Surface morphology of AlN buffer layer and its effect on GaN growth by metalorganic chemical vapor deposition

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(Received 13 April 2004; accepted 25 June 2004)

The in situ optical reflectivity measurements are employed to monitor the GaN epilayer growth process above low-temperature AlN buffer layer on c-plane sapphire substrate by metalorganic chemical vapor deposition. It is found that the lateral growth of GaN islands and their coalescence is promoted in the initial growth stage if the AlN buffer layer is treated with a long annealing time and has an optimal thickness. As confirmed by atomic force microscopy observations, the quality of GaN epilayers is closely dependent on the surface morphology of AlN buffer layer, especially the grain size and nuclei density after the annealing treatment. © 2004 American Institute of Physics.

Beyond our expectation, we have observed that the annealing time of AlN buffer layer exerts a very strong influence on the growth of GaN epilayers. Figure 1 shows the traces of in situ optical reflectivity measured from the two GaN epilayers grown on a 20-nm-thick AlN buffer layer with different annealing processes during the temperature elevation after the growth of low-temperature AlN buffer layer. The annealing time of the AlN buffer layer used in the growth of samples A and B are 1000 s and 300 s, respectively. In Figs. 1(a) and 1(b), two traces are divided into three parts corresponding to the three growth stages of GaN deposition on low-temperature AlN buffer layer as follows: (i) the low-temperature AlN buffer layer deposition, (ii) temperature ramp and anneal of the AlN buffer layer, (iii) the growth of GaN epilayers. The differences in the surface evolution processes during the growth of samples A and B are observed. In the initial growth stage of sample A where the GaN epilayer is deposited on the AlN buffer layer with a 1000 s annealing time, the surface of the GaN layer becomes rough and the intensity of the in situ optical reflectivity decreases. Then the surface of the GaN layer turns optically smoother step by step, which means the lateral growth and coalescence of GaN islands emerge. Finally, the quasi-two-dimensional growth of the GaN layer occurs. An oscillation of the reflectivity intensity with large and equal amplitude is well observed. However, the growth procedures of sample B where the GaN epilayer is deposited on the AlN buffer layer with 300 s annealing time shows a different kind of trace in Fig. 1(b). The surface roughing and lateral growth of GaN islands does not clearly appear. There is nearly no change in the intensity of in situ optical reflectivity during the starting period of the growth of the GaN epilayer, as shown by the arrow in Fig. 1(b). The quality of sample A is much better than that of sample B as revealed by the characterization results which are shown in Table I. Therefore, it is indicated that the longer annealing time of low-temperature AlN buffer layer tends to promote a lateral growth of GaN islands, and the quality of GaN epilayers is improved. It also suggests that the lateral growth of GaN islands is helpful to decrease...
the edge threading dislocations, since the FWHM of the x-ray \( \omega \)-scan rocking curve for (0002) and (10-12) planes represents indirectly the density of screw and edge threading dislocation.\(^{13}\)

It is found that not only the annealing time, but also the thickness of low-temperature AlN buffer layer has an enormous influence on the quality of GaN epilayers. The traces of in situ optical reflectivity measured from GaN epilayers growth on low-temperature AlN buffer layer with different thickness are shown in Figs. 2 (a)–2 (d), where the dashed lines denote the start of GaN epilayers growth. For the four samples, the same 1000 s annealing time of low-temperature-grown AlN is employed and the growth conditions of GaN epilayers are almost the same. However, the thickness of low-temperature AlN buffer layer is different. They are 45, 30, 20, and 16 nm for samples C, D, E (where sample E and sample A are the same sample with different names) and F, respectively. It can be seen from Fig. 2 that there exist a lot of differences in the reflectivity curves measured during the initial stage of the growth process of GaN epilayers. Nearly no lateral growth of GaN islands and their coalescence is observed in the starting period of the growth process of sample C. There is a little lateral growth of GaN islands and their coalescence in the growth process of sample D. With thinner AlN buffer layer, however, the obvious lateral growth of GaN islands is observed in the growth process for sample E, as shown in Fig. 2 (c). The growth process of sample F is stopped as shown in Fig. 2 (d), indicating that the AlN buffer layer is too thin to lead to the coalescence of GaN islands and to start a quasi-two-dimensional growth. In this case the quality of GaN epilayers becomes very bad. The FWHM of the x-ray \( \omega \)-scan rocking curve and electron mobility of the four samples are shown in Table I. The narrowest FWHM of the x-ray \( \omega \)-scan rocking curve and the highest mobility are observed for sample A (or sample E). The optimal thickness of the AlN buffer layer is around 20 nm. A too thick or too thin AlN buffer layer will lead to the deteriorated quality of GaN epilayers.

