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MBE Growth of AlGaAs on (100)- and (111)-Oriented Substrates Using As_2

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Systematic study has been made for the first time on the basic properties of $Al_xGa_{1-x}As$ (x=0.2-0.7) grown by molecular beam epitaxy on (100)- and (111)-oriented substrates using As_2. 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-$Al_{0.3}Ga_{0.7}As$ as a function of growth temperature.

1. INTRODUCTION

A lot of works have been reported on the molecular beam epitaxy (MBE) of GaAs[1-5] and AlGaAs[6-10] using the dimetric arsenic (As_2) instead of the conventional tetrametric arsenic (As_4) beam. However, there are no systematic studies on the basic properties of AlGaAs grown with As_2 on (100)- and (111)B-oriented substrates. Previous studies have shown that the quality of GaAs on (100) substrate is improved by using As_2 in terms of higher purity[4-5], and lower defect density[1-3] as compared with the GaAs grown with As_4. By contrast, the effect of As_2 on the growth of AlGaAs is controversial. Erickson et al.[6] reported that the surface morphology of $Al_xGa_{1-x}As$ (x=0.2 and 0.3) on (100) face was improved by employing As_2 in the *forbidden* growth temperature region (FTR) of 630-670°C, where only the hazy morphology is obtained when using As_4. They, however, could not realize the specular smooth surface on AlGaAs in the FTR even by using As_2. There is also no report of AlGaAs on (111)B substrates using As_2 although the successful preparation of (111) quantum well structures has been reported using As_4[11].

We present the systematic study on the MBE growth of AlGaAs on (100)- and (111)B- oriented GaAs substrate using both As_2 and As_4 for the first time. In particular, the surface morphology is studied on $Al_xGa_{1-x}As$ (x=0.2-0.7) grown in a wide substrate temperature (T_s) 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 T_s 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-$Al_{0.3}Ga_{0.7}As$ is also presented.

2. EXPERIMENTAL

The solid-source cracking cell with the graphite cracking zone was employed to generate As_2 beam at a cracking temperature of 900°C. The As_4 beam was generated using a standard Knudsen cell or using a cracking cell with a cracking temperature of 550 °C. 2 μm-thick $Al_xGa_{1-x}As$ (x=0.2-0.7) layers doped with Si were grown on (100)- and 0.5°-tilted (111)B-GaAs substrates (Si=2×10^{18} cm^{-3}). The GaAs buffer layer (0.5 μm thick) was grown prior to the growth of AlGaAs. The Si doping concentration was 4×10^{17}, 1×10^{18}, and 2×10^{18} 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 T_s. 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 T_s 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.

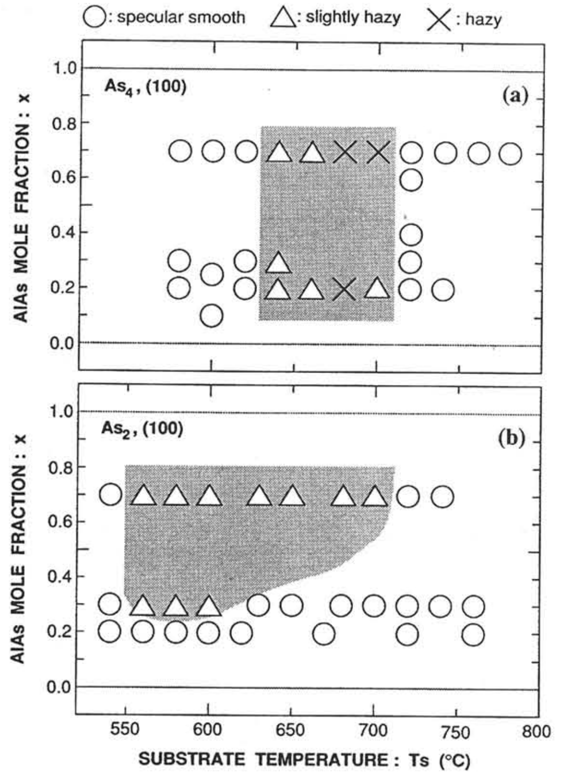


Fig.1 Surface morphology of $Al_xGa_{1-x}As$ as a function of AlAs mole fraction and substrate temperature grown with (a) As_4 and (b) As_2 in the case of (100) orientation. Shaded region correspond to the region where the specular smooth surface cannot be realized.

