High-pressure magneto-optical studies of two-dimensional-electron and exciton transitions in GaAs-$Al_xGa_{1-x}As$ quantum-well heterostructures

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High-pressure photoluminescence measurements on modulation-doped and undoped GaAs-$Al_xGa_{1-x}As$ quantum-well structures have been performed for the first time in magnetic fields up to 15 T. We have observed Landau fans from interband transitions of the two-dimensional free-electron gas in the modulation-doped sample between 0 and 9 kbar. In this pressure regime the slope of the Landau fan changes at the rate of 2.6%/kbar; this value is surprisingly larger than the predicted rate of increase for the reduced effective mass. Above 9 kbar, the free Landau transitions disappear and magnetoexciton behavior dominates the spectrum. The influence of pressure on the band gaps causes a controlled trapping of the free electrons from the GaAs well to *DX* centers (Si deep donors) in the $Al_xGa_{1-x}As$ layers. Many-body effects are reduced and excitonic effects are enhanced. This is observed as a larger than predicted change in slope of the Landau transitions with pressure. The measurements were repeated on an undoped quantum-well sample. From the measured diamagnetic shift, an increase in the electron effective mass of 0.9%/kbar was determined. This value is comparable to that predicted by $\mathbf{k}\cdot\mathbf{p}$ theory.

I. INTRODUCTION

We report the first high-pressure, magnetophotoluminescence investigations of GaAs-$Al_xGa_{1-x}As$ quantum-well (QW), structures at low temperature. Our measurements show that in an undoped quantum well the pressure dependence of the electron effective mass, determined from the excitonic diamagnetic shift, is comparable to the value predicted by $\mathbf{k}\cdot\mathbf{p}$ theory. However, in modulation-doped GaAs-$Al_xGa_{1-x}As$ heterostructures, the corresponding change in the electron effective mass with pressure is considerably larger. In addition, pressure causes a controlled trapping of the free electrons from the GaAs well to *DX* centers in the $Al_xGa_{1-x}As$ layer. Consequently, in a single sample, using magnetophotoluminescence spectroscopy, we can measure the relative influence of many-body effects and exciton effects on the electron effective mass.

GaAs-$Al_xGa_{1-x}As$ QW systems are ideal for studying two-dimensional (2D) carriers in semiconductors. Modulation doping in the $Al_xGa_{1-x}As$ layer and the incorporation of undoped buffer regions near the GaAs interface have led to electrons and holes with extremely high mobilities.[1] As such these systems have important applications in high-speed electrophotonic devices.[2] The presence of a two-dimensional electron gas (2D EG) in the GaAs well causes many-body interactions, band bending and band-gap renormalization, etc.[3,4] There is much interest attached to these fundamental interactions, especially in systems of reduced dimensionality. Interband transitions can be conveniently monitored by photoluminescence (PL) spectroscopy.

Hydrostatic pressure (HP) has a strong influence on the electronic states in semiconductors. For example, in bulk GaAs, HP is known to cause the Γ and L bands to increase at the rate of 10.7 and 2.8 meV/kbar, respectively, while the X band decreases by 1.3 meV/kbar.[5] These changes affect the curvature of the E-$\mathbf{k}$ dispersion curves, thereby modifying the electron and hole effective masses. In QW's, just as in bulk semiconductors, various pressure-induced phenomena have been studied experimentally. The shifts of the confined quantum levels with respect to bulk bands have been observed,[6] the crossing of band extrema has been used as a means of determining band offsets[7,8] and structural phase transitions between layers[9] have been investigated. Mercy *et al.*[10] in HP transport studies of modulation-doped QW's found that the carrier concentration could be decreased with increasing pressure when the samples were cooled to low temperatures. Perry *et al.*[11] used PL spectroscopy to monitor and analyze the pressure-induced transition reported by Mercy *et al.* They determined the Fermi energy E_F, from the PL linewidth in the 0–10-kbar range; the results were consistent with those of Mercy *et al.* and they concluded that electrons in the GaAs could be driven into metastable deep levels within the $Al_xGa_{1-x}As$ band gap by the application of high pressure.

