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Gas source MBE growth and doping characteristics of AlInP on GaAs

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Abstract

The ternary wide bandgap AlInP alloys have been grown on GaAs substrates by using gas source molecular beam epitaxy, and the relationship between various growth parameters and the composition, lattice mismatch, surface morphology as well as doping concentration of the AlInP epi-layers have been investigated in detail. The AlInP epi-layer with lattice mismatch of $+4.3 \times 10^{-4}$ and full-width at half-maximum of X-ray diffraction peaks of 21.6″ and 14.9″ for epi-layer and substrate respectively have been obtained. The maximum reachable p and n type carrier concentration for Be or Si doping were found to be around 1×10^{18} and 5×10^{18} cm^{-3} respectively around lattice match composition.

Keywords: AlInP; Gas source molecular beam epitaxy; Doping

1. Introduction

Ternary $Al_xIn_{1-x}P$ is the alloy of two binaries AlP and InP with indirect and direct bandgap respectively, the bandgap structure and parameters is shown in Fig. 1 [1]. When the Al composition is around $x = 0.52$, $Al_xIn_{1-x}P$ could be lattice matched to GaAs substrate, which makes it an important epitaxial material from both research and application points of view. The $Al_{0.52}In_{0.48}P$ on GaAs, which shows many similar characteristics as the AlGaAs/GaAs or AlInAs/InP system, has the largest bandgap among the practical non-nitride III–V alloys, so a great deal of applications could be expected on this wide bandgap material.

In the last years, the epitaxial AlInP lattice matched to GaAs has been studied for the applications such as window/anti-reflection (AR) layer of GaInP/GaAs multi-junction solar cells [2,3] and cladding layer of visible lasers and modulators [4], mainly by using metalorganic chemical vapor deposition (MOCVD) techniques. The gas source molecular beam epitaxy (GSMBE) growth of relative thin AlInP layers for the tunnel junction or window/AR layer of tandem solar cells also have been reported [5,6], whereas the study of the growth process and doping characteristics of AlInP on GaAs remains quite insufficient, especially for the growth of thicker and composition diversified layers.

Compared to MOCVD, MBE yields a higher doping efficiency and less diffusion effects for its lower growth temperatures, and the use of gas source for group V elements in GSMBE makes the process more realizable, especially for the growth of phosphide [7]. In this paper, the GSMBE growth and doping characteristics of wide bandgap AlInP on GaAs have been investigated in detail.

2. Experiments

All growths presented in this work were performed in a VG Semicon V80H GSMBE system. The best background vacuum achieved in this system was about 1×10^{-11} Torr. The elemental indium (In) SUMO-cell and aluminum (Al) standard effusion cell were used as group III sources, and their fluxes were controlled by changing the cell temperatures. Arsine (AsH_3) and phosphine (PH_3) high-pressure cracking cells were used as group V sources, their fluxes were pressure controlled, and the cracking temperature was around 1000 °C. Standard beryllium (Be) and silicon (Si) effusion cells were used as p- and n-doping sources, and the doping level was also controlled by changing the cell temperatures. Before the growth, the fluxes of group III sources were calibrated by using an in situ ion gauge.

The AlInP layers were grown on (1 0 0) oriented GaAs semi-insulating epi-ready substrates, which were placed on indium

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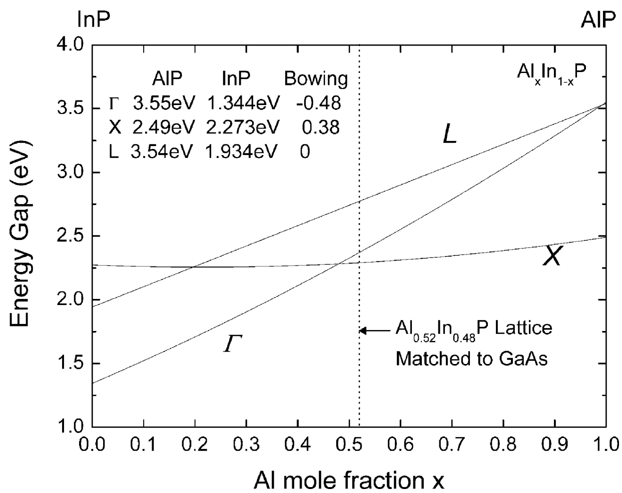

Fig. 1. Band parameters and Γ-, X-, L-valley gaps for ternary $Al_xIn_{1-x}P$ at 300 K.

