MBE Growth of AlGaAs on (100)- and (111)-Oriented Substrates Using As₂

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Systematic study has been made for the first time on the basic properties of AlₓGa₁₋ₓAs (x=0.2-0.7) grown by molecular beam epitaxy on (100)- and (111)-oriented substrates using As₂. In the case of (100) substrate, the forbidden growth temperature region, where the specular smooth surface cannot be obtained, does not exist for x=0.2, and it increases with x from 0.3-0.7. In the case of (111)B substrate, the specular surface morphology cannot be obtained. Potoluminescence intensity has been studied for n-Al₀.₃Ga₀.₇As as a function of growth temperature.

1. INTRODUCTION

A lot of works have been reported on the molecular beam epitaxy (MBE) of GaAs using the dimetric arsenic (As₂) instead of the conventional tetrametric arsenic (As₄) beam. However, there are no systematic studies on the basic properties of AlGaAs grown with As₂ on (100) and (111)B-oriented substrates. Previous studies have shown that the quality of GaAs on (100) substrate is improved by using As₂ in terms of higher purity and lower defect density as compared with the GaAs grown with As₄. By contrast, the effect of As₂ on the growth of AlGaAs is controversial. Erickson et al. reported that the surface morphology of AlₓGa₁₋ₓAs (x=0.2 and 0.3) on (100) face was improved by employing As₂ in the forbidden growth temperature region (FTR) of 630-670°C, where only the hazy morphology is obtained when using As₄. However, they could not realize the specular smooth surface on AlGaAs in the FTR even by using As₂. There is also no report of AlGaAs on (111)B substrates using As₂ although the successful preparation of (111) quantum well structures has been reported using As₄.

We present the systematic study on the MBE growth of AlGaAs on (100)- and (111)-oriented GaAs substrate using both As₂ and As₄ for the first time. In particular, the surface morphology is studied on AlₓGa₁₋ₓAs (x=0.2-0.7) grown in a wide substrate temperature (Tₛ) range of 540-740°C, and as a result, we have found that the FTR varies with both the As species and the AlAs mole fraction in the case of (100) substrates and the surface morphology strongly depends upon both As species and Tₛ and it is not so sensitive to the AlAs mole fraction in the case of (111)B substrates. The result of photoluminescence (PL) on n-Al₀.₃Ga₀.₇As is also presented.

2. EXPERIMENTAL

The solid-source cracking cell with the graphite cracking zone was employed to generate As₂ beam at a cracking temperature of 900°C. The As₄ beam was generated using a standard Knudsen cell or using a cracking cell with a cracking temperature of 550°C. 2 μm-thick AlₓGa₁₋ₓAs (x=0.2-0.7) layers doped with Si were grown on (100)- and 0.5°-tilted (111)B-GaAs substrates (Si=2x10¹⁸ cm⁻³). The GaAs buffer layer (0.5 μm thick) was grown prior to the growth of AlGaAs. The Si doping concentration was 4x10¹⁷, 1x10¹⁸, and 2x10¹⁸ cm⁻³ for x=0.2, 0.3, and 0.7, respectively. The growth rate of AlGaAs in all cases was 1.5 μm/h. The As pressure was set to 1.5-2 times higher than the lowest limit of the As stabilized growth condition at each temperature, and thus, it was increased with Tₛ. The surface morphology of epitaxial layers was observed with the Nomarski interference microscope.

