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GaN Epitaxial Growth on Sapphire Substrate with Al Buffer Layer Prepared by E-beam Evaporation

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Abstract. GaN epitaxial layers were grown on sapphire substrate deposited an aluminum (Al) buffer layer using a hydride vapor phase epitaxy (HVPE) system with a two-zone resistance furnace. A 10nm-thick Al buffer layer was prepared by an e-beam evaporation in order to reduce the stress resulted from thermal mismatch between the GaN layer and the substrate. The growth temperature and growth rate for GaN epitaxial layer were 1050°C and 40 μm/hr, respectively. GaN epitaxial layer grown on substrate with Al buffer layer exhibited uniform and smooth morphology on 2-inch whole substrate and a bow value of 33.5 μm. The addition of Al-buffer layer apparently reduced the full width at half maximum (FWHM) value of GaN layer, which indicated the improvement of crystal quality.

Introduction

Gallium nitride (GaN), a semiconductor with a direct bandgap of 3.4eV, has emerged as the key materials for optoelectronic and microelectronic applications. It is currently manufactured for light emitting diodes (LEDs) and laser diodes (LDs) with peak emission from green through blue to ultraviolet wavelength. Although most commercially available III-nitride LEDs are grown on the c-plane of sapphire substrate, a large mismatch in lattice constant and thermal expansion coefficient between GaN and sapphire produce a high density of undesirable defects. SiC has also been used as an alternative substrate for the high brightness LED fabrication because there are two main advantages in using SiC substrate; electrically conductive substrate enabling the LED with vertical geometry and thermally conductive substrate enhancing heat removal from LED chips. [1, 2] However, due to the difference in thermal expansion coefficients between GaN layers and SiC substrate, a large number of structural defects such as cracks, cavity and dislocation formed in GaN layer could restrict long lifetime performance of commercial devices.

Therefore, many efforts to reduce these structural defects in GaN layer have been accomplished and most ideas have been based on annihilation of defects by a use of underlying structure like the epitaxial lateral overgrowth (ELO) structure or a formation of low temperature GaN layer or the buffer layer on the initial GaN growth period. [3, 4] In spite of continuing efforts, it is still limited to obtain high quality GaN thick epitaxial layer maintaining high growth rate. Therefore, the present research was focused on improvement of GaN crystal quality with adding Al buffer layer on substrate. The effect of Al buffer layer was extensively investigated by comparing with the crystal property of GaN grown on substrate without Al buffer layer.

Experimental procedure

A hydride vapor phase epitaxy (HVPE) technique has been attracted much attention because of its rapid growth for thick GaN epitaxial layer. In this study, GaN epitaxial layers were grown on sapphire substrate using the HVPE system with a two-zone resistance furnace. A 10nm-thick Al buffer layer prepared by e-beam evaporation and the process modification were adopted to reduce the lattice mismatch between GaN layer and substrate and to decrease the stress in the GaN epitaxial layer.

Fig. 1 exhibits schematic diagram of conventional process procedure for GaN epitaxial layers prepared by the HVPE method. Before the main GaN growth, sapphire substrate with and without Al buffer layer was annealed in NH_3 atmosphere for a nitridation process. The GaCl vapor was synthesized within the reactor vessel by the reaction of HCl with Ga metal at 800°C and then was transported to the substrate maintained to a growth temperature of 1050°C in order to react with NH_3 gas for GaN layer growth. The resultant growth rate for GaN epitaxial layer was about 40 μm/hr. The surface morphology of GaN layers was observed by a polarizing microscope in Nomarski mode. X-ray diffraction patterns and rocking curves of GaN single crystal were analyzed by a high resolution XRD diffractometer (*PANalytical*-MRD). Flatness characteristics of GaN wafer were measured by a Flatness tester (FT-900) from *NIDEK Inc.*

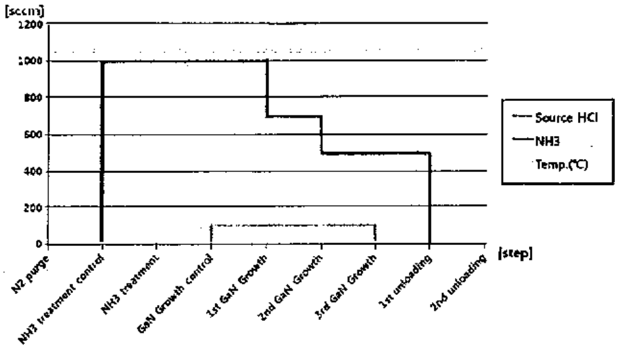

Fig. 1. Schematic diagram of process procedure for GaN epitaxial layers prepared by an HVPE method.

Result and Discussion

Fig. 2 shows optical pictures and Nomarski images of GaN epitaxial layers grown on 2-inch sapphire substrates without Al buffer layer and with Al buffer layer. Although both GaN epitaxial layers grown on two different substrates were uniformly formed on 2-inch whole substrate, shown in optical photographs of Fig. 2(a) (b), Nomarski images on inset of figure exhibited totally different morphologies. While GaN epitaxial layers prepared without buffer layer had rough surface composed of many hillocks and pits, GaN epitaxial layers grown on substrate with buffer layer exhibited very smooth surface without many structural defects.

The phase formation of GaN epitaxial layers was confirmed from the θ-2θ scan data of XRD, shown in Fig. 3(a) and the crystal quality of GaN epitaxial layers was investigated by the measurement of GaN (0002) rocking curves. The addition of Al buffer layer on substrate apparently reduced the full width at half maximum (FWHM) value of GaN layer, which indicated the improvement of GaN crystal quality. The broadening of rocking curve on GaN layer prepared without buffer layer is considered to be resulted from the tilt of lattice plane due to mosaic structure of GaN layer.

