Direct evidence of intervalley scattering in liquid-phase epitaxy $Al_xGa_{1-x}As/GaAs$ heterostructures

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Hall mobility measurements at 300 K as a function of hydrostatic pressure (0–8 kbar) have been presented for high-purity liquid-phase epitaxy $Al_xGa_{1-x}As$ alloys grown on semi-insulating GaAs substrates. It has been shown that intervalley scattering lowers the electron mobility in $Al_xGa_{1-x}As$ near the alloy composition for direct-indirect minima crossover and that its scattering rate changes with the composition.

For $Al_xGa_{1-x}As$ compositions near the direct-indirect minima crossover,[1,2] intervalley scattering could be expected to play a significant role in addition to other scattering processes. This scattering should lead to a reduction in the electron mobility and also of the high-field saturation velocities. The presence of intervalley scattering in $Al_xGa_{1-x}As$ was first assumed to explain the minimum in the measured Hall mobility (μ_H) as a function of alloy composition[3] (x) and supported by the fact that a similar minimum in μ_H was also observed for various crystals ($0.2 \lesssim x \lesssim 0.4$) subjected to hydrostatic pressure. It was also concluded that the strength of the intervalley scattering depends strongly on x.[3–5] Later, the critical pressure for the minimum in μ_H was used to derive the conduction-band structure of the alloys[5] and surprisingly, it led to the same results as obtained by other well established techniques. This created some confidence about the importance of intervalley scattering in alloys. The presence of this scattering was also to be included in the Monte Carlo method to simulate the pressure dependence of μ_H.[6] Subsequently, intervalley scattering had to be included to explain the x dependence of μ_H and the various scattering parameters were derived from a theoretical fit to the experimental data on μ_H having a minimum at $x \simeq 0.5$.[7] Recently, Chand *et al.*[8] have also reported a minimum in μ_H near $x \simeq 0.5$ for Si-doped $Al_xGa_{1-x}As$ crystals grown by molecular beam epitaxy (MBE) but the data have not been explained.

It is the purpose of this Brief Report to provide direct evidence of intervalley scattering in $Al_xGa_{1-x}As$ crystals, particularly for alloy compositions where the direct and indirect minima are expected to interact strongly.

The crystals used for the present study were grown on semi-insulating GaAs substrates by liquid phase epitaxy (LPE). The crystals turned out to be n-type without any intentional doping and had room-temperature electron concentration in the range $(5-10)\times 10^{15}$ cm^{-3}. These are the same crystals as used by Saxena previously for other investigations.[1–7,9] The high-pressure experiments in the range 0–8 kbar were performed on van der Pauw samples using a similar piston and cylinder assembly[10] developed at the University of Surrey. A bridge circuit was used to eliminate spurious signals during measurements. To check the accuracy and reproducibility of the results, measurements were repeated both with increasing and decreasing pressures. The pressure inside the cell was accurately controlled by monitoring the resistance of the Manganin gauge.

In Fig. 1, we have plotted the pressure dependence of μ_H normalized to its atmospheric value μ_0 for various compositions of $Al_xGa_{1-x}As$ alloys. The full circles and squares are the measured data for increasing and decreasing pressures,

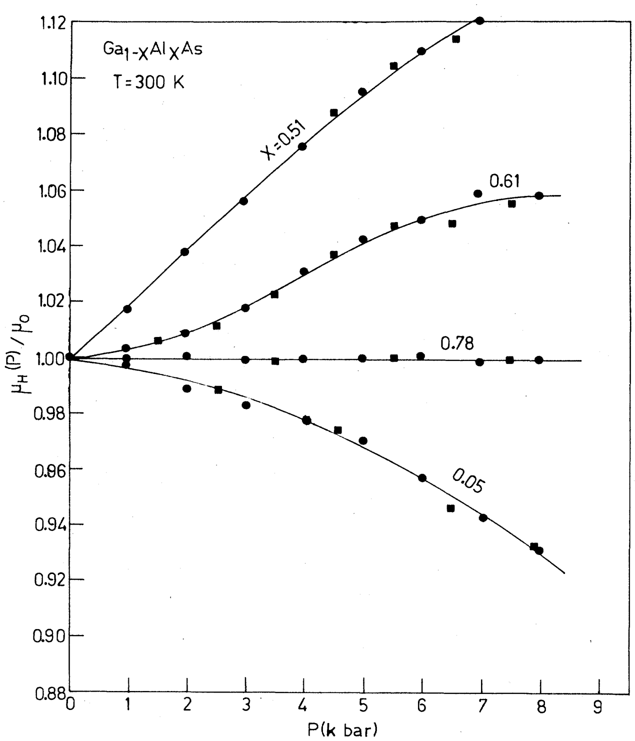

FIG. 1. Pressure dependence of the Hall mobility μ_H normalized to its atmospheric value μ_0 for $Al_xGa_{1-x}As$ alloys at 300 K. Full circles and squares are the data for increasing and decreasing pressures, respectively.

respectively. The alloy compositions and the pressure range has been so selected that over 0–8 kbar there is no multivalley conduction involving the higher-energy minima. For the present studies, this restricts the compositions in the ranges $0 \leq x \leq 0.23$ and $x \gtrsim 0.5$ subject to a maximum pressure of about 8 kbar up to $x \simeq 0.23$. For $x \gtrsim 0.5$, higher pressures could be applied without involving the higher-energy minima.

