Interface effects on magnetopolarons in GaAs/Al_xGa_{1-x}As quantum wells at high magnetic fields

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Effects due to interface optical-phonon modes on the cyclotron resonance in high magnetic field are investigated for GaAs/Al_xGa_{1-x}As quantum wells with the inclusion of band nonparabolicity. The polaron cyclotron resonant frequencies are obtained from the magneto-optical absorption spectrum which exhibits magnetopolaron resonances near the GaAs and AlAs-like phonon frequencies. Our theoretical results are in good agreement with recent cyclotron resonance experiments. Furthermore, we present calculations of interface-phonon-assisted harmonics at high frequency whose positions are determined by the resonant phonon frequencies. [S0163-1829(98)04936-4]

I. INTRODUCTION

The effects of interface phonons on magnetopolarons in quasi-two-dimensional (Q2D) systems of semiconductor heterostructures have received considerable attention in the last decade. In quantum wells (QW's), the electron motion is confined in one direction, which leads to an increased localization of the electron wave function. This results in an increase of single polaron effects. A second effect of the confinement is the modification of the phonon modes. The confinement is a result of the sandwiching of the electron between different dielectric materials, which will also modify the phonons resulting in confined slab phonons, interface phonons, and barrier bulk phonons.[1–3]

For zero magnetic field, there exists a sum rule[3] indicating that the polarization due to different modes is practically the same as for bulk phonon modes. This makes it difficult to discriminate the relative importance of the interaction of the various phonon modes from the result one would obtain from a calculation using only bulk-phonon modes. But increasing the magnetic field allows one to bring the cyclotron frequency into resonance with the different confined phonon modes, resulting in magnetopolaron effects which are markedly different from those found using only the bulk phonons. Such a study provides information on the frequency of the confined phonons and on the strength of their interaction with the electrons.

Although a large amount of theoretical work has been done[1,2,4] concerning the effects of interface phonons on the position of the cyclotron resonance (CR) peak, only recently has the magnetopolaron resonance due to interface phonon modes been observed experimentally.[5] In Ref. 5, a detailed experimental and theoretical study of the polaron cyclotron resonance in modulation-doped GaAs/$Al_{0.3}Ga_{0.7}$As multiple quantum wells was carried out in magnetic fields up to 30 T. Resonant magnetopolaron effects due to the interaction between the electrons and the interface optical phonon modes were observed for the first time. Splitting of the polaron CR frequency was found in the region of the AlAs-like optical-phonon modes. Our calculation confirmed that this resonance resulted from the AlAs-like interface optical phonons in the quantum wells.

In this paper, we present a detailed theoretical calculation of the magnetopolaron CR spectrum with interface effects in GaAs/Al_xGa_{1-x}As quantum wells based on our previous work of polaron cyclotron resonance in GaAs/AlAs systems.[1] The calculation is improved by taking into account the nonparabolicity of the conduction band, and we extend our theory to GaAs/Al_xGa_{1-x}As structures for $x \neq 1$, where the GaAs- and AlAs-like phonon modes appear in the barrier material. The QW width dependence of the resonance magnetopolaron effect due to interface phonons is studied in detail and compared to experimental results. The oscillator strength of the different peaks in the CR spectrum are investigated as a function of the magnetic field. Furthermore, we investigate the interface and slab-phonon-assisted harmonics which occur above the optical-phonon frequencies. Such phonon-assisted harmonics have been studied in three-dimensional (3D) systems[6] and were observed in InSb (Ref. 7) and Hg_xCd_{1-x}Te.[8] Here we generalized this to lower dimensional systems.

II. MAGNETOPOLARON RESONANCE

In the presence of a magnetic field **B** applied in the z direction perpendicular to the interface, the energy levels of an electron are given by

$$E^0_{n,l}=E^z_l+\hbar\omega_c(n+1/2), \tag{1}$$

where E^z_l is the level ($l=1,2,\ldots$) due to the QW confinement corresponding to the motion in the z direction, $\omega_c=eB/m_\parallel$ is the unperturbed cyclotron frequency, n is the Landau-level index, and $m_\parallel$ is the electron band mass in the xy plane given by

$$m_\parallel=\frac{m^*_e m^*_{eb}}{P_w m^*_{eb}+P_b m^*_e}, \tag{2}$$

where P_w (P_b) is the probability to find the electron inside (outside) the quantum well, and m^*_e and m^*_{eb} are the electron effective mass in the well and in the barrier, respectively. Equation (2) includes the penetration of the electron wave function into the barrier resulting in a renormalization of the effective electron mass. This leads to an increase of the electron mass because $m^*_{eb}>m^*_e$, which is appreciable for narrow quantum wells. Here we are interested in the Landau levels $E^0_{n,1}=E^z_1+\hbar\omega_c(n+1/2)$ associated with the lowest electric subband E^z_1.