It is noted that the initial stages of GaN epilayer growth on GaN buffer layer or on the low-temperature AlN buffer layer has a distinct difference. The surface of the GaN buffer layer becomes rough after annealing, and only a rough surface of GaN buffer layer promotes the lateral growth of GaN islands.\(^{13}\) However, a 20-nm-thick AlN buffer layer keeps optically smooth even after 1000 s annealing as shown in Fig. 1. Although the surface of the AlN buffer layer keeps relatively flat, at the initial stage of GaN growth, a rapid

FIG. 1. The traces of in situ optical reflectivity measurements for the three stages in the whole growth process of GaN epilayers on low-temperature AlN buffer layer with different annealing time: (a) 1000 s (b) 300 s.

FIG. 2. The traces of in situ optical reflectivity measurements for the whole growth process of GaN epilayers on low-temperature AlN buffer layer with the same 1000 s annealing time and different thickness: (a) 45 nm, (b) 30 nm, (c) 20 nm, (d) 16 nm. The dashed lines denote the start of GaN epilayers’ growth.

<table>
<thead>
<tr>
<th>Sample</th>
<th>AlN buffer layer Thickness (nm)</th>
<th>X-ray FWHM (arcmin) (0002) (10-12)</th>
<th>Mobility (cm²/V s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, E</td>
<td>1000 20</td>
<td>6.9 11.2</td>
<td>360</td>
</tr>
<tr>
<td>B</td>
<td>300 20</td>
<td>8.1 19.1</td>
<td>142</td>
</tr>
<tr>
<td>C</td>
<td>1000 45</td>
<td>10.2 28.6</td>
<td>73</td>
</tr>
<tr>
<td>D</td>
<td>1000 30</td>
<td>7.2 13.9</td>
<td>217</td>
</tr>
<tr>
<td>F</td>
<td>1000 16</td>
<td>... ...</td>
<td>...</td>
</tr>
</tbody>
</table>
surface roughening and decrease of optical reflectivity then take place. The lateral growth of GaN islands and their coalescence are observed in the subsequent GaN epilayer growth. Consequently, the high quality GaN epilayers are obtained. In comparison with the growth of samples C and E, growth. Consequently, the high quality GaN epilayers are obtained. In comparison with the growth of samples C and E, growth. Consequently, the high quality GaN epilayers are obtained. A rough surface of starting AlN buffer layer leads to the degradation of quality of GaN epilayers, while a smooth surface of starting AlN buffer layer can lead to an improved quality of GaN epilayers when the same annealing process is employed before the GaN growth. This is a very interesting difference between the AlN and GaN buffer. Therefore, the growth mechanism of the GaN deposit on AlN or GaN buffer layer must be different.

In order to gain further insights into the effect of AlN buffer layer on the quality of GaN layers, three AlN buffer layers $a$, $b$, and $c$ with growth stopped just before the growth of high temperature GaN epilayer [indicated by a arrow in

Figs. 1(a) and 1(b) and Fig. 2(a)] are prepared and examined by AFM. These AlN buffer layers are grown under the same growth conditions as those in samples A, B, and C, i.e., $a$ (1000 s annealing, 20 nm thickness), $b$ (300 s annealing, 20 nm thickness), and $c$ (1000 s annealing 45 nm thickness), respectively. The surface morphology of these AlN buffer layers is shown in Figs. 3(a)–3(c), respectively. They are quite different, and sample $a$ has the largest grain size and the lowest nuclei density as shown in Fig. 3. It is known that the GaN epilayer A grown on the AlN buffer layer $a$ has the best quality, implying that the quality of GaN epilayers is closely related to the surface morphology of AlN buffer layer. Because the GaN islands in the initial growth stage will coalesce quickly if the AlN buffer layer has small grain size and high nuclei density, a lot of the formed dislocations will go through the GaN epilayers, leading to a deteriorated quality. On the other hand, the quality of GaN epilayers deposited on AlN buffer layer with large grain size and low nuclei density will be much better, since the lateral growth and coalescence of GaN islands will be promoted, which leads to an increased volume of defect-free columnar domains and improves the crystal quality. Of course, when the AlN buffer layer has too large grain size and too low nuclei density, it will take too long a time for the lateral growth of GaN islands, and the quality of GaN epilayers will also become bad. A long annealing time and a suitable thickness of the AlN buffer layer are very important to the growth of high quality GaN epilayers.

In summary, we have studied the growth of GaN epilayers on a low-temperature buffer layer by metalorganic chemical vapor deposition. The traces of in situ optical reflectivity measurements reveal that the initial stage of the growth process of GaN epilayers is distinctly influenced by the annealing time and thickness of the AlN buffer layer. High quality GaN epilayers can be deposited on AlN buffer layers with a long annealing time and an optimal thickness. The quality of the GaN epilayers is strongly dependent on the grain size and nuclei density of the AlN buffer layer after the annealing treatment.