3. RESULTS AND DISCUSSION

Figure 1 shows the surface morphology of AlGaAs as a function of Tₛ and the AlAs mole fraction for the case of the (100) orientation. We have divided the surface morphology into three categories; hazy, slightly hazy, and specular smooth as shown in Fig.1.
The "hazy" surface can be recognized as hazy by the naked eyes. The "slightly hazy" surface appears to be smooth to the naked eyes, however, some undulation can be observed by using Nomarski microscope. The "specular smooth" surface shows no undulation even with the Nomarski microscope. When \(x = 0.2\), the FTR is in the range of 630-710°C, which does not depend upon the AlAs mole fraction [Fig.1(a)]. By contrast, when \(x = 0.2\), the FTR does not exist for \(x = 0.2\), and it varies from 550-610°C for \(x = 0.3\) to 550-710°C for \(x = 0.7\) [Fig.1(b)]. Moreover the low end of FTR shifts to lower temperature by about 80°C when \(x = 0.2\) is used. These results cannot be explained by a simple model. It is important to note that the surface morphology is, at least, improved within the FTR and vanished FTR for \(x = 0.2\) by using \(x = 0.2\). This, however, does not necessarily mean the enhancement of the specular smooth surface region.

In Fig 2, surface morphology is shown for the (111)B orientation. We add the one more category, "faceted" surface. The "faceted" surface exhibits well-known pyramid-like\(^{12}\) textured surface. The specular smooth surface cannot be obtained in the whole range of \(T_s\) when using \(x = 0.2\). This result indicates that the specular smooth surface obtained at high \(T_s\) using \(x = 0.2\) does not result from the cracking of \(x = 0.2\) at the growth surface. We have observed that the shape of some of surface defects in case of the As4 growth is different from that of As4 growth. Thus the growth kinetics is different depending on the As species. The dissociate reaction of As4 into As2 at the growth surface might play an important role for the case of As4.

The PL intensity has been measured at room temperature for \(\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}\) layers. As shown in Fig. 3, the PL intensity is lower for the layers grown with \(x = 0.2\) than that for the layers grown with \(x = 0.2\) in both cases of (100) and (111)B orientations. In the case of (111)B orientation [Fig 3.(b)], samples grown at low \(T_s < 620-630\) °C both with \(x = 0.2\) and \(x = 0.2\) show almost same PL intensity, which increases with \(T_s\). In this \(T_s\) region, the surface morphology shows the faceted morphology shown in Fig. 2. We have found a large density of microtwins and stacking faults in \(\text{Al}_{0.7}\text{Ga}_{0.3}\text{As}\) with faceted surface by TEM observations\(^{13}\). These defects have never been found in the samples in the other categories. Therefore the
Fig. 3 Room-temperature photoluminescence intensity of Al$_{0.3}$Ga$_{0.7}$As (Si=10$^{18}$ cm$^{-3}$) grown on (a)(100) and (b)(111)B orientation with As$_4$ and As$_2$ as a function of substrate temperature.

PL intensity in the low $T_S$ range should be determined by the high density of crystallographic defects, such as microtwins and stacking faults. We consider that these results are due to the stable As trimers structure[13-15] which hinders Ga incorporation into proper lattice sites[13]. On the other hand, the PL intensity strongly depend upon the degree of As stabilization in the high $T_S$ range and it is determined by the density of point defects, such as, As interstitials and antisite defects. In addition, the formation of the pyramid-like surface morphology is strongly related with the formation of stacking faults and/or microtwins.

4. CONCLUSION

We have grown AlGaAs on (100)- and (111)B-oriented GaAs substrates by MBE using As$_2$ and As$_4$. We have observed that FTR does not exist for $x=0.2$ and it increases with $x$ from 0.3 to 0.7 in the case of (100) orientation. We cannot obtain the specular smooth surface in the whole range of $T_S$ of 540-740°C of $T_S$ in the case of (111)B orientation. This can be partly attributed to the shorter migration length of Al due to the higher reactivity of As$_2$ than As$_4$. The second order reaction process of As$_4$ should play an important role for realizing good quality. The first order reaction process of As$_2$ possibly required the tighter control of As pressure because the lack of the intermediate or associate reaction, and the second order reaction of As$_4$ favorably act as on limiting process in the MBE growth of AlGaAs.

ACKNOWLEDGEMENTS

Authors would like to thank to S. Chen (Eastman Kodak Company) for TEM measurements and fruitful discussion.

REFERENCES