To compare theoretical results for the cyclotron resonant frequency with the experimental results, it is necessary to include the band nonparabolicity of the conduction band in the calculation. The electronic structure of III-V compound semiconductors in the presence of external magnetic fields can be described very well within the framework of **k**·**p** theory.[9–11] Ruf and Cardona[9] studied the electronic structure of GaAs by the technique of resonant Raman scattering in magnetic fields. They showed that the nonparabolicity of the bulk GaAs conduction band can accurately be described by the expression

$$E_n=-\frac{E^*_g}{2}+\left[\left(\frac{E^*_g}{2}\right)^2+\left(1-\frac{m^*_e}{m_0}-\frac{m^*_e}{m_0}C^*\right)E^*_g E^0_n\right]^{1/2}+\frac{m^*_e}{m_0}(1+C^*)E^0_n, \tag{3}$$

with the fitting parameter $C^*=-2.3$, and $E^*_g=E_g+\Delta_0/3$, $E_g=1520$ meV, $E_g+\Delta_0/3=1631$ meV, $E^0_n=\hbar\omega_c(n+1/2)$, and $m^*_e=0.0665m_0$. Here we generalized this expression to the quasi-two-dimensional case by (1) replacing the bulk mass m^*_e by the effective electron mass in the 2D plane $m_\parallel$, and (2) by including the confinement energy in the band gap energy $E^*_g=E_g+\Delta_0/3+E^z_1$. The CR frequency including the correction due to band nonparabolicity is now obtained from

$$\omega^{np}_c=(E_1-E_0)/\hbar. \tag{4}$$

The present calculation of the magneto-optical absorption spectrum is similar to the one described in Ref. 1 for GaAs/AlAs quantum wells, except that we additionally include band nonparabolicity and consider the different effective phonon modes of the GaAs/Al$_x$Ga$_{1-x}$As system. Within the linear-response theory, the polaron magneto-optical absorption is proportional to[1,12]

$$\frac{-\mathrm{Im}\,\Sigma(\omega)}{[\omega-\omega^{np}_c-\mathrm{Re}\,\Sigma(\omega)]^2+[\mathrm{Im}\,\Sigma(\omega)]^2}, \tag{5}$$

where $\Sigma(\omega)$ is the so-called memory function and ω^{np}_c is the unperturbed CR frequency. In the absence of Landau-level broadening we have $\mathrm{Im}\Sigma(\omega)=0$, and the position of the CR peak is determined by the equation $\omega-\omega^{np}_c-\mathrm{Re}\Sigma(\omega)=0$. When we calculated the CR frequency of the polarons in the GaAs/AlAs quantum well,[1] the memory function could be decomposed into

$$\Sigma(\omega)=\Sigma^{slab}(\omega)+\Sigma^{S+}(\omega)+\Sigma^{S-}(\omega), \tag{6}$$

which is a sum of the contribution from the slab phonon modes, the $S+$ interface mode (supported by the AlAs phonons), and the $S-$ interface mode (supported by the GaAs phonons).

In GaAs/Al$_x$Ga$_{1-x}$As quantum-well structures, the barrier material is the Al$_x$Ga$_{1-x}$As alloy which has two LO- and two TO-phonon modes. They are the GaAs- and AlAs-like modes, respectively. In the small-magnetic-field regime, it is possible to replace, in an approximate way, the two TO- and LO-phonon modes by single effective TO and LO modes as introduced in Ref. 13 and used, e.g., in Ref. 2, in the study of the electron-phonon renormalization of the electron energy and mass. However, for magnetopolaron effects in high magnetic fields, this approximation is no longer valid because resonant polaron effects occur and the electron energy can be comparable to the energy of the different TO- and LO-phonon modes. In principle, we should consider all the TO- and LO-phonon modes in the different materials in order to obtain the ''exact'' interface phonon modes.

