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IT-9-P-1516 Substrate threading dislocations imaged by weak beam dark field TEM on samples with GaN nano-LEDