Growth of $Ga_{1-x}In_xAs$ layers with excellent compositional uniformity on InP by OMVPE

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Abstract. $Ga_{1-x}In_xAs$ layers with excellent compositional uniformity have been obtained on 2 inch diameter InP substrates by reduced pressure organometallic vapor phase epitaxy. The reproducibility of composition in run-to-run was also excellent.

1. Introduction

$Ga_{1-x}In_xAs$ lattice-matched to InP is a promising material for the fabrication of high speed transistors, optoelectronic devices operating in the wavelength of 1.3 - 1.55 μm, and optoelectronic integrated circuits. For these applications, organometallic vapor phase epitaxy (OMVPE) is one of the most advantageous growth methods in respect of the controllability of layer thickness and composition (Razeghi et al. 1983, Smeets et al. 1986), large area growth, and high throughput. In this paper, we report OMVPE growth of $Ga_{1-x}In_xAs$ layers with excellent compositional uniformity on 2 inch diameter InP substrates. The compositional uniformity of the $Ga_{1-x}In_xAs$ epilayers was evaluated by double crystal x-ray diffraction and photoluminescence measurement.

2. OMVPE Growth

$Ga_{1-x}In_xAs$ epilayers were grown directly on a 2 inch diameter Fe-doped InP substrate oriented 2° off the (100) in a water-cooled vertical reactor at reduced pressure. Triethylgallium (TEG), trimethylindium (TMI) and arsine (AsH_3, 10 % in H_2) were used as the starting sources, and were introduced together with the carrier gas into the reactor from the top. The substrate was positioned perpendicular to the gas stream on a RF-heated carbon susceptor. Hydrogen was used as the carrier gas. 1 - 2 μm-thick epilayers were typically grown under the conditions listed on Table 1.

Table 1. Typical growth conditions.

Growth temperature	600, 650 and 700°C
Growth pressure	60 Torr
Total gas flow rate	3.4 slm
TEG flow rate	2.6×10^{-6} mole/min
TMI flow rate	3.5×10^{-6} mole/min
AsH_3 flow rate	5.4×10^{-4} mole/min
V/III	90
Growth rate	1 μm/hr
Substrate rotation rate	12 rpm

As shown in Fig. 1, the controllability in composition of the epilayers was examined by measuring the lattice mismatch to the InP substrate for the epilayers grown at different TMI flow rates with the constant TEG flow rate. The linearity of the lattice mismatch against the composition broke due to the misfit dislocations at the large lattice mismatch in the InAs-rich region in Fig. 1.

The variation of epilayer thickness was less than ±4 % against the mean epilayer thickness over a 2 inch diameter wafer. The morphology of the epilayers showed a mirrorlike surface.

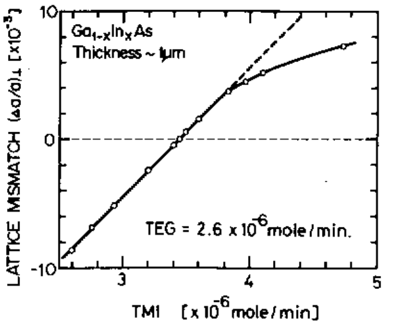

Fig. 1. The lattice mismatch as a function of TMI flow rate.

3. Results

Fig. 2 shows the variation of lattice mismatch to the InP substrate in each epilayer grown at different growth temperatures of 600, 650 and 700°C. Other growth conditions except for the growth temperature were kept constant in the growth of the epilayers shown in Fig. 2. The best compositional uniformity was obtained from the epilayer grown at 600°C. On the other hand, the epilayers grown at 650 and 700°C showed the unfavorable variation of composition in the GaAs-rich region although the tendencies of the variation in composition were different from each other. The variation of composition in the epilayers grown at 650 and 700°C was considered to be caused by the depletion of TMI in the gas phase above the hot substrate.

In order to evaluate the accurate variation of lattice mismatch in the epilayer grown at 600°C, we have grown an intentionally lattice-mismatched epilayer. In a lattice-mismatched epilayer, we can evaluate the accurate lattice mismatch of the epilayer to the substrate from the separated x-ray diffraction peaks of the epilayer and the substrate. As shown in Fig. 3, the variation of lattice mismatch to the InP substrate was less than 1.5×10^{-4} in the 2 inch diameter epilayer grown at 600°C, which corresponded to the variation in composition of less than 0.1 % mole fractions in consideration of the tetragonal distortion.

