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Growth of Perfect Crack-Free GaN/Si(111) Epitaxy Using CBL and Superlattice

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1. Introduction

The Si substrate has many advantages of its high crystal quality, low cost, large area size, good electrical and thermal conductivity as compared with sapphire and SiC. However, due to large mismatch of lattice constant (-16.9%) and thermal expansion coefficient (about 57%) between GaN and Si, difference of crystal structure (GaN:hexagonal, Si:cubic) and thermal instability of Si in high temperature, it is really difficult to grow high quality GaN on Si substrate. The major problem which indeed prevents direct growth of GaN on Si surface is poor nucleation of GaN on Si, which leads to an island-like GaN structure [1].

In recent years, several groups have reported on the removal of these cracks for the growth of GaN on Si substrate using various methods by MOCVD and MBE, such as laterally epitaxial overgrowth (LEO) technique by S. Zamir et al. [2] selective area growth (SAG) method by N. Sawaki et al. [3], graded AlGaN interlayer growth by Min-Ho Kim et al.[4], and AlGaN/GaN superlattice by Nikishin et al. [5]. But, these methods have not achieved yet perfect crack free GaN/Si(111) epitaxy compared with growth of GaN on sapphire substrate. Among the above mentioned methods, GaN/Si(111) MBE growth with AlGaN/GaN superlattice, between AlN nucleation layer and GaN epitaxy used by Nikishin et al. Strain relief by reducing lattice and thermal mismatches was performed successfully.

In this study, in order to reduce of cracks which result from lattice and thermal mismatch, we have specially designed a composite buffer layer (CBL) consisted of AlN seed layer and $Al_{0.2}Ga_{0.8}N$ intermediate buffer layer and 20 pairs $Al_{0.2}Ga_{0.8}N$/GaN superlattice layers. Using these optimized CBL and superlattice, we have successfully carried out 2 inch wafer crack-free GaN/Si(111).

2. Experimental procedures

GaN growth was performed in MARVEL 260-A MOCVD with a vertical flow reactor. At first, an approximately 100 nm AlN seed layer and a 10 nm $Al_{0.2}Ga_{0.8}N$ layer were deposited at 1040 ^{0}C as a CBL growth. TMAl, TMGa and ammonia (NH_3) were used as precursors for Al, Ga and N source with hydrogen gas as a carrier gas. After the CBL growth, short-period superlattices with 2 nm GaN layer and 2 nm $Al_{0.2}Ga_{0.8}N$ layers of 20 pairs were deposited, and finally u-GaN with 0.5 μm thickness is grown as shown in Fig. 1.

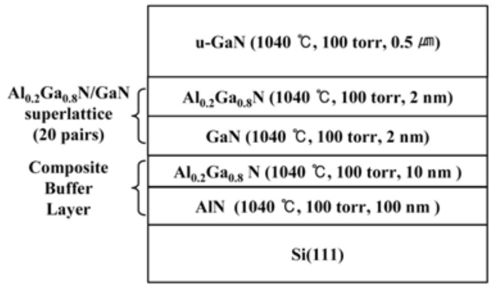

Fig. 1 Layer structure of GaN/Si(111) epitaxy grown with superlattice and composite buffer layer.

All growth procedures were carried out at 1040 ^{0}C under 100 torr pressure condition. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) were used for evaluating surface morphology and thickness, also double crystal X-ray diffractometer (DCXRD) and photoluminescence (PL) were used for characterizing the crystallinity and optical properties, respectively.

3. Results and Discussion

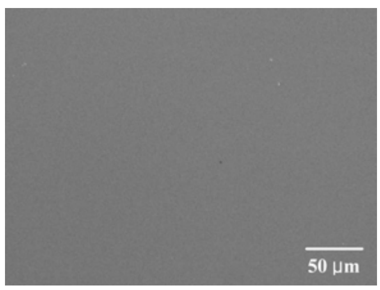

Fig. 2 Plan-view SEM images of GaN surface. All over the area shows mirror-like surface with no pits and cracks.

Fig. 2 shows the plan-view SEM image of GaN surface that reveals good quality mirror-like surface over the entire 2 inch wafer. No pits and cracks were observed on the film with the 0.5 μm thickness of the GaN. The growth of CBL and superlattices between GaN and Si avoids the abrupt change in the lattice mismatch and thermal expansion coefficient, therefore, the strains induced by the large lattice and thermal mismatch between the GaN epilayer and Si substrate were reduced.

