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Characteristic comparision of GaN epitaxy grown on patterned and unpatterned Si(111)

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1. Introduction

The heteroepitaxial growth of GaN based light emitters on Si substrate has attracted much interest, because this method allows the low cost fabrication of devices having a large diameter, large size, and high electrical and thermal conductivity, as compared to those fabricated on sapphire and SiC. In recent years, several groups have reported on the MOCVD [1], HVPE [2] and MBE [3] systems growth of GaN on Si substrates. However, it is difficult to obtain GaN/Si(111) epitaxy, whose quality is as good as that of GaN layers on sapphire or SiC, due to the large difference in the lattice constant, crystal structure, thermal expansion coefficient as well as for other reasons, all of which caused many cracks and pits to develop in the GaN surface. In order to improve these lattice and thermal mismatches, some research groups have attempted to improve the crystal quality of the GaN layers grown by MOCVD, by using the pendeo epitaxy [4] and the ELO (epitaxial lateral overgrown) [5] technique via the use of a selective mask. Although these techniques have been proven to be very efficient at reducing the density of the defects when using Si substrates, it still needs a multiple regrowth steps procedure and an ex-situ processing step. Such two-step MOCVD is complex and could often result in a much lower production yield.

Based on these methods, we specially designed a periodically patterned Si substrate process, which we refer to as LEPS (lateral epitaxy on patterned Si substrate). Using this technique, we are able to obtain high crystalline-quality GaN without any impurity contamination or process damage [6], because only one lithography step is involved and the GaN layer is grown in a single step.

In this paper, we compared the quality of the GaN layer that was grown using patterned Si(111) with that of the layer that was grown using unpatterned Si(111). Moreover, we report on the basic mechanisms of the LEPS process. The crystal quality, structural and optical properties of the GaN films is also discussed.

2. Experiments

The GaN epilayers were deposited on Si(111) by MOCVD with a horizontal quartz reactor. Prior to growth, the Si(111) substrates were patterned with periodic stripes using conventional photolithography and ICP (inductively coupled plasma) techniques. The planar Si(111) substrates were patterned into 1.5 cm^2 areas of parallel stripes along or perpendicular to the Si <1-10> direction. The depth of the trenches was about 0.8 μm. The width and the period were 4 and 3 μm, respectively.

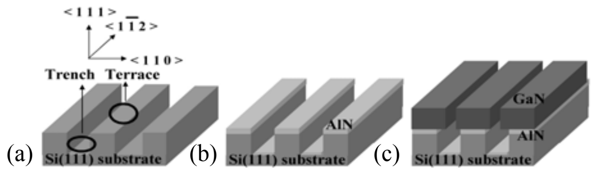

Fig. 1 A schematic diagram of the processing steps for the lateral epitaxy of patterned Si(111).

A schematic view of the GaN/Si(111) layer structure for the patterned GaN on Si(111) is shown in Fig. 1. The LEPS approach involves three major steps: (i) the Si substrate were patterned with periodical stripes via conventional photolithography and ICP techniques (Fig. 1(a)), (ii) the growth of the buffer layer (Fig. 1(b)) and (iii) the growth of the GaN layer (Fig. 1(c)).

The source materials for gallium, aluminum and nitrogen were TMG (trimethylgallium), TMA (trimethyaluminum) and NH_3, respectively. After preparation, the Si(111) substrate was heated to 900 ^oC under hydrogen ambient for 5 min, in order to obtain a clean and oxide-free surface. A 100 nm AlN buffer layer was deposited by feeding TMA and NH_3 with hydrogen as a carrier gas. Subsequently, the GaN layer was grown.

The X-ray diffraction (XRD), photoluminescence (PL) and transmission electron microscopy (TEM) were performed to characterize the crystal, optical and structural properties of the GaN films.

3. Results and discussion

Fig. 2 shows the FWHMs of DCXRD rocking curves for the GaN(0002) grown (a) unpatterned GaN/Si(111) and (b) patternted GaN/Si(111) layer. The FWHM value of the GaN layer on the patterned Si(111) was drastically reduced compared to that of the unpatterned GaN/Si(111) layer. The structural quality of the GaN layer grown by LEPS process that reflected by the reduction of the FWHM of the rocking curve of the symmetric (0002) reflection down to 635 arcsec. Using standard process and for the same thickness of the GaN layer that represent FWHM was 732 arcsec.

