Epitaxial growth of GaN on $ScAlMgO_4$ substrates

GaN layers grown on sapphire still suffer from copious dislocation arising from the huge (13%) lattice mismatch between the substrate and overgrowth. ScAlMgO4 substrates offer a mismatch of only 1.8% and an atomically-smooth growth surface free of polishing damage obtained by cleaving. One of the main challenges in this approach is the incorporation of impurities in the overgrown films, particularly Mg, from the substrate. The aim of this work was to reduce dislocations and control the unwanted impurities.

High-quality GaN films can be epitaxially grown on $ScAlMgO_4$ (SCAM) (0001) substrates by metalorganic chemical vapor deposition (MOCVD) due to a small lattice mismatch between GaN and SCAM, which is only 1.8%. In addition, scam crystal can be easily cleaved along the (0001) planes, offering an atomically smooth surface free of polishing damage.

However, even 1.8% lattice mismatch still results in copious dislocations and strain the GaN epitaxial films. Therefore a new growth route was devised whereby first a GaN film is grow at high supersaturation to a thickness of about 200 nm, resulting in 3D pyramidal islands, and then transitioned to a lower supersaturation growth mode, by either increasing growth temperature or decreasing V/III ratio, to smoothen the growth surface. This process further reduces dislocation density by one or two orders of magnitude and reduces in-plane strain.

Strain relaxation is practically impossible on the c-plane GaN due to unavailability of adequate slip systems while the low index pyramidal facets of GaN provide many such slip systems. This relaxation process is shown as an illustration in the cross-sectional image in Figure 2, where GaN pyramids were grown to relax AlGaN films with a similar mismatch as encountered in the growth of GaN on SCAM. In this process, a SiO_2 layer of approximately 40 nm thickness was deposited on a GaN substrate and the oxide film was patterned by RIE etching leading to 2 μm wide openings. Subsequently, a GaN layer was grown by MOCVD on this substrate at high supersaturation, resulting pyramids, which provide relaxation planes for the overgrown AlGaN. When an AlGaN is grown on these planes, misfit dislocations form at the AlGaN/GaN interface leading to relaxation of the AlGaN film and allowing for growth of nearly strain-free thick epitaxial layers. As the last step, AlGaN is grown at low supersaturation to promote lateral growth and flattening of the surface. After a fully coalesced AlGaN film is grown, a strain-free device structure can be grown on it.

In Figure 2, the SiO_2 mask layer can be seen as the dark stripes at the interface between the substrate and the epitaxial layers. The two different grey tones of the GaN pyramids are related to different oxygen incorporation (and as a result different conductivity) in these regions, which are due to growth in two different crystallographic directions, c and r. For the AlGaN layer that was grown on the GaN pyramids, two grey tones are observed as well: First, a diamond shaped layer is grown on the pyramidal facets of GaN, which is then followed by coalescence and growth of a homogenous AlGaN layer. The diamond shaped region has a different Al-content than the topmost layer. This behavior again arises from the growth in different crystallographic directions.

These results show, that the proposed strategy for growth of GaN on SCAM could be templates for growth of device structures of exceptional quality.

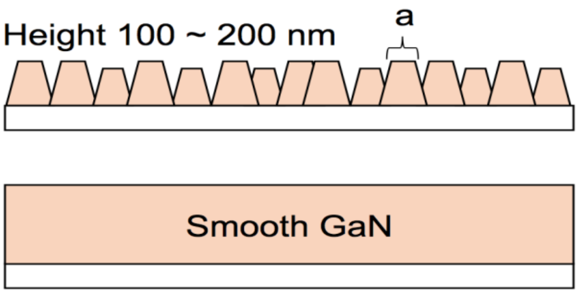

Figure 1: Schematic of the two step growth process for further reduction of dislocations: (top) pyramidal growth at high supersaturation bends dislocation toward the free surface and (bottom) subsequent growth at low supersaturation promotes lateral growth, which aids in dislocation annihilation and formation of a flat surface.

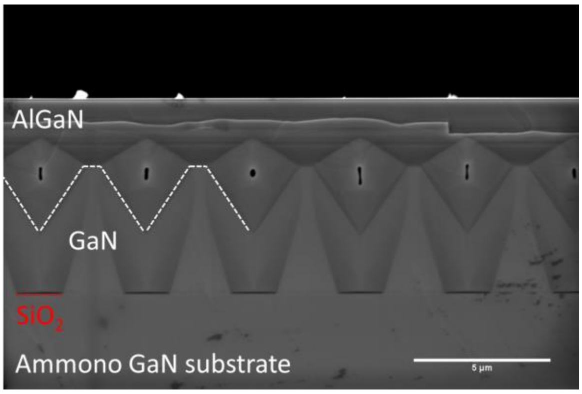

Figure 2: Cross-sectional Scanning electron micrograph of AlGaN grown on GaN using the relaxation scheme described above. The growth of GaN pyramids is outlined in white.

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