In this work we have used HP (i) as an effective probe of the deep donor states, and (ii) to tune the 2D electron density over a wide range. The motivation was to investigate many-body effects of 2D EG, to determine the pressure dependence of the effective mass, and to monitor a metal-insulator transition when electrons in the wells are transferred back in to the barriers and neutralize their parent Si donors. This was achieved by combining magnetic field PL studies with high-pressure investigations; the combination allowed us to distinguish free-carrier recombination from exciton recombination as we tuned the carrier density in a modulation-doped QW sample. The 2D EG displays interband Landau transitions in a magnetic field.[16] The PL energies of the associated Landau fan are linear with field and the slopes directly give the inverse reduced mass, $(1/\mu = 1/m_e^* + 1/m_h^*)$.[12,13] In contrast, magnetoexcitons observed in undoped quantum-well structures show a diamagnetic shift $(\sim aB^2)$ in the small-field limit,[14] where a is inversely proportional to the cube of μ. Therefore, using both modulation-doped and undoped QW samples, we are able to determine both the pressure dependence and many-body effects on the GaAs Γ electron effective mass.

II. EXPERIMENT

We have studied the effects of hydrostatic pressure (0–40 kbar) and magnetic field (0–15 T) on the low-temperature photoluminescence spectra of both modulation-doped and undoped GaAs-$Al_xGa_{1-x}As$ quantum-well heterostructures.

The samples were grown by molecular-beam epitaxy. The modulation-doped sample (No. 1) consisted of 15 cycles of the following layers: 258-Å-wide GaAs well, 495-Å-wide $Al_{0.21}Ga_{0.79}As$ barrier; Si donors were doped in the center portion of the barrier layer with an undoped 110-Å buffer layer on either side. The electron areal concentration, N_e, in each well at 4.2 K and atomospheric pressure was 5.1×10^{11} cm^{-2}, giving a Fermi energy E_F of $\sim$16 meV (with respect to the lowest confinement energy E_0). The undoped QW sample (No. 2) had a 60-Å-wide GaAs well; the Al fraction of the $Al_xGa_{1-x}As$ barrier was 0.3.

The samples (approximately 100 μm$\times$100 μm$\times$30 μm) were mounted in a specially constructed Be-Cu diamond-anvil cell (DAC). A 1:1 mixture of n-pentane:isopentane was employed as a pressure transmitting medium. The pressure was applied and clamped at room temperature. The cell was immersed in liquid helium in a cryostat inserted into a 15-T Bitter magnet. A multiple optical fiber system with a graded-index input-output lens coupler was used to illuminate and to collect the PL signal from the sample in the DAC. The luminescence spectra from small ruby chips in the DAC were used to calibrate the pressure and to monitor the homogeneity of the pressure medium. A slight broadening of the ruby peak indicated a $\sim$5% inhomogeneity in the hydrostatic pressure at 4.2 K; this caused a corresponding increase in the intrinsic linewidths in the PL spectrum from each sample.

PL was excited by a 514.5-nm radiation from an Ar^+-ion laser. The input laser intensity to the optical fiber was between 10 and 80 mW; such powers can produce relatively high electron temperatures.[11]

III. RESULTS AND DISCUSSION

The zero-field PL spectrum of the modulation-doped multiple-quantum-well (MQW) heterostructures consists of several broad peaks (with widths $\sim E_F$). They are attributed to conduction-band-to-valence-band (BB) and conduction-band-to-acceptor-impurity (BA) radiative transitions. In a magnetic field each of these PL peaks splits into a series of interband Landau transitions (0-0, 1-1, etc.)[12,13,15,16]

PL spectra taken as a function of pressure between 0 and 40 kbar for a modulation-doped MQW sample at zero magnetic field have been reported previously by Perry *et al.*[10] In Fig. 1 we show a selection of PL spectra taken at a fixed magnetic field of 5 T as a function of pressure between 0 and 13.4 kbar for the modulation-doped sample No. 1. This figure is representative of the PL data taken at other magnetic fields and at pressures up to 40 kbar. Below 9 kbar the intensities of the lowest (0-0) Landau BB and BA transitions increase by about a factor of 3 between 0 and 15 T. The intensity of the (1-1) BB peak decreases with increasing pressure at each field. These effects are due to changes in the electron density and redistribution below the Fermi level. At $\sim$9 kbar a marked change takes place in the spectrum. The respective Landau transitions disappear and the BB and the BA fans are each replaced by a single peak. The PL peak energies are plotted versus magnetic field in Fig. 2 for some