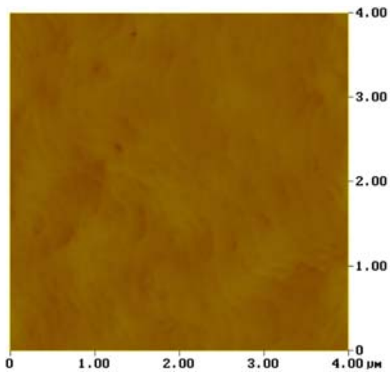

Fig. 3 AFM image of a 0.5 μm GaN layer on Si(111). Threading dislocation were observed as a dark point on the surface.

Atomic force microscopy (AFM) has been used to characterize the surface morphology of the sample and the threading dislocation. Root mean square (RMS) value was 1.427 nm measured on 4×4 μm^2 area. The roughness of the GaN layer is considerably improved by the use of CBL and superlattice, compared to our previous report [6]. The average of the threading dislocation density was measured to 1.32 × 10^{-9} cm^{-2}. This value is comparable to that obtained for GaN on sapphire. These results explain that CBL and superlattice in the sample play a key role for minimizing the tensile strain in the upper GaN layer.

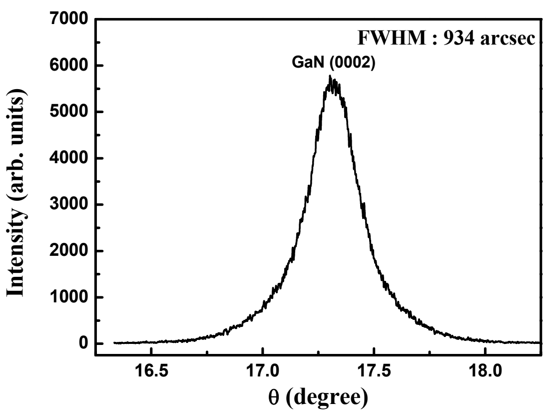

Fig. 4 FWHM value of GaN(0002) DCXRD rocking curve.

The FWHM value of the double-crystal X-ray rocking curve (DCXRC) for the GaN on Si with superlattice and CBL was 984 arcsec, as shown in Fig. 4. The value of FWHM is relatively high, that because a crystallinity is getting worse as decreasing thickness [7]. The crystal quality of the GaN epilayer is expected to be high with increasing thickness. On the other hand, cracks will be observed on the thick GaN layer surface due to thermal strain when the Si substrate is cooled down from the growth temperature to room temperature.

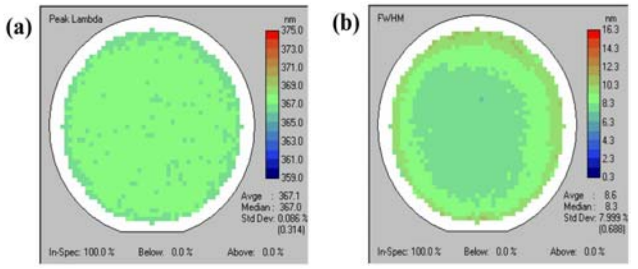

Fig. 5. PL mapping images of the GaN with CBL and SLs on Si substrate : (a) band edge emission peak, (b) FWHM of the PL spectra.

Fig. 5 shows the PL measurement that was carried out for evaluating optical properties of GaN on Si with CBL and superlattices using 325 nm He-Cd laser under room temperature. 367.1 nm average band edge emission peak corresponding to 3.39 eV was observed with a FWHM of 70 meV. The band edge of the GaN/Si(111) was shifted by 10 meV to slightly lower energy, which indicate that a tensile stress is remained in the GaN film due to the large difference of thermal expansion coefficient and lattice mismatch between GaN and Si substrate.

3. Conclusions

In summary, we have realized the growth of a high quality and crack-free GaN layer on Si(111) epitaxy employing optimized CBL and $Al_{0.2}Ga_{0.8}N$/GaN superlattice. CBL with the AlN/$Al_{0.2}Ga_{0.8}N$ and superlattice with the GaN/$Al_{0.2}Ga_{0.8}N$ made it possible to achieve crack-free GaN/Si(111) by reducing the strain effect, possible for the application to LED or other photonic devices.

Acknowledgements

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