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Selective Area Growth of N-face GaN (000-1) Films by Group-III-Source Flow-Rate Modulation Epitaxy

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Abstract

We demonstrate group-III-source flow-rate modulation epitaxy for selective area growth of N-face GaN (000-1) films with smooth surfaces, wherein the flow-rate of group-III sources are sequentially modulated under a constant supply of NH_3. We successfully formed hillock-free surfaces of N-face GaN (000-1) within selective areas of up to 100 μm in diameter.

1. Introduction

Ultrathin InN quantum wells (QWs) of a few monolayers have great potential for the development of high-performance optoelectronic quantum devices in the green and red regions because they overcome the quantum-confined Stark effect and the immiscibility problem in high-In-composition InGaN. Since thickness fluctuation in ultrathin QWs of even one monolayer causes broadening of the luminescence spectrum, a step-free surface is necessary. We have fabricated step-free GaN surfaces [1] and step-free ultrathin InN QWs [2] for Ga(In)-face (0001) using selective-area metalorganic vapor phase epitaxy (SA-MOVPE). An N-face GaN (000-1) surface is also attractive for obtaining high-quality InN and InGaN because of its higher affinity to N. We have formed an almost step-free N-face GaN (000-1) surface by SA-MOVPE [3]. However, hexagonal hillocks are generated in the selective area (SA) as the SA diameter increases, because of the low surface migration of Ga adatoms on N-face (000-1) surface. Flow-rate modulation epitaxy (FME) is expected to solve this problem by enhancing the surface migration of Ga adatoms [4]. In this study, we investigated a modified FME (group-III-source FME) for the SA-MOVPE of N-face GaN (000-1), wherein the flow-rates of trimethylgallium (TMG) and triethylgallium (TEG) are modulated sequentially.

2. Experimental

GaN films were grown on N-face GaN (000-1) bulk substrates by SA-MOVPE. The substrate has the threading dislocation density (TDD) of less than 5×10^{6} cm^{-2}. SAs were hexagonal openings (diameters of 15 – 100 μm) surrounded by SiO_2 masks. The source gases were TMG, TEG and NH_3, and the carrier gas was purified H_2. NH_3 was continuously supplied with the flow rate of 0.067 mol/min. On the other hand, the group-III source, TMG or TEG, was supplied during the periods of higher or lower flow-rate, respectively, as shown in Fig. 1. The durations of the higher and lower flow-rate periods for one cycle were kept at 1 and 10 s, respectively. The low-flow-rate supply of the group-III source during the migration enhancement period was required to prevent desorption of Ga from the growing surface. In other words, neither deposition nor etching of GaN occurs during the period of lower flow rate. Totally 900 cycles were repeated at the growth temperature of 1015°C. Some samples were prepared by conventional continuous growth for comparison.

3. Results and Discussion

Figure 2 shows surface morphologies of N-face GaN (000-1) grown selectively within SAs of 100-μm diameter. The GaN film grown by group-III-source FME is free from hillocks, whereas that grown by continuous growth exhibits hillocks. Figure 3 shows the percentage of GaN films with hillocks on the surface, plotted as a function of the diameter of SAs. For continuous growth, the percentage increases monotonically with increasing diameter. On the other hand, the surfaces of GaN grown by group-III-source FME are almost hillock-free independently of the SA's diameter. In order to clarify the mechanism for the formation of surfaces with or without hillocks, we further examined the structure of the films by AFM and cross-sectional TEM. An AFM image taken near the top of a hillock is shown in Fig. 4. A growth spiral with one- or two-monolayer-thick steps can be seen in the image, implying that there is a screw-type dislocation near the top; *i.e.*, the hillock is formed in the spiral growth mode. Next, we performed dark-field cross-sectional TEM observation around the top of the hillock (Fig. 5). A white line, corresponding to a dislocation, is clearly observed for g=0002 (a), while such a line is hardly discernible for g=11-20 (b). The results suggest that the observed dislocation is a screw-type one. Therefore, the origin of a hillock is plausibly a screw-type dislocation. However, the density of screw-type dislocations in N-face GaN (000-1) films prepared by group-III-source FME is almost the same as that in films prepared by continuous growth [5]. These experimental results indicate that the reduction in the hillock density by group-III-source FME is not due to a decrease in screw-type dislocation. Group-III-source FME might enhance the surface migration of Ga atoms and promote step-flow growth rather than form a hillock around a screw-type dislocation.

