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Defect reduction in (11$\underline{2}$0) a-plane GaN by two step epitaxial lateral overgrowth

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ABSTRACT

We report a two-step growth method to obtain uniformly coalesced epitaxial lateral overgrown *a*-plane GaN by metalorganic chemical vapor deposition (MOCVD). By obtaining a large wing height to width aspect ratio in the first step followed by enhanced lateral growth in the second step via controlling the growth temperature, we reduced the tilt angle between the advancing Ga-polar and N-polar wings for improved properties. Transmission electron microscopy (TEM) showed that the threading dislocation density in the wing area was 1.0×10^{8}cm^{-2}, more than two orders of magnitude lower than that in the window area (4.2×10^{10}cm^{-2}). However, a high density of basal stacking faults, 1.2×10^{4} cm^{-1}, was still observed in the wing area. Near field scanning optical microscopy (NSOM) at room temperature revealed that the luminescence was mainly from the wing regions with very little contribution from the windows and meeting fronts. These observations suggest that due to significant reduction of threading dislocations radiative recombination is enhanced in the wings.

INTRODUCTION

In *c*-axis-oriented hexagonal GaN system, the spontaneous and strain induced piezoelectric polarizations produce strong electric fields, which cause spatial separation of electrons and holes in quantum wells that are used for active regions in optical devices. Such a separation increases the radiative lifetime[i] at the expense of the quantum efficiency,[ii] and also results in a red shift of the emission. One approach to overcome this problem is to grow *m*-plane or *a*-plane hexagonal GaN, which are nonpolar. Recent studies on *a*-plane AlGaN/GaN quantum wells [iii,iv] and related LEDs[v] have already demonstrated the absence of polarization-induced electric field. In order to realize high-performance nitride devices, epitaxial lateral overgrowth (ELO) method has been used to reduce the density of threading dislocations in *a*-plane GaN using MOCVD.[vi,vii] However, one should consider the wing tilt, which was shown to be an important matter for *c*-plane GaN ELO.[viii] In this paper, we investigate the effects of growth parameters on overgrown *a*-plane GaN, and report on structural and optical characterization for the optimized GaN ELO samples grown by MOCVD.

EXPERIMENT

The (11$\bar{2}$0) *a*-plane GaN films were grown on (1$\bar{1}$02) *r*-plane sapphire substrates.[ix] A 1.5 μm-thick *a*-plane GaN film with a low temperature GaN nucleation layer was used as the ELO template. An approximately 100 nm-thick SiO_2 layer was grown on the *a*-plane GaN template by remote plasma enhanced chemical vapor deposition. Using conventional photolithography and buffer oxide etch (BOE), a striped mask pattern was transferred to SiO_2. The pattern consisted of 4 μm-wide open windows and 20 μm- or 10 μm-wide SiO_2 stripes that were oriented along the [1$\bar{1}$00] direction of GaN. Two *a*-GaN ELO samples, samples A and B, were grown with TMG and NH_3 flow rates of 157 μmol/min and 3000 sccm, respectively. Sample A was grown in a single stage at 1050 ºC for 3 h while sample B was grown in two stages: at 1000 ºC for 2 h in stage I and at 1050 ºC for 3 h in stage II. Each growth experiment was carried out on templates containing 10 μm- and 20 μm-wide SiO_2 stripes placed side by side in the growth chamber. The as-grown samples were characterized by scanning electron microscopy (SEM), TEM, and NSOM. NSOM measurements were performed at room temperature in the illumination mode where a 325 nm HeCd laser was used for excitation through a metal coated cantilevered optical fiber probe with 350 nm aperture. NSOM photoluminescence (PL) intensity mapping was carried out using a photomultiplier tube to collect the overall PL spectrum with the scattered and reflected laser light blocked with an optical filter. The cross-sectional SEM measurements were performed on the 20 μm stripe samples, while the rest of the analysis was focused on the 10 μm stripe samples.

DISCUSSION

As shown in Figure 1(a) the surface of sample A was fully coalesced after a total of 3 h of growth but with striations along and steps perpendicular to the *c*-axis. As observed from the cross-sectional SEM (Figure 1 (c)), wings with Ga-polarity were 4-6 times wider than those with N-polarity. As a consequence of the inherent wing tilt and largely different growth rates of the opposing wings, a clear height difference appears at the coalescence front. This height difference causes a significant surface undulation in *a*-plane GaN, in addition to defects, and is the origin of steps observed in Figure 1 (a). In order to obtain uniform coalescence and smooth overall surface, this height difference should be decreased or even eliminated if possible by reducing the difference between the widths or growth rates of the two opposite wings.

