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Low Temperature Growth of InGaAs on GaAs(100) by Chemical Beam Epitaxy Using Unprecracked Monoethylarsine

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InGaAs layers were grown on GaAs(100) by chemical beam epitaxy(CBE) using triethylgallium(TEGa), trimethylindium(TMIn) and unprecracked monoethylarsine(MEAs). The temperature dependent growth rates, carrier concentrations, and photoluminescence(PL) responses were measured at the growth temperature range from 410 to 590℃. The carrier concentrations and PL responses have shown a little variation over the growth temperature range. This result indicates that the electrical properties and PL responses of InGaAs are not degraded even in the low growth temperature regions unlike those of molecular beam epitaxy and organometallic vapor phase epitaxy grown InGaAs.

1. Introduction

Indium containing compound semiconductors such as InGaAs are important for high speed optoelectronic device application. Because of their superior transport properties, homomorphic or psuedomorphic heterostructures employing InGaAs have shown much improvement in device performance compared to that of GaAs. In recent years, the growth of strained film applicable to quantum microstructure has become a field of intense study. In particular, low temperature growth of highly strained InGaAs on GaAs is very important due to an abrupt temperature-dependant transition in the critical thickness of pseudomorphic growth.[1,2] This, however, may have deleterious effects on the material quality. In this study, we have investigated the feasibility of growing InGaAs at relatively low growth temperatures using unprecracked monoethylarsine(MEAs) with triethylgallium(TEGa) and trimethylindium(TMIn) without much degradation of electrical and optical properties. MEAs, which is a volatile liquid at room temperature and atmospheric pressure, can replace arsine since it is less toxic and can be decomposed at lower temperature on the growing surface than arsine. To study growth characteristics of InGaAs grown on GaAs(100) using unprecracked MEAs, growth rates and material properties were measured as a function of growth temperature, V/III ratio and indium composition.

2. Experimentals

The growth of InGaAs was performed in a conventional CBE system which consists of an ultrahigh vacuum growth chamber and a source gas control system. The group V and III source gases were introduced by automatic absolute pressure controlled leak valves without hydrogen carrier gas. The detailed configuration of system used in this work was described in the previous work.[3] The growth of InGaAs was on Cr-doped GaAs(100) with 2° off towards (110). The gas pressure in the growth chamber during the growth was in the range of 10^{-5} - 10^{-4} Torr depending on the V/III ratio. The growth temperature of InGaAs was in the range of 400 to 600℃. The growth rate of InGaAs layer was measured by scanning electron microscopy(SEM) on stain and etched cleavage planes. The samples were inspected by Nomarski optical microscope and SEM for evaluation of their morphology. Low temperature PL and Hall measurements were done for optical and electrical characterization of grown layers. Indium composition of grown layer was determined by double crystal X-ray diffraction(DCXD) and PL.

3. Results

Figure 1 shows a typical surface morphology of fully relaxed InGaAs layer grown at 410℃ and V/III ratio of 10 with the indium composition of 0.2. Ga or In droplets were not observed on the sample surface grown at a temperature range between 410 and 590℃ when unprecracked MEAs was used. Absence of Ga or In droplets on the surface is attributed to the complete decompositon of MEAs on the growing surface. Fig. 1 shows a typical cross-hatch pattern, which is developed when the thickness of epilayer is far beyond the critical thickness in the lattice mismatched system.

Figure 2 illustrates the substrate temperature dependent growth rate measured by SEM using a

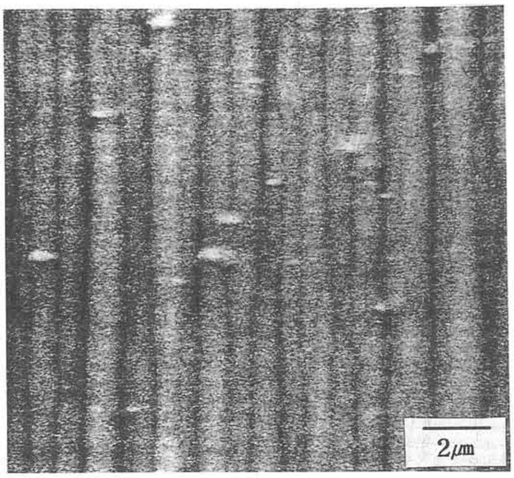

Fig. 1. SEM micrograph of InGaAs layer at the substrate temperature of 410℃ with V/III ratio of 10 and total pressure of $5x10^{-4}$Torr.

