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GaN Heteroepitaxy on Si(111) substrates Using AlN/AlGaN Superlattice Buffer Layers

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1. Introduction

Due to the lack of inexpensive homoepitaxial substrates, heteroepitaxy of GaN films on foreign substrates is essential for realizing the GaN-based optoelectronic and electronic devices at reasonable prices. Si substrates are attractive candidates for GaN heteroepitaxy because of their low cost, large area, perfect crystallinity, and high thermal and electrical conductivity. However, the large difference in the lattice constants and the thermal expansion coefficients between GaN and Si can produce a large number of threading dislocations (TDs) and cracks. Various kinds of buffer layers have been proposed, including AlN, SiC, and AlN/GaN superlattices (SLs) [1]. AlN/GaN SL buffers can effectively decrease TDs and cracks in GaN films on Si. In this paper, an AlN/$Al_xGa_{1-x}N$ SL was first used for GaN heteroepitaxy on a Si(111) substrate as a novel buffer. Obtained GaN films were crack-free and smooth. We also found that there is an optimum range of the Al composition in $Al_xGa_{1-x}N$.

2. Experimental

GaN films were grown on Si(111) substrates by metalorganic vapor phase epitaxy. The source gases were trimethylgallium, trimethylaluminum (TMA), and NH_3. The sample consisted of a Si(111) substrate, a 10-nm-thick AlN layer, an AlN/$Al_xGa_{1-x}N$ SL, and a 1000-nm-thick GaN layer. Thicknesses of AlN and $Al_xGa_{1-x}N$ in the SL were set to 5 and 20 nm, respectively, and the Al composition x in $Al_xGa_{1-x}N$ was varied from 0 to 0.11. The surface morphology of the GaN films was observed by optical microscopy and atomic force microscopy (AFM). The crystallinity and the biaxial strain were evaluated by X-ray diffraction (XRD).

3. Results and Discussion

Figure 1 shows XRD ω–2θ scan charts measured around the GaN(0002) and SL satellite peaks. The 0-order peak of the AlN/GaN SL is weak and there are few satellite peaks, which indicate poor crystallinity and rough interfaces. Since the surface energy of GaN is larger than that of AlN and larger than the GaN-AlN interface energy, GaN tends to grow three-dimensionally on AlN. However, in the case of the AlN/AlGaN SL, a sharp and strong 0-order SL peak and many satellite peaks can be seen. The resulting GaN surface was much smoother than that using an AlN/GaN SL as shown in Fig. 2. The root mean square (RMS) roughness of GaN surfaces was measured by AFM as a function of the Al composition x in AlN/$Al_xGa_{1-x}N$ SLs (Fig. 3). It can be seen that even low x (0.01) dramatically decreased the RMS roughness of the GaN surface. Al atoms in $Al_xGa_{1-x}N$ might provide nucleation sites on AlN and enhance 2D-like growth.

Figure 4 shows the full width at half maximum (FWHM) of the rocking curves of GaN(0002) and GaN($1\underline{1}01$) peaks plotted as a function of the Al composition x in AlN/$Al_xGa_{1-x}N$ SLs. The FWHM of GaN(0002) peak is almost constant (~1000 sec.) independent of the Al composition, while that of GaN($1\underline{1}01$) peak is wider than GaN(0002) and increases monotonically with increasing Al composition. These results indicate that a large portion of TDs in our GaN films are pure edge-type and that the AlN/$Al_xGa_{1-x}N$ SLs with smaller x effectively reduce them. It is considered that the larger difference in the lattice constants between AlN and $Al_xGa_{1-x}N$ with smaller x can enhance the bending and annihilation of TDs. We will also report further reduction in the FWHM of GaN (0002) and ($1\underline{1}01$) peaks by TMA pre-flow before the growth of SLs.