4. Conclusions

We successfully formed hillock-free surfaces of N-face GaN (000-1) within SAs of up to 100 μm in diameter by group-III-source FME. The density of the screw-type dislocations, which are the origins of the hillock formation, remains constant. Group-III-source FME might enhance the surface migration of Ga atoms and promote step-flow growth rather than form a hillock around a screw-type dislocation.

Acknowledgements

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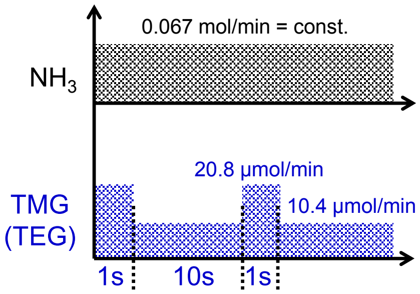

Fig. 1: Time sequences of group-III-source FME.

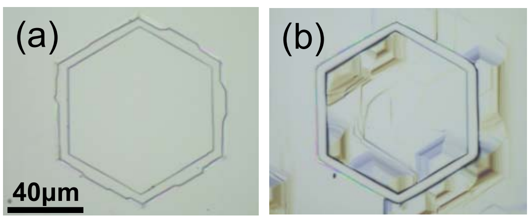

Fig. 2: Optical micrographs of N-face GaN (000-1) grown selectively within SAs of 100-μm diameter using group-III-source FME (a) and continuous growth (b).

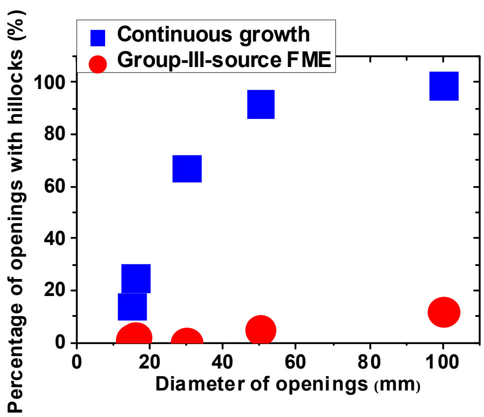

Fig. 3: Percentage of GaN films with hillocks on the surface, plotted as a function of the diameter of SAs. Growth methods are continuous growth (closed squares) and group-III-source FME (closed circles).

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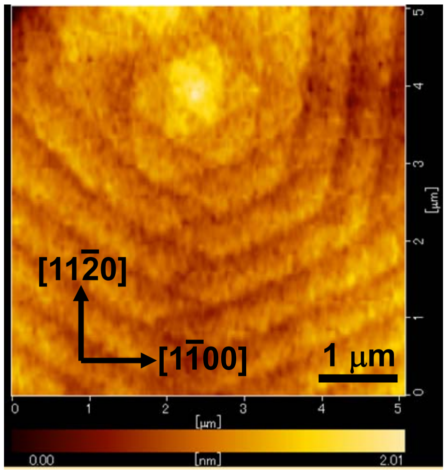

Fig. 4: AFM image taken around the top of a hillock on the N-face GaN (000-1) surface.

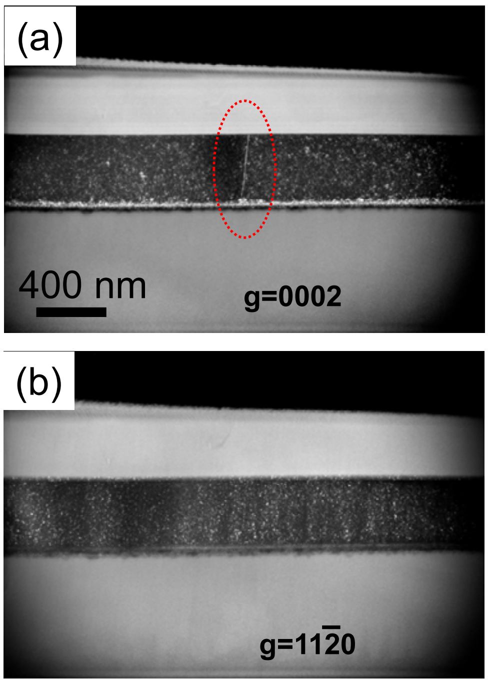

Fig. 5: Dark-field cross-sectional TEM images taken around the top of a hillock on the N-face GaN (000-1) surface for g=0002 (a) and g=11-20 (b), respectively.