For the GaAs/Al$_x$Ga$_{1-x}$As structures, frequencies of the AlAs-like phonon modes in the Al$_x$Ga$_{1-x}$As alloy are given by $\Omega^{AlAs}_{LO}=360+70.8x-26.8x^2$ cm^{-1} and $\Omega^{AlAs}_{TO}=360+4.4x-2.4x^2$ cm^{-1}. Those of the GaAs-like phonon modes are $\Omega^{GaAs}_{LO}=296-52.8x+14.4x^2$ cm^{-1} and $\Omega^{GaAs}_{TO}=270-5.2x-9.4x^2$ cm^{-1}. Typically, one uses $x=0.3$, and we have $\Omega^{AlAs}_{LO}=379$ cm^{-1}, $\Omega^{AlAs}_{TO}=361$ cm^{-1}, $\Omega^{GaAs}_{LO}=281$ cm^{-1}, and $\Omega^{GaAs}_{TO}=268$ cm^{-1}. In this work, we are interested in the magnetopolaron resonance close to the GaAs phonon frequencies and the AlAs-like phonon frequencies. Notice that the frequencies of the GaAs-like phonons are close to those of bulk GaAs, which are $\omega_{LO}(GaAs)=296$ cm^{-1} and $\omega_{TO}(GaAs)=270$ cm^{-1}. In a full theory one should calculate the interface phonon modes of the GaAs/Al$_x$Ga$_{1-x}$As interface which for $x\neq 0$ leads to six different modes of which two are AlAs like and the four others GaAs like. Two of these four GaAs-like interface modes are supported by the GaAs in the quantum well (corresponding to the $S-$ modes) and the two others are from the GaAs-like modes (with weight $1-x$) in the barrier material whose frequencies are between the TO and LO GaAs-like phonon frequencies. In order to avoid this extra complication, it is physically more transparant to weight the different interface phonon modes of the GaAs/AlAs system by the concentration of Al or Ga in the Al$_x$Ga$_{1-x}$As alloy. Therefore, as in

Ref. 1, in the present paper we approximate the memory function of the $S+$ interface phonon mode as

$$\Sigma^{S+}(\omega)\rightarrow x\Sigma^{S+}(\omega)+(1-x)\Sigma^{S-}(\omega). \qquad (7)$$

Then Eq. (6) becomes

$$\Sigma(\omega)=\Sigma^{slab}(\omega)+x\Sigma^{S+}(\omega)+(2-x)\Sigma^{S-}(\omega). \qquad (8)$$

We see that Eq. (8) reduces to Eq. (6) for $x=1$. On the other hand, for $x\rightarrow 0$ we also have the correct limit because $\Sigma^{S+}(\omega)$ and $\Sigma^{S-}(\omega)$ approach each other and vanish. The approximation in Eq. (7) indicates that we have separated the contribution of the barrier material $Al_xGa_{1-x}As$ to the interfcace polaron effect into two parts. The first part is from the AlAs-like phonons and is weighted by x, and the second part is from the GaAs-like phonons and is weighted by $1-x$. Furthermore, the momery function of the second part is approximated by that of the $S-$ mode.

In the calculation of the magneto-optical-absorption spectrum in $GaAs/Al_{0.3}Ga_{0.7}As$ quantum wells, we take $\alpha=0.068$, $\epsilon_0=12.85$, and $\epsilon_\infty=11.00$ in GaAs; and $\epsilon_0=11.91$ and $\epsilon_\infty=10.18$ in $Al_{0.3}Ga_{0.7}As$ in Eqs. (59) and (60) of Ref. 1. The CR frequency is determined by the position of the peaks in the magneto-optical-absorption spectrum. Figure 1 shows the polaron CR frequency as a function of magnetic field in $GaAs/Al_{0.3}Ga_{0.7}As$ quantum wells of widths (a) 120 Å and (b) 240 Å. The thin-dashed lines are the CR frequencies within the parabolic band approximation in the absence of electron-phonon interaction. The thin-solid lines are the results including band nonparabolicity which decreases the CR frequency, in particular at high magnetic fields. The CR frequencies of the polarons using the 3D GaAs phonon modes and band nonparabolicity are indicated by the dot-dashed curves, and exhibit only one magnetopolaron resonance around the GaAs phonon frequency. The thick-solid curves are the CR frequencies including band nonparabolicity and the electron-phonon interaction with interface and slab phonons. The experimental results are indicated by the dots. Away from the resonant magnetopolaron region around the AlAs phonons, the theory based on only bulk GaAs phonons describes the experimental results quite well, and coincides with our theory which includes interface and slab phonons. Therefore, earlier claims[4] that interface phonons are needed to describe the resonant magnetopolaron effect near the GaAs phonons, i.e., $\omega<340\ \mathrm{cm}^{-1}$, are questionable. Those claims are often based on crude approximations which, e.g., did not include band nonparabolicity and/or the finite height of the quantum well and/or the electron mass difference between the well and barrier region which result in important corrections to the CR peak position. The present calculation with interface and slab phonons is in agreement with the experimental results not only near the GaAs phonon region but also near the AlAs phonon region. Deviations from the experimental results near the AlAs resonant region can be attributed to (i) many-electron effects which are not included here, (ii) fluctuation of the frequncies of the AlAs-like phonons of the $Al_xGa_{1-x}As$ alloy barrier from sample to sample, and (iii) the larger error bar in the experimental data. From the experimental results, we also could not observe a decrease of the resonant frequency near an AlAs-like phonon frequency with an increasing width of

