Growth of a-Plane GaN Films on r-Plane Sapphire Substrates by Metalorganic Chemical Vapour Deposition *

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Nonpolar a-plane GaN films were grown on r-plane sapphire substrates by metalorganic chemical vapour deposition (MOCVD) under various conditions. The surface morphologies of epitaxial films are studied by atomic force microscopy. The pit density and size both decrease with the increasing growth temperature, decreasing growth pressure or V/Ⅲ ratio, while the roughness of the surface increases. Formation mechanisms of the pits in the films are discussed.

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In recent years, great progress has been made with the optoelectronics and microelectronics of nitride semiconductors.[1−3] Usually epitaxial nitrides are in the [0001] orientation, however polarization-induced electrostatic fields along the polar *c*-axis of the wurtzite crystal structure can affect the operation of nitride devices. For example, internal electric fields in GaN/InGaN quantum wells spatially separate electrons and holes within quantum wells.[4,5] This results in a reduction in oscillator strength and redshift of optical transitions. A promising means of eliminating these polarization effects is through the growth of nonpolar wurtzite nitrides. Recently, interest in growth of $(11\bar{2}0)$ a-plane GaN films on $(1\bar{1}02)$ r-plane sapphire substrates has greatly increased.[6−8] The surface morphology of this kind of GaN film was usually quite rough with pits and a ridge-like facet running along the [0001] direction.[7,8] However, to our knowledge, there have been no detailed studies investigating the effects of growth temperature, pressure or V/Ⅲ ratio on the growth of GaN on r-plane sapphire substrates by MOCVD, which is very important for understanding the growth mechanism.

In this Letter, we investigate the growth mechanism by growing GaN films on r-plane sapphire substrates via MOCVD under various growth conditions. AFM was used to study the surface morphologies of the epitaxial films.

All a-plane GaN samples were grown on r-plane sapphire using a low-pressure MOCVD-type Aix2400G3(HT) system. The substrates were initially treated in hydrogen ambient at 1150°C for 10 min, and then the temperature was decreased to 530°C for growth of the GaN buffer layer with a 25-nm thickness at low-temperature, followed by the growth of an about 1.5-μm GaN layer at high temperature. The primary precursors were trimethylgallium (TMGa) and ammonia (NH_3). Hydrogen was used as a carrier gas.

In order to study the effect of growth temperature on the films, three samples were grown under 200 mbar reactor pressure at 1100°C, 1150°C and 1200°C, respectively. The AFM images of the surface morphologies are shown in Fig. 1 for the three samples. The sample grown at 1100°C is decorated with a high density of large pits as shown in Fig. 1(a). These pits are composed of $\{1\bar{1}01\}$ and $(000\bar{1})$ facets. Wu *et al.*[6] reported similar results by scanning electron microscopy (SEM), $\{1\bar{1}01\}$ and $(000\bar{1})$ planes are N-polarity surfaces. The surfaces with the N-polarity planes are stabilized under a low-temperature condition.[9] These planes become less stable at elevated temperature, therefore the pit density and size decrease dramatically at 1150°C as shown in Fig. 1(b) in comparison with Fig. 1(a). The pit density decreases further at 1200°C, however the pit size does not decrease further as shown in Fig. 1(c). The reason is that the gallium atom can be evaporated at such a high temperature, so the V/Ⅲ ratio will increase. Under the N-rich condition, N-polarity planes are stable, which may be responsible for changing the pit size. We confirm this in the following text.

The surface morphology of the GaN films was quite rough with stripe features along the [0001] direction besides pits. The stripe features may result from the anisotropy of migration lengths of adatoms in plane. We notice that the roughness of the films increases with increasing temperature as shown in Fig. 1, which is similar as for GaAs (331). It has been reported that the step height of the epitaxial film grown on a GaAs (331) substrate can increase with temperature because the migration lengths of adatoms increases with temperature.[10,11]

Figures 2(a) and 2(b) show the AFM images of the surface morphologies of the two samples grown at 1200°C, under reactor pressures 200 mbar and 110 mbar, respectively. The pit density and size decrease slightly when the reactor pressure reduces from 200 mbar to 110 mbar. N-polarity planes are more stable under higher reactor pressure,[9] therefore the pit

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density and size are expected to decrease with the decreasing reactor pressure. We find that the stripe features become more noticeable under lower reactor pressure, because the adatoms on the surface can migrate a longer distance under such a condition. Therefore reducing reactor pressure has the same effect on the surface stripe features as increasing growth temperature, as mentioned above.

