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A study of GaN regrowth on the micro-facetted GaN template formed by in-situ thermal etching

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We report a study of GaN regrowth on micro-facetted GaN templates formed by in-situ thermal etching in a low-pressure metalorganic chemical vapor deposition system. First, the 1.5 µm-thick GaN epilayers were grown on *c*-plane sapphire substrates. This was followed by an in-situ thermal etching process under hydrogen and ammonia ambient with the etching time being a parameter. The thermally etched GaN templates showed hexagonal GaN pyramids, which were aligned along the growth direction on the *c*-plane substrate. The 3 µm-thick GaN regrowth was performed on these micro-facetted GaN templates. The surface of the overgrown GaN was atomically smooth. The full width at half maximum of (102) peak in the X-ray rocking curve profile decreased from 9.5 to 6.5 arcmin as the thermal etching time increased from 0 to 45 min. Etch pit density measurements revealed that the pit density of regrown GaN decreased by about one order of magnitude, compared to that of the control sample.

1 Introduction

Recently, great advances in GaN-based semiconductor thin film technology have paved the way for high-power ultraviolet to visible light-emitting diodes and laser diodes, high-performance ultraviolet detectors and field effect transistors. However, GaN-based semiconductors have a major drawback in terms of the lack of native substrates in large size and quantity [1]. High-performance GaN-based optoelectronic devices with high reliability critically require high material quality with low defect density. Currently, the best way to significantly reduce the threading dislocation density in GaN is to use epitaxial lateral overgrowth technique [2]. But, this method requires additional ex-situ processes, resulting in high cost and unintentional doping as well as increased thermal conductivity, both caused by the mask. Up to now, a great deal of effort with a variety of effective growth methods based on the lateral overgrowth concept has been reported [3–8]. In this vein, we studied GaN regrowth on micro-facetted GaN templates formed by in-situ thermal etching in a low-pressure metalorganic chemical vapor deposition (MOCVD) system. In this paper, we report that the in-situ thermal etching method can efficiently reduce the density of defects, as viewed by defect revealing etches, in GaN overlayers by an epitaxial lateral overgrowth process at the initial stage of regrowth on micro-facetted hexagonal GaN pyramids formed by thermal etching.

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2 Experimental

GaN epilayers were grown in a low-pressure MOCVD system, using *c*-plane sapphire as a substrate. Trimethylgallium and ammonia were used as sources of Ga and N, respectively. The substrate was preheated in a stream of H_2 at 1030 °C for 3 min, on which a 30 nm-thick GaN buffer layer was grown at 560 °C. This was followed by the growth of a 1.5 μm-thick undoped GaN template at 1030 °C. Thermal etching of GaN was performed in the growth chamber under hydrogen and ammonia ambient with etching times of 15, 30, and 45 min at 1030 °C to form a micro-facetted GaN template. A regrowth of 3 μm-thick GaN was performed on the thermally etched GaN. The evolution of the GaN template surface morphology with varying thermal etching time was investigated using scanning electron microscopy (SEM). A high resolution X-ray diffraction (XRD) system (X'Pert-MPD™, Philips) was used to help examine the crystalline quality of GaN thin films. Atomic force microscope (MultiMode™, Digital Instruments) was used to investigate the surface morphology of GaN using a silicon tip in the tapping mode.

3 Results and discussion

Figures 1(a), (b), and (c) show the evolution of surface morphology of a 1.5 μm GaN template as the thermal etching time increases, in order, from 15, 30 to 45 min. When the GaN template was thermally etched for 15 min at 1030 °C under hydrogen and ammonia (H_2 : NH_3 = 3 : 1) ambient, pyramidal protrusions appeared on the surface (Fig. 1(a)). When the thermal etching was performed for 30 min, the atomically smooth GaN template was converted into a porous GaN that took the appearance of porous layer and was composed of micro-size conical grains without facetted surfaces (Fig. 1(b)). Further increase of the etching time to 45 min converted the smooth GaN template into an assembly of micro-facetted hexagonal GaN pyramids that were aligned along the growth direction on the *c*-plane sapphire substrate (Fig. 1(c)).

