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Influence of AlN buffer layer thickness and deposition methods on GaN epitaxial growth

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ABSTRACT

A gallium nitride (GaN) epitaxial layer was grown by metal-organic chemical vapor deposition (MOCVD) on Si (111) substrates with aluminum nitride (AlN) buffer layers at various thicknesses. The AlN buffer layers were deposited by two methods: radio frequency (RF) magnetron sputtering and MOCVD. The effect of the AlN deposition method and layer thickness on the morphological, structural and optical properties of the GaN layers was investigated. Field emission scanning electron microscopy showed that GaN did not coalesce on the sputtered AlN buffer layer. On the other hand, it coalesced with a single domain on the MOCVD-grown AlN buffer layer. Structural and optical analyses indicated that GaN on the MOCVD-grown AlN buffer layer had fewer defects and a better aligned lattice to the *a*- and *c*-axes than GaN on the sputtered AlN buffer layer.

1. Introduction

With its direct and wide bandgap of 3.39 eV at room temperature, high thermal stability, high breakdown field voltage and high saturation drift velocity, gallium nitride (GaN) is considered a promising material for optoelectronic applications in the blue and UV wavelengths, as well as in high-power and high-temperature electronics [1]. Commercially available devices, such as light emitting diodes, are usually grown by metal-organic chemical vapor deposition (MOCVD) on sapphire or SiC substrates due to the lack of large and inexpensive GaN substrates. Compared to these substrates, Si substrates have the advantage of significantly lower cost, and good electrical and thermal conductivities [2]. However, it is difficult to grow single crystalline GaN directly on Si substrates due to the large lattice mismatch (17%) between GaN and Si and the large difference in thermal expansion coefficients (54%) [3]. Therefore, a range of buffer layers, including SiC [4], low temperature-deposited GaN [5], aluminum arsenide [6] and AlN [7], has been investigated as an intermediate layer to minimize the lattice and thermal expansion mismatch between the GaN layer and Si substrate. AlN is the most universal buffer layer because it supports a high-quality GaN epitaxial layer due to the good wettability of GaN, which produces two-dimensional (2D) growth [8], thereby preventing a meltback-etching reaction of Si with Ga [5,9]. In addition, it reduces the lattice and thermal mismatch between GaN and Si.

AlN is easily deposited by radio frequency (RF) magnetron sputtering but the properties of sputtered AlN buffer layers are different from those of MOCVD-grown AlN buffer layers. This study examined the effect of the AlN buffer layer deposition method and thickness, which controls the stresses and crystallinity of the GaN epitaxial layer, on the optical and structural properties of GaN.

2. Experimental details

AlN was selected as a buffer layer to overcome the difference in thermal expansion coefficient and lattice mismatch between GaN and Si (111). RF magnetron sputtering and MOCVD were used to grow the buffer layer. An AlN buffer layer with three different thicknesses (20 nm, 50 nm, 100 nm) was deposited by RF magnetron sputtering. AlN was reactively sputtered on Si substrates at room temperature using Al metal target and nitrogen gas. After sputtering, the samples were annealed in a horizontal quartz tube furnace at temperature up to 950°C for 30 min in an ammonia (NH_3) atmosphere.

An AlN buffer layer was also prepared by MOCVD. For comparison with the sputtered AlN buffer, AlN buffer layers with four different thicknesses (4 nm, 45 nm, 60 nm, 100 nm) were deposited by MOCVD at 1070 °C using an AIXTRON AIX2400G3 HT MOCVD system. The precursors for Al and N were trimethyl-aluminum (TMAl) and NH_3, respectively. The flow of TMAl and NH_3 was 45 sccm and 2000 sccm, respectively, and the group V/III ratio was 2320.

The same MOCVD system was used to grow the GaN epitaxial layer (1 μm) using trimethyl-gallium (TMGa) and NH_3 as the Ga and N precursors, respectively. The growth temperature was 1045 °C. The TMGa and NH_3 flow rates were 100 sccm and 4500 sccm, respectively, and the group V/III ratio was 450.

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Field emission scanning electron microscopy (FE-SEM) was used to examine the morphological changes to the GaN layer. High-resolution X-ray diffraction (HRXRD) and Raman spectroscopy were used to determine the structural properties and crystallinity of the GaN layer. Photoluminescence (PL) was used to investigate the optical properties of the GaN layer. All characterization experiments were carried out at room temperature.

3. Results and discussion

Fig. 1 shows the FE-SEM images of the GaN layer grown on the sputtered AlN buffer layer with different thicknesses. The GaN layers in Fig. 1(b) show no coalescence between the GaN islands. M.A. Moram et al. reported that low crystallinity of the buffer layer affects the disturbance of the coalescence between GaN islands [10]. Therefore, it was concluded that these AlN buffer layers have low crystallinity. Fig. 1(a) and (c) shows non-uniform GaN islands formed by the residual stress of the buffer layer. It was concluded that annealing after sputtering could not improve the quality of the buffer layer for GaN epitaxial growth.

