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Pressure dependence of the Hall—to—drift-mobility ratio and its significance in $Ga_{1-x}Al_xAs$ alloys

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Hall-effect measurements have been made as a function of hydrostatic pressure on n-type $Ga_{1-x}Al_xAs$ ($0.23 \leq x \leq 0.78$) epitaxial layers at 300 K. The Hall—to—drift-mobility ratio has been derived from the experimental results for the alloy compositions investigated and is found to show a maximum near the pressure for the direct (Γ) and indirect (X) conduction-band minima crossover. The peak value of the ratio increases with the alloy compositions in the range $0.23 \leq x \leq 0.38$, showing that the strength of the intervalley scattering among the indirect (L) and (X) minima increases with the alloy composition. For $x=0.78$, this ratio is found to be close to unity and remains unchanged with increasing pressure.

I. INTRODUCTION

It is known that the conduction-band structure of $Ga_{1-x}Al_xAs$ alloys can be continuously changed by controlling the alloy composition x.[1–4] In GaAs the higher energy subsidiary minima L and X lie 0.285 and 0.485 eV, respectively, above the lowest energy Γ minimum. When controlled amount of Al is added to GaAs, the energies of the the Γ, L, and X minima increase with x. The changes in the minima energies with x are such that the first lowest energy direct (Γ) and indirect (X) crossover occurs at $x=0.43$, and the energy of the direct band gap increases up to this composition. For $x > 0.43$, although the energy of the X states increases, the band gap is indirect. In addition, a non-Γ deep level is also present in the alloys and its activation energy changes with x. Because of the significant changes in the band structure of the alloy with composition, magical changes in the transport properties are expected, which could be useful for optical and microwave devices of $Ga_{1-x}Al_xAs$. Particular attention has been paid to the study of the properties of this alloy as compared to other ternary alloys because of the minimal lattice mismatch ($\sim 0.16\%$) between the end compounds GaAs and AlAs.[5]

For careful device design, the electron mobility is a very important parameter, but it has received considerably less attention as compared to other material properties. The problem arises due to the fact that it is the Hall mobility which is experimentally measured. Because of the multiconduction band structure of $Ga_{1-x}Al_xAs$ alloys, it will be different than the true drift mobility which can be theoretically calculated. Hence a knowledge of the Hall—to—drift-mobility ratio as a function of x is essential. In turn, this will require a detailed knowledge of the band structure of the alloys. For high-field devices of $Ga_{1-x}Al_xAs$, it is necessary to know the velocity (v) and field (E) characteristics of the alloys for each composition. Immorlica and Pearson[6] and Sugeta *et al.*[7] have determined the v-E characteristics in $Ga_{1-x}Al_xAs$ from measurements of the current (I) and voltage (V) characteristics of typical Gunn devices. To derive the v-E characteristics from the I-V, the value of the Hall—to—drift-mobility ratio must be precisely known. Saxena[8] has recently shown that at atmospheric pressure, this ratio is found to be close to unity for alloy compositions $0 \leq x \lesssim 0.30$ and $0.6 \lesssim x \leq 0.78$, but attains a maximum value of 3.8 at $x=0.42$ due to the multiconduction Hall effect. The results, however, do not give any information about the dominant scattering process near the Γ-X crossover and the variation of scattering parameters with the alloy composition, which could also play a significant role in the high-field transport for low-alloy compositions.

In the present work, we have measured the Hall electron concentration and mobility as a function of hydrostatic pressure for high-purity $Ga_{1-x}Al_xAs$ samples ($0.23 \leq x \leq 0.78$). The experimental details are presented in Sec. II and the results in Sec. III. The conduction-band structure used in the calculations is described in Sec. IV and

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the experimental data are analyzed in Sec. V. The results derived from the analysis are discussed in Sec. VI and the main conclusions are reported in Sec. VII.

