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Structural Properties on GaN Film through the Introduction of AlN Buffer Layers with Variable Growth Temperatures by Plasma-Assisted Molecular Beam Epitaxy

Byoung-Rho Shim, Hideyuki Okita[1], Kulandaivel Jeganathan, Mitsuaki Shimizu and Hajime Okumura

Power Electronics Research Center, National Institute of Advanced Industrial Science and Technology, Tsukuba Central 2
1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan
Phone: +81-298-61-5302 Fax: +81-298-61-5434 E-mail: shim-br@aist.go.jp
[1]Science University of Tokyo, Department of Electrical Engineering
2641 Yamazaki, Noda, Chiba 278-8510, Japan

1. Introduction

The III-V semiconductor of AlN, GaN, and InN and their ternary alloys have great potential applications for use in optoelectronic and high temperature/power electronic devices due to their wide range of bandgaps and high-temperature stability etc. Large bandgap, high dielectric breakdown field, good electron transport properties [1], and favorable thermal conductivity of GaN make these materials attractive for high temperature/power electronic devices [2].

Dislocations are an important scattering mechanism in films having dislocation densities above $1\times10^8/cm^2$ [3]. Depending on the particulars of the growth and the substrate preparation, GaN films grown by MBE typically have dislocation densities in the range of 5×10^9 ~ $5\times10^{10}/cm^2$ [4]. Dislocation reduction is really the key to achieving high mobility GaN which goes to the heart of the need for a buffer layer and/or early stages of growth.

We have worked on the surface flatness of GaN, and the optimization for reduction of a surface structure defects such as threading dislocation density, surface pits etc. Therefore, we introduce the contents which analyzed the improvement in the quality of the GaN surface and the reduction of threading dislocation density in GaN film by the introduction of AlN buffer layers with variable growth temperatures by plasma-assisted molecular beam epitaxy (PAMBE).

2. Experiments

GaN/AlN structure was grown on sapphire (0001) substrates by MBE system with a radio frequency (RF) nitrogen plasma source. The plasma was operated at a discharge power of 380 W and a N_2 flow of 0.7 sccm. The sapphire substrates which it uses in growth used quarter pieces of 2 inch wafer. For sapphire substrates, 3 : 1 solution of H_2SO_4 : H_3PO_4 is used as the etchant. The substrate is dipped in this solution, kept at 110 °C, for 30 min. This is followed by a rinse in DI water for 5 min. The nitridation of the substrate surface was performed at 200 °C for 1 hour. Reflection high-energy electron diffraction (RHEED) patterns were bright streaks after the nitridation step, indicating the formation of thin AlN layer at the surface.

X-ray measurements were performed with high-resolution triple-axis diffractometers from Philips X'pert MRD system. For each sample, triple-axis scans with lower angle were measured in ω and in ω/2θ or 2θ/ω mode for the GaN symmetric (0002) reflection and high-resolution curve scans with upper angle were measured in ω, ω/2θ or 2θ/ω and in ϕ mode for the GaN asymmetric (10-12) reflection. Surface morphology was observed by an optical microscope, a SEM using a Hitachi S-4500 system.

3. Results and Discussion

X-ray rocking curve measurements were carried out to investigate the structural properties of GaN epilayers grown on c-plane sapphires with single-step AlN buffer layers. The FWHM values of ω, ω/2θ and ϕ scans of symmetric (0002) and asymmetric (10-12) reflection in these samples with different T_{sub} are shown in Table I.

Table I FWHM values of ω scan and ϕ scan of asymmetric (10-12) reflection with different growth temperature of AlN buffer layer

Substrate Temp.		750 °C	850 °C	950 °C	1020 °C
XRD FWHM (arcsec)	(0002)				
	ω scan	122.5	14.6	133.2	513.4
	ω/2θ scan	69.3	58.1	64.7	75.4
	(10-12)				
	ω scan	2084.4	1740.4	1750.5	2860.6

The strong differences of FWHM values in the both scan directions are reflected in the typical elliptic shape of (0002) reciprocal lattice points, which has also been reported for MOCVD grown layers [5]. This shape is usually explained by mosaicity in the layers [6]. The smallest FWHM values of ω and ω/2θ scans in these samples are of the sample with the AlN buffer layer grown at 850 °C. The very small FWHM of 14.6 arcsec for the sample is comparable to extremely low values reported by other groups [7], [8]. This indicates an increase of lateral coherence length due to a reduction of the tilt of the mosaic blocks in the layer, base on the model of mosaic layer. However, FWHM values (ω and ϕ scans) in asymmetric (10-12) reflection of the 850 °C sample are almost the same as that in the 950 °C sample. The (10-12) reflection FWHM values of ω scan in the 850 °C sample were 1740.4 arcsec, and those in the 950 °C sample were 1750.5 arcsec. This means that the density of edge dislocation in two samples is almost the same.