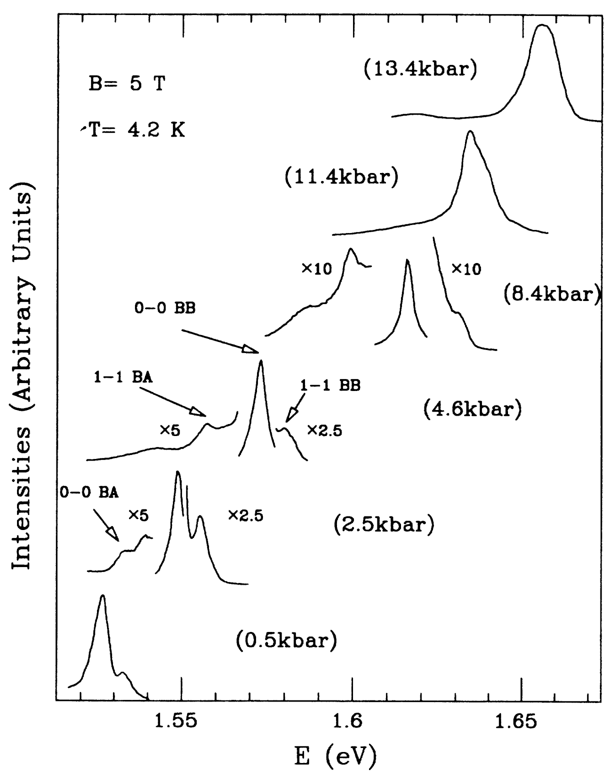

FIG. 1. Photoluminescence (PL) spectra of modulation-doped MQW sample No. 1 at 4.2 K over pressure range 0–13.4 kbar at $B=5$ T. The peaks below 8.4 kbar display Landau-like behavior and are labeled (0-0), (1-1), . . . band-to-band (BB), and (0-A), (1-A), . . . band-to-acceptor (BA) transitions, respectively. In contrast, the spectra at 11.4 and 13.4 kbar display magnetoexcitonic (ME) behavior.

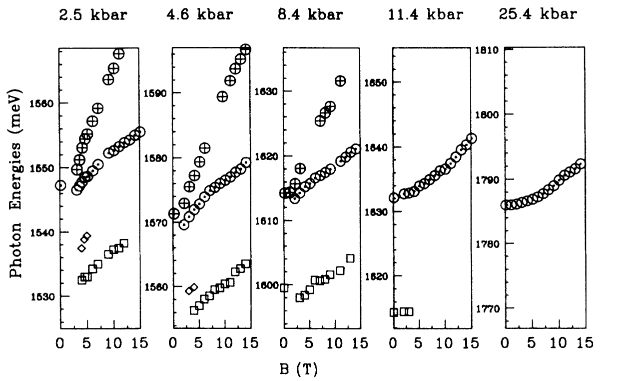

FIG. 2. PL peak energy vs magnetic field B at 4.2 K. Examples of Landau fans are shown at 2.5, 4.6, and 8.4 kbar. Here, ⊙, ⊕, □, and ◇ indicate the 0-0 BB, 1-1 BB, 0-A BA, and 1-A BA transitions, respectively. Diamagnetic shifts associated with the magnetoexcitons are clearly observed at 11.4 and 25.4 kbar.

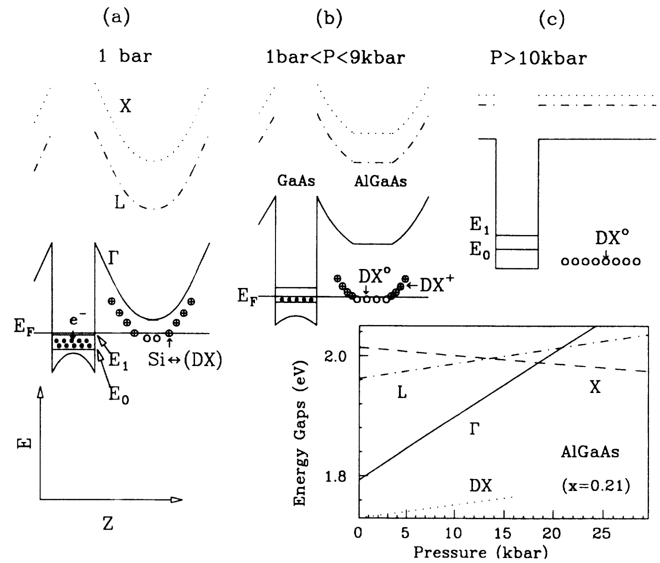

FIG. 3. A schematic representation of the Γ (——), L (— — —), and X (· · · ·) conduction bands, the confined subbands E_0, E_1, and the Fermi level E_F of a quantum well in the z direction (in real space) at 4 K are shown for three pressure regimes. The diagram is applicable to the Si modulation doped GaAs-$Al_xGa_{1-x}As$ MQW sample (No. 1). Electrons in the GaAs well are denoted by e; ionized DX centers and neutral DX centers in the barrier are denoted by ⊕ and ○, respectively. Three pressure regimes are indicated: (a) $P=1$ bar, (b) 1 bar $<P<9$ kbar, and (c) $P>10$ kbar. The inset (window) shows the Γ, L, X, and DX energy levels with respect to the top of the valence band as a function of pressure at 4 K for the $Al_{0.21}Ga_{0.79}As$ barrier. The plots are based on parameters given in Refs. 5, 17, and and 19.