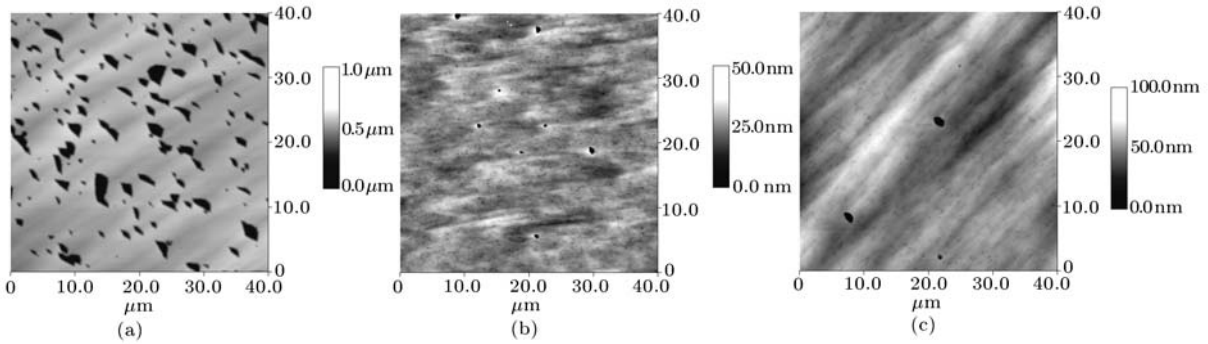


Fig. 1. AFM morphology of a-plane GaN grown under 200 mbar reactor pressure at growth temperatures (a) 1100°C, (b) 1150°C, (c) 1200°C.

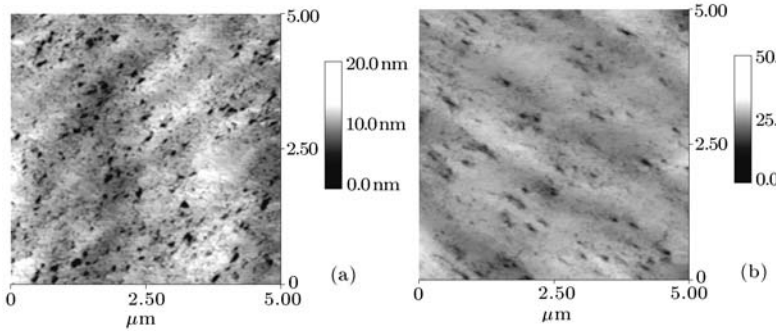


Fig. 2. AFM morphology of a-plane GaN grown at 1200°C under reactor pressures (a) 200 mbar, (b) 110 mbar.

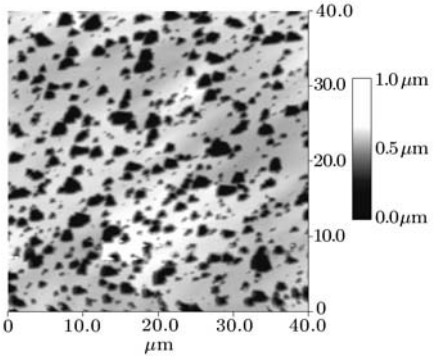


Fig. 3. AFM morphology of a-plane GaN grown under the same condition as the sample shown in Fig. 2(b), but the V/Ⅲ ratio is three times that of the latter.

The pit size in Fig. 2(a) is in a nanometre scale, while there are submicron and nanometre pits in Fig. 1(c). The only difference of the growth condition is the V/Ⅲ ratio between the two samples shown in Figs. 2(a) and 1(c). The V/Ⅲ ratio used in the former is half of that in the latter. The pit size decreases dramatically under a low V/Ⅲ ratio. This means that N-polarity planes are less stable under a low V/Ⅲ ratio. In order to confirm this, we grew a sample under a high V/Ⅲ ratio. The surface morphology is shown in Fig. 3 by the AFM image. The growth condition of the sample shown in Fig. 3 is the same as that shown in Fig. 2(b), but the V/Ⅲ ratio of the former is three times that of the latter. As we can see from Fig. 3, there are many submicron pits that are absent in Fig. 2(b). This obviously shows that the higher the V/Ⅲ ratio, the more stable the surface of the N-polarity plane can be. Submicron pits are easy to form under high V/Ⅲ ratio.

In conclusion, the surface morphology of a-plane GaN films grown on r-plane sapphire substrates by MOCVD changed under various conditions. The growth mechanism is investigated by study of the surface morphology with AFM. The surface morphology is controlled by stability of N-polarity planes and in-plane migration lengths of adatoms. The pit density and size decrease while the roughness of the surface increases with increasing growth temperature, decreasing growth pressure or V/Ⅲ ratio. Therefore, the growth condition must be optimized by consideration of a compromise between the presence of pits and roughness.

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