cleave and stain method. Partial growth rates of InAs and GaAs in InGaAs were estimated from indium composition measured by low temperature PL. The growth rate in Fig. 2 are divided into two regions. Growth rate increased and decreased with increasing substrate temperature at the temperature below and above 460℃, respectively. Since partial growth rate of InAs is almost constant independent of substrate temperature, the temperature dependent trend of the InGaAs growth rate can be considered to be determined by partial growth rate of GaAs. In the low temperature region, the growth rate is believed to be determined by decomposition process of TEGa on the surface. Above 460℃, the desorption of partially cracked TEGa species on the growing surface reduces the growth rate of InGaAs. The presence of surface In has a major effect on such decomposition and desorption process in the different ways. At low temperatures, the presence of indium enhances the GaAs growth rate. However, at higher temperatures the growth rate decreases as InAs concentration.[4] Unlike the metallorganic molecular beam epitaxy(MOMBE) grown samples[5,6], severe temperature dependent variation of growth rate and indium composition were not observed in CBE grown InGaAs using unprecracked MEAs. It is presumably due to the different surface reaction of MEAs.

Figure 3 shows the carrier concentrations of the InGaAs layers with an indium composition of 0.18, grown at the growth temperatures from 410 to 590 ℃. Hall measurements were performed to determine the carrier concentrations at room temperature. At the temperature range from 460 to 590℃, the carrier concentrations were measured to be about $n=5x10^{15}$ cm^{-3}. They were about 10 times lower than that of MOMBE grown samples[7] presumably due to the efficient removal of surface bounded carbon containing species by the hydrogen atoms and arsine radicals dissociated from unprecracked MEAs. In case of MOMBE[5], carrier concentration increases rapidly with decreasing growth temperature, but in our study, carrier concentrations are almost constant at the entire growth temperature range. No degradation of electrical properties of InGaAs grown by CBE using unprecracked MEAs is observed in the low growth temperature region. Around 460℃, the type conversion of free carrier occurred due to amphoteric nature of carbon in InGaAs.

Figure 4 represents a PL spectrum of strain relaxed InGaAs grown at 410℃ showing an intense excitonic transition peak indicative of high optical property of the grown layer. To estimate the optical quality of grown layer in the low temperature region, intensity and FWHM(full width at half maximum) of PL response were measured as a function of growth temperature as shown in Fig. 5.

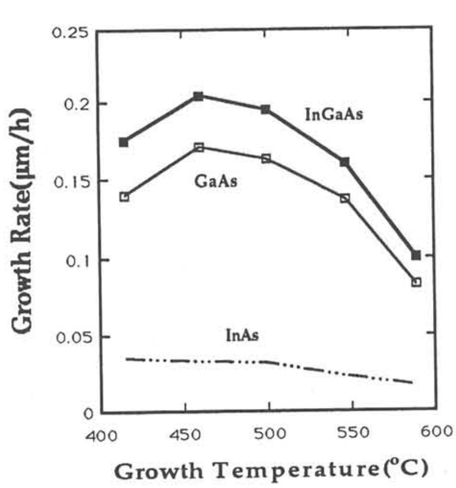

Fig. 2. Effect of growth temperature on the growth rate(V/III=10, $P=5x10^{-4}$Torr).

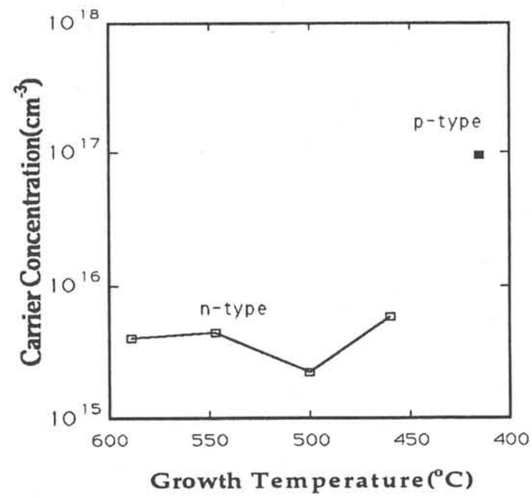

Fig. 3. Dependence of carrier concentration in InGaAs layer on the substrate temperature(V/III =10, $P=5x10^{-4}$Torr).