II. EXPERIMENTAL PROCEDURE

The high-purity layers with room temperature electron concentrations in the range $(5-10)\times 10^{15}$ cm^{-3}, used in the experiments were grown on Cr-doped semi-insulating GaAs substrates by liquid phase epitaxy. The alloy compositions were determined by converting the measured room-temperature cathodoluminescence band-gap energies into compositions by means of the energy-gap-composition curve given by Panish.[9] Ohmic contacts to Van-der Pauw samples were formed by deposition of Sn and alloying at 600 °C for 2 min in H_2 atmosphere. A small correction ($\sim$ 5%) was made to the measured values to account for the finite size of the contacts relative to the sample.[10] Care was taken to avoid spurious effects of contact resistances and the ohmic heating of the samples during measurements. Hydrostatic pressures were applied by using a magnesia filled epoxy resin[11] and liquid[12] pressure transmitting medium for high-pressure (up to 70 kbar) and low-pressure (up to 18 kbar) measurements, respectively.

III. EXPERIMENTAL RESULTS

The experimentally measured Hall electron concentration n_h and mobility μ_h normalized to their atmospheric values are shown in Fig. 1 for a typical alloy composition $x=0.23$. Qualitatively and for the sake of simplicity, the results can be explained on a two-conduction-band model involving the Γ and a subsidiary minima at higher energy. With increasing pressure ($0\leq P\lesssim 15$ kbar), the energy separation between the low density of states and high mobility Γ minimum and high density of states and low mobility subsidiary minima decreases,[1,3] thereby lowering n_h and μ_h due to electron transfer from the Γ to the subsidiary minima. At $P=40$ kbar, the subsidiary minima are considerably lower in energy than the Γ minimum and almost all the electrons are transferred from the Γ minimum to the subsidiary minima. With further increase in pressure ($P>40$ kbar), n_h and μ_h saturate, since the electron transfer is almost complete. If the pressure is slowly decreased ($P<40$ kbar), the energy separation between the two minima again decreases and more electrons are transferred

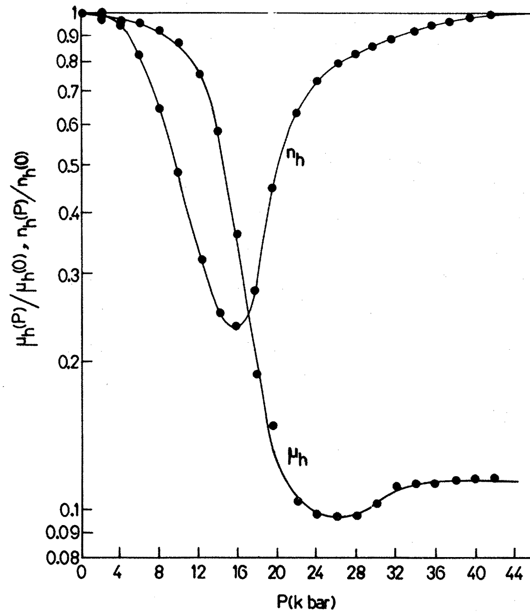

FIG. 1. Pressure dependence of the Hall electron concentration $n_h(P)$ and mobility $\mu_h(P)$ normalized to their atmospheric values, i.e., $n_h(0)=1.2\times 10^{16}$ cm^{-3} and $\mu_h(0)=3350$ cm^2/V sec for $Ga_{1-x}Al_xAs$ ($x=0.23$) crystal at 300 K.

to the Γ minimum from the subsidiary minima, thereby lowering n_h ($15<P<40$ kbar) and increasing μ_h ($15<P<28$ kbar). The minimum in n_h at $P\simeq 15$ kbar occurs when the conductivities in both the minima are approximately equal and a few kbar before the states are equal in energy (Ref.13). As will be shown later, the minimum in μ_h at $P\simeq$ 26 kbar occurs due to the intervalley scattering mainly among the L and X minima.

IV. CONDUCTION BAND STRUCTURE OF $Ga_{1-x}Al_xAs$ ALLOYS

It has been shown that in $Ga_{1-x}Al_xAs$, the minimum in n_h with pressure occurs mainly due to the carrier redistribution between the Γ and X minima,[13] while the thermal electron-transfer process[2-4] and the current saturation in Gunn devices[13] involve the Γ and L minima. For a full analysis of the results, one must consider all the electrons involved in the conduction process and they must satisfy the charge neutrality condition, i.e.,

$$N_d=n_d+n_\Gamma+n_L+n_X, \quad (1)$$

where N_d is the net density of donors and n_d that of the electrons on the donor sites, which is given by the equation[14]

$$n_d=N_d\left[1+\sum_i g_i\exp[(E_F-E_i)/kT]^{-1}\right]^{-1}, \tag{2}$$

where g_i is the degeneracy of the ith level ($g_i = 2$ is assumed), E_i is the activation energy of shallow and deep levels in $Ga_{1-x}Al_xAs$, and E_F is the Fermi energy. The terms n_Γ, n_L, and n_X are the densities of electrons in the Γ, L, and X minima, respectively.

