LIGHT SCATTERING FROM PHONONS IN GaAs-AlAs SUPERLATTICES
C. Colvard, R. Merlin, M. Klein, A. Gossard

To cite this version:
C. Colvard, R. Merlin, M. Klein, A. Gossard. LIGHT SCATTERING FROM PHONONS IN GaAs-AlAs SUPERLATTICES. Journal de Physique Colloques, 1981, 42 (C6), pp.C6-631-C6-633. <10.1051/jphyscol:19816183>. <jpa-00221266>

HAL Id: jpa-00221266
https://hal.archives-ouvertes.fr/jpa-00221266
Submitted on 1 Jan 1981

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.
LIGHT SCATTERING FROM PHONONS IN GaAs-AlAs SUPERLATTICES

C. Colvard*(1), R. Merlin*(1),(2), M. V. Klein*(1),(2) and A.C. Gossard**

*Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, U.S.A.

**Bell Laboratories, Murray Hill, New Jersey 07974, U.S.A.

Abstract. Raman scattering data have been taken on several GaAs-AlAs superlattices with d<40 Å. Folded LA and TA modes are both seen whose frequencies are well fit by an elastic model involving the bulk sound velocities of GaAs and AlAs. A number of peaks appear near the bulk LO and TO frequencies. Selection rules and a partial examination of resonance behavior are presented.

In a semiconductor superlattice composed of alternating layers of GaAs and AlAs one expects the increased lattice period d along the [001] growth direction to fold the Brillouin zone and produce new zone-center modes derived from bulk wavevectors \(q_z = 2\pi n/d\), where \(n\) is an integer. Raman scattering spectra, which probe \(q \approx 0\), clearly show the presence of these modes in the acoustic region \(6100\text{ cm}^{-1}\). The optical region around the bulk LO and TO phonons, however, is more difficult to probe because the smaller dispersion of these branches causes many peaks in the spectra to overlap. In addition, light scattering from phonons with \(q \parallel [001]\) may in some cases become allowed. We have used the resonant enhancement of the light scattering when the laser energy nears the band gap to try to separate these peaks.

The samples are single crystal superlattices \(\approx 4\) microns thick grown by molecular beam epitaxy on GaAs substrates. We have looked at three samples, designated \(A=(4.81, 4.03)\), \(B=(7.3,4.4)\), and \(C=(9.4,3.85)\). Here \((\ell,m)\) means \(\ell\) monolayers of GaAs and \(m\) monolayers of AlAs per period, where one monolayer is \(\approx 2.83\) Å. Light scattering is done in backscattering geometry from the (001) surface.

Several folded acoustic modes have been seen in addition to those reported in Ref. 1. They are identified by their selection rules and their proximity to frequencies calculated by the elastic model described in that paper. The transverse modes have \(E\) symmetry and appear in both the \((x,x)\) and \((x,y)\) spectra. Here \((x,y)\) denotes incident light polarized along [100], scattered along [010]. Such \(E\) modes become partially allowed when the laser is incident at the Brewster angle, giving an angle in the sample of \(\approx 15^\circ\) to the normal. We see them in sample A at 43 and 47 cm\(^{-1}\) and in sample B at 35 and 38 cm\(^{-1}\), corresponding to the first zone-center gap \(q=2\pi/d\). The longitudinal modes, which should have \(A_1\) and \(B_2\) symmetry, appear only in \((x,x)\). The appearance of \(B_2\) in \((x,x)\) and not in \((x,y)\), even apparently out of resonance, is puzzling since the Raman tensor for the \(D_{2d}\) point group implies that \(B_2\) only should be seen in \((x,y)\). These modes appear in sample A at 63.1 and

