Growth of strained cubic GaN on GaAs(100) by low−temperature MOVPE

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GaN is a wide band−gap material with applications in short wavelength light emitting devices and power electronics. GaN can be grown in the cubic phase on a substrate that has a zinc blende lattice structure, but the material quality is often hampered by the fractional inclusion of the hexagonal phase. Furthermore, high quality cubic GaN on e.g. GaAs is difficult to achieve due to the large (25 %) lattice mismatch between the materials, which in turn may lead to a high dislocation density. However, very thin layers of GaN are expected to remain smooth and strained.

Although the growth of cubic GaN has been under some investigation, there are still issues that are not very well known, regarding especially the initial stages of the growth. For example, the pre−growth nitridation of the GaAs surface has been used by some groups, but not all. Besides providing insight into the growth process, pseudomorphic, coherent GaN on GaAs could have novel applications, such as surface passivation and barrier layers in GaAs devices such as the resonant tunneling diode.

In our study, we have investigated the effect of layer thickness, growth temperature, V/III molar ratio and post−growth thermal annealing procedure on the morphology of GaN layers grown by low−temperature atmospheric pressure MOVPE. DMHy and TMGa were used as precursors for nitrogen and gallium, respectively. The morphology of the grown samples was characterized using atomic force microscopy (AFM). The role of the surface kinetic mechanisms such as the effective Ga adatom diffusion length and the surface nitrogen coverage in determining the growth mode of GaN were considered.

To study the effect of the layer thickness on the morphology, samples with nominal GaN thicknesses between 2.26 − 22.6 nm were grown at 600°C with a V/III ratio of 100. As Fig. 1 shows, samples with 2.26 nm and 5.0 nm of GaN had smooth surfaces with monolayer steps visible, indicating mainly a 2D layer−by−layer growth mode. At 8.0 nm thickness, the surface was still smooth, but became rougher as the layer thickness was increased. Further growth was more 3D than 2D type due to the relaxation of the lattice mismatch strain.

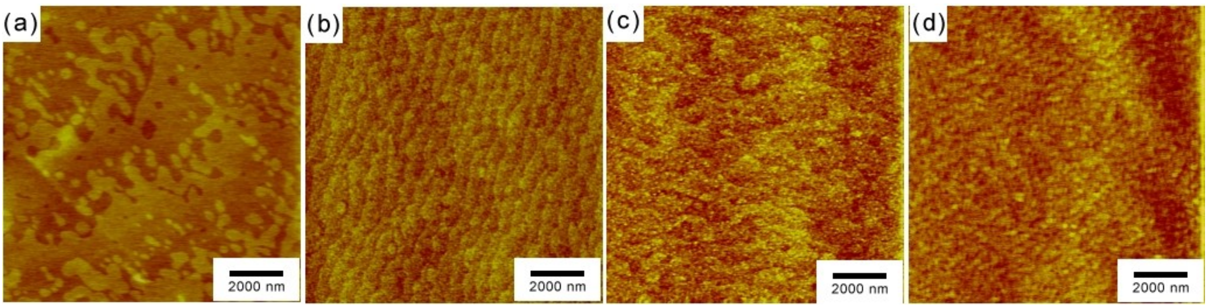

Figure 1. AFM scans of the GaN samples grown at 600°C with nominal thicknesses of (a) 2.26 nm, (b) 5.0 nm, (c) 8.0 nm, and (d) 22.6 nm.

The impact of the growth temperature was investigated by preparing samples with nominally 5 nm of GaN at varying temperatures with a V/III ratio of 100. At 550°C, shown in Fig. 2 (a), the surface was smooth, similar to the one grown at 600°C. At 650°C and above, however, the morphology was drastically different. As Figs. 2 (b) and (c) show, the surface was composed of GaN clusters with an areal density of 2.2×10^{7} cm^{-2} separated by a flat region, which was presumed to be GaAs or nitridated GaAs. Clearly, the growth mode of GaN was now 3D.