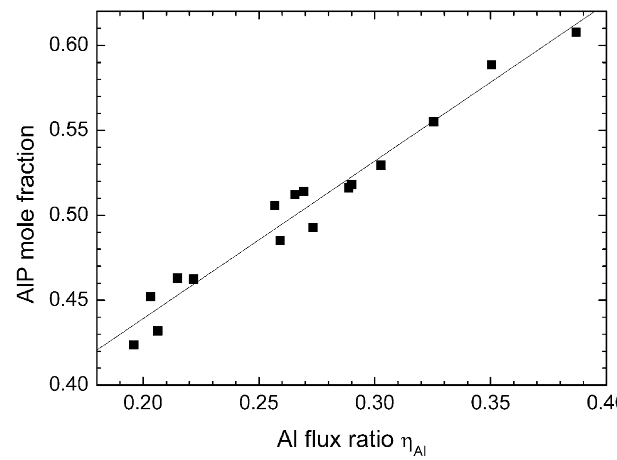

Fig. 2. The AlP mole fraction vs. the Al flux ratio η_{Al} in the GSMBE growth.

free Mo blocks. Prior to the growth, the surface oxide desorption of the substrate was carried out under As_2 flux. This process involved a slow ramp-up of the substrate temperature until the reflection high energy electron diffraction (RHEED) pattern showed an abrupt transformation to 2 × 4 surface reconstruction, the substrate desorption temperature measured by thermocouple was usually about 630 °C, then the substrate temperature was decreased to appropriate temperature to begin the growth. Prior to the growth of AlInP, an appropriate As–P flux exchange procedure with pump down of As for 1 min before open P flux was used.

After growth, the morphology of the grown samples was observed using a Normasky microscope, their structural characteristics were measured by using a Philips X-pert X-ray diffraction (XRD) meter including a Ge (2 2 0) four-folded monochromater, and the room temperature carrier concentration of the epi-layer was determined by using Hall measurement in Van der Pauw scheme and electrochemical C-V (EC-V) method using a PN4300 Profiler.

3. Results and discussions

The optimized substrate temperature for the growth of AlInP was found around 470 °C measured by thermocouple, and the pressure in the growth chamber during growth, which is related to the flux of group V sources, was adjusted to about 2×10^{-5} Torr. The growth rate of AlInP epi-layer was controlled to be about 1 μm/h, and the epi-layer thickness of all grown samples was around 1 μm.

The fluxes of Al and In and their ratio in the growth of $Al_xIn_{1-x}P$ were investigated in detail, Fig. 2 shows the AlP mole fraction of the AlInP versus the Al flux ratio during the growth. The Al flux ratio (η_{Al}) is defined as $\eta_{Al} = f_{Al}/(f_{Al} + f_{In})$, in which f_{Al} and f_{In} is the flux of Al and In cell, respectively. The AlP mole fraction shows a quite linear function with η_{Al} in our experiment range, which could be used to predict the AlP mole fraction before sample growth. The non-unity slope of the line shows that In and Al elements have quite different sticking coefficient, at this growth temperature the sticking coefficient of Al is much higher than that of In. It could be seen from Fig. 2 that the Al flux ratio of around 0.29 leads to the AlP mole fraction of about 0.52, at this flux ratio the AlInP epi-layer could be lattice-matched to GaAs.

Since the thermal expansion coefficient of $Al_{0.52}In_{0.48}P$ is larger than that of GaAs, the amount of lattice mismatch determined at room temperature is shifted to positive side compare to that at growth temperature, therefore, at room temperature a slightly positive lattice mismatch should be preferable, the estimated lattice mismatch of $+5 \times 10^{-4}$ at room temperature may leads to the precise lattice match of $Al_{0.52}In_{0.48}P$ to GaAs at growth temperature around 470 °C. In this work, the XRD measurement showed the optimized AlInP epi-layer had a positive mismatch around $+4.3 \times 10^{-4}$ to the GaAs substrate, with a full-width at half-maximum (FWHM) of 21.6″ for the epi-layer and 14.9″ for the substrate, as shown in Fig. 3, which is among the best for epitaxial grown layers. In this condition, a perfect mirror-like surface could be reached as shown in Fig. 4(a). The Normasky micrographs of other grown samples with larger lattice mismatch to GaAs are shown in Fig. 4(b–d). Fig. 4 (b) shows the micrograph of AlInP epi-layer with large negative mismatch around -4.7×10^{-3}, at this condition light ripple pattern could

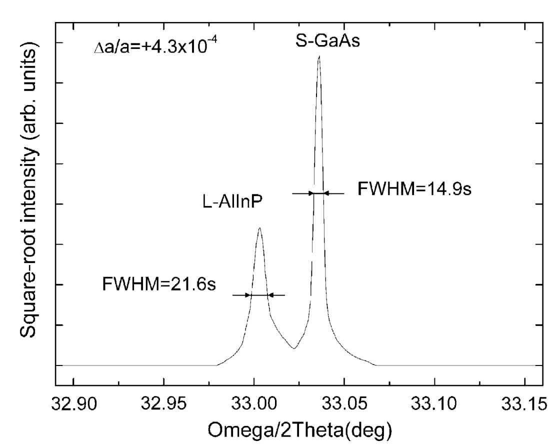

Fig. 3. Measured X-ray rocking curve of the GSMBE grown $Al_{0.52}In_{0.48}P$ on (1 0 0) GaAs substrate.