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Raman study of epitaxial lateral overgrowth of GaN on patterned sapphire substrate

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Abstract. Structural and optical properties of gallium nitride (GaN) epilayers grown on lens shape patterned sapphire substrate (PSS) using metalorganic chemical vapor deposition (MOCVD) for various growth times were evaluated. From Raman spectra, a blue shift and reduction in the FWHM of Raman modes of GaN grown on PSS were observed when compared to GaN grown on unpatterend sapphire substrate (UPSS). From the DCXRD spectra, full width at half maximum (FWHM) value was decreased with increasing growth time. FWHM of the sample grown at 80 min was 473.5 arc sec. This indicates that there is an improvement in crystalline quality of the GaN grown on PSS as the growth time increases. From photoluminescence (PL) spectra, an increase in band edge emission intensity and a decrease in defect related yellow luminescence were observed for GaN on PSS as the growth time increased.

Introduction

III-nitride compound semiconductors like GaN and its ternary alloys have a wide and direct bandgap ranging from 0.7 eV for InN to 6.2 eV for AlN [1]. They are currently most promising materials for optoelectronic devices like light emitting diodes (LEDs) and laser diodes (LDs) operating in the red to ultraviolet wavelength region [2, 3]. These devices have been extensively used in various applications such as outdoor full-color display, back light unit in liquid crystal display and solid-state lightning and show a greater potential to replace fluorescent lamps [4]. A large lattice mismatch and thermal expansion coefficient difference between GaN and sapphire substrate lead to many defects such as threading dislocation (TD) in the epitaxial GaN film. In order to reduce the TD density, lateral overgrowth techniques such as epitaxial lateral overgrowth (ELOG) or pendeoepitaxy (PE) are introduced [5]. Recently, GaN layers grown on the patterned sapphire substrate (PSS) were successfully developed to fabricate high quality optical devices with lower TD density [6]. Improved emission efficiency is also one of the advantages of using PSS techniques. In this work, we grew high quality GaN epilayers using a lens shape PSS. The growth behaviors, structural and optical characters of GaN grown on PSS have been discussed.

Experimental process

The GaN epilayers (0002) were deposited on c-plane patterned sapphire substrate using low pressure metal organic chemical vapor deposition (MOCVD) in a horizontal quartz reactor. First, a 150 nm thick GaN buffer layer was deposited on PSS at 560 ^{o}C for 2 min to get a minimum surface roughness and dislocation density. Subsequently, GaN epilayers were deposited at 1040 ^{o}C under an ambient pressure 100 Torr. During the growth of the GaN epilayers, the flow rate of TMGa and NH_3 were 3.0 standard cubic centimeter per minute (sccm) and 1.5 standard liters per minute (slm), respectively. Samples were prepared for various growth times from 10 to 80 min. Structural and optical characterizations were investigated by using double crystal X-ray diffraction (DCXRD), Raman spectroscopy and Photoluminescence (PL).

Results and discussions

A Schematic diagram of GaN on PSS is shown in Fig. 1. The SEM micrograph of the PSS after ICP dry etching is also given in Fig. 1. The lens height and diameter of the patterned sapphire are 1.5 and 5.8 μm, respectively. The distance between each lens is 3.7 μm.

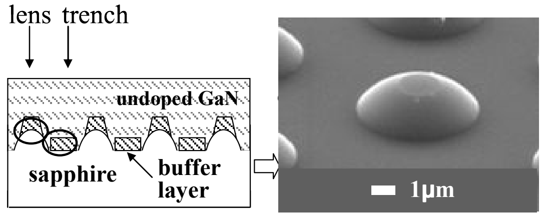

Fig.1 Schematic diagram of GaN on PSS. The SEM micrograph shows the patterned sapphire substrate after dry etching

The structural characteristics of GaN on PSS samples with respect to growth time were analyzed by the DCXRD spectra (ω-scan) as shown in Fig. 2. The GaN (0002) peak is observed clearly at 17.3° which indicates the GaN is highly oriented along c-axis and has single crystalline character. The FWHM value of DCXRD decreased and the peak height of DCXRD increased as time increased. This indicates that the crystalline quality of the PSS GaN improves as the growth time increased with less TD density. Figure 3 shows DCXRD spectrum of GaN grown on unpatterned sapphire and patterned sapphire substrates. The FWHM of the (0002) peak is 534.41 and 473.48 arcsec, respectively. The high XRD peak intensity of the GaN epilayers using the patterned substrate with a low FWHM indicates an improved quality of the GaN when compared to the layer grown on unpatterned substrate. The narrow XRD peak of the GaN grown on PSS also suggests that a reduction of the TD density compared to the GaN grown on unpatterned substrate.