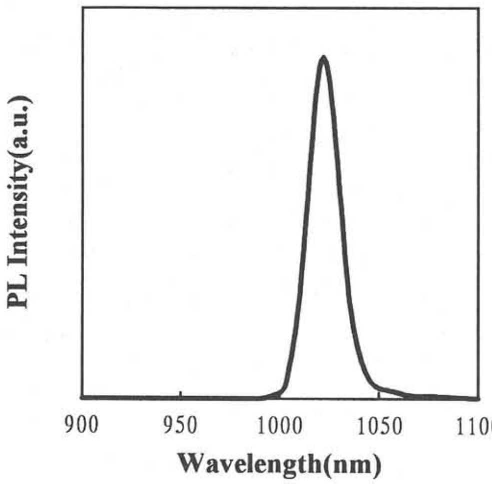

Fig. 4. Photoluminescence spectrum at T=5K of a p-type InGaAs epilayer with a hole concentration of $9.4\times10^{16}cm^{-3}$(T=410℃, V/III=10, $P=5\times10^{-4}$Torr).

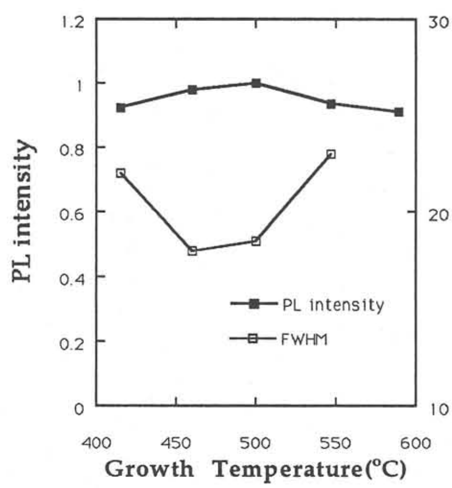

Fig. 5. Dependence of PL intensities and FWHM on the substrate temperature. PL intesnsities are normalized to maximum value.

Over the growth temperature range, a little variation of PL peak intensity was observed. At about 460℃, good interface ordering process seemed to occur resulting in reduction of PL linewidth. Previously reported results have shown that improvements in the PL response of InGaAs are necessary for the high temperature growth in OMVPE[8] and MBE[9] due to the increase in nonradiative recombination resulted from high concentration of impurity.[10] Our results indicate that any degradation of optical property in InGaAs/GaAs layer grown by CBE using unprecracked MEAs is not observed in the low growth temperature region.

4. Summary

We have studied effects of growth temperature on PL response, impurity concentration, and growth rate of InGaAs/GaAs(100) grown by CBE using TEGa, TMIn and unprecracked MEAs. The growth temperature dependent impurity concentration was almost constant even in the low temperature region. Furthermore, any decrease in PL intensity which would result from increase in nonradiative recombination due to the residual donor concentration was not observed even in the low growth temperature. These results indicate that optical and electrical properties of InGaAs/GaAs grown by CBE using unprecracked MEAs are not degraded in the low temperature region.

References

[1] G. L. Price, Phys. Rev. Lett. 66(1991) 469.
[2] M. J. Ekenstedt, S. M. Wang, and T. G. Andersson, Appl. Phys. Lett. 58(1991) 854.
[3] S. J. Park, J. R. Ro, J. K. Sim, and E. H. Lee, J. Cryst. Growth 136(1994) 138; S. J. Park, J. R. Ro, J. K. Sim and E. H. Lee, J. Cryst. Growth 136(1994) 143.
[4] N. K. Singh, J. S. Ford, P. J. Skevington, and G. J. Davis, J. Cryst. Growth 120(1992) 33.
[5] E. Tokumitsu, J. Shirakashi, M. Qi, T. Yamada, S. Nozaki, M. Konagai, and K. Takahashi, J. Cryst. Growth 120(1992) 301.
[6] N. Kobayashi, J. L. Benchimol, F. Alexandre, and Y. Gao, Appl. Phys. Lett. 51(1987) 1907.
[7] M. Kamp, R. Contini, K. Werner, H. Heinecke, M. Weyer, H. Lüth, and P. Balk, J. Cryst. Growth 95(1989) 154.
[8] K. W. Carey, Appl. Phys. Lett. 46(1985) 89.
[9] W. T. Tsang, IEEE E. D. L. EDL-4(1983) 275.
[10] Z. M. Fang, K. Y. Ma, R. M. Cohen, and G. B. Stringfellow, Appl. Phys. Lett. 59(1991) 1446.