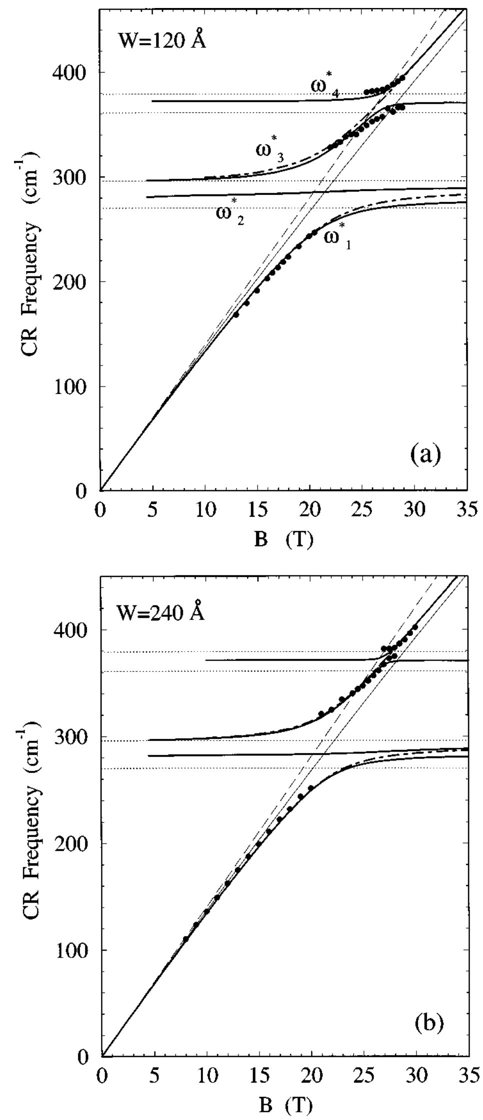

FIG. 1. The polaron CR frequency due to interface and slab phonons (thick solid curves), and due to 3D LO phonons (dotted-dashed curves) as a function of magnetic field in (a) 120-Å, and (b) 240-Å-wide $GaAs/Al_{0.3}Ga_{0.7}As$ quantum wells with the inclusion of band nonparabolicity. The thin-dashed and thin-solid lines are the unperturbed CR frequencies for parabolic and nonparabolic bands without inclusion of polaron effects, respectively. The dots indicate the experimental results. The horizontal dotted lines indicate the LO- and TO-phonon frequencies of GaAs and AlAs-like modes. The four branches of the CR frquencies in (a) are indicated by ω_1^*, ω_2^*, ω_3^*, and ω_4^* in increasing order of frequency.

the quantum well, which is expected from our theoretical calculations. We notice that only three of the four branches of the calculated magnetopolaron CR frequency are observed in the experiment. In order to see the relative importance of the different branches in the CR spectrum, we calculate the oscillator strength of the different absorption peaks in the magneto-optical spectrum which, for $\mathrm{Im}\Sigma(\omega)=0$, is given by $[1-\partial\ \mathrm{Re}\Sigma(\omega)/\partial\omega]^{-1}$. The results are shown in Fig. 2 for a 120-Å QW. This figure shows the following: (1) There are only experimental results available in certain magnetic-field regions for the different branches; e.g., for the lowest CR frequency branch, i.e., ω_1^*, the oscillator strength re-

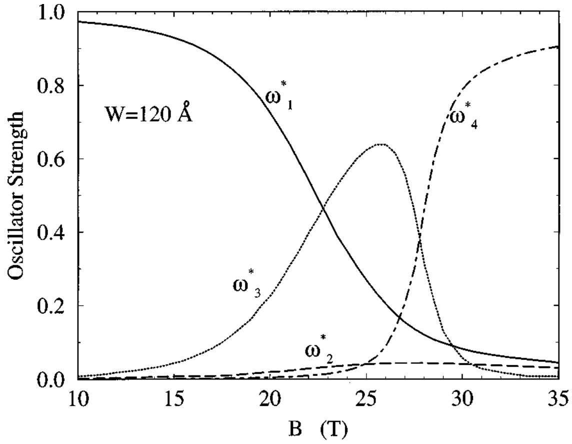

FIG. 2. The oscillator strength of the first four peaks in the magneto-optical-absorption spectrum as a function of the magnetic field in a 120-Å-wide GaAs/$Al_{0.3}Ga_{0.7}As$ QW. They are indicated by ω_1^*, ω_2^*, ω_3^*, and ω_4^* in increasing order of frequency.

