Liquid phase epitaxial growth of lattice-matched $Al_{0.48}In_{0.52}As$ on InP

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(Received 22 March 1982; accepted for publication 6 May 1982)

The liquid phase epitaxial (LPE) growth condition to obtain lattice-matched $Al_{0.48}In_{0.52}As$ on (100) InP was found. Using this growth condition, smooth and lattice-matched $Al_{0.48}In_{0.52}As$ layers could be grown for the first time on InP by the LPE method. The growth temperature near 800 °C was necessary to grow the ternary epitaxial layers. It was found by photoluminescence measurements that the energy gap of lattice-matched $Al_{0.48}In_{0.52}As$ was 1.42 eV.

PACS numbers: 68.55. + b

$Al_{0.48}In_{0.52}As$ can be lattice matched to InP, and has a larger energy gap than InP. Therefore, more effective carrier confinement effects can be expected in double heterostructure lasers which have an $In_{1-x}Ga_xAs_{1-y}P_y$ active layer and $Al_{0.48}In_{0.52}As$ confining layers instead of InP confining layers. However, no reports on the liquid phase epitaxial (LPE) growth of $Al_{0.48}In_{0.52}As$ on InP have been made until now because the LPE growth of $Al_{0.48}In_{0.52}As$ is difficult due to the very large distribution coefficient of Al.[1]

In this letter, the LPE growth condition of lattice-matched $Al_{0.48}In_{0.52}As$ on InP was found. Using this condition, smooth and lattice-matched $Al_{0.48}In_{0.52}As$ layers could be grown for the first time on InP by the LPE method. The band gap of lattice-matched $Al_{0.48}In_{0.52}As$ was experimentally determined by photoluminescence measurements.

The Al-In-As liquidus isotherms at 700, 750, and 800 °C were calculated using a simple solution model.[2] The interaction parameters necessary for the calculation are listed in Table I, where T^F_{AB} and ΔS^F_{AB} are respectively, the temperature and entropy of fusion of the AB compound, and Ω^l and Ω^s are the interaction parameters in the liquid and solid, respectively. These values are quoted from Ref. 3. The calculated liquidus isotherms are shown in Fig. 1, where X^l_i represents the atomic fraction of an element i in the ternary solution. This figure indicates that the main effect of the addition of Al to the liquid is to appreciably decrease the solubility of As in the liquid. The Al compositions shown in Fig. 1 were selected to permit the growth of $Al_{0.48}In_{0.52}As$ epitaxial layers on InP within a reasonable temperature range.

$Al_xIn_{1-x}As$ LPE layers were grown onto InP (100) substrates from ternary liquid solutions on the basis of the calculated liquidus isotherm at 800 °C. The experimental apparatus consisted of a horizontal furnace system and a conventional sliding graphite boat, as reported previously.[4] Pd-purified H_2 flowed through the fused-silica tube set in the furnace. Materials used were semiconductor-grade Al, In, and InAs. AlIn mother alloy which contained 0.1 at. % Al was used as Al source because it was very difficult to dissolve Al into In melts directly at the growth temperatures, by reason of the miscibility gap in the liquid state of the Al and In binary system.[5]

TABLE I. Thermodynamic input data[3] for the Al-In-As phase diagram calculation.

$T^F_{AlAs} = 2043$ K	$T^F_{InAs} = 1215$ K
$\Delta S^F_{AlAs} = 15.60$ cal/mol K	$\Delta S^F_{InAs} = 14.52$ cal/mol K
$\Omega^l_{AlIn} = 1060$ cal/mol	$\Omega^l_{AlAs} = 600 - 12.0$ T cal/mol
$\Omega^l_{InAs} = 3860 - 10.0$ T cal/mol	$\Omega^s_{AlAs\text{-}InAs} = 2500$ cal/mol

At the start of the growth run, the furnace was heated rapidly to 30–40 °C above the starting growth temperature, and the ternary solution was held there for about 30 min. It was then cooled with a constant cooling rate of 0.3 °C/min. Prior to growth, the thermal damage of the surface of the InP substrates was removed using an undersaturated In + P solution. $Al_xIn_{1-x}As$ was grown starting from various temperatures between 795 and 770 °C.

The amount of supercooling is not clear because of the lack of an experimental phase diagram. When the starting growth temperature near 800 °C was used, InP substrates were melted back into the ternary solution a little. These growth conditions of melting back are shown by crosses (×) in Fig. 2. When slightly lower starting growth temperatures were adopted, the ternary layers with rough surfaces could be grown as shown in Fig. 3. The growth conditions of these rough layers are shown by triangles (△) in Fig. 2. The ternary layers with smooth surfaces, as shown in Fig. 4, could be grown using the growth conditions marked with open circles (○) in Fig. 2. The solid line shown in Fig. 2 expresses

