Reducing Dislocations in AlGaN Grown on Patterned GaN

by **D. M. Follstaedt, A. A. Allerman, S. R. Lee, J. R. Michael, K. H. A. Bogart, M. H Crawford, and N. A. Missert**

Motivation—The development of methods to grow GaN with good crystalline quality has allowed this light-emitting semiconductor to be used as a template for laser diodes and light-emitting diodes (LEDs) operating at blue to near-ultraviolet (UV) wavelengths. Alloying GaN with AlN increases its bandgap to give emission further into the UV. Devices emitting at 340 nm are needed to fluoresce biomaterials in order to detect and identify biotoxins. This wavelength requires $Al_xGa_{1-x}N$ alloys with x = 0.25-0.35; however, emission is very weak from such alloys. The high level of dislocation defects (~$10^{10}/cm^2$) in the alloys is widely thought to limit their light output. Therefore, we have examined AlGaN grown on patterned GaN as a method to achieve lower dislocation densities, as suggested in some reports [see Bell, et al., Appl. Phys. Lett. 85, 3417 (2004)].

Accomplishment—The substrate pattern used was 10 µm-wide, 1 µm-deep trenches along the [1-100] direction, formed by inductively coupled plasma etching into GaN grown on c-axis sapphire. Growth was done by metal-organic vapor phase epitaxy. A 30 nm-thick AlN interlayer was first grown to strain-relax the subsequently grown $Al_{0.26}Ga_{0.74}N$ alloy and thus prevent its cracking. During growth of AlGaN to 15 µm thickness, the growth was periodically interrupted and the surface examined with scanning electron microscopy (SEM). The images showed that growth proceeded with inclined surfaces emerging from the corners on each side of the trench.

Focused ion beam milling was used to prepare thin cross-section specimens extending down to the sapphire to investigate the growth modes using transmission electron microscopy. Several adjoining sections with different types of growth and distinct microstructures appeared, as seen in Fig. 1. First, on the flat trench bottom, vertical growth occurs with vertical dislocation lines. Second, horizontal growth and disloca- tions emerge from the sidewalls of the trench and intersect the vertical growth. Third, over the horizontal mesa surface next to the trench, growth and dislocations are again vertical.

Fourth, angled-growth sections emerge from the corners of the mesa on each side of the trench. These overgrow the vertical growth from the bottom of the trench. The cross-section image also shows that the surface at the time of a growth interruption contains a tilted section, just as seen with SEM. With continued growth, the two angled growths meet above the trench centerline. Most dislocations in these sections remain within them and are directed toward the center. Figure 2 shows that when the vertical dislocations from the trench bottom contact the angled growth section, they are bent toward the center and are annihilated. These dislocation interactions produce a fifth type of growth with low dislocation density above the angled growths. These two sections on either side of the trench centerline continue to the top surface with a dislocation density of only ~$1.5 \times 10^8/cm^2$.

Significance—Microscopy shows the top surface has low dislocation-density areas 4 µm wide, extending for 10's of microns on either side of the trenches. This indicates that the growth modes and dislocation removal seen in Fig. 1 are typical of this material. These areas are sufficiently wide for UV laser diodes. This growth scheme may therefore become important for producing AlGaN with low dislocation densities as needed for efficient UV light emission.

Sponsors for various phases of this work include: Defense Advanced Research Projects Agency (DARPA)/Semiconductor AlGaN Injection Lasers (SAIL) and Laboratory Directed Research & Development

Contact: Andrew A. Allerman, Advanced Materials Sciences, Dept. 1126
Phone: (505) 845-3697, Fax: (505) 844-3211, E-mail: aaaller@sandia.gov

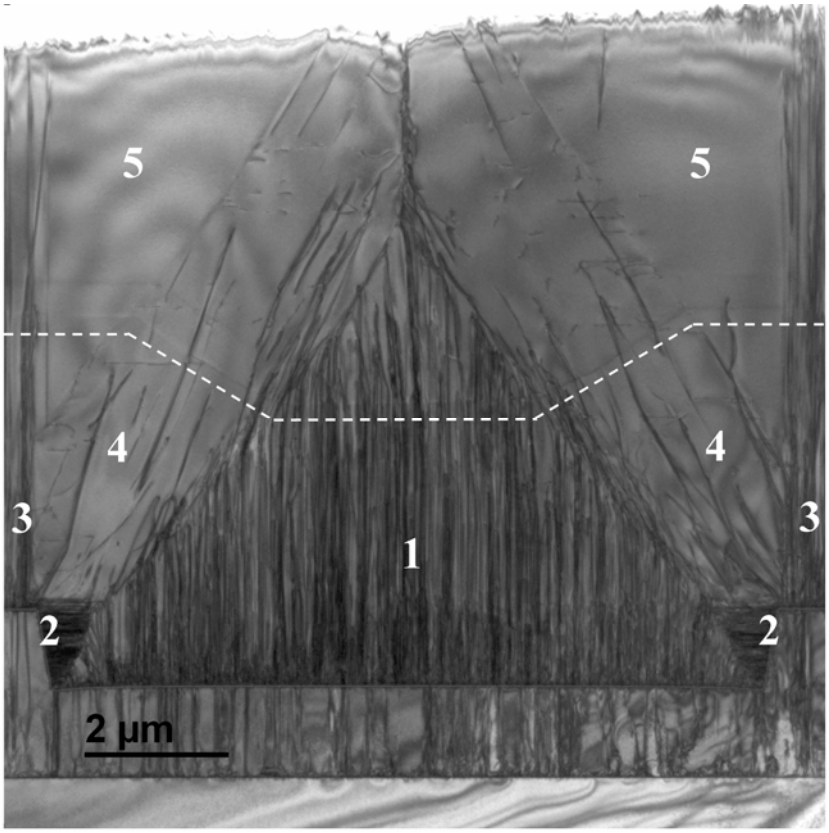

Figure 1. Cross-section TEM image showing the five growth areas discussed (numbered as introduced in the text) and the interrupted growth surface (dashed line) with tilted sections on each side of the trench.

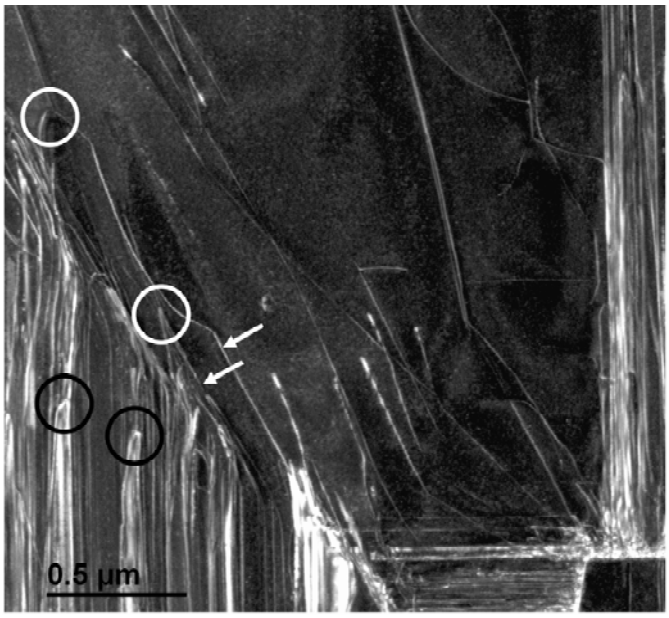

Figure 2. Enlarged, weak-beam TEM image from left corner of Fig. 1 showing vertical dislocations bending upon reaching the angled growth section (arrowed) and dislocation annihilations (circled).