duces with increasing magnetic field, and near B=22 T a large part of its oscillator strength is transfered to the ω_3^* peak which becomes now experimentally observable, while the ω_1^* peak becomes too weak to be seen experimentally. (2) The second CR frequency, i.e., ω_2^*, exhibits on oscillator strength which is typically one order of magnitude smaller than the main CR peak. Notice that the ω_2^* peak is in the reststrahlen region, which is a second reason why it is not observed experimentally.

A direct measure for the strength of the electron-phonon interaction is the splitting of the avoided-level-crossing resonance near the GaAs- and AlAs-like phonon modes. For simplicity, we define the splitting near the AlAs-like phonons as the frequency difference between ω_4^* and ω_3^* at the magnetic field, where ω_c^{np} equals ω_∞^{S+} (the frequency of the interface phonon mode $S+$ at wave number $q\rightarrow\infty$), and that near the GaAs-like phonon is the difference between ω_3^* and ω_1^* at $\omega_c^{np}=\omega_{LO}$ of GaAs. These splittings are shown in Fig. 3 as a function of the well width of the GaAs/$Al_{0.3}Ga_{0.7}As$ system. The solid (dashed) curve indicates the resonance in the region of the AlAs (GaAs)-like optical-phonon frequencies. The solid dots are the experimental results. The present theoretical results predict that the largest splitting as due to the AlAs-like interface phonons (solid curve in Fig. 3) occurs in a GaAs/$Al_{0.3}Ga_{0.7}As$ quantum well of width $W=18$ Å. The largest splitting near the GaAs phonon frequency occurs for a much larger well width of about $W=100$ Å. The decrease of the resonant splitting for a large well width near the AlAs-like optical phonon is mainly a consequence of the reduced overlap between the electron wave function and the interface phonon polarization which falls off like e^{-kz} from the interface. The polaron splitting near the GaAs optical-phonon modes is largely due to the interaction with GaAs slab modes, and consequently the reduction for large widths is due to the smaller confinement of the electrons and is similar to the decrease of the polaron effects when one goes from a 2D system to a 3D system. The reduction of the splitting for $W<18$ Å is a consequence of the finite height of the quantum well, which results in a large penetration of the electron wave function into the $Al_xGa_{1-x}As$ barrier and consequently a reduced probability of finding the electron in the QW or near the interface. The reduction of the splitting near the GaAs phonon for $W<100$ Å is a consequence of the reduced number of slab modes with decreasing W.

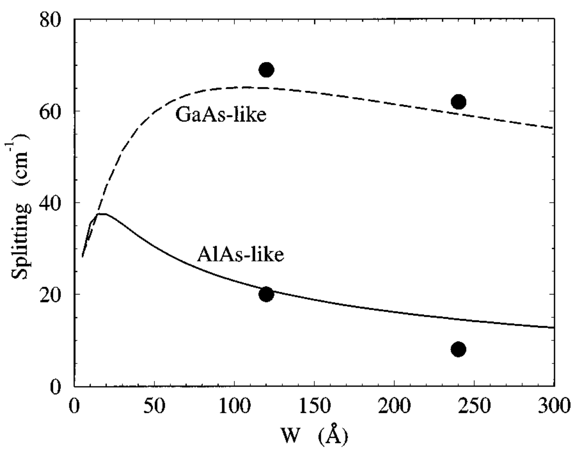

FIG. 3. The splitting of the magnetopolaron resonance around the GaAs-like (dashed curve) and AlAs-like phonon frequencies (solid curve). The dots are the experimental results.