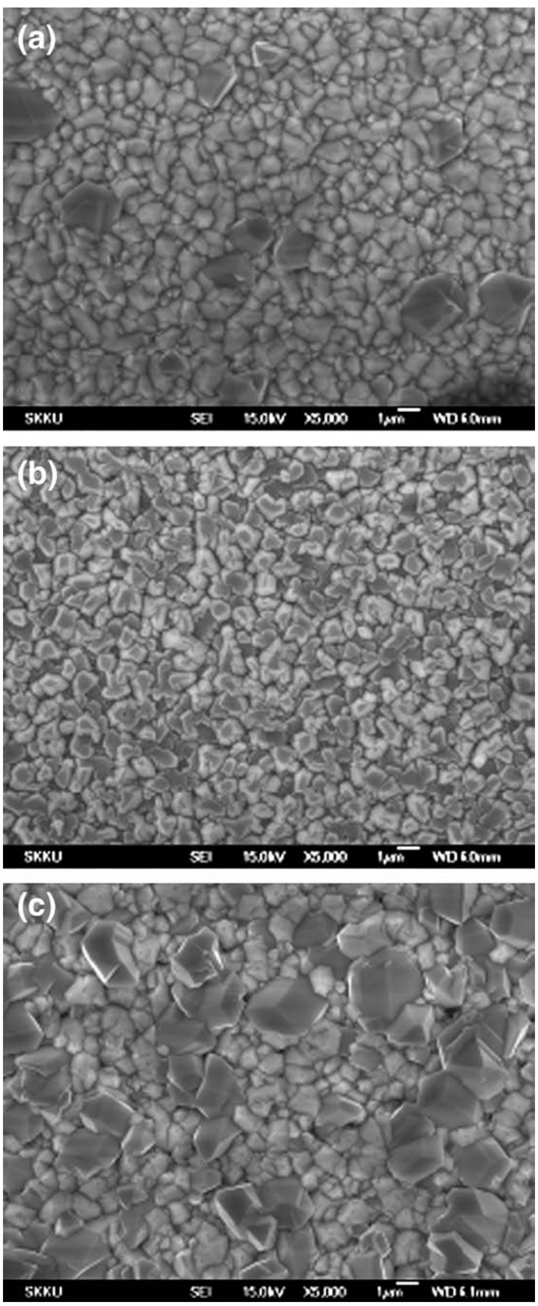

Fig. 1. FE-SEM images of GaN layer according to sputtered, AlN buffer layer thickness: (a) AlN 20 nm, (b) AlN 50 nm, and (c) AlN 100 nm.

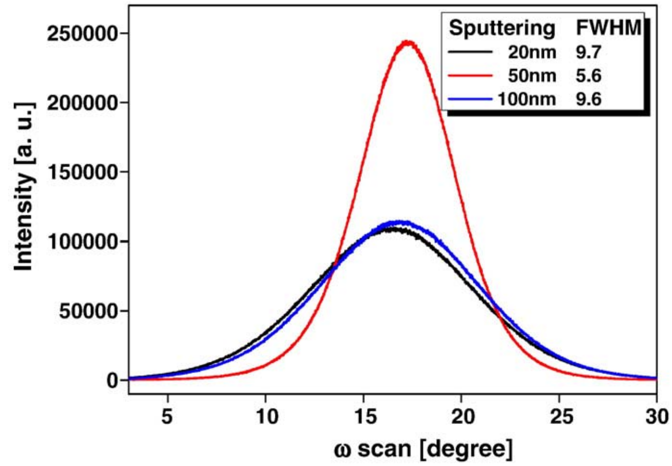

Fig. 2. GaN (002) ω rocking curves of sputtered AlN buffer layer samples.

Fig. 2 shows the HRXRD GaN (002) ω rocking curves of the GaN layer on the sputtered AlN buffer layer. The (002) ω scan full width at half maximum (FWHM) of GaN on the sputtered AlN buffer layer varied from 5.7–9.7°, which is much larger than that on the MOCVD-grown AlN buffer layer, indicating strong out-of-plane misorientation in the GaN layer on the sputtered AlN layer. The θ–2θ scan shows only (002) and (004) peaks but the (102) phi scan showed no six-fold symmetry. These results showed that an annealing process after sputtering only assists in recrystallization of the *c*-plane preferred orientation of the AlN buffer layer, which makes an a-direction tilt and twist, and increases the FWHM value of the GaN epitaxial layer.

Fig. 3 shows the FE-SEM image of the GaN layers grown on the MOCVD-grown AlN buffer layer with different thicknesses. Fig. 3(a) shows severe V-shaped pits, which were formed by a high density of threading dislocations bending to reduce the surface energy [11], indicating that the thickness of the buffer layer is inadequate. Fig. 3(d) shows cracks arising from a failure of stress control due to the excessive thickness of the 100 nm-thick buffer layer. These results suggest that higher crystallinity and adequate thickness of the buffer layer are essential for ensuring high-quality GaN epitaxial layer growth.

Fig. 4 shows the HRXRD GaN (002) ω rocking curves of the GaN on MOCVD-grown AlN buffer layer. The FWHM value of GaN was affected by the AlN buffer layer thickness. As the AlN buffer layer thickness was increased from 4 nm to 60 nm, the FWHM value of GaN decreased from 1.466° to 1.027°, but then increased to 1.188° for the 100 nm-thick AlN buffer layer. These values were lower than the (002) ω scan FWHM of the GaN grown on the sputtered AlN buffer layer (5.7–9.7°), indicating higher crystallinity in the GaN layer grown on the MOCVD-grown AlN buffer layer. A slight increase in the FWHM with the 100 nm-thick AlN indicates that the excessive thickness of the buffer layer caused cracks and reduced the GaN crystallinity, as mentioned above. The θ–2θ scan shows only (002) and (004) peaks, and the (102) phi scan shows six-fold symmetry. The FWHM values of the (102) ω rocking curve of the GaN on MOCVD sample were lower than 0.6, which means the edge dislocation toward ⟨002⟩ direction is effectively eliminated by applying an AlN buffer layer. This suggests that a single crystalline GaN epitaxial layer was grown successfully on Si.

Fig. 5 shows the Raman spectra of the GaN on the sputtered and MOCVD-grown AlN buffer layers. The strong peak at 520 cm^{-1} was