Structural Defects in Laterally Overgrown GaN Layers Grown on Non-polar Substrates

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ABSTRACT

Transmission electron microscopy was used to study defects in lateral epitaxial layers of GaN which were overgrown on a template of a-plane (11$\underline{2}$0) GaN grown on (1$\underline{1}$02) r-plane Al_2O_3. A high density of basal stacking faults is formed in these layers because the c-planes of wurtzite structure are arranged along the growth direction. Density of these faults is decreasing at least by two orders of magnitude lower in the wings compared to the seed areas. Prismatic stacking faults and threading dislocations are also observed, but their densities drastically decrease in the wings. The wings grow with opposite polarities and the Ga-wing width is at least 6 times larger than N-wing and coalescence is rather difficult. Some tilt and twist was detected using Large Angle Convergent Beam Electron Diffraction.

INTRODUCTION

The total polarization of nitride films used for devices is aligned along the polar [0001] axis of the wurtzite crystal structure. This direction coincides with the growth direction of the GaN-based layers. This, in turn, causes spontaneous and piezoelectric polarizations within the active layers, which influences the electrical and optical properties of devices [1-3]. One of the possible solutions to eliminate these undesirable effects is to grow GaN-based epilayers in nonpolar orientations. However, regardless of the growth direction (c-axis or non-polar) a high defect density is usually observed for all GaN-based layers, since they are grown heteroepitaxially on foreign substrates (Al_2O_3 or SiC). These defects are detrimental for the application of these materials for laser diodes. An established method to decrease the defect density is lateral overgrowth. Two related methods; laterally epitaxial overgrowth (LEO) and pendeo-epitaxy have been developed. It was found that defects formed in GaN layers grown on polar and non-polar substrates are different. For the growth in polar direction the main defects are threading dislocations, which propagate along the growth direction. In case of growth in non-polar direction stacking faults are formed on c-planes that are along growth direction [4], since their formation energy on these planes is the lowest [5]. In this report we describe laterally overgrown GaN grown on (1$\underline{1}$02) r-plane of Al_2O_3 studied by transmission electron microscopy (TEM) in the cross-section configuration. The aim of this study was to investigate structural defects present in the layers and tilt/twist between wings. The JEOL 3010 microscope with 300 keV acceleration voltage was used for this work.

EXPERIMENTAL

The $(11\bar{2}0)$ a-plane GaN layers were grown on the $(1\bar{1}02)$ r-plane of Al_2O_3. A 1.5 μm thick GaN with a low-temperature nucleation layer was used as a template. A 100 nm-thick SiO_2 layer was grown on a-plane GaN template by plasma enhanced chemical vapor deposition. Using conventional polithography a striped mask pattern was transferred to SiO_2 with a pattern oriented along the $[1\bar{1}00]$ GaN direction, creating of 4μm open windows and ~10μm wide SiO_2 stripes, which were subsequently overgrown using a growth temperature of 1000°C, or slightly higher, and growth time of~ 3 hrs. Samples were studied by conventional transmission electron microscopy (TEM) using a JEOL 3010 microscope operated at 300kV. Cross-sectional samples for these studies were prepared by mechanical polishing followed by dimpling and Ar ion milling to get sample transparent for electrons.

RESULTS AND DISCUSSION

A high density ($\sim 1.3\text{x}10^6 cm^{-1}$) of basal stacking faults (BSFs) formed on the basal plane of hexagonal GaN was observed in cross-sectional TEM images from ‘seed’ areas. They appear as thin lines arranged perpendicular to the c-direction of the wurtzite GaN under two beam condition with $\boldsymbol{g}=1\bar{1}00$. One can notice a drastic decrease in the density of BSFs ($\sim 1.2\text{x}10^4$ cm^{-1}) in the ‘wing’ areas in comparison to the ‘seed’ areas. In addition to BSFs, formed on c-planes, faults are also observed on prismatic planes of wurtzite GaN in both the ‘seed’ and ‘wing’ areas of studied LEO layers. Their displacement vector was determined as $1/2[0\bar{1}11]$. This fault was found to intersect and terminate I_1 type BSFs that are described by a sequence of …AB**ABC**BC... Stair-rod dislocations (partial dislocations) with Burgers vectors $\boldsymbol{b}=1/6\langle 20\bar{2}3\rangle$ and $\boldsymbol{b}=1/3\langle 1\bar{1}00\rangle$ are often formed at such intersections. The density of dislocations is reduced by more than two orders of magnitude from $\sim 4.2\text{x}10^{10} cm^{-2}$ in ‘seed’ areas to $\sim 1.0\text{x}10^8 cm^{-2}$ in ‘wing’ areas.