In Fig. 4 we plot the absorption spectra of the magnetopolarons around (a) the GaAs and (b) AlAs-like phonon frequencies at different magnetic fields for a QW of width $W=120$ Å. The results are obtained for a Landau-level broadening $\Gamma=1$ meV. Figure 4(a) shows the magnetopolaron resonance due to GaAs-like interface and slab phonons. Notice that only two absorption peaks are observed, and that the peak corresponding to the second branch in Fig. 1(a), situated between the TO- and LO-phonon frequencies of GaAs, is absent. This is a consequence of its small oscillator strength, which makes it disappear in the tail of the other Landau-level broadened peaks. It is seen that, at $B=20.5$ T, most of the absorption strength is in the lower peak at $\omega=244$ cm^{-1}. When the magnetic field is increased, this peak is pinned ''around'' the ω_{TO} of GaAs, and its absorption strength is transfered to the higher peak located above the ω_{LO} of GaAs. Figure 4(b) demonstrates the magnetopolaron resonance due to AlAs-like interface phonons. It is seen that, at lower magnetic fields ($B<26.5$ T), the absorption peak at higher frequency is in the reststrahlen region of the AlAs-like phonons. With increasing magnetic field, the peak at lower frequency enters this reststrahlen region. It becomes very broad, and it loses most of its oscillator strength to the higher-frequency peak.

III. PHONON-ASSISTED HARMONICS

Figure 5 shows the magneto-optical-absorption spectrum for a polaron interacting with interface and slab phonon modes in the frequency region above the AlAs optical phonon in GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells of widths (a) 20 Å and (b) 120 Å for two different values of Landau-level broadening: $\Gamma=0.5$ meV (solid curves) and $\Gamma=1$ meV (dotted curves). The scale of these figures is multiplied with a factor of 300 as compared to the one of Fig. 4(a). We clearly observe optical-phonon-assisted harmonics[6,12] for the slab and interface phonons (namely, three series can clearly be discriminated), as indicated by $S-$, slab, and $S+$, respec-

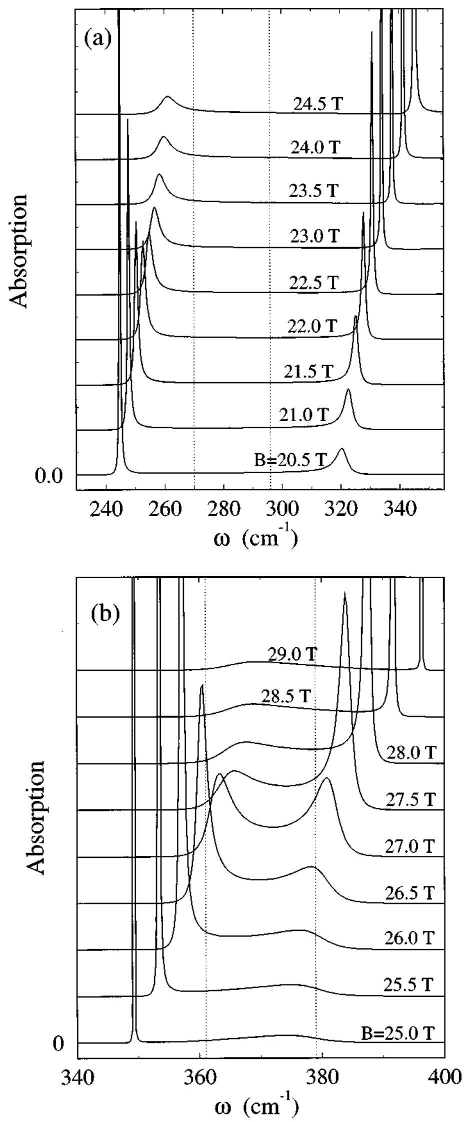

FIG. 4. The magnetopolaron absorption spectrum around (a) the GaAs-like and (b) the AlAs-like phonon frequencies at different magnetic fields in a $GaAs/Al_{0.3}Ga_{0.7}As$ QW of width $W=120$ Å. The two vertical dotted lines in (a) indicate the TO- and LO-phonon frequencies of GaAs, and those in (b) indicate the frequencies of the AlAs-like phonons. The Landau-level broadening is $\Gamma=1$ meV. The intensity in (b) is enlarged by a factor of 2 as compared to (a). The different curves are offset for clarity.