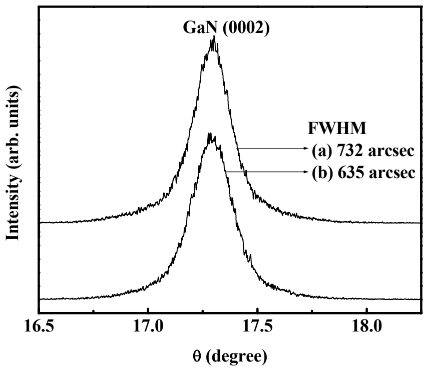

Fig. 2 DCXRD results of GaN epitaxy grown (a) Unpatterned GaN/Si(111) and (b) patterned GaN/Si(111) layer.

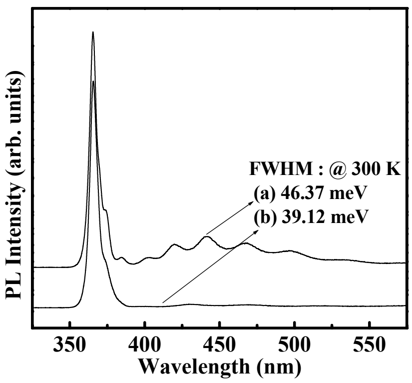

Fig. 3 PL results of GaN epitaxy grown (a) Unpatterned GaN/Si(111) and (b) patterned GaN/Si(111) layer.

Fig. 3 shows the optical properties of the GaN layer, PL measurements were carried out at room temperature. The intensity of the PL in the patterned GaN/Si(111) was strongly enhanced when compared to that of the unpatterned GaN/Si(111). Internal reflections at the boundaries of the pattern or the reduction of crack density may be the cause of this effect. Moreover, PL FWHM values clearly decreased in comparison with that of the unpatterned GaN/Si(111) layers.

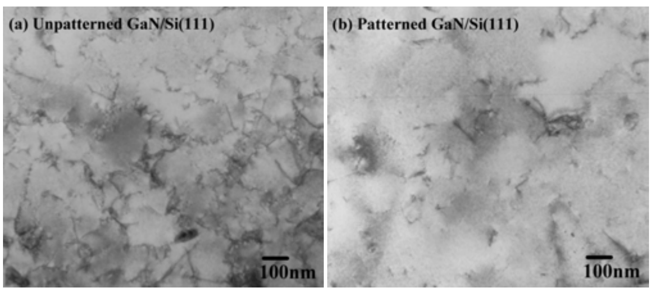

Fig. 4 Plan-view TEM images of (a) unpatterned GaN/Si(111), (b) patterned GaN/Si(111) layers at their center.

Fig. 4 shows plan view TEM images of (a) unpatterned GaN/Si(111), (b) patterned GaN/Si(111) layers at their center. The black dots and the short black lines are surface terminations of threading dislocations, which originate at the substrate/layer interface. The threading dislocation density in the top GaN surface is evaluated. The threading dislocation density is about 1.32 x 10^9 cm^2 for (a) unpatterned GaN/Si(111) and 2.1 x 10^8 cm^2 for (b) patterned GaN/Si(111).

3. Conclusions

We compared the quality of the GaN layer grown using the patterned Si(111) with that of GaN layer grown using the unpatterned Si(111). The crack density of the GaN layer on the patterned Si(111) was drastically reduced compared to that of the unpatterned GaN/Si(111) layer. In fact, no cracks were found in the GaN layer grown using the patterned Si(111). Moreover, the XRD and PL FWHM values clearly decreased in comparison with that of the unpatterned GaN/Si(111) layers. The threading dislocation density in the patterned GaN/Si(111) was drastically reduced.

Consequently, it is considered that the LEPS technique not only improves the quality of the GaN layer, but also reduces the tensile stress caused by the thermal and lattice mismatch. This technique was effective for growing GaN with improved epitaxial quality, in the case of highly mismatched epitaxial systems, such as III -nitride semiconductors

Acknowledgements

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