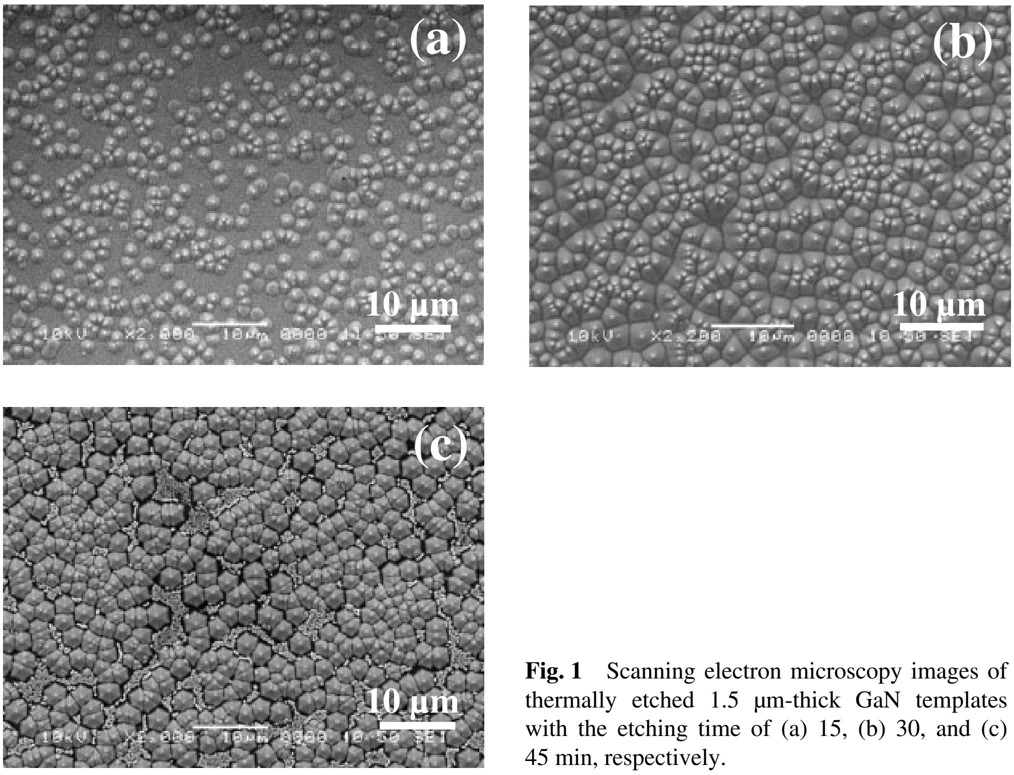

Fig. 1 Scanning electron microscopy images of thermally etched 1.5 μm-thick GaN templates with the etching time of (a) 15, (b) 30, and (c) 45 min, respectively.

Table 1 Effects of in-situ thermal etching time on the (002) and (102) XRD θ-rocking FWHM, and surface rms roughness of 3 µm-thick GaN overlayers grown on the thermally etched GaN templates.

In-situ etching time (min)	XRD rocking FWHM (arcmin)		Surface rms roughness (nm)
	(002)	(102)	
0	4.60	9.52	0.17
15	5.55	9.03	0.27
30	5.73	7.23	0.19
45	4.65	6.54	0.17

The 3 µm-thick GaN regrowth was performed on the thermally etched GaN templates and on the control sample without etching. SEM images revealed that the surfaces of the overgrown GaN films were flat without any cracks or hexagonal protrusions. Atomic force microscopy (AFM) analysis showed that the overgrown GaN layers were atomically smooth. For a 45 min etching time, the surface root-mean-square (rms) roughness of the overgrown GaN was similar with that of the control sample (Table 1). High-resolution XRD measurements revealed that the full width at half maximum (FWHM) of (102) peak in the X-ray rocking curve significantly decreased from 9.5 to 6.5 arcmin as the thermal etching time increased from 0 to 45 min although the FWHM of (002) peak was almost the same (Table 1). This result may be understood by considering that the out-of-plane crystal quality of the overgrown GaN may be mainly influenced by the GaN template while the in-plane crystal quality of the overgrown GaN can be improved by the epitaxial lateral overgrowth process at the initial stage from pyramidal GaN protrusions formed by thermal etching.

Figure 2 shows the AFM surface morphology of the control sample (Fig. 2(a)) and the overgrown GaN on the 45 min-etched template (Fig. 2(b)). The overgrown GaN showed a relatively well-defined step flow surface morphology while the step flow of control sample was disturbed due to a high density of threading dislocation-related pinholes. An etch pit density measurement was performed to estimate the threading dislocation density of the overgrown GaN layers. The samples were etched by H_3PO_4 at about 160 °C for 1 min and then investigated by AFM in several regions. The average etch pit density of the overgrown GaN was about 1×10^8 cm^{-2} while the pit density of the control sample was in the low 10^9 cm^{-2}.

The reduction of etch pit density in the overgrown GaN may be understood based on the so-called facet-controlled ELO concept by considering the micro-facetted hexagonal GaN pyramids formed by thermal etching (Fig. 1(c)). Hiramatsu et al. [7] reported the facet-controlled ELO that was composed of two-step ELO processes with different growth conditions to reduce the threading dislocation density of second-step ELO GaN by controlling the inclined facet structure of first-step ELO GaN. The inclined

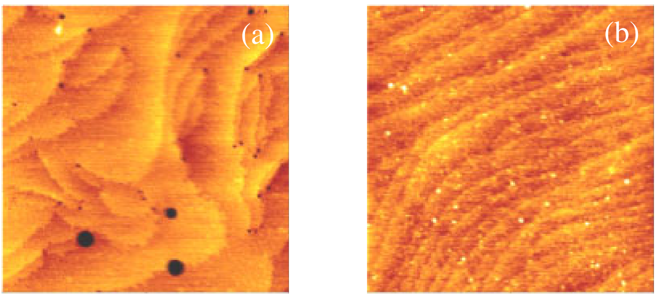

Fig. 2 (online colour at: www.pss-a.com) 2 µm × 2 µm AFM surface images of 3 µm-thick GaN overlayers grown on the 1.5 µm-thick GaN templates (a) without thermal etching, and (b) with 45 min etching, respectively.

facets of hexagonal GaN pyramids (Fig. 1(c)) can cause bending of threading dislocations at the early stage of regrowth. The exposed sapphire substrate between the GaN pyramids may act as a mask material during the regrowth step. Thus, it is plausible that the laterally propagating dislocations may interact with each other or terminate at the coalescence area, resulting in the reduction of threading dislocation density in the overgrown GaN.

4 Conclusions

We investigated the GaN regrowth on micro-facetted GaN templates formed by in-situ thermal etching in a low-pressure metalorganic chemical vapor deposition system. The thermally etched GaN templates showed micro-facetted hexagonal GaN pyramids which were aligned along the growth direction on the *c*-plane substrate. The overgrown GaN on the micro-facetted GaN template was atomically smooth. Etch pit density measurements revealed that the pit density of the regrown GaN decreased by about one order of magnitude, compared to that of the control sample.

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