Biaxial strain $\Delta a/a_0$ (a_0=0.32nm) in GaN films were measured by XRD (Fig. 5). The c-lattice constants were determined from the peak position of GaN(0002) and a-lattice constants were calculated using the equation $\Delta a/a_0 = -\nu \Delta c/c_0$, where ν is the Poisson ratio of GaN (0.37). A GaN film for x=0 was almost strain-free. Although the biaxial strain (tensile) monotonically increases with increasing x, GaN films with x of 0.06 or less were crack-free. When x was 0.11, cracks appeared on the GaN surface. Therefore, in order to obtain smooth and crack-free GaN films, Al composition x in $Al_xGa_{1-x}N$ should be between 0.01 and 0.06.

4. Conclusions

An AlN/$Al_xGa_{1-x}N$ SL buffer layer was used for GaN heteroepitaxy on Si(111). By choosing an optimum range of the Al composition in $Al_xGa_{1-x}N$, that is, x=0.01-0.06, crack-free GaN films with smooth surface can be obtained.

Acknowledgements

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Reference

[1] E. Feltin, B. Beaumont, M. Laügt, P. de Mierry, P. Vennéguès, H. Lahrèche, M. Leroux, and P. Gibart, Appl. Phys. Lett. **79** (2001) 3230.

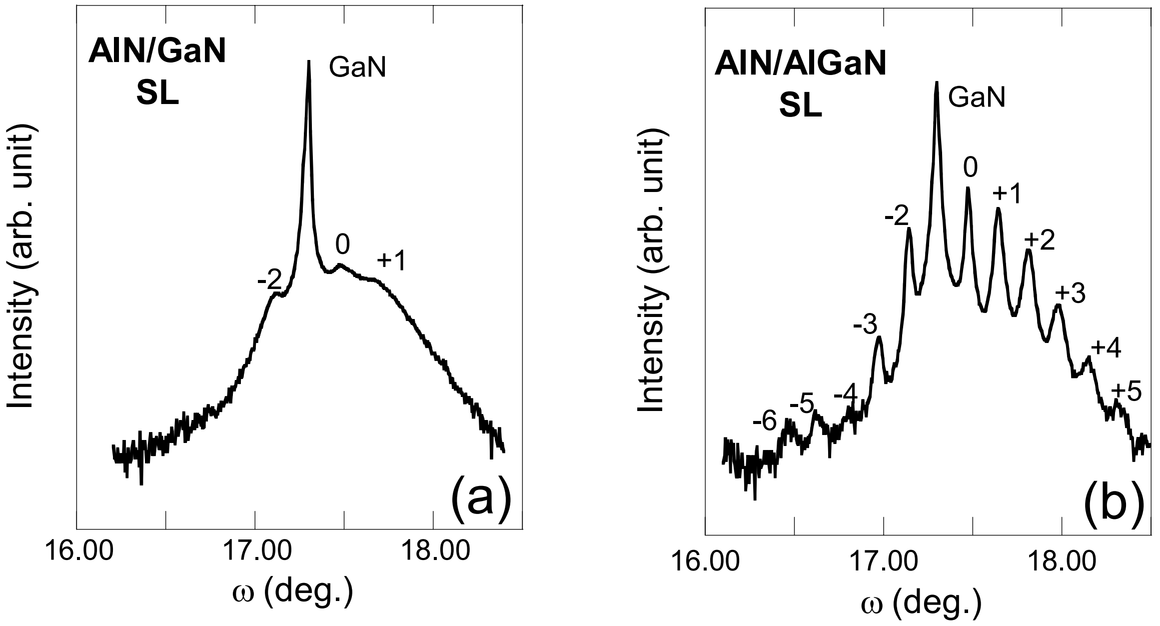

Fig. 1 XRD ω–2θ scan charts for samples using an AlN/GaN SL (a) and an AlN/Al$_{0.06}$Ga$_{0.94}$N SL (b), respectively.

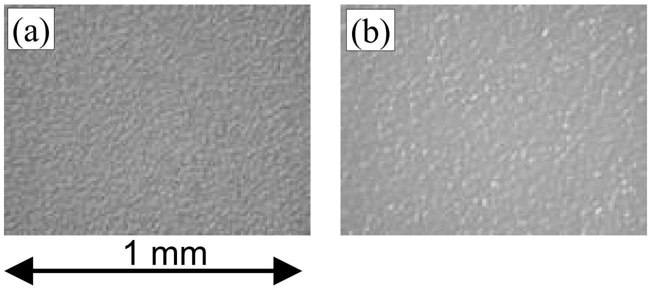

Fig. 2 Optical micrograph of GaN surfaces using an AlN/GaN SL (a) and an AlN/Al$_{0.06}$Ga$_{0.94}$N SL (b).