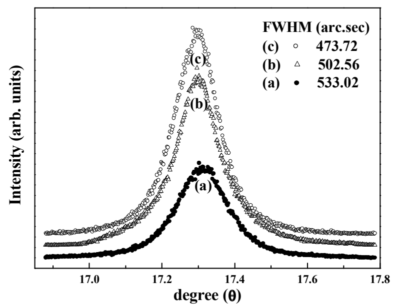

Fig. 2 DCXRD spectra of GaN on PSS for growth times (a) 10 min, (b) 40 min and (c) 80 min.

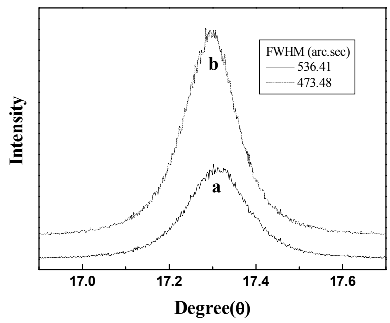

Fig. 3 DCXRD spectra of GaN (0002) grown on (a) unpatterned sapphire substrate and (b) patterned sapphire substrate.

Raman scattering provides information on vibrational states of GaN, which are sensitive to microscopic disorder. The crystalline quality can be judged from the peak shapes. Figure 4 shows Raman spectra of GaN grown on UPSS and PSS, recorded at room temperature. Lorentzian line shape was fitted to the Raman spectra and the parameters like peak position and FWHM have been obtained. Two Raman modes $E2^{(high)}$ and A1 (LO) were observed at the frequencies 570.9 and 737.7 cm^{-1}, respectively for GaN grown on PSS as seen in Fig. 4 (b). Two Raman modes $E2^{(high)}$ and A1 (LO) were observed at the frequencies 569.5 and 736.1 cm^{-1}, respectively for GaN grown on UPSS as seen in Fig. 4 (a). A blueshift is observed for E2 and A1 (LO) phonon mode from 569.59 cm^{-1} to 570.9 and 736.1 to 737.7 cm^{-1} respectively for GaN on PSS compared to GaN on UPSS. FWHM of $E2^{(high)}$ and A1 (LO) Raman mode for GaN grown on PSS are 3.93 cm^{-1} and 11.6 cm^{-1} which is relatively less compared to FWHM values of GaN grown on UPSS. The blue shift of Raman modes peak position and reduction in FWHM clearly indicates that there is a strain relaxation during the growth in the trenchs as compared to GaN on UPSS.

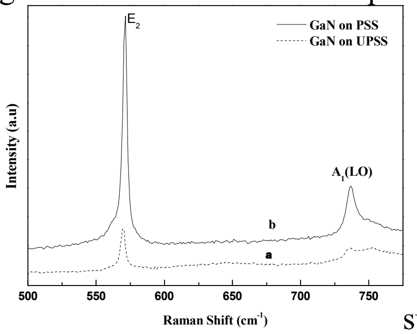

Fig. 4 Raman spectra of GaN grown on (a) unpatterned sapphire substrate and (b) patterned sapphire substrate

Fig. 5 shows the PL spectra of GaN epilayers grown on PSS at room temperature for various growth times. PL spectra of the GaN on PSS are dominated by band-edge emission at 365 nm. It is observed that the spectra exhibit significant increases in peak intensity and decreases in FWHM with the growth time. Such an enhancement in the PL intensity is due to the internal reflection on the lens surface and the decrease of the TD-induced non-radiative recombination centers. A defect related luminescence peak which observed at around 440 nm is not seen in the sample grown at 80 min. This result indicates that crystalline quality is improved and the TD density is reduced with increasing growth time.

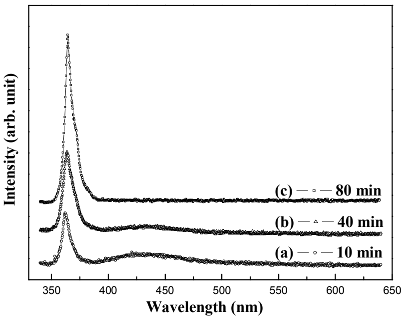

Fig. 5 PL spectra of GaN layer on PSS for growth times (a) 10 min, (b) 40 min and (c) 80 min.

Summary

In summary, GaN epilayers were grown on lens shaped patterned sapphire substrate for various growth times. DCXRD results suggest that high quality crystalline GaN is achieved with less threading dislocations. From Raman spectra, reduction in FWHM and blueshift of Raman modes of the GaN layers grown on PSS compared to GaN grown on UPSS implies enhancement in the crystalline quality. From the PL spectra, peak intensity has increased enormously. Such an enhancement in the peak intensity may be attributed to reduction in TD. Hence, by using lens shaped PSS for GaN epilayer growth after a growth time 80 min, threading dislocation density was reduced and optical properties were improved

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