selected pressures up to 25 kbar. The linear behavior of free Landau transitions transforms to a diamagnetic shift for the single peaks that displays magnetoexcitonic (ME) character. In the pressure regime above 9 kbar the intensities of the ME peaks remain constant with magnetic field. The relatively large spectral widths are primarily due to the pressure inhomogeneity. A 5% variation can cause the ME line shape to be broadened by about 10 meV at 20 kbar.

A. The role of *DX* centers

1. Trapping of free electrons by DX centers

It has been shown recently that deep donor states, known as DX centers in $Al_xGa_{1-x}As$-GaAs structures, can participate in emission and capture processes. Using the expression $E_{DX}=0.54x+1.57$ eV quoted by Chand[17] for Si-doped $Al_xGa_{1-x}As$, we obtain the energy of the DX level relative to the top of the valence band, $E_{DX}=1.683$ meV. This is about 272 meV below the L conduction band of $Al_xGa_{1-x}As$. Saxena[18] states that the DX level lies ~ 205 meV below the L point. The DX level seems to closely follow the L level either for increasing x (for $0.19<x<0.43$),[17,18] or for increasing pressure (for $P<20$ kbar) (Ref. 19) before the Γ-X crossover. Shan *et al.*[19] reported $dE_{DX}/dp \simeq 0.8\, dE_L/dp = 0.8 \times 2.8$ meV/kbar. For $x=0.21$, the Γ conduction-band-edge energy shifts with pressure by ~ 10.4 meV/kbar. Using these results and those of Ref. 5, the calculated Γ, L, X, and DX energies with respect to the top of the valence band at 4 K are shown as a function of pressure in the inset of Fig. 3.

The real-space conduction bands for three different pressure regimes are depicted in Fig. 3. In the case of sample No. 1, the Si donors start to form DX centers already at 1 atm. These donors are influenced by a parabolic potential due to the band bending of the barrier as shown in Fig. 3(a). For our sample, which is heavily doped, we estimate that the Fermi level coincides with the bottom of the parabolic DX level. Consequently, DX centers lying below E_F cannot contribute electrons to the GaAs well and these neutralized DX centers cause a flattening of the bottom of the parabolic bands of the doping barrier.

With increasing pressure, the separation between Γ and L conduction-band minima decreases. As this energy difference becomes much smaller than the L-DX energy separation (Fig. 3, inset), the energy level of the DX centers decreases with respect to the GaAs Γ level. Photoexcited electrons from the GaAs Γ well can recombine with the DX centers via L or X states in the $Al_xGa_{1-x}As$. At the relatively high electron temperatures encompassed in our experiments, electrons that recombine with the DX centers that drop below the Fermi level are trapped, thus reducing the electron concentration in the GaAs well [Fig. 3(b)]. As the concentration of electrons decreases, band-bending effects are reduced. Finally, when all the DX centers lie below the lowest confined subband E_0, all the electrons are trapped and the well is essentially empty [Fig. 3(c)]. This situation takes place at ~ 10 kbar, where free Landau BB transitions transform to ME behavior.

2. Self-consistent calculations

In order to confirm the model described above, the electron subband energies, the band bending, and E_F of the quantum-well structure were calculated self-consistently as a function of the electron density n_e, which is varied from 0 to N_e. (N_e is the initial density $=5.1\times10^{11}$ cm^{-1}.) As can be seen in Fig. 3(b) the $Al_xGa_{1-x}As$ barrier potential is linear in the buffer layer, parabolic in the layer where ionized *DX* centers lie above the Fermi level, and flat in the center portion where the neutral *DX* center coincides with E_F. Since n_e is directly related to the ratio of the length of the depletion layer (parabolic potential portion) to the length of the initially ionized doping layer at 1 atm (parabolic + flat portions), we can distribute the charge of n_e uniformly (assuming that all the Si donors become *DX* centers), according to the appropriate length of the doping layer. Assuming that $dE_{DX}/dP \simeq 0.8\, dE_L/dP$,[19] we can determine the pressure from the energy difference between the center of $Al_xGa_{1-x}As$ Γ band and E_F using the pressure coefficients of the L and Γ points. At the center of the barrier,