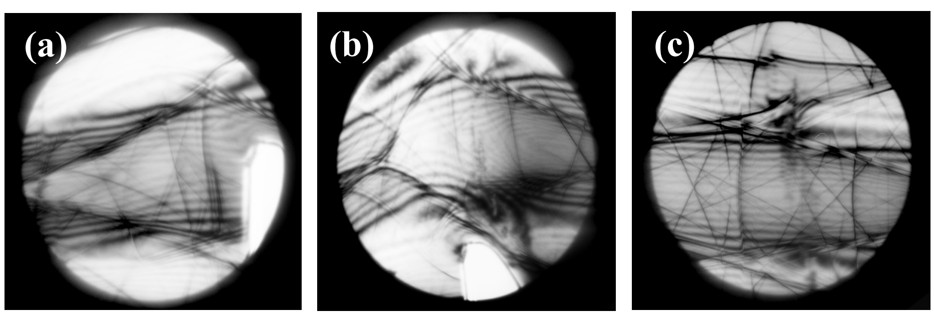

Fig. 1. LACBED pattern at the meeting front of two wings; $(\bar{2}110)$ Kikuchi lines: (a) left hand side of the void (N-wing), (b) at MF slightly above the void. Note upward bending of Kikuchi lines; (c) at MF close to the surface where only slight bending is observed.

Similarly as in pendeo-epitaxial layers, in LEO layers wings with Ga-polarity grow faster than wings grown with N-polarity and it is difficult to coalesce them. However, the wing length ratio is much smaller (6:1) instead of 17:1, as observed in the pendeo-layers [6]. The growth rate difference in LEO layers is also observed along $[11\bar{2}0]$ direction (vertically to the substrate) and this often leads to crack formation and an uneven surface. Two-step growth employing lower growth temperature in the first stage of growth and enhanced lateral growth in the second, further decreases growth rate difference between two wings, but a new boundary is formed on a prismatic plane. Voids were found between two wings, but they can be overgrown if a larger layer thickness is grown. Usually dislocations are found at the meeting fronts.

Using Large Angle Convergent Beam Electron Diffraction (LACBED) patterns it was noticed that Kikuchi lines are shifted across the MFs. The observed shift indicates a tilt of 0.15°-0.25° as well as some twist (0.09°). This was measured only across the MFs, which did not experience a difference in height or crack formation. The LACBED method was also used for the observation of plane bending in the areas close to the void and above the void. One can notice that $(11\underline{2}0)$ planes are almost parallel to the substrate on the left hand side of the void but they start to bend upward when two wings start to meet, with much more bending in the N-wing than in the Ga wing (Fig. 1). In the area close to the sample surface the bending of the planes is much smaller.

SUMMARY

Lateral epitaxial overgrowth (LEO) of GaN-layers grown on r-plane Al_2O_3 has been investigated by conventional and high-resolution electron microscopy. In this crystallographic configuration the wurtzite c-plane is arranged along growth direction. A high density of basal stacking faults is observed in both the seeds and the wings of the overgrown areas, but due to lateral overgrowth their density in the wings is decreased by at least two orders of magnitude. Prismatic stacking faults, often terminating BSFs are also observed. The wings grown with Ga-polarity are wider than those grown with N-polarity, but the ratio of the wing lengths is smaller in the LEO layers than these observed in the coalesced pendeo-epitaxial layers. Some tilt and twist between Ga- and N-wings was measured using LACBED.

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