(1) Also at Dept. of Physics, Univ. of Illinois at Urbana-Champaign
(2) Also at Coordinated Science Laboratory, Univ. of Illinois at Urbana-Champaign
(3) Present address : Dept. of Physics, Univ. of Michigan, Ann Arbor, MI
66.9 cm\(^{-1}\), in B at 52 and 57 cm\(^{-1}\), and in C at 39 and 45 cm\(^{-1}\), corresponding to 
\(q=2\pi/d\), and in sample C at 80 and 85 cm\(^{-1}\) corresponding to the next higher zone-
center gap \(q=4\pi/d\). In addition, when the laser is tuned near the gap energy, the 
\((x,x)\) spectrum shows peaks in sample A at 30 and 36 cm\(^{-1}\) which apparently correspond 
to scattering from the zone edge \(q=\pi/d\) gap. Possible reasons for their appearance 
are i) a doubled periodicity folding this gap to the zone center, resulting for 
example from an odd number \(\ell\) of monolayers in one compositional period, or ii) 
momentum conservation relaxation due to the presence of disorder. A broad struc-
ture \((\sim30\text{ cm}^{-1}\) wide) that may be due to higher gaps is also seen near 100 cm\(^{-1}\) in 
both samples A and B.

An example typical of the structure in the optical region is shown in Fig.1, 
taken near resonance in sample B at 180 K. 
Brewster angle backscattering gives \(q\) in 
the \(x\)-\(z\) plane inclined \(\sim7^\circ\) to [001]. Five 
peaks are clearly visible, none corre-
spending exactly to the bulk GaAs values of 
270.4 cm\(^{-1}\) for TO and 293.7 cm\(^{-1}\) for LO 
at this temperature. The peak labeled 1 
is \(E(TO)\) and disappears in exact back-
scattering. It corresponds to the unfolded 
GaAs TO phonon shifted down in frequency by 
the superlattice. Other spectra show a 
clear shoulder on this peak in \((x,y)\) 
around 255 cm\(^{-1}\). Peak 2 is similar to that 
labeled \(E(LO)\) in Ref.2, where it is attri-
buted to an interface-like mode propagating 
parallel to the layers. Such a peak may 
become allowed near resonance.\(^4\) Its 
frequency is rather well described by a 
dielectric constant model,\(^2\) but in these 
thin-layer samples it is also near pre-
dictions for the position of the first folded LO mode.\(^3\) More samples need to be 
studied to see if the frequency is dependent upon total period, as for folding, or 
only dependent upon the ratio of layer thicknesses as our model predicts for \(E(LO)\). 
The thinness of the superlattice and sample absorption of the laser make angle-
dependent studies of this mode difficult. It appears at 276,280, and 283 cm\(^{-1}\) at 
room temperature in samples A, B, and C respectively.

Peaks 4 and 5 were originally interpreted in sample A as the allowed and for-
bidden scattering from a single \(B_2(LO)\) unfolded mode.\(^2\) Their splitting is now 
well established. At 300K peak 5 occurs at 287, 288.5, and 290.5 cm\(^{-1}\) in samples 
A, B, and C, and peak 4 is seen at 284.3 and 287.5 cm\(^{-1}\) in samples A and B, res-
pectively. A possible explanation of peaks 2 through 5 is that they show the folding

![Fig. 1: Spectrum of sample B at 180K.](image)
of the GaAs-like LO branch, in which case the symmetry assignments would be B$_2$ for peaks 3 and 5 and A$_1$ for peaks 2 and 4. However, a linear chain model for a (4,4) superlattice by Barker et al.[3] suggests that the highest folded mode should lie closer to peak 2 in sample A, as mentioned above. If q-dependence is involved as in Fröhlich type forbidden scattering, B$_2$ modes may appear in the (x,x) spectrum. It is not clear why no forbidden scattering is seen at resonance for peak 5 in (x,x) or why it might be shifted to the position of peak 4.

The resonance behavior of these peaks is demonstrated in Fig. 2. The spectra were taken on sample B with 1.833 eV laser light by changing the gap with temperature between 100K and 300K. The photoluminescence peak was measured by exciting well above the gap. The energy of the room temperature peak is 1.805 eV. The curve labeled A is the folded acoustic mode at 50 cm$^{-1}$. Both peaks 1 and 3 show little change with laser energy.

This work was supported in part by the Joint Services Electronics Program (U.S. Navy, U.S. Army and U.S. Air Force) under Contract No. N00014-79-C-0424, the National Science Foundation under Grant No. DMR 7902780, and profited from institutional support by the National Science Foundation for the Materials Research Laboratory under Grant No. DMR 7723999.

Fig. 2: Resonance behavior of peaks in Fig. 1. $\omega_0$ is energy of the photoluminescence peak. Corrected for thermal factor but not absorption.