$$\begin{aligned}\Delta(E_\Gamma - E_F) &= \Delta(E_\Gamma - E_{DX}) \\ &= \Delta E_\Gamma - 0.8\,\Delta E_L \\ &= (\alpha_\Gamma - 0.8\alpha_L)\Delta P \ , \end{aligned} \tag{1}$$

where $\alpha_\Gamma = dE_\Gamma/dP$ and $\alpha_L = dE_L/dP$. $E_\Gamma - E_F$ depends on the valence-band offset which is chosen to be 35% in our calculation. We neglect the pressure dependence of the conduction-band-gap offset and choose an average value of $E_{DX}=1.72$ eV (Refs. 17 and 18) for a qualitative verification. By varying the percentage of the length of the initial depletion layer width to the length of the total doping layer, we can cause E_F to be degenerate with the lowest E_{DX} to match the initial conditions at 1 atm. After several reiterations of the calculation, we found that the initial depletion layer width was about 74% of doping layer thickness in the case of our sample. Figure 4 shows the result of the calculation, confirming the observation that the electron population decreases almost linearly with pressure until the empty state is reached at ~ 10 kbar. We estimate the average change in the electron concentration with pressure, $dn_e/dP \simeq -0.5\times10^{11}$ $\text{cm}^{-2}\,\text{kbar}^{-1}$. E_F decreases likewise almost linearly with pressure, but there is a discontinuity in the slope when the second occupied subband E_1 becomes empty at ~ 2.5 kbar.

B. Pressure dependence of the electron effective mass and the influence of many-body effects

1. Results from the modulation-doped sample

From the slopes of the Landau fans for *BB* and the *BA* transitions, we can determine both the electron and hole effective masses. At 1 atm, we find $m_e^* = 0.067m_0$ and $m_h^* = 0.62m_0$, in reasonable agreement with accepted values. As the pressure is increased in the range 0–9 kbar, the slopes of both the *BB* and the *BA* Landau fans decrease slightly. It is not possible to distinguish the difference in the change in slopes between the *BB* and the *BA* fans because the difference is smaller than the experimental error. Since

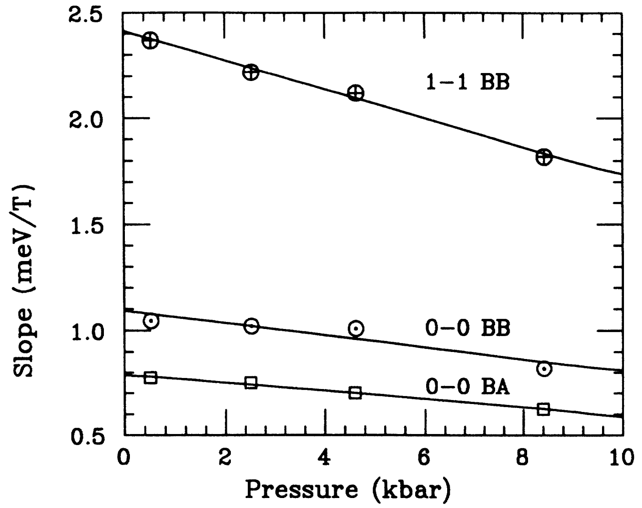

FIG. 4. Slopes of the Landau fans vs pressure (0–9 kbar) for sample No. 1. Solid lines are least-squares fits to the data points from the 0-0 *BB* (⊙), 1-1 *BB* (⊕), and 0-*A BA* (□) transitions, etc. From the fits we obtain $\Delta(\text{slope})/\Delta P = -0.028$, -0.069, and -0.020 $\text{meV}\,\text{T}^{-1}\,\text{kbar}^{-1}$ for 0-0 *BB*, 1-1 *BB*, and 0-0 *BA*, respectively.

$$\frac{\Delta\mu}{\mu^2} = \frac{\Delta m_e^*}{m_e^{*2}} + \frac{\Delta m_h^*}{m_h^{*2}} \ , \tag{2}$$

where $|\Delta m_h^*/m_h^*| \le 10^{-2}$ kbar^{-1} (Ref. 20) and $m_h^* \gg m_e^*$; the change that we observe is due primarily to a change in the electron effective mass, m_e^*, with pressure. The pressure shift of the hole mass can thus be neglected. From Fig. 5 we estimate $-\Delta(\text{slope})/$