With pressure a linear change in the energies of the Γ, L, and X minima is considered according to the equations

$$\begin{aligned} E_\Gamma(P)&=E_\Gamma(0)+\alpha P,\\ E_L(P)&=E_L(0)+\beta P,\\ E_X(P)&=E_X(0)-\gamma P, \end{aligned} \tag{3}$$

where α, β, and γ are the corresponding pressure coefficients. Considering the Γ minimum as the energy reference, the density of electrons in the Γ minimum and the ratios of densities of electrons in the X and L minima relative to the Γ minimum are given by the equations

$$\begin{aligned} n_\Gamma&=2\left[\frac{2\pi m_\Gamma^x kT}{h^2}\right]^{3/2}\exp(-E_F/kT),\\ \frac{n_X}{n_\Gamma}&=\left[\frac{m_X^x}{m_\Gamma^x}\right]^{3/2}\exp\{-[\Delta E_{\Gamma X}(0)-\delta P]/kT\},\\ \frac{n_L}{n_\Gamma}&=\left[\frac{m_L^x}{m_\Gamma^x}\right]^{3/2}\exp\{-[\Delta E_{\Gamma L}(0)-\xi P]/kT\}, \end{aligned} \tag{4}$$

respectively. Here $\xi = (\alpha-\beta)$ and $\delta = (\alpha + \gamma)$ are the pressure coefficients in eV/bar for $\Delta E_{\Gamma L}$ and $\Delta E_{\Gamma X}$, the subband gaps between the Γ-L and Γ-X minima, respectively.

Since the energies of the Γ and L minima increase with x and pressure, the electron effective masses in these minima also increase. The variation in m_Γ^x, the mass in the Γ minimum, is calculated from the standard $\vec{k}\cdot\vec{p}$ theory and is given by the equation[15]

$$\frac{m_0}{m_\Gamma^x(P)}=1+E_{p\Gamma}\left[\frac{2}{E_\Gamma(P)}+\frac{1}{E_\Gamma(P)+\Delta 0}\right], \tag{5}$$

where $E_{p\Gamma}$ and $\Delta 0$ are the energies related to the momentum matrix element and the spin-orbit splitting of the valence band, respectively, and m_0 is the free-electron mass. The density of states mass in the L minima is calculated from the equation

$$m_L^x=N^{2/3}m_t^{2/3}m_l^{1/3}, \tag{6}$$

where N is the number of equivalent L minima and m_t, m_l are the transverse and longitudinal mass of the minima, respectively. The mass m_t has also been calculated from the $\vec{k}\cdot\vec{p}$ theory and is given by the equation

$$\frac{m_0}{m_t(P)}=1+19.3\left[\frac{1}{E_L(P)}+\frac{1}{E_L(P)+\Delta 1}\right], \tag{7}$$

where $\Delta 1$ is the spin-orbit splitting of the valence band.

The Hall electron mobility μ_h and concentration n_h for a three-conduction-band semiconductor are given by the equations[15]

$$\mu_h=\frac{\mu_\Gamma\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]^2+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]^2\right]}{\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]\right]}, \tag{8}$$

$$n_h=\frac{n_\Gamma\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]\right]^2}{\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]^2+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]^2\right]}. \tag{9}$$

The drift mobility μ_d is given by the equation (Ref.16)

$$\mu_d=\frac{\mu_\Gamma\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]\right]}{\left[1+\left[\frac{n_X}{n_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\right]}. \tag{10}$$

Therefore, from Eqs. (8) and (10), it follows that

$$\frac{\mu_h}{\mu_d}=\frac{n_T}{n_h}=\frac{\left[1+\left[\frac{n_X}{n_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\right]\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]^2+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]^2\right]}{\left[1+\left[\frac{n_X}{n_\Gamma}\right]\left[\frac{\mu_X}{\mu_\Gamma}\right]+\left[\frac{n_L}{n_\Gamma}\right]\left[\frac{\mu_L}{\mu_\Gamma}\right]\right]^2}, \tag{11}$$

where

$$n_T = n_\Gamma + n_L + n_X . \quad (12)$$

The mobilities μ_Γ, μ_L, and μ_X are the electron mobilities in the Γ, L, and X minima, respectively.