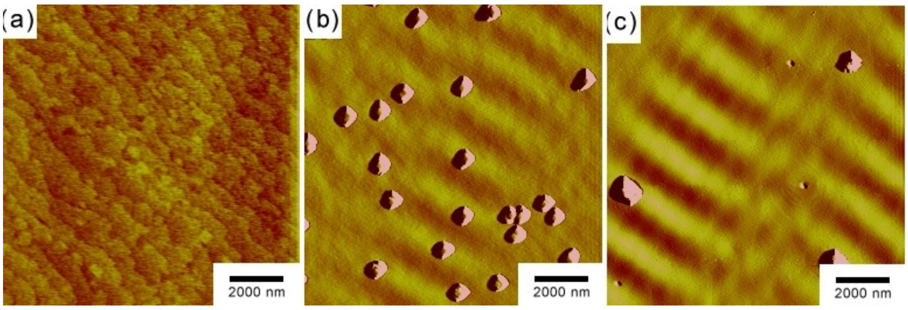

Figure 2. AFM scans of the GaN samples with a nominal GaN thickness of 5 nm grown at (a) 550°C, (b) 650°C, and (c) 700°C with a V/III ratio of 100.

Furthermore, the effect of the V/III ratio was studied by growing a set of samples with nominally 5 nm of GaN at 650°C. With V/III ratios of 100 and below, shown in Fig. 3 (a) and (b), the surface was made up of clusters like the ones described above, indicating 3D growth. The sample grown with a V/III ratio of 200 (Fig. 3 (c)), however, had a smooth surface with traces of monolayer steps visible, indicating that the growth was 2D−like.

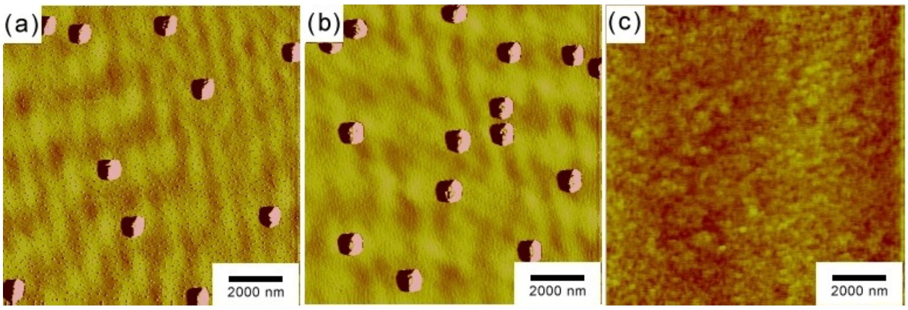

Figure 3. AFM scans of the GaN samples with a nominal thickness of 5 nm, grown at 650°C with a V/III ratio of (a) 12.5, (b) 50, and (c) 200.

Based on these findings, it was concluded that there is a critical temperature T_c, below which the growth mode of GaN is 2D. This critical temperature was also found to increase with increasing V/III ratio. Above T_c, the growth takes place in the 3D mode, and clusters are formed. This seemingly abrupt change of the growth mode might be due to the temperature dependent 3D nucleation and As desorption from the GaAs surface. As the growth temperature is raised, the surface concentration of the nitrogen species drops leading to a smaller probability of crystallization and an increased effective Ga surface diffusion length promoting 3D growth. Moreover, the exposed GaAs surface may decompose. On the other hand, with the raise in the V/III ratio or a drop in the temperature below T_c, the surface nitrogen coverage and the chance of Ga crystallization are increased. As a consequence, the GaAs surface is protected by nitridation and the growth of GaN is 2D−like.

Finally, the effect of post−growth thermal treatment on the smooth GaN layers was investigated by annealing a set of samples, grown originally at 600°C, in a DMHy flux of 56.4 µmol/min at 700°C for 5 minutes. Upon annealing, the smooth surfaces were found to recrystallize forming 3D clusters. Samples with initially 5.0 nm of GaN or less were found to recrystallize almost completely. In samples with thicker layers, only a part of GaN was in the clusters.

In summary, to achieve smooth, coherent layers of GaN, the growth mode should be 2D. This can be achieved by keeping the effective Ga surface diffusion length below a critical limit. Also, the decomposition of GaAs should be avoided. These effects can be controlled by keeping the temperature low and the V/III ratio high enough. In this study, we achieved a smooth strained layer of GaN nominally 8 nm thick at 600°C with a V/III ratio of 100.