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Fabrication of GaN/Alumina/GaN Structure to Reduce Dislocations in GaN

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1. Introduction

A III-nitride semiconductor is an attractive material for short-wavelength optical devices and high-frequency electronic devices operating with high power. The reduction of dislocations is necessary for these III-nitride semiconductor devices. In addition, these devices need insulating layers. Alumina is an attractive material for an insulating layer with its wide bandgap of 7–9 eV and large conduction-band discontinuity against AlGaN [1, 2]. And insulating interlayers such as alumina, Si_3N_4 and SiO_2 are expected to terminate dislocations [3, 4]. Therefore, we fabricated GaN/alumina/GaN structures to reduce dislocations, and investigated the growth mechanism of GaN-on-alumina. In this conference, we report on a relatively wide defect-free GaN layer.

2. Experimental

A GaN layer was grown with H_2 carrier gas in a vertical MOVPE system. The growth pressure was 300 Torr, and the growth temperature was ranging from 1000°C to 1050 °C. GaN templates were grown on c-plane sapphire substrates. Their thickness was about 2-3 μm. Trimethylgallium and NH_3 were the precursors for Ga and N, respectively. Alumina films were deposited in the thickness from 5 nm to 15 nm by electron cyclotron resonance (ECR) plasma sputtering in Ar ambience at room temperature. Then, GaN on alumina was regrown by MOVPE. Surface roughness of GaN regrown on the alumina was monitored by in-situ reflectance monitoring with He-Ne laser (633nm). Line defects extending the layer were observed by cross-sectional transmission electron microscopy (TEM). The crystalline structure of regrown GaN and alumina were also investigated by TEM diffraction pattern and energy dispersive X-ray (EDX). Surface morphology of alumina was observed by atomic force microscopy (AFM).

3. Results and discussions

Alumina layers were annealed in H_2 and NH_3 ambient prior to GaN regrowth. Figure 1 shows the AFM images of the 5-nm thick alumina surfaces after annealing. This revealed pinholes generated after annealing. Their density became high and their size became large as the annealing time increased from 0 min to 10 min. Using the in-situ monitoring, it was found that the GaN regrowth mode was changed by annealing time of alumina. On the alumina annealed for 1 min, the regrown GaN surface was rough at the beginning, and it took 40 min to become flat. On the other hand, GaN grew 2-dimensionally on the alumina annealed for 10 min even at the beginning. The surface roughness of the regrown GaN depended on the alumina thickness in the range from 5nm to 15nm. GaN on thicker alumina took more time to become flat. These results indicate that the annealing changed the alumina surface and then influenced the GaN-regrowth mode. The GaN regrowth process is considered as follows: At the initial stage of the GaN regrowth, GaN probably grew selectively from the pinholes where GaN were exposed to the surface. In the next stage, GaN grew laterally over the alumina layer. So, the regrown GaN surface was rough at the beginning due to its island growth, and then became flat due to its lateral growth. As the annealing time increased, the density of the pinholes became higher and their size became larger. As a result, the density of the GaN islands at the initial stage is considered to become high. Therefore, the GaN surfaces easily became flat, because the islands were easily coalesced.

Figure 2 shows a cross-sectional TEM image of a GaN/alumina/GaN structure. It should be noted that the alumina layer terminated the propagation of dislocations from the GaN template. In the regrown GaN layer, two types of defects were newly observed. One is horizontally propagated defects, and the other is vertically propagated defects. The horizontal defects were also observed in GaN on a SiO_2 film after the epitaxial lateral overgrowth [4, 5]. In those reports, it is considered that the internal stress near the prismatic plane in 3-dimensional growth generated such horizontal dislocations. This internal stress was probably introduced by the 3-dimensional growth at the initial regrowth of GaN on alumina. The high-density horizontal dislocations were observed near the interface, supporting this assumption. The vertical defects were straightly propagated along the growth direction, so these defects are associated with the inversion domain boundaries [6]. From the conversion beam electron diffraction, it was found that the polarization of these defects was inverted. In spite of the inversion domain generation, a defect-free region in regrown GaN became wider than that in GaN template. However, it is necessary to control the polarity of regrown GaN on the alumina surface.

Figure 3 shows a GaN/alumina/GaN structure by the high-resolution TEM observation. Lattice images of GaN and alumina were clearly seen, indicating that the alumina in this study was a single crystal. In this figure, the vertical crystal periodicity in a circled region was the same as that of GaN. Its width was about 10-nm, which agreed with the size of pinholes observed by AFM. Therefore, the circled region corresponds to the GaN crystal grown in the pinhole. These results indicate that GaN overgrew laterally from the pinholes. The TEM diffraction pattern and EDX showed that the symmetry of this alumina crystal belonged to space group of $P6_3mc$, which is the same as a wurtzite structure, and that their lattice constants were measured to be a = 5.5 Å and c = 9.0 Å.

4. Conclusion

To reduce dislocations, GaN/alumina/GaN structures were fabricated by MOVPE regrowth of GaN on alumina, which was deposited by ECR plasma sputtering on GaN templates. From the AFM and TEM observation, the mechanism of GaN regrowth on alumina seems to be selective overgrowth through the pinholes generated by annealing with NH_3. The TEM observation revealed that the dislocations were terminated at the interface between GaN and alumina, and that new types of defects were generated in regrown GaN. Horizontal defects and vertical defects are considered to be the horizontal dislocations and the inversion domain boundaries, respectively. In spite of their generation, wide dislocation-free regions were obtained in regrown GaN.

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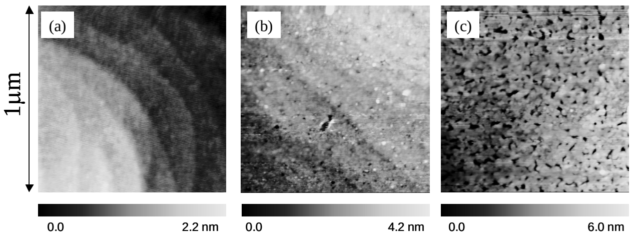

Fig. 1. AFM images of alumina surfaces deposited on GaN: (a) as deposited alumina, (b) alumina annealed for 1 min, (c) alumina annealed for 10 min.

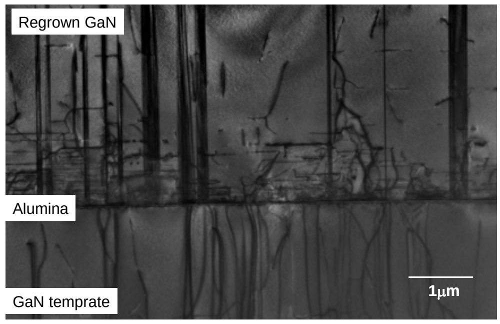

Fig. 2. Cross-sectional TEM image of a GaN/alumina/GaN structure.

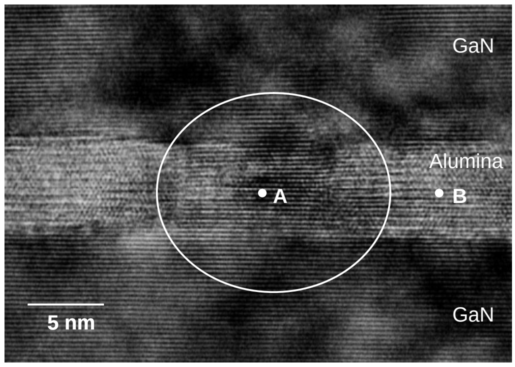

Fig. 3. High-resolution cross-sectional TEM image of a GaN/Alumina/GaN structure. The area enclosed with circle corresponds to a pinhole generated after annealing.