Improvement of the crystallinity of GaN epitaxial films grown on sapphire substrates due to the use of AlN quantum dot buffer layers

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Potential applications of electronic and optoelectronic devices utilizing GaN thin films have driven extensive efforts to grow high-quality GaN epitaxial films [1–5]. GaN thin films and related materials are particularly attractive for applications in high-frequency and high-power transistors [6], as well as light-emitting diodes and lasers operating in the green–blue region of the spectrum [7]. High-quality GaN epilayers are necessary for successful fabrication of high-efficiency devices utilizing GaN epitaxial layers. AlN buffer layers have been introduced to improve the GaN active layer [8]. Since the existence of the AlN buffer layer plays an important role in improving the GaN active layer [9–12], investigations of the effects of the AlN buffer layer on the structural properties of the GaN active layer are necessary to enhance the efficiencies of electronic and optoelectronic devices utilizing GaN-based epilayers. Even though many works concerning GaN thin films have been reported [9–12], almost all the thin films were grown by molecular beam epitaxy (MBE) and metalorganic chemical-vapor deposition. However, very few studies on the growth of high-quality GaN thin films via a hydride vapor-phase epitaxy (HVPE), which can grow thick GaN layers at very high growth rates, have been performed [13].

This letter reports data for the effect of AlN quantum dot (QD) buffer layers on the structural properties of GaN epilayers grown on (0001) sapphire substrates by using a HVPE method. Atomic force microscopy (AFM) measurements were performed to investigate the surface of the AlN buffer, and scanning electron microscopy (SEM) and double-crystal X-ray rocking curve (DCRC) measurements were carried out in order to characterize the structural properties of the GaN epilayers. The GaN epilayers grown on (0001) sapphire substrates with and without AlN QD buffer layers were compared with each other.

The two kinds of GaN epilayers studied in this work were grown on (0001) sapphire substrates by using a HVPE system. The deposition of the GaN epilayers on the AlN buffer layers grown at 510 °C was done at a substrate temperature of 710 °C. The GaN epilayers were also grown directly on (0001) sapphire substrates without the AlN buffer layers.

Fig. 1 shows an AFM image of 2.7-monolayer (ML) AlN buffer layers grown on (0001) sapphire substrates. The AlN buffer layers grown on sapphire substrates are quantum dots (QDs). The AlN QDs are relatively uniformly distributed, and their average heights and diameters are approximately 6 and 35 nm, respectively, as shown in Fig. 1.

Fig. 2 shows SEM images of the surfaces of GaN thin films grown on the (0001) sapphire substrates (a) with and (b) without the AlN QD buffer layer. When the GaN thin film is grown directly on the (0001) sapphire substrate, the surface of the GaN thin film is very rough and contains many defects due to the large lattice mismatch between the GaN active layer and the sapphire substrate ($\Delta a/a \cong 15.4\%$). However, when the GaN thin film is grown on the AlN QD buffer layer, the surface of the GaN epilayers has no columns or Ga droplets due to the small lattice mismatch between the GaN active layer and the AlN buffer layer ($\Delta a/a \cong 2.5\%$). When the AlN QD buffer layer is grown on a sapphire substrate, the AlN buffer layer receives a compressive strain, so the surface energy is minimized [8]. Since the AlN QD buffer layer acts as a nucleation layer for the growth of the GaN active layer, the crystallinity of the GaN active layer grown on the AlN QD buffer layer is improved.

DCRCs for the GaN epilayers grown on the (0001) sapphire substrates with and without the AlN QD buffer layers are shown in Figs. 3a and b, respectively. The full widths at half maxima (FWHM) for symmetric reflection of the DCRCs for the GaN epilayers grown on sapphire substrates with and without the AlN buffer layers are approximately 480 and 1500 arcsec, respectively. The value of the FWHM of the DCRC for the GaN active layer grown on the AlN QD buffer layer is dramatically decreased due to the existence of the AlN QD buffer layer, and the FWHM value of the DCRC is much smaller than those for the GaN thin films grown

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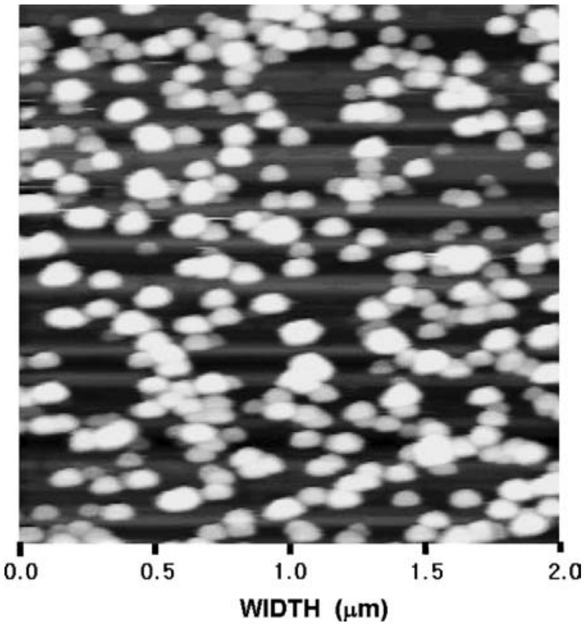

Figure 1 Atomic force image of AlN buffer layers grown on (0001) sapphire substrates.