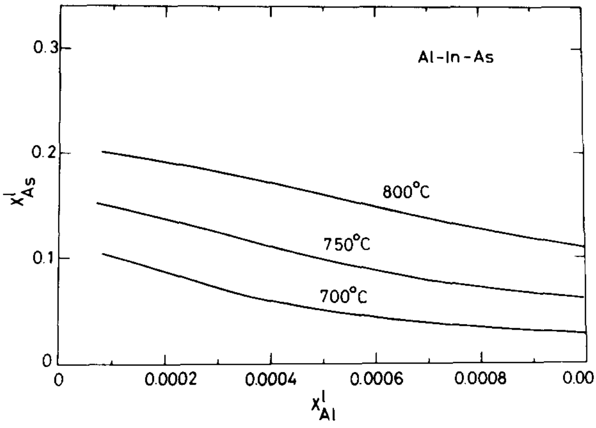

FIG. 1. Calculated liquidus isotherms of the Al-In-As system.

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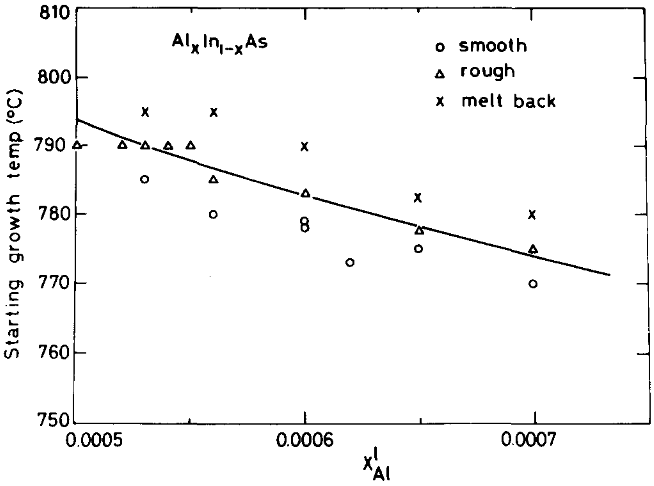

FIG. 2. Growth conditions to obtain $Al_xIn_{1-x}As$ layers with smooth surfaces.

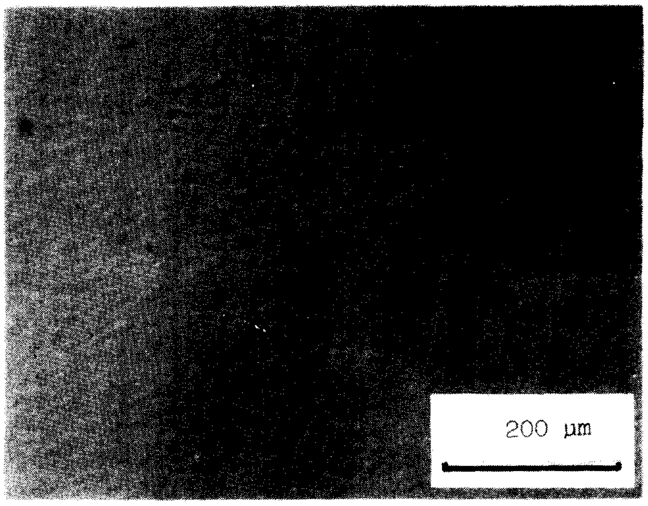

FIG. 4. Smooth surface of an $Al_xIn_{1-x}As$ layer.

approximately the real liquidus temperatures of the solution compositions on the basis of the calculated 800 °C liquidus isotherm, because melting back of the substrates occurs above this solid line. Therefore, the calculated liquidus isotherm at 800 °C in Fig. 1 is lower than the real liquidus isotherm at 800 °C. The samples marked with the open circles are considered to be grown from supercooled solutions.

The layer thickness of these wafers was about 0.5 μm when the growth temperature interval was 5 °C. When the growth temperature was 700 °C, only growth islands appeared on the surface of the substrates, and epitaxial layers could not be grown at all because of the violent depletion of Al in the solutions.

The LPE growth condition of a lattice-matched $Al_{0.48}In_{0.52}As$ layer on (100) oriented InP was found from the results shown in Fig. 2 and the lattice constant measurements. Lattice constants were measured by an x-ray diffraction technique. The precise diffraction angle of the layer was determined from the (400) Cu*kα* reflection by using the substrate reflection as an internal standard. The result is shown in Fig. 5. The lattice constant is displayed as a function of $X^l_{\rm Al}$. The broken line represents the lattice constant of InP. The lattice-matched ternary layer can be grown starting from 777 °C using the solution composition of $X^l_{\rm Al} = 0.00066$, $X^l_{\rm As} = 0.142$, and $X^l_{\rm In} = 0.85734$.

