWIN, J. C., *Can. J. Phys.* **51** (1973) 63.
- [4] SUSHCHINSKY, M. M., GORELIK, V. S. and MAXIMOV, O. P., *J. Raman Spectros.* **7** (1978) 26.
- [5] BAYRAMOV, B. Kh., VISHNEVSKII, V. N., DEMCHUK, M. I., TOPOROV, V. V., UBAYDULAEV, Sh. B., HILDISCH, L. and ULRICI, B., *Fiz. Tverd. Tela* **23** (1981) 23.
- [6] KOTELES, E. S. and DATARS, W. R., *Solid State Commun.* **19** (1976) 221.
- [7] ULRICI, B. and JAHNE, E., *Phys. Status Solidi (b)* **86** (1978) 517.
- [8] ZAKRZHEVSKII, V. I., PIKHTIN, A. N. and YASKOV, D. A., *Fiz. Tverd. Tela* **13** (1971) 2635.
- [9] BESERMAN, R. and SCHMELTZER, D., *Solid State Commun.* **24** (1977) 793.
- [10] KLEIMAN, D. A. and SPITZER, W. G., *Phys. Rev.* **118** (1960) 110.
- [11] PHILLIPS, J. C., *Phys. Rev.* **113** (1959) 147.
- [12] BIRMAN, J. L., *Theory of Crystal Space Groups and Infra-Red and Raman Lattice Processes of Insulating Crystals*, in Encyclopedia of Physics, Ed.-in-Chief S. Flugge (Springer, Berlin) 1974, Vol. 25/2b.
- [13] WEINSTEIN, B. A. and PIERMARINI, G. J., *Phys. Lett.* **48A** (1974) 14.
- [14] WEINSTEIN, B. A. and PIERMARINI, G. J., *Phys. Rev. B* **12** (1975) 1172.
- [15] MÖLLER, K. D. and ROTSCHILD, W. G., *Far-Infrared Spectrometry* (Wiley, New York) 1971.
- [16] BANERJEE, R. and VARSHNI, Y. P., *Can. J. Phys.* **47** (1969) 451.
- [17] PÖDÖR, B. and LACZKÓ, Z., to be published.