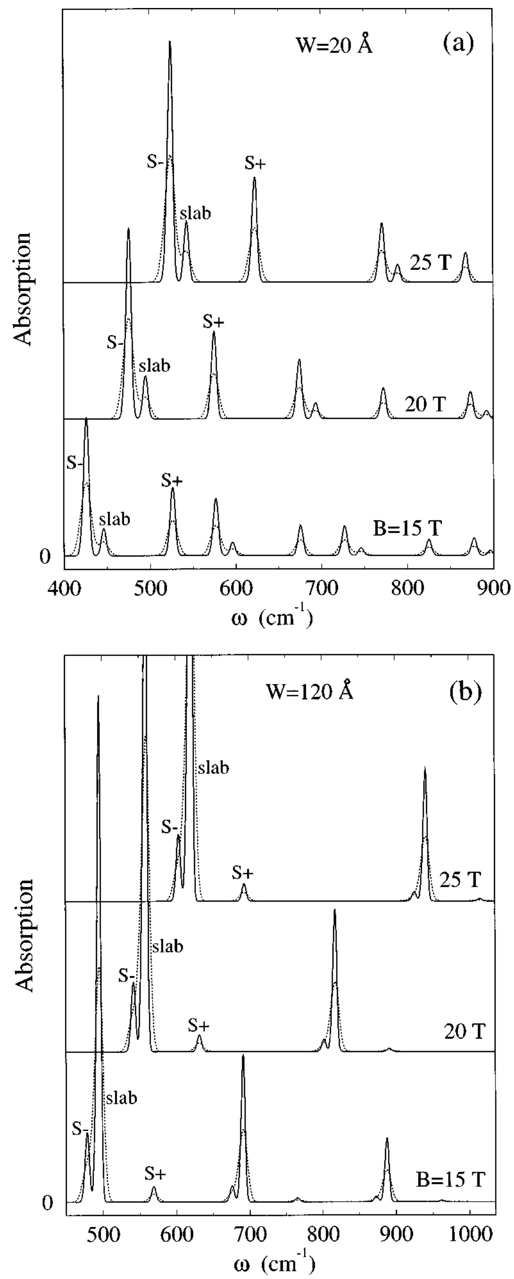

FIG. 5. The phonon-assisted harmonics in the polaron magneto-optical-absorption spectrum in (a) 20-Å and (b) 120-Å-wide $GaAs/Al_{0.3}Ga_{0.7}As$ quantum wells for three different magnetic fields and two values of the Landau-level broadening $\Gamma=0.5$ meV (solid curves) and $\Gamma=1$ meV (dotted curves). The intensity is enlarged 300 times as compared to Fig. 4(a).

tively. In Fig. 5(a) for $W=20$ Å, we notice that the absorption strength of the interface-phonon-assisted harmonics $S-$ and $S+$ is larger than the one due to the slab phonons. These three peaks are repeated periodically with period ω_c, but their strength decreases with increasing frequency. For a 120-Å QW, as shown in Fig. 5(b), the slab-phonon-assisted harmonics become much stronger than those of the interface phonons, indicating the decreased (increased) interaction of the electron with the interface (slab) phonons with increasing QW width.

The position of the first ten absorption peaks in a QW of width 120 Å are plotted in Fig. 6. We found that the position of the phonon-assisted harmonics depends only on the resonant optical-phonon frequencies ω_j^r, and is given by $\omega_{n,j}=\omega_j^r+n\omega_c^{np}$ with $n=1,2,\ldots$. For the slab phonons we have $\omega_{slab}^r=\omega_{LO}$ because the slab modes were taken dispersionless. On the other hand, the interface phonons have dispersion, and consequently the resonant frequency depends on the width of the QW. We found that the resonant frequencies of the $S+$ and $S-$ modes in a 120-Å QW are $\omega_{S+}^r=371.4$ cm^{-1} and $\omega_{S-}^r=281.7$ cm^{-1}, respectively.

In order to investigate the importance of the phonon-assisted harmonics, we calculated the strength of the different peaks for the situation of Fig. 6. They are shown in Fig. 7(a) for the first phonon-assisted harmonics $\omega_{1,j}=\omega_j^r+\omega_c^{np}$, and in Fig. 7(b) for the second phonon-assisted harmonics $\omega_{2,j}=\omega_j^r+2\omega_c^{np}$. Notice that they are

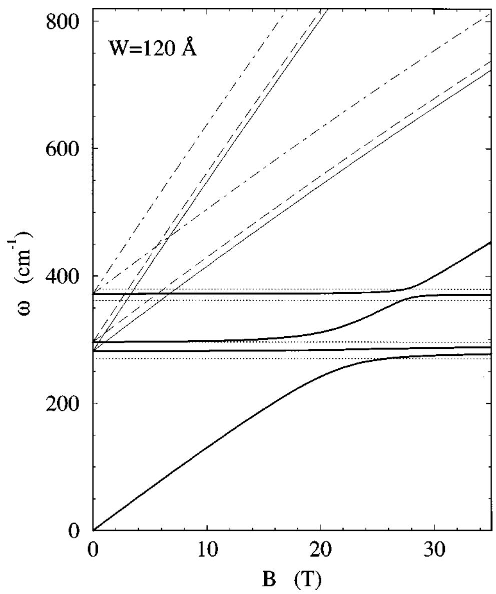

FIG. 6. The positions of the first ten peaks in the magneto-optical-absorption spectrum as a function of the magnetic field in a 120-Å-wide QW. The positions of the harmonics due to the GaAs-like interface mode ($S-$), slab modes, and AlAs-like interface mode ($S+$), are indicated by thin-solid, dashed, and dotted curves, respectively. The horizontal dotted lines are the frequencies of the GaAs and AlAs-like phonons.