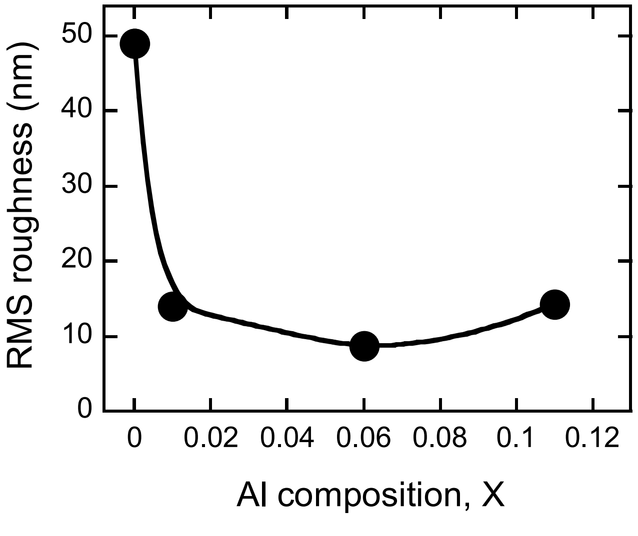

Fig. 3 Dependence of the RMS roughness of GaN surfaces on Al composition x in AlN/Al$_x$Ga$_{1-x}$N SLs . The RMS roughness was measured by AFM and the measured areas were 50x50 μm^2.

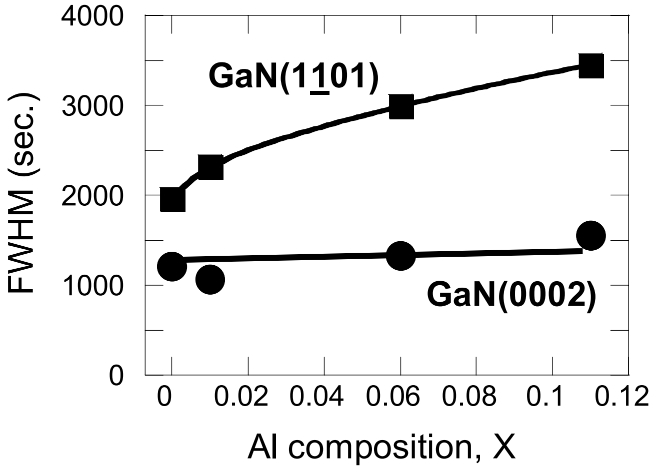

Fig. 4 Dependence of the FWHM of rocking curves of GaN(0002) and GaN(1$\underline{1}$01) peaks on Al composition x in AlN/Al$_x$Ga$_{1-x}$N SLs .

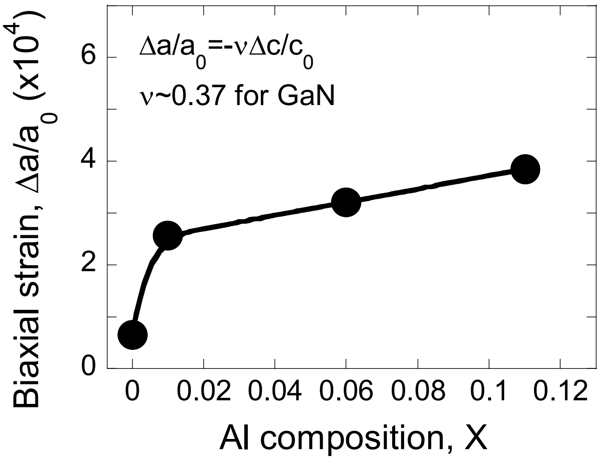

Fig. 5 Dependence of the biaxial strain, $\Delta a/a_0$, in GaN films on Al composition x in AlN/Al$_x$Ga$_{1-x}$N SLs .