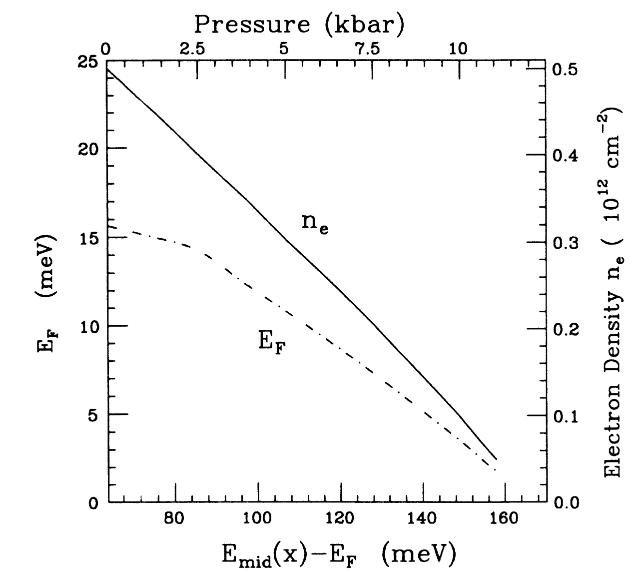

FIG. 5. Fermi energy E_F and electron areal density n_e as a function of energy difference, $E_{\text{mid}}(x)-E_F$ and as a function of pressure. The results were obtained from a self-consistent calculation (for sample No. 1 with the Al fraction, $x=0.21$.) Here, $E_{\text{mid}}(x)$ is the energy of the midpoint of the Γ-$Al_xGa_{1-x}As$ barrier layer. The discontinuity in slope of E_F at ~ 2.5 kbar occurs when E_1 is completely empty.

(slope$\times\Delta p$) for each Landau transition and obtain a best overall value of 0.026±0.006 kbar^{-1}.

2. Theoretical estimate of $d\ln(m_e^*)/dP$

A theoretical prediction of the variation of the effective masses in GaAs can be calculated using four-band $\mathbf{k}\cdot\mathbf{p}$ perturbation theory[21,22] based upon a simplified single-particle model. To first order, the eigenvalue corresponding to the conduction-band energy can be written as[22]

$$\mathcal{E} \simeq \mathcal{E}_c + \frac{k^2\mathcal{P}^2}{E_g} , \tag{3}$$

where $\mathcal{E}_c$ is the conduction-band edge energy, $\mathcal{P}=(\hbar/m_0)\langle u_s|p_x|u_x\rangle$ is the matrix element, u_s represents the s-like conduction-band Bloch function, u_x represents the p-like valence-band Bloch function, and E_g is the band gap. Since

$$\mathcal{E}_c(k) \equiv \mathcal{E}_c + \frac{\hbar^2k^2}{2m_e^*} , \tag{4a}$$

then

$$m_e^* \propto \frac{E_g}{\mathcal{P}^2} . \tag{4b}$$

The theoretically predicted increase in the electron effective mass with pressure should thus follow the change in the band gap ($d\ln m_e^*/dP = d\ln E_g/dP = 0.007$ kbar^{-1}). This value is 3 to 4 times smaller than our experimentally determined value from the modulation-doped sample No. 1. The theoretical model is strictly for single "free" electron in a crystal lattice. In our case, many-body effects are important and are known to cause a reduction in m_e^*.[23] This reduction in m_e^* should thus diminish as the number of 2D electrons in the well decreases with pressure causing a reduction in many-body effects. Consequently a larger increase in m_e^* with pressure is to be expected. When the electron density becomes so small that many-body effects can be neglected, the slope of the Landau fan is further reduced due to an increasing excitonic contribution. (i.e., the slope at any point for a pure excitonic diamagnetic shift particularly in the low-field region is less than that for a pure free-carrier linear Landau transition.) The overall effect causes an increase in m_e^* with pressure that is more than the ($m_e^* \propto E_g$) prediction for a single-particle model; these arguments are in qualitative agreement with our experimental observations of the significantly steeper decrease in the "Landau" slopes.