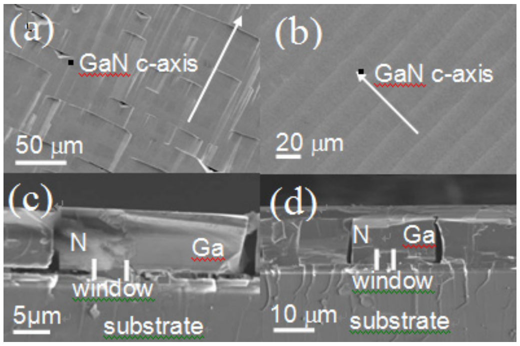

Figure 1: (a) Plan-view and (c) cross-sectional SEM images for sample A after 3.0 h of growth. (b) Plan-view and (d) cross-sectional SEM images for sample B, after a total of 5 h of growth.

Growth temperature is a highly effective parameter to control the difference in the growth rates of the Ga- and N- wings. Therefore, for sample B, a two-stage growth method was employed where a 1000 ºC growth temperature was used in stage I to favor vertical growth while maintaining a relatively low lateral growth rate which is not drastically different for the lateral Ga- and N-fronts at this temperature. In stage II, temperature was elevated to 1050 ºC to enhance the lateral growth for complete coalescence. After full coalescence, the surface was quite smooth, and the Ga-polar wing is only 1.5-2 times wider than the N-polar wing (See Figure 1 (b) and (d)). These results indicate that the attempts to suppress the uneven average growth rates of Ga- and N- wings by enhancing the vertical growth rate in the early stage of the growth were successful in reducing step height at the meeting fronts.

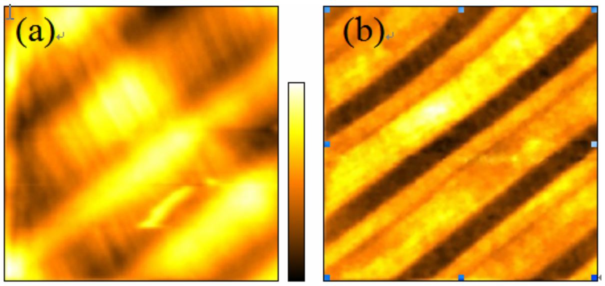

Figure 2: (a) AFM and (b) NSOM scans from a 40 μm x 40 μm area of the a-plane ELO GaN sample. The vertical scale bars in (a) correspond to 85 nm.

TEM studies indicated a reduction of the TD density from 4.2×10^{10} cm^{-2} in the windows to 1.0×10^{8} cm^{-2} in the wings for sample A. However, a relatively high density of basal stacking faults (BSFs), 1.2×10^{4} cm^{-1}, was still observed in the wing areas compared to 1.3×10^{6} cm^{-1} in the windows, which is not surprising considering their low formation energy in the basal plane during *a*-plane GaN epitaxy.[x,xi] Sample B also showed almost two orders of magnitude reduction of dislocations in the wings and generation of new dislocations at the meeting fronts.

Figures 2(a) and 2(b) show the AFM and NSOM images, respectively, taken from a 40 μm x 40 μm area of the *a*-plane ELO sample. The window and the wing regions are clearly distinguishable from the NSOM image in Figure 2(b). The windows appear as dark regions with bright wings of different widths on both sides. The narrow and the wide bright regions are due to N and Ga-polar wings, respectively, with no significant difference between the intensities from the two.

CONCLUSIONS

By employing a two-stage ELO of *a*-plane GaN with an initially enhanced vertical growth that was followed by enhanced lateral growth at an elevated temperature, Ga to N wing width ratio and the wing height difference at the coalescence fronts has been reduced, resulting in a relatively flat fully coalesced surface. TEM studies indicated a two orders of magnitude reduction of density for both threading dislocations and basal stacking faults in the wings compared to the windows. The improvement in the overgrown layer quality by ELO was also verified by NSOM measurement, which showed strongly enhanced luminescence from the wing regions.

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