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Transmission Electron Microscopy Study of Defects in Nanopyramidal InGaN LEDs Structures

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The III-nitride materials system is of high interest for light emitting diode (LED) applications. There are, however, a number of factors that limit device performance, including a large lattice mismatch between the III-nitrides and potential substrate candidates which results in high densities of threading dislocations, the strong polarization-induced electric fields within c-plane grown quantum wells and the presence of a miscibility gap between InN and GaN. Here, we report on the characterization of GaN based LED nanostructures formed by a non-lithographic process which attempts to overcome these issues.

Structures were grown by conventional organometallic vapor phase epitaxy on 5–7 μm thick c-plane GaN substrates grown by hydride vapor phase epitaxy (HVPE) and patterned with an electron-beam evaporated dielectric SiO_x growth template. Porous anodic alumina (PAA) was used as a reactive ion etch mask to create openings in the SiO_x template with diameters ranging from 50 to 80 nm. Further details on growth conditions and the dielectric growth template fabrication parameters can be found in [1].

TEM images reveal that the nanopyramids grow epitaxially on the GaN substrate. GaN rods are formed initially, and these terminate with a hexagonal pyramid cap upon emergence from the SiO_x template (Fig. 1). Despite a typical dislocation density of $\sim10^9$ cm^{-2} in the HVPE-grown GaN substrate, we found that of nearly 3000 pyramids studied only a few had threading dislocations from the substrate that were captured within the growing nanorods. In these few cases, the dislocations propagate from the substrate into the rod portion of the structures, as illustrated by Fig. 1b and Fig. 1c; even in this worst-case scenario, image forces on the dislocations drive them to the free surface. This results in a region free of threading dislocations for quantum well growth. Basal stacking faults (BSFs) and zinc-blende (c-GaN) inclusions were found in the low temperature grown p-doped GaN capping layers (Fig. 2). For pyramids with base diameters smaller than 150 nm, the BSFs and c-GaN inclusions extended completely across the pyramid without termination. For larger pyramids (>300 nm at the base) Frank partial dislocations and prismatic stacking faults terminating the BSFs were also observed.

This approach demonstrated effective filtering of threading dislocations from the substrate for template openings ranging from 50 nm to 80 nm. The caps of the nanopyramids were formed by set of six semipolar $\{1\bar{1}01\}$ wurtzite planes, which makes (In,Ga)N quantum wells grown on such semipolar planes less susceptible to polarization-induced electric fields in comparison with those in quantum wells of the same composition grown on c-plane GaN. 3-D stress modeling suggests that there is substantial strain relaxation during QW growth that is probably responsible for the higher In concentration attainable without the generation of misfit dislocations [2].

References

[1] P. Deb et al., Nano Lett. 5 (2005) 1847; I.H. Wildeson et al., to be published
[2] This research was partially supported by the Department of Energy under Award No. DE-FC26-06NT42862.

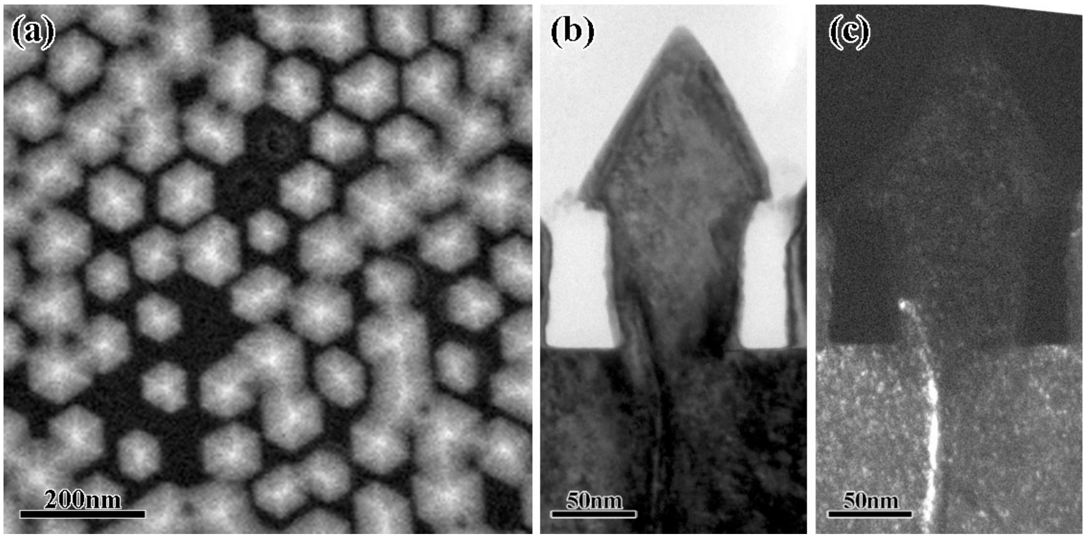

FIG. 1. (a) SEM image of nanopyramids in plan-view configuration. Pyramids exhibit hexagonal shape with facets formed by a set of $\{1\bar{1}01\}$ GaN planes. (b) Bright and (c) Dark field TEM images showing effective dislocation filtering.

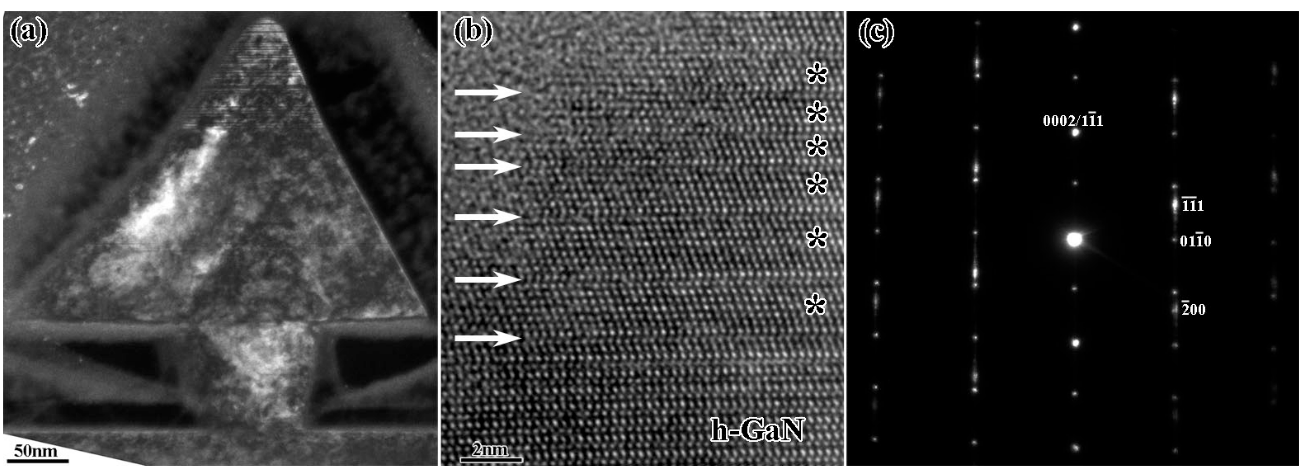

FIG. 2. (a) Dark field TEM image of a single nanopyramid. Stacking faults (SFs) and zinc-blende inclusions are revealed as horizontal lines and bands. (b) HREM image. SFs are marked by arrows. Zinc-blende inclusions are marked by asterisks. (c) Selected area diffraction pattern from (b) shows superposition of diffractions patterns from wurtzite and zinc blende structures. Diffraction spots indexed with (h,k,u,l) and (h,k,l) denote h-GaN and c-GaN, respectively.