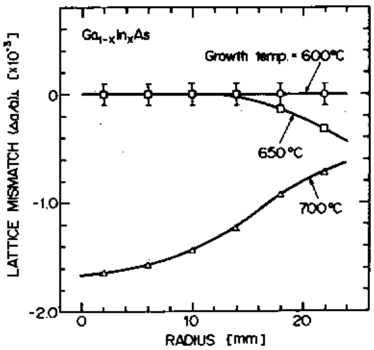

Fig. 2. The variation of lattice mismatch in $Ga_{1-x}In_xAs$ epilayers grown at 600, 650 and 700°C.

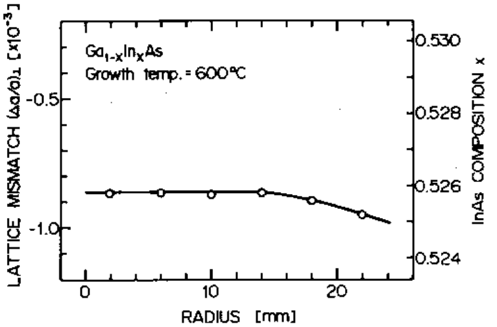

Fig. 3. The variation of composition in an intentionally lattice-mismatched $Ga_{1-x}In_xAs$ epilayer grown at 600°C.

A narrow x-ray diffraction peak of the epilayer was observed over the whole substrate area. The typical x-ray rocking curve of an intentionally lattice-mismatched epilayer on the InP substrate is shown in Fig. 4. The full width at half the maximum (FWHM) of the (400) reflection from a 2 μm-thick epilayer was as narrow as 16 arcsec, and was comparable to the FWHM of the InP substrate. We also observed the FWHM of 20 arcsec for a 1 μm-thick epilayer. These narrow FWHM of the epilayers indicate that the compositional uniformity of the epilayers depthwise was also excellent. In addition, so far as we are aware, these FWHM are the narrowest that were ever reported for $Ga_{1-x}In_xAs$ epilayers grown by any method.

We performed the photoluminescence measurements at 4.2 K for the epilayers with the excellent compositional uniformity. As shown in Fig. 5, an excitonic transition peak with the FWHM as narrow as 1.5 meV was observed. This narrow FWHM of the excitonic transition peak was consistent with the uniformity results obtained by x-ray diffractions.

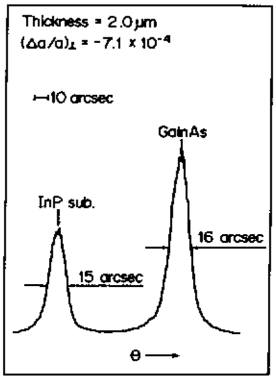

Fig. 4. The x-ray rocking curve of an intentionally lattice-mismatched $Ga_{1-x}In_xAs$ epilayer.

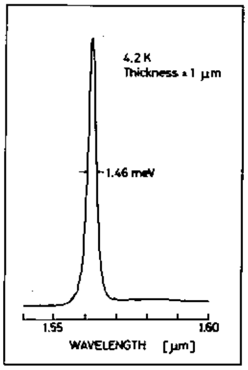

Fig. 5. The photoluminescence measurement of a $Ga_{1-x}In_xAs$ epilayer at 4.2 K.

Further, we evaluated the reproducibility of composition in run-to-run for 17 growth runs which were performed over a period of 4 months under the same lattice-matching growth conditions. As shown in Fig. 6, almost all epilayers except for 2 epilayers exhibited the only one double crystal x-ray diffraction peaks with the narrow FWHM of 15 - 22 arcsec. The variation of lattice mismatch in 17 growth runs was less than 3 x 10^{-4}, which corresponded to the variation in composition of less than 0.2 % mole fractions.

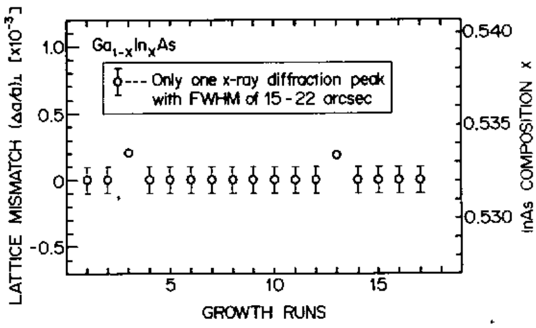

Fig. 6. The reproducibility of composition in run-to-run for 17 growth runs performed under the same lattice-matching growth conditions.

4. Summary

We demonstrated the growth of $Ga_{1-x}In_xAs$ layers with excellent compositional uniformity over the area of a 2 inch diameter InP substrate by reduced pressure OMVPE using TEG, TMI and AsH_3 in a vertical reactor. The compositional uniformity in a wafer and the reproducibility of composition in run-to-run of the $Ga_{1-x}In_xAs$ layers described here would be sufficient for the production of optoelectronic devices.

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