From the result of the calculation [9] which asks the FWHM of XRD peak for dislocation density, threading dislocation densities of symmetric (0002) and asymmetric (10-12) reflections in 850 °C sample were $1.9\times10^{6}/cm^{2}$ and $4.0\times10^{10}/cm^{2}$, and those in 950 °C sample were $3.5\times10^{7}/cm^{2}$ and $4.1\times10^{10}/cm^{2}$. The dislocation density of symmetric reflection showed that the GaN layer had gathered in the direction of c-axis well. The dislocation density of asymmetric reflection showed that much edge dislocation existed. The FWHM values from symmetric (0002) and asymmetric (10-12) reflections of the 850 °C sample are narrower than other samples. But, the range of optimum growth condition in order to remove droplets and islands even with 850 °C sample is narrow. From the atomic force microscopy (AFM) image, moreover, surface roughness and undulations are greatly observed. We, here, tried two-step growth of AlN buffer layer for the improvement of the surface quality, having such FWHM values. All layers of the sample, AlN buffer layer with two-step growth, show a two-dimensional streaky pattern, sufficient to speculate that the layers are free from Al, Ga metal droplets, of RHEED during the growth.

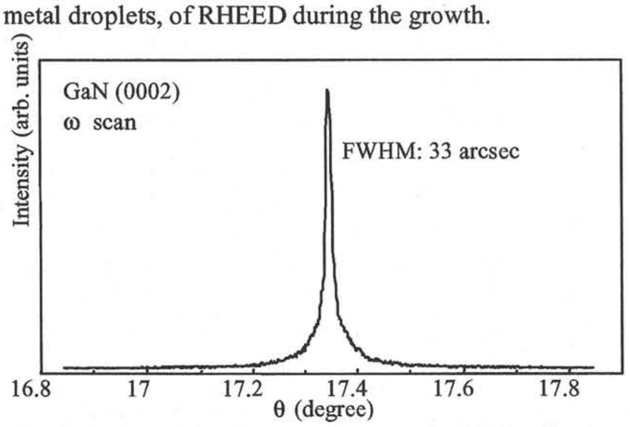

Fig. 1 GaN ω triple axis scans of symmetric (0002) reflection on the sample of AlN buffer layer with two-step growth.

Fig. 1 shows ω scans of symmetric (0002) reflection on the sample of AlN buffer layer with two-step growth. The FWHM value of (0002) rocking curve has 32.8 arcsec. This low value may only be achieved with a low density of screw threading dislocations. Threading dislocation densities of symmetric (0002) reflection in this sample were $4.8\times10^{6}/cm^{2}$. Also, pronounce layer thickness interferences are observed in the logarithmic plot of the $2\theta/\omega$ direction. The interferences point to a large coherence length along the c-axis.

Fig. 2 shows the surface morphology of the sample with two-step growth observed by SEM. Small undulations can be seen, however the surface has good morphology free from pits and grooves. The surface roughness is approximately 1 nm RMS in this sample. This SEM morphology is good evidence supporting the results from XRD peaks.

These results could be asked for an improvement of surface morphology and reduction of dislocation density. We are continuously researching in order to look for the GaN film growth conditions on sapphire substrate by PAMBE method with the better optical and electrical characteristics.

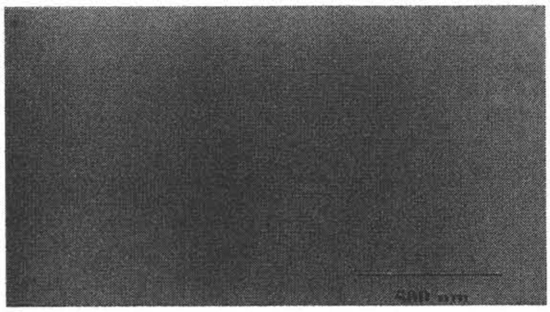

Fig. 2 SEM photography of the surface of GaN epilayer on AlN buffer layer with two-step growth.

4. Conclusions

For GaN film grown on AlN buffer layer PAMBE method, extremely small FWHM values could be achieved. From the surface morphology observed by SEM and diffraction peaks from XRD, we obtained the good surface flatness and structural characteristics. The FWHM of ω-scan from symmetric (0002) reflection was 14.6 arcsec, and from asymmetric (10-12) reflection was 1740.4 arcsec. The sample surface with two-step growth has good morphology free from pits and grooves. Each calculated screw and edge dislocation densities from symmetric (0002) and asymmetric (10-12) reflections measured by XRD peaks were $4.8\times10^{6}/cm^{2}$ and $1.5\times10^{9}/cm^{2}$, respectively. Further intensive works are necessary to understand these results.

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