Pitt and Lees[11] have reported that the experimentally measured μ_H for epitaxial GaAs decreases by about 9%–10% by kbar. This magnitude of decrease in μ_H can be explained considering the increase in the electron effective mass in the Γ minimum and the pressure coefficient of the polar phonon angular frequency.[12] Since the band structure of the alloys for $0 \leq x \lesssim 0.23$ is similar to that of GaAs,[1,2] a decrease in μ_H with pressure is also expected for these compositions. The experimental results obtained for these compositions confirm this and a typical result for $x = 0.05$ is shown in Fig. 1. This variation has also been explained elsewhere[13] and the calculated variation is in close agreement with the measured data. On the contrary, an increase in μ_H of about 14% and 6% has been obtained by 8 kbar for the high composition crystals $x = 0.51$ and 0.61, respectively. No change in μ_H was measured with pressure for $x = 0.78$, as shown in Fig. 1. We interpret these results in terms of decreasing magnitude of the nonequivalent intervalley scattering for $x \gtrsim 0.5$ which vanishes completely for $x = 0.78$. For $x = 0.78$ and higher compositions, the higher-energy minima are far away from the lowest-energy X minima[1,2] and, therefore, the nonequivalent scattering is absent, resulting in a constant value of μ_H. For $x = 0.51$ and 0.61, the L minima lie about 75 and 100 meV above the X minima, resulting in nonequivalent scattering. Since the pressure coefficient of the L minima is positive with the best value of 5.5×10^{-6} meV/kbar while the X minima have a negative coefficient of 1.5 meV/kbar,[1] the energy separation between the two increases with pressure, thereby reducing the L-X scattering. This directly increases the mobility μ_H with pressure as observed. The decreasing magnitude of $\mu_H(P)/\mu_0$ by 8 kbar for $x \gtrsim 0.51$ indicates that the strength of the intervalley scattering decreases with composition which supports our earlier predictions.[3–5]

The minimum in μ_H for $x \simeq 0.5$ (Ref. 3) has earlier been explained to occur as a result of nonequivalent scattering.[3,5–7] Since the changes in the band structure of $Al_xGa_{1-x}As$ under pressure are similar to those obtained by varying x, it will be interesting to compare Fig. 1 with the variation of μ_H with x^3. For $x \gtrsim 0.78$, there is no change in μ_H with x^3 which is in perfect agreement with the experimental data for $x = 0.78$. For $x = 0.61$, μ_H is slightly lower than for $x \gtrsim 0.78$, implying that under pressure, the sample $x = 0.61$ should show a small increase in μ_H by 8 kbar. For $x = 0.51$, μ_H is considerably lower than for $x \gtrsim 0.78$ and thus the change in μ_H for $x = 0.51$ should be larger by 8 kbar than obtained for $x = 0.61$. Considering the equivalence of 0.863 kbar/at.% Al between pressure and composition,[5] the changes in μ_H obtained from Fig. 1 and the variation in μ_H with x^3 are found to be in quantitative agreement. It is, therefore, established that near the direct-indirect minima crossover, nonequivalent minima scattering lowers the electron mobility and its strength decreases for $x \gtrsim 0.51$.

In conclusion, it has been shown that intervalley scattering is found to lower the electron mobility in $Al_xGa_{1-x}As$ near the compositions for direct-indirect minima crossover.

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[1] A. K. Saxena, J. Phys. C **13**, 4323 (1980).
[2] A. K. Saxena, Phys. Status Solidi (b) **105**, 777 (1981).
[3] A. K. Saxena, J. Appl. Phys. **52**, 5643 (1981).
[4] A. K. Saxena, Phys. Rev. B **25**, 5428 (1982).
[5] A. K. Saxena, Int. J. Electron. **51**, 779 (1981).
[6] A. K. Saxena, Phys. Lett. **89A**, 351 (1982).
[7] A. K. Saxena and K. S. Gurumurthy, J. Phys. Chem. Solids **43**, 801 (1982).
[8] Naresh Chand, Tim Henderson, John Klem, W. Ted Masselink, Russ Fischer, Yia-chung Chang, and Hadis Morkoc, Phys. Rev. B (to be published).
[9] A. K. Saxena, Solid State Electron. **25**, 127 (1981).
[10] G. D. Pitt and D. A. Gunn, High Temp. High Pressures **2**, 547 (1970).
[11] G. D. Pitt and J. Lees, Phys. Rev. B **2**, 4144 (1970).
[12] A. K. Saxena, A. K. Sinha, and A. R. Adams (unpublished).
[13] A. K. Saxena and A. R. Adams (unpublished).