Cheng *et al.*[6] reported that the variation of the lattice constant of $Al_xIn_{1-x}As$ grown by an ordinary molecular beam epitaxial (MBE) method was less than 2×10^{-4}/cm in the lateral direction of the wafers. In order to compare the present LPE results with the MBE results, the variation of the lattice constant of several $Al_xIn_{1-x}As$ wafers grown by the LPE method was measured in the lateral direction. The size of the wafers was 18 × 18 mm. The variation of the lattice constant was about 2–3×10^{-4}/cm. The present LPE results are similar to the ordinary MBE results. Cheng *et al.*[6] also reported that zero lateral variation ($\sim10^{-5}$/cm) in lattice constant was obtained by their special MBE method. Further studies on the LPE growth of $Al_xIn_{1-x}As$ are desired in order to know whether lateral variation as small as 10^{-5}/cm can be achieved or not by the LPE method.

The energy gap of $Al_xIn_{1-x}As$ layers was determined

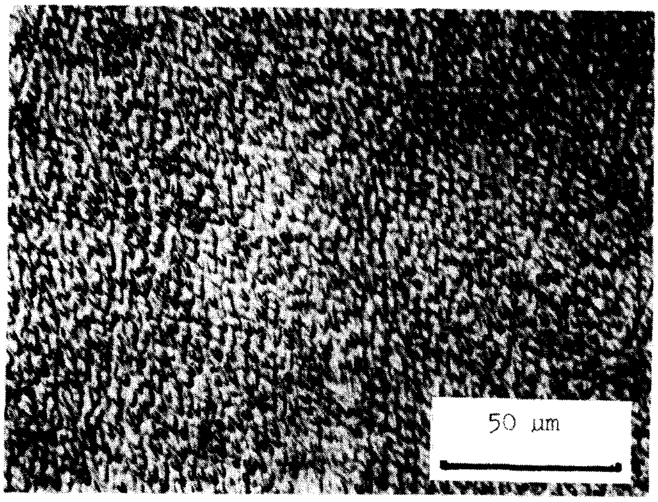

FIG. 3. Rough surface of an $Al_xIn_{1-x}As$ layer.

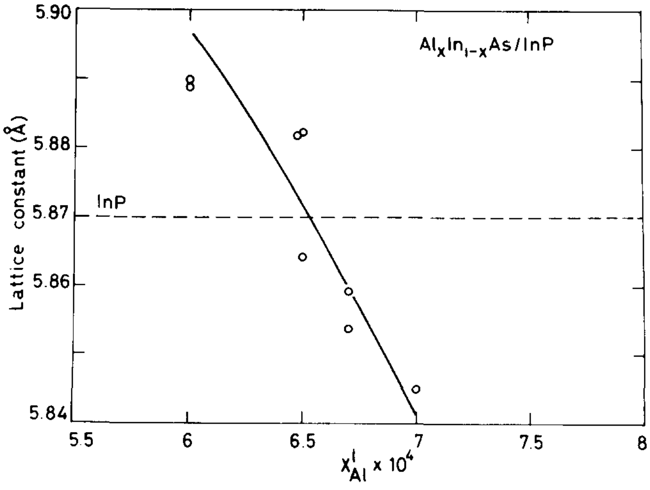

FIG. 5. Lattice constant of $Al_xIn_{1-x}As$ layers as a function of $X^l_{\rm Al}$.

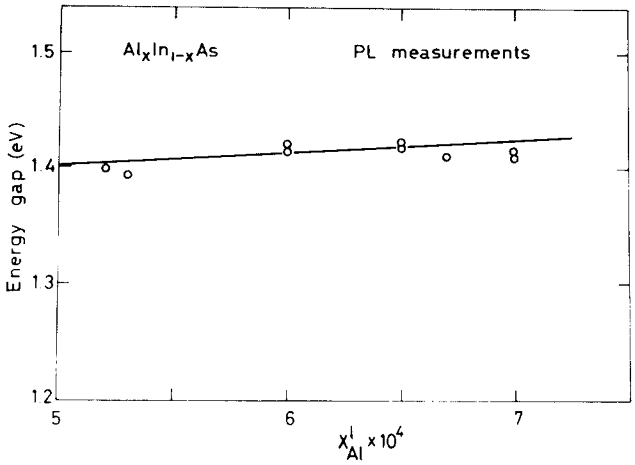

FIG. 6. Energy gap of $Al_xIn_{1-x}As$ layers determined by photoluminescence (PL) measurements.

by photoluminescence measurements which were reported previously.[7] Figure 6 shows the energy gap as a function of X^1_{Al}. The energy gap increases gradually with X^1_{Al}. The energy gap of lattice-matched $Al_{0.48}In_{0.52}As$ was measured to be 1.42 eV. This value is slightly smaller than the previously reported value (1.45 eV).[8]

In conclusion, the LPE growth condition of lattice-matched $Al_{0.48}In_{0.52}As$ on InP was found, and $Al_{0.48}In_{0.52}As$ layers were first grown by the LPE method. It was found that $Al_xIn_{1-x}As$ epitaxial layers could not be grown below 700 °C. The energy gap of lattice-matched $Al_{0.48}In_{0.52}As$ was found to be 1.42 eV by photoluminescence measurements.

The authors wish to acknowledge the double-crystal x-ray and photoluminescence measurements of S. Komiya. Useful discussions were held with S. Yamakoshi and I. Umebu.

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