V. ANALYSIS

The energy $E_\Gamma(0)$ of the Γ minimum for compositions $0 \le x \le 1$ was obtained from the data of Dingle *et al.*[17] at 2 K, converted to 300 K using the Varshini equation,[15] and the mass m_Γ^x was then obtained from Eqs. (3) and (5). We have used $E_{p\Gamma} = 7.51$ eV and $\Delta 0 = 0.341$ eV for $Ga_{1-x}Al_xAs$ as given for GaAs.[15] The energy separation $\Delta E_{\Gamma X}(0)$ and hence $E_X(0)$ as a function of x has been determined from the pressure dependence of n_h.[3,18] For a given value of x the mass m_L^x was calculated using Eqs. (6) and (7) with $N = 4$, $m_l = 1.9m_0$, and $\Delta 1 = 0.22$ eV as given for GaAs.[15] A value of $0.55m_0$ was obtained for this mass in GaAs. The pressure dependence of m_L^x was similarly calculated using Eqs. (3), (6), and (7). The mass m_X^x in the X minima was taken as $0.73m_0$ considering $N = 3$ and the mass in a single minimum of $0.35m_0$.[19] The mass m_X^x was kept constant as a function of x and pressure since the variation in the X minima energy is negligible as compared to that of the Γ and L minima.

The pressure coefficients for the energies of the Γ, L, and X minima used in the calculations have been determined from the pressure dependence of n_h and are given by the equations[18]

$$\frac{dE_\Gamma}{dP} = +(12.6 \pm 0.2) \times 10^{-6},$$

$$\frac{dE_L}{dP} = +(5.5 \pm 0.2) \times 10^{-6},$$

$$\frac{dE_X}{dP} = -1.5 \times 10^{-6}, \quad (13)$$

$$\delta = +(14.1 \pm 0.2) \times 10^{-6},$$

and

$$\xi = +(7.1 \pm 0.4) \times 10^{-6},$$

in units of eV/bar.

The activation energy E_i of the shallow and deep levels in $Ga_{1-x}Al_xAs$ ($0 \le x \le 0.78$) has been determined from low-temperature Hall measurements, while the energy separation $\Delta E_{\Gamma L}$ from measurements of n_h at temperatures where significant number of electrons are transferred to the L minima from the Γ minimum.[2-4] The energy separation $\Delta E_{\Gamma X}$ has been determined from the pressure dependence of n_h and the donor concentration N_d was obtained from the saturation value of n_h at high pressures when most of the electrons occupy the lowest energy X minima and almost all the centers in the deep level are ionized.[3,18]

At $P = 0$ kbar and for a given set of parameters, Eq. (1) is solved iteratively for E_F, and in turn n_Γ, n_L, and n_X are calculated from Eq. (4). Finally μ_h, n_h, and (μ_h/μ_d) are calculated from Eqs. (8), (9), and (11), respectively. Next the energies of the various minima and subband gaps are varied in accordance with Eq. (13) and the data calculated as a function of pressure.

The unknown parameters in the calculations are the electron mobilities $\mu_{\Gamma,L,X}$. We have theoretically calculated these mobilities as a function of pressure and for various alloy compositions using Matthiesan's rule. The following mobilities were considered: (i) polar-optical scattering μ_{po}, (ii) deformation-potential scattering μ_{dp}, (iii) alloy scattering μ_a, (iv) space-charge scattering μ_{sc}, (v) equivalent intervalley scattering among the X minima μ_{XX}, and (vi) nonequivalent intervalley scattering among the L and X minima μ_{LX}. Since at room temperature, the mobilities due to ionized impurity and piezoelectric scatterings are found to make negligible contributions to the resultant mobility, these have been neglected in the present analysis. The relevant equations and the various parameters involved in the calculations have already been discussed before.[19] The equations are

$$\mu_{po} = 25.54 \frac{T^{1/2}(e^{T_c/T} - 1)G}{(m^x/m_0)^{3/2}(1/\epsilon_\infty - 1/\epsilon_0)T_c}, \quad (14)$$

$$\mu_{dp} = 3.17 \times 10^{-5} \frac{C_l T^{-3/2}}{E_1^2 (m^x/m_0)^{5/2}}, \quad (15)$$