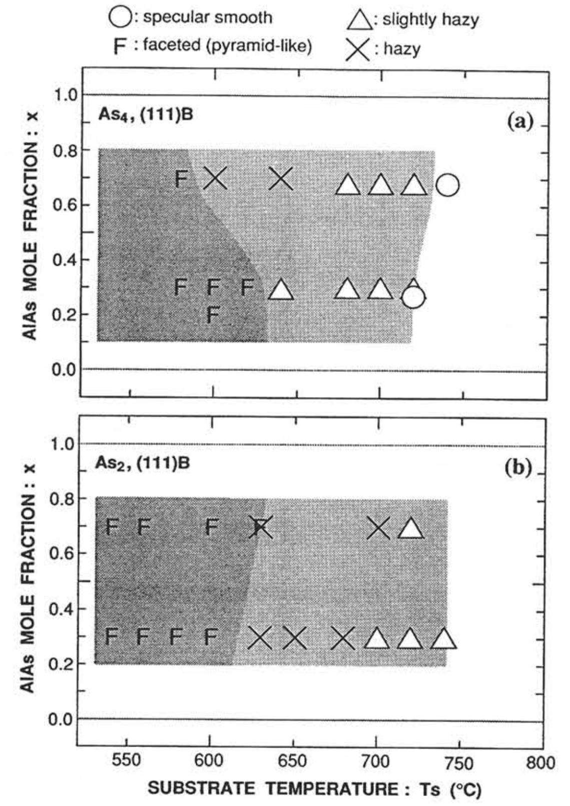
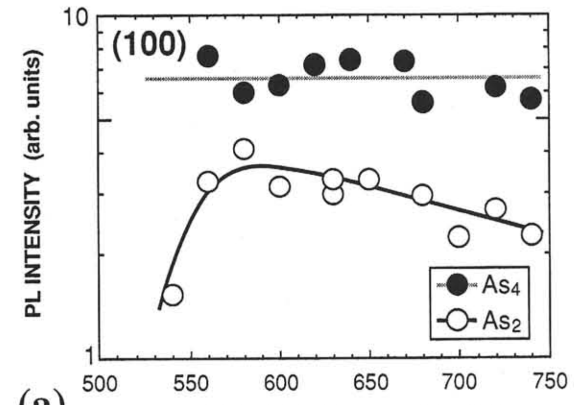


Fig.2 Surface morphology of $Al_xGa_{1-x}As$ as a function of AlAs mole fraction and substrate temperature grown with (a) As_4 and (b) As_2 in the case of (111)B orientation. Deeper shade region correspond to the region of the faceted (pyramid-like) morphology.

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 As_4 is used, 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 As_2 is used, 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 As_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 As_2. This, however, dose not necessarily mean the enhancement of the specular smooth surface region.

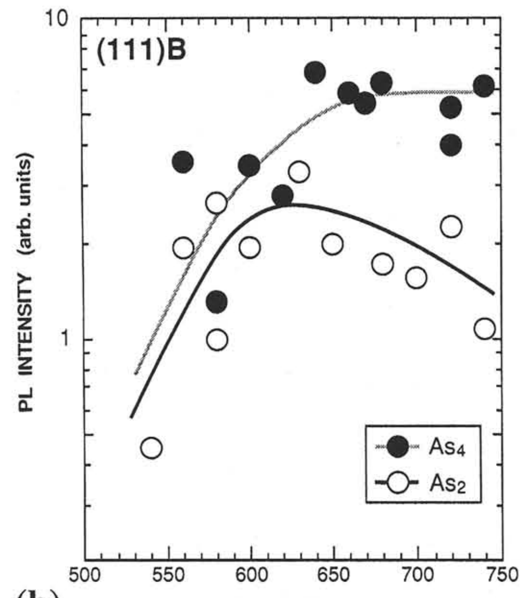
In Fig 2, surface morphology is shown for the (111)B orientation. We add the one more category, "faceted" surface. The "faceted " surface exhibits well-known pyramid-like[12)] textured surface. The specular smooth surface cannot be obtained in the whole range of T_s when using As_2. This result indicates that the specular smooth surface obtained at high T_s using As_4 does not result from the cracking of As_4 at the growth surface. We have observed that the shape of some of surface defects in case of the As_2 growth is different from that of As_4 growth. Thus the growth kinetics is different depending on the As species. The dissociate reaction of As_4 into As_2 at the growth surface might play an important role for the case of As_4.

The PL intensity has been measured at room temperature for $Al_{0.3}Ga_{0.7}As$ layers. As shown in Fig. 3, the PL intensity is lower for the layers grown with As_2 than that for the layers grown with As_4 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 As_2 and As_4 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 $Al_{0.7}Ga_{0.3}As$ with faceted surface by TEM observations[13)]. These defects have never been found in the samples in the other categories. Therefore the



(a)

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.



(b)

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 Ts 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.

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