3. Results from the undoped sample

We have repeated the pressure-PL measurements in a magnetic field on the undoped quantum-well sample No. 2. In this sample the magnetoexciton transitions allow us to measure the pressure dependence of the effective mass free from the influence of many-body effects present in a modulation-doped MQW. In Fig. 6 we plot a selection of the PL peak energies (for the undoped GaAs/$Al_xGa_{1-x}As$ quantum well) versus magnetic field from 0 to 15 T for several pressures from 0 to 19 kbar. In the small-field region the energy shift for a 1s ME state can be written[14]

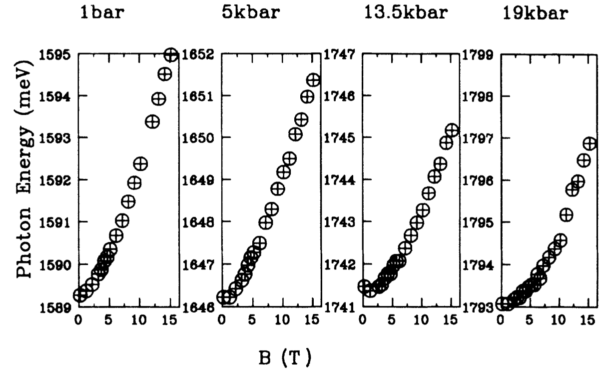

FIG. 6. PL peak energy of the undoped QW sample No. 2 vs magnetic field B at 4.2 K for some selected pressures between 0 and 20 kbar. The PL peak is a magnetoexciton 1s transition from the lowest confined conduction subband to the corresponding valence subband.

$$\Delta E_{1s} = \frac{D\epsilon^2\hbar^4}{4c^2e^3\mu^{*3}}H^2 \text{ cgs units} . \tag{5}$$

Here, ϵ is the delectric constant in GaAs, D is a parameter which is unity for a purely three-dimensional system, and $\frac{3}{16}$ for a purely two-dimensional system. The energy shifts parabolically with magnetic field H, and is inversely proportional to the cube of the reduced effective mass μ^*. Using $E_{1s}=aB^2+E(0)$, we have fitted the diamagnetic shift below 5 T to obtain the coefficient a for different pressures. A plot of a versus the pressure P is shown in Fig. 7. The value of a calculated from Eq. (5) [using

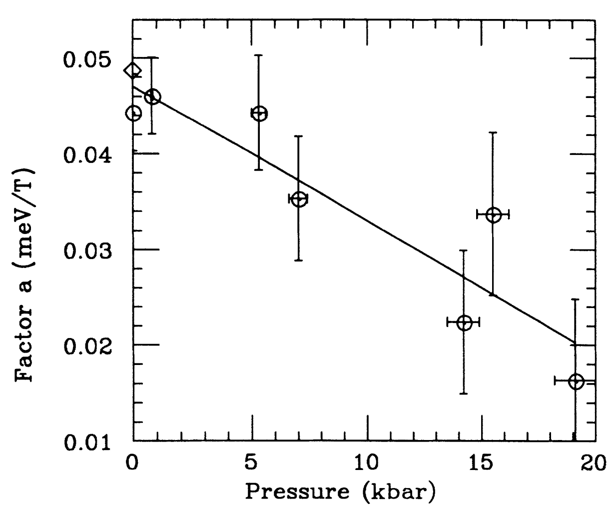

FIG. 7. The factor a from $\Delta E_{1s}=aB^2$ vs pressure from 0 to 20 kbar for sample No. 2. The data points (⊙ with associated error bars) were obtained from least-squares fits to the pressure-dependent diamagnetic shifts in the small field limit ($B<5$ T). A calculated a obtained from Eq. (5) at 1 bar is shown by (◇). The solid line is the least-squares fit to the data ⊙; it gives $da/dP = 0.0014$ meV T^{-2}kbar^{-1}.

$D=1$ (Ref. 14) and the accepted value $\mu^*=0.06\mu_0$] at 1 atm is also shown in Fig. 7. This value is in good agreement with the value determined from fitting to experimental result. Using

$$\frac{da}{a\,dP}=-3\frac{d\mu^*}{\mu_*\,dP}\simeq-3\frac{dm_e^*}{m_e^*\,dP}\ , \quad (6)$$

where $1/m_h^*$ has been neglected [see Eq. (2)], we obtain the rate of increase of the electron effective mass with pressure,

$$\frac{dm_e^*}{m_e^*\,dP}=(0.9\pm0.3)\%\ \text{kbar}^{-1}\ . \quad (7)$$

This value is in closer agreement with the theoretical prediction. We can only conclude that the difference between $\Delta\ln(\text{slope})/\Delta P=2.1\%$ kbar^{-1} for the modulation-doped MQW and $d\ln m_e^*/dP=0.9\%$ kbar^{-1} for the undoped QW is due to the many-body effects (including the excitonic effects). We estimate that the electron population affects the slope of the Landau fan on average by about

$$\frac{\Delta(\text{slope})}{(\text{slope})\times\Delta n_e}\simeq-3\%/(10^{11}\ \text{cm}^{-2})\ . \quad (8)$$