$$\mu_a = 52.83 \frac{T^{-1/2}}{(m^x/m_0)^{5/2} x(1-x)(0.3)^2}, \quad (16)$$

$$\mu_{\rm sc}=3.2\times 10^{9}\frac{T^{-1/2}}{(m^{x}/m_0)^{1/2}(N_sA)}\,, \tag{17}$$

$$\mu_{\rm iv}=4(\tfrac{2}{3})^{1/2}\frac{1}{(Z_j-1)}\mu_{\rm dp}\left[\left[\frac{T_c}{T}\right]^{3/2}\left[\frac{(T/T_c+\frac{2}{3}-\frac{2}{3}\Delta E/kT_c)^{1/2}}{(e^{T_c/T}-1)}+\frac{(T/T_c-\frac{2}{3}-\frac{2}{3}\Delta E/kT_c)^{1/2}}{(1-e^{-T_c/T})}\right]\right]^{-1}, \tag{18}$$

where ΔE is the subband gap among the minima involved in the process. For equivalent intervalley scattering, since all the X minima are at the same energy, $\Delta E = 0$ and $\mu_{\rm iv} = \mu_{XX}$. For nonequivalent intervalley scattering among the L and X minima, $\mu_{\rm iv} = \mu_{LX}$, $(Z_j - 1) \rightarrow Z_j$, and the mass in Eq. (15) corresponds to the electron mass in the L minima. For the Γ minimum the equivalent intervalley scattering will be absent since there is only one minimum, and the nonequivalent scatterings have also been neglected since the density of states in this minimum is very small compared to that in the L and X minima.

In addition to the relevant discussion already covered in a previous article by the author,[19] the value of E_1 of 8.6 eV for the Γ minimum has been assumed the same for all the alloy compositions. Its value in the X minima and as a function of x has been obtained from an analysis of the temperature dependence ($14 \lesssim T \leq 300$ K) of μ_h for the electrons in the X minima of $Ga_{1-x}Al_xAs$.[20] To mention a typical result, a value of E_1 of 6 eV has been determined for $x = 0.23$. The calculated results of μ_Γ and μ_X are shown in Fig. 2 for $x = 0.23$, together with μ_L. Since not much is known about the scattering parameters for the L minima in $Ga_{1-x}Al_xAs$, we have kept μ_L as an adjustable parameter in the calculations. Using the values of $\mu_{\Gamma,L,X}$ shown in Fig. 2 and those of n_Γ, (n_X/n_Γ), and (n_L/n_Γ), we have calculated n_h and μ_h as a function of pressure and compared these with the experimental data shown in Fig. 1. An excellent agreement is found between experimental and calculated values. Once the experimental results are explained, the ratio (μ_h/μ_d) is calculated from Eq. (11) and the results for a few compositions are shown in Fig. 3.

VI. DISCUSSION

From Eq. (11) it is evident that for a given density of total conduction electrons, the ratio (μ_h/μ_d) is inversely proportional to n_h. Thus the maximum in the ratio (Fig. 3) occurs at a pressure corresponding to the minimum in n_h which, in turn, occurs at a pressure a few kbar lower than needed for the Γ-X minima crossover. With increasing composition ($0.23 \leq x \leq 0.38$), the peak value of the ratio is found to increase and the pressure for this value to decrease with x. This is justified since with increasing x, the energy separations $\Delta E_{\Gamma X}$ and $\Delta E_{\Gamma L}$ decrease. Hence the pressure needed for the Γ-X crossover also decreases. This lowers the value of the pressure for the occurrence of maximum in the ratio (μ_h/μ_d). For the alloy composition $x = 0.78$, the ratio maintains the value close to unity as a function of pressure because even at $P = 0$ kbar, the majority of the electrons occupy only the lowest energy X minima. With further increase in pressure, the Γ and L minima move further away from the X minima and their effect on n_h and μ_h can be safely neglected. Our results are consistent with similar measurements on n-GaAs by Pitt and Lees,[21] where the