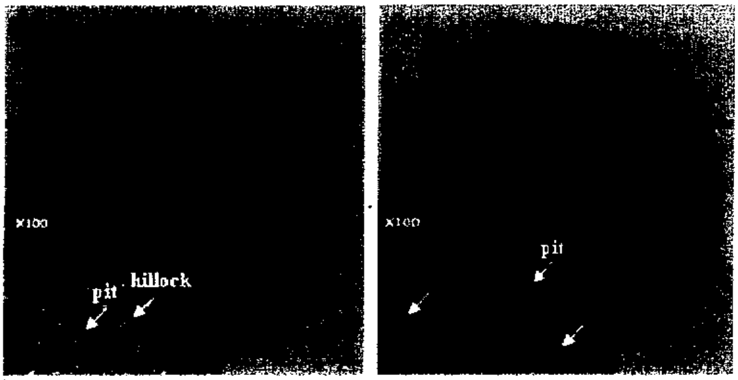

Fig. 2. Optical pictures and Nomarski images of GaN epitaxial layers on 2-inch substrate. (a) without Al buffer layer and (b) with Al buffer layer.

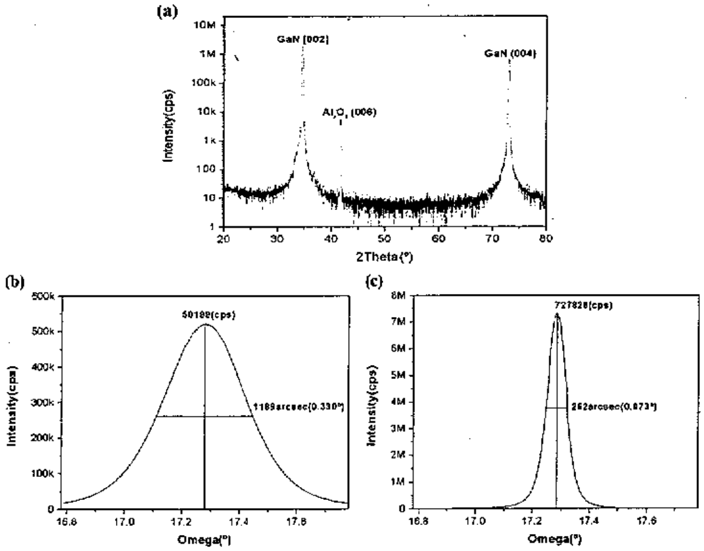

Fig. 3. XRD pattern and GaN (0002) rocking curves of GaN epitaxial layer on different substrate. (a) XRD pattern by the θ-2θ scan, (b) substrate without Al buffer layer and (c) substrate with Al-buffer layer.

In order to evaluate the stress distribution generated on GaN epitaxial layer, flatness characteristics of wafers were measured by a Flatness tester. Fig. 4 shows flatness characteristics of GaN epitaxial layers grown on 2-inch substrate without Al buffer layer and substrate with Al buffer layer. The bow value on GaN epitaxial layers grown on 2-inch substrate with Al buffer layer was measured to be 33.53μm, which resulted from thermal mismatch between GaN and sapphire substrate. As shown in Fig. 4(b), the formation of convex shape could be explained that the higher thermal expansion coefficient of sapphire substrate (7.5×10^{-6}/K) than that of GaN layers (5.6×10^{-6}/K) generally produced the compressive stress in GaN epitaxial layer. The bow value of GaN epitaxial layers grown on substrate without Al buffer layer could be not measured because the resultant stress generated on GaN epitaxial layer was completely relaxed through the formation of hillocks and other structural defects during growth process. In conclusion, to use Al buffer layer as an underlying structure for annihilation of defect was definitely advantageous in high quality GaN growth.

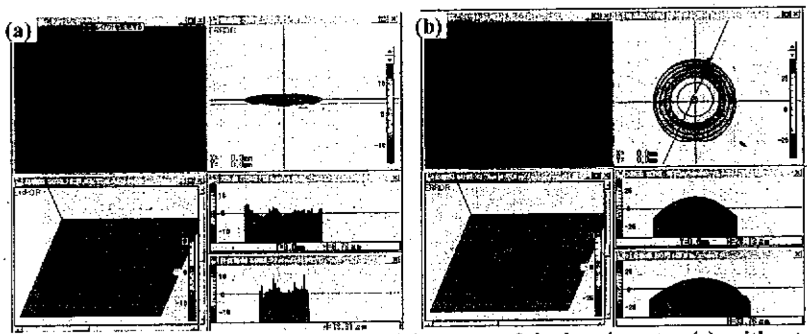

Fig. 3. Flatness characteristics of GaN epitaxial layers on 2-inch substrate. (a) without Al buffer layer (bow value was not measured) and (b) with Al buffer layer (bow value = 33.53µm).

Summary

The present research was focused to improve the quality of GaN epitaxial layer by adding an Al buffer layer on 2-inch sapphire substrate. A 10nm-thick Al buffer layer was prepared by an e-beam evaporation in order to reduce the stress resulted from thermal mismatch between the GaN layer and the substrate. The addition of Al buffer layer considerably reduced the full width at half maximum (FWHM) value of GaN layer which indicated the improvement of crystal quality. Though GaN epitaxial layer grown on 2-inch substrate with Al buffer layer exhibited slightly convex shape with a bow value of 33.5 µm, uniform and smooth morphology on 2-inch whole substrate were obtained.

Acknowledgement

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