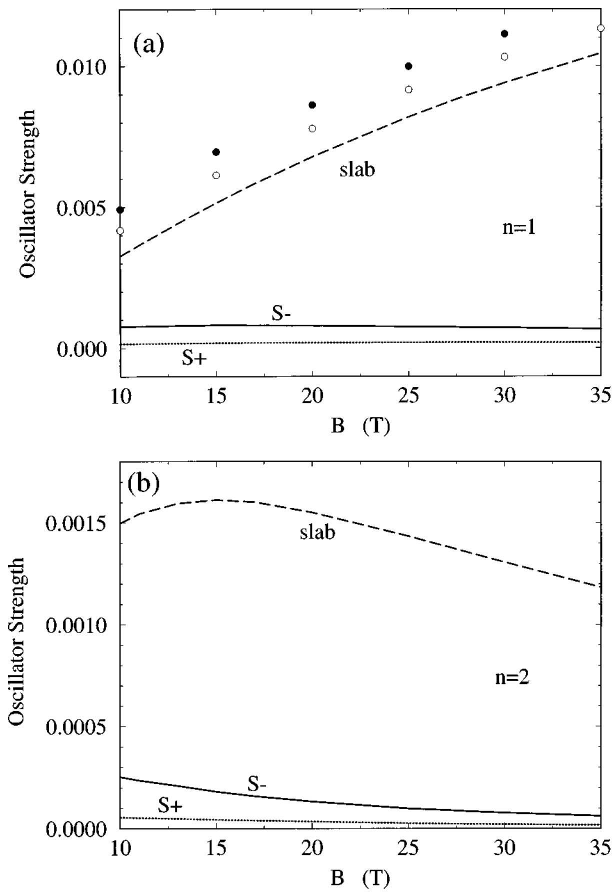

FIG. 7. The oscillator strength of (a) the first ($n=1$) and (b) the second ($n=2$) phonon-assisted harmonics in the magneto-optical-absorption spectrum as a function of the magnetic field in a 120-Å-wide QW. The solid dots in (a) are the results using the GaAs bulk-phonon modes, and the open dots are the sum of the oscillator strength of the $S+$, $S-$, and slab peaks.

typically two orders of magnitude smaller than the oscillator strength of the experimentally studied resonances (see Fig. 2). This result agrees with the earlier calculation of Wu, Peeters, and Devreese,[12] who included only interaction with bulk GaAs phonons for a Q2D system of GaAs heterojunction. The results using the 3D phonon modes are shown as solid dots in Fig. 7(a), and are compared with the present results (open dots), where we added the oscillator strength of the $S+$, $S-$, and slab peaks. The present results for the oscillator strength of the first phonon-assisted harmonics are one order of magnitude smaller than the theoretical results of Tanatar and Singh.[14] Our theoretical results are in agreement with recent experimental results[15] which were unable to observe the first phonon-assisted harmonics in a number of different GaAs quantum wells, and where it was estimated that the oscillator strength of this line must be less than 1% of the main CR peak. On the other hand, in a recent experiment,[16] a phonon-assisted *impurity* transition was observed in a donor-doped sample using photoconductivity at high frequencies. These results are not in disagreement with the present results, because here we considered free electrons and calculated the CR absorptions, while the experiment in Ref. 16 is for shallow bound electrons and where photoconductivity was used. Therefore, we expect that it will be extremely hard to see these phonon-assisted harmonics experimentally in GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells.

IV. SUMMARY AND CONCLUSIONS

A detailed theoretical analysis of the magneto-optical absorption spectrum of low density electrons in GaAs/$Al_xGa_{1-x}As$ quantum wells was presented. From our calculation of the polaron CR spectrum in GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells and a comparison with the experimental results of Ref. 5, we demonstrated that, in order to achieve good agreement with the experiments, it is important to include correctly (1) an appropriate electron effective mass for motion in the plane of the QW which is renormalized by the penetration of the electron wave function into the barriers, (2) band nonparabolicity effects, and (3) interface phonon modes in order to explain the magnetopolaron resonance around the AlAs-like optical phonons. The phonon-assisted harmonics exhibit clear signatures of the different interface phonons, and the slab phonons, but their oscillator strengths are two orders of magnitude smaller than the main CR resonances.

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