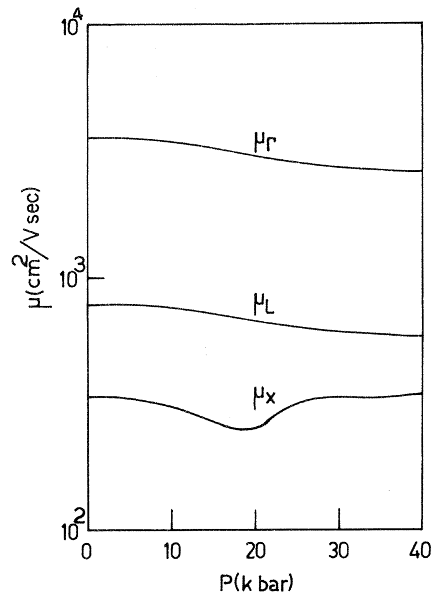

FIG. 2. Pressure dependence of the calculated electron mobilities μ_Γ, μ_L, and μ_X in the Γ, L, and X minima, respectively, for the alloy composition $x = 0.23$.

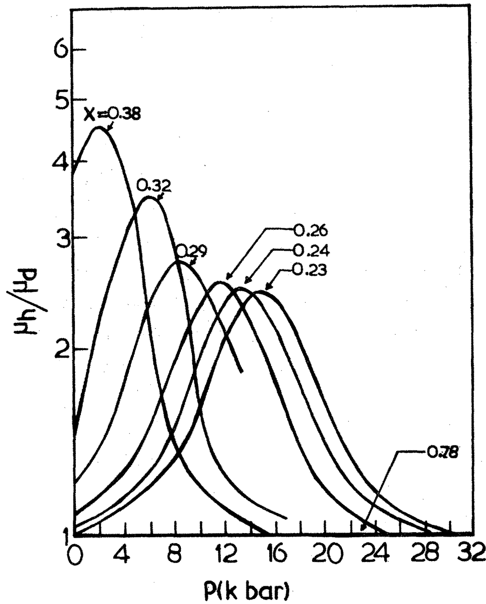

FIG. 3. Pressure dependence of the Hall—to—drift-mobility ratio for various alloy compositions.

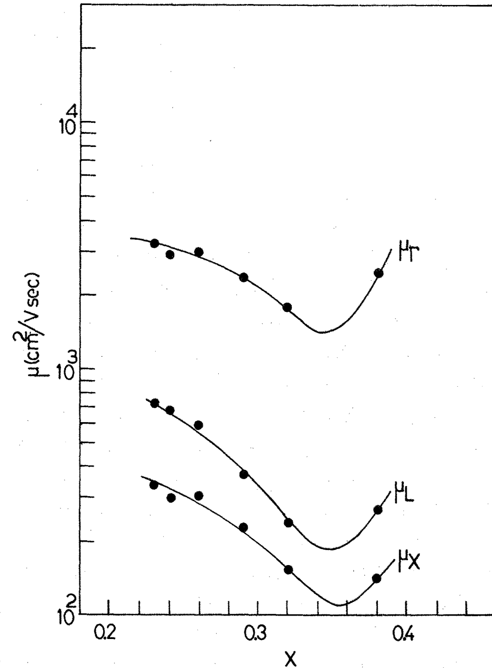

FIG. 4. Composition dependence of the electron mobilities in the Γ, L, and X minima for the minimum in the Hall electron concentration $n_h(P)$ (Fig. 1).

minimum in n_h was observed at a pressure of 32—33 kbar. Therefore, for GaAs, the maximum in (μ_h/μ_d) should occur in this pressure range.

The value of the ratio (μ_h/μ_d) depends on two factors: (1) the conduction-band structure through the ratios of electron population in the various minima, i.e., n_X/n_Γ and n_L/n_Γ, (2) and the ratios of the electron mobilities, i.e., μ_X/μ_Γ and μ_L/μ_Γ. Since the band structure of the alloys is nearly the same for each alloy composition subject to the pressure for the minimum in n_h and, therefore, the maximum in the ratio (μ_h/μ_d), the contribution of the band structure is nearly the same for all the compositions. This clearly means that the values of the ratios (μ_X/μ_Γ) and (μ_L/μ_Γ) must decrease with the alloy composition $(0.23 \leq x \leq 0.38)$ in order to increase the peak value of the ratio (μ_h/μ_d). This is indeed the case and the mobilities $\mu_{\Gamma,L,X}$ needed to explain the data (Fig. 1) for various compositions at the pressure corresponding to the minimum in n_h are shown in Fig. 4. The value of the ratio (μ_X/μ_Γ) decreases from 0.095 to 0.055 for $x = 0.23$ to $x = 0.38$, while that of μ_L/μ_Γ changes from 0.28 to 0.11, thus increasing the peak value of μ_h/μ_d with composition x.

The mobilities $\mu_{\Gamma,L,X}$ decrease with x in the range $0.23 \leq x \lesssim 0.36$ (Fig. 4), and it is important to identify the scattering processes which lower these mobilities. For alloy compositions $0 \leq x \lesssim 0.32$, the temperature dependence $(14 \lesssim T \lesssim 300$ K) of μ_h has been successfully explained and it is shown that at atmospheric pressure mainly the alloy and space-charge scatterings limit the electron mobility at 300 K and no intervalley scattering is required to explain the data.[19] With change in pressure on the crystals, neither the mobilities due to alloy [Eq. (16)] nor the space-charge scattering [Eq. (17)] and hence $\mu_{\Gamma,L,X}$ are expected to change appreciably. Near the pressure for the Γ-X crossover, the low-electron mobility in the X minima (Fig. 2) is found to be limited mainly by the polar-optical scattering but the contributions from the L-X nonequivalent intervalley scattering cause the minimum in μ_X at $P \simeq 18$ kbar. With increasing pressure, μ_X makes an increasing contribution to the measured μ_h due to large density of states in the X minima compared to the Γ minimum. But the contributions become significant only for $P \gtrsim 26$ kbar $(x = 0.23)$ due to the fact that most of the electrons occupy the X minima, and that only a few electrons are left in the Γ minimum. Thus the X minima mobility variation is reflected in the minimum in μ_h at $P \simeq 26$ kbar as shown in Fig. 1. It has been found that in $Ga_{1-x}Al_xAs$ alloys with compositions in the range $0.0 \leq x \lesssim 0.30$, the electron mobilities in the Γ and X minima are limited

mainly by polar-optical scattering and the contributions of μ_a, μ_{sc}, μ_{dp}, and μ_{XX} to the total mobilities in these minima are very small compared to other scattering mechanisms.[20] It is difficult to make a similar argument for μ_L since it could not be calculated theoretically. It has earlier been shown that the L minima do not play any significant role in the transport in GaAs at high pressures.[15] Since the band structure of $Ga_{1-x}Al_xAs$ is similar to that of GaAs under pressure, the same argument holds and is found to be true for $Ga_{1-x}Al_xAs$. Hence it becomes obvious that the decrease in $\mu_{\Gamma,L,X}$ with x $(0.23 \leq x \lesssim 0.34)$ shown in Fig. 4 mainly occurs due to increasing contributions from the nonequivalent intervalley scattering among the L and X minima, which in turn means that the values of the various scattering parameters increase with x in this range. For $x \gtrsim 0.36$, the mobilities increase with x, probably due to the reason that the coupling constants decrease with x. But at the same time the ratios (μ_X/μ_Γ) and (μ_L/μ_Γ) decrease, resulting in larger peak value for (μ_h/μ_d). Since the minimum in n_h disappeared for $x > 0.38$, the maximum value of (μ_h/μ_d) could not be obtained for these compositions. For the reason that the various coupling constants for the intervalley scattering change with x, the Hall mobility data for alloy compositions in the range $0.32 < x < 0.61$ could not be analyzed.[19] For these compositions the L-X minima intervalley scattering will make a significant contribution to the measured μ_h because of the close proximities in the energies of the various minima, and must be considered in the analysis of the data. The present data should be useful for deriving the various scattering parameters for $Ga_{1-x}Al_xAs$ alloys, which are largely unknown.

VII. CONCLUSIONS

The Hall—to—drift-mobility ratio has been derived for various alloy compositions $(0.23 \leq x \leq 0.78)$ from the experimental results on the pressure dependence of the Hall electron concentration and mobility. For the alloys investigated, the ratio is found to show a maximum near the pressure needed for the Γ-X minima crossover and the peak value of the ratio increases with x $(0.23 \leq x \leq 0.38)$. For $x = 0.78$, the ratio is found to be independent of pressure and close to unity. It is concluded that the strength of the L-X minima intervalley scatterings increases with x for alloy compositions in the range $0.23 \leq x \leq 0.38$.

VIII. ACKNOWLEDGMENTS

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