C. The pressure coefficient α_Γ

In Fig. 8 we have plotted (for the doped MQW sample No. 1) the energy of the lowest PL transition as a function of pressure at zero field. Above 9 kbar the energy of the transition from the $n=1$ level in the conduction band to the $n=1$ heavy-hole level in the valence band shifts at the rate of 10.4±0.6 meV/kbar. This value is obtained from the solid line in Fig. 8, which is a least-squares fit to the data over the pressure range 10–37 kbar and is slightly smaller than that found for $dE_g^\Gamma/dP=10.7$ meV/kbar in bulk GaAs.[5] Such a result is expected since the confinement energy of the electron in the well is proportional to the inverse of the effective mass μ, which is increasing with pressure. Consequently, the confinement energy decreases with respect to the top of the GaAs band gap with increasing pressure, thus reducing the pressure coefficient. The transition from BB to excitonic behavior at 9 kbar is clearly observed as a shift in the peak energy. Below 9 kbar the peak displays a nonlinear shift with pressure due the continuous reduction in the band bending in the GaAs well and a concomitant change in the band-gap renormalization, as the electron concentration is decreased with increasing pressure.

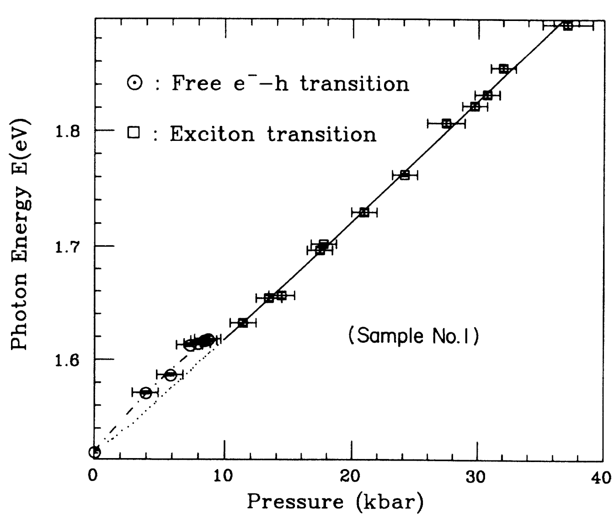

FIG. 8. The 4.2 K PL peak energy of (i) the BB transition (○) and (ii) the exciton transition (□) from 0 to 40 kbar for the MQW sample No. 1. The solid line is a least-squares fit in the exciton regime; the slope is 10.4 meV/kbar.

IV. CONCLUSIONS

We have performed magnetophotoluminescence measurements on GaAs-$Al_xGa_{1-x}As$ MQW heterostructures at high pressures between 0 and 40 kbar. Free Landau transitions of the 2D EG in a modulation-doped sample are observed up to 9 kbar. The slopes of the Landau transitions as a function of magnetic field change at the rate of 2.6% per kbar. This change is brought about by an increase in the electron effective mass with increasing pressure; the increase is due to a decrease in curvature of the conduction band in k space and due to a decrease of many-body effects as the electron subband depopulates with increasing pressure. In addition, the decrease in many-body effects leads to an increase in excitonic effects, which causes a further decrease in slope of the Landau fan. At ~9 kbar the Landau fans disappear completely and are replaced by a single peak, which exhibits the familiar diamagnetic shift associated with magnetoexciton behavior. Si donors in $Al_xGa_{1-x}As$ provide DX centers that act as electron traps. The relative shifts in the Γ and L band gaps cause a controlled trapping of free electrons in the GaAs well to the DX centers. In the high-pressure regime the pressure coefficient of the Γ conduction-band edge was found to be 10.4±0.6 meV/kbar, which is comparable to the accepted value in undoped GaAs quantum-well heterostructures. We determined the change in the GaAs electron effective mass with increasing pressure to be 0.9%/kbar from the diamagnetic shifts of the undoped sample. This increase is comparable with the theoretically predicted value of 0.7%/kbar obtained from a $\mathbf{k}\cdot\mathbf{p}$ calculation. Analysis of the experimental results yields that the population of the 2D electron affects the slope of the Landau fan by about $-3\%/10^{11}$ cm^{-2}.

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