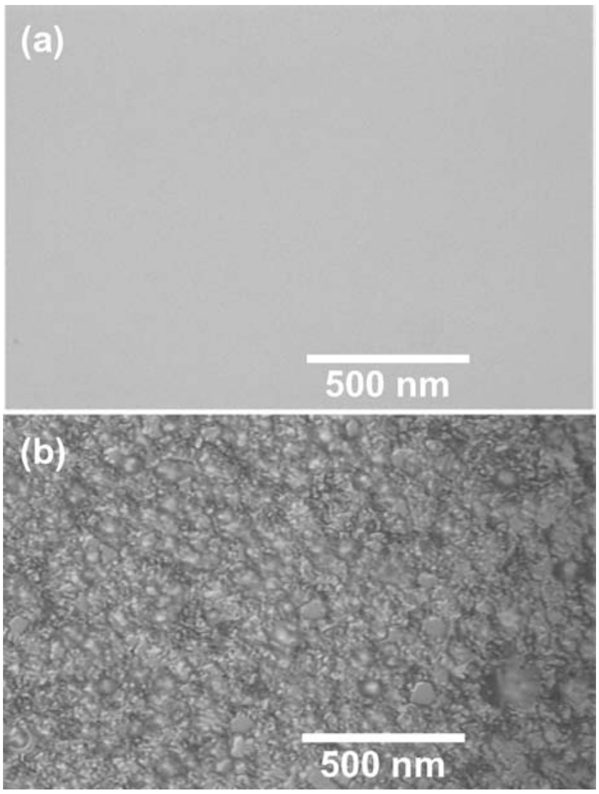

Figure 2 Scanning electron microscopy images of the surfaces of GaN thin films grown on the (0001) sapphire substrates (a) with and (b) without AlN quantum dot buffer layers.

on AlN thin film buffer layers by using MBE [8]. Therefore, when the GaN thin film is grown on an AlN QD buffer layer by using HVPE, the structural quality of the GaN thin film is better than what it is when the GaN thin film is grown on the AlN buffer layer by using MBE [8] or when a free-standing GaN layer is grown by using HVPE [14]. The large lattice mismatch between the GaN active layer and the sapphire substrate requires deposition of the AlN buffer layer to act as a nucleation layer [10]. If a strain is generated in

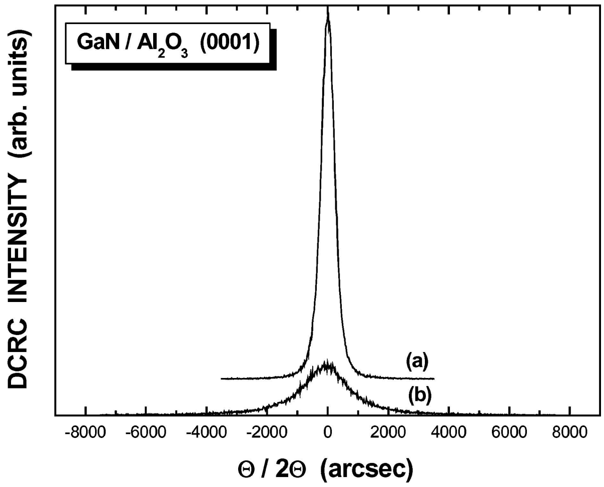

Figure 3 Double-crystal X-ray rocking curves for the GaN epilayers grown on (0001) sapphire substrates (a) with and (b) without AlN quantum dot buffer layers.

the AlN buffer layer, it propagates from the AlN buffer film to the GaN epilayer. Thus, when the GaN film is grown on a thin AlN QD buffer layer, high quality GaN epilayers with no defects can be obtained.

In summary, GaN active layers on (0001) sapphire substrates with and without AlN QD buffer layers were grown by using HVPE. The crystallinity of the GaN active layer grown on the AlN QD buffer layer was significantly improved due to strain relaxation resulting from a decrease in the lattice mismatch between the GaN active layer and the AlN buffer layer. These results indicate that the crystallinity of the GaN active layers grown on sapphire substrates is improved by using AlN QD layers and that GaN epilayers grown on AlN QD buffer layers hold promise for potential applications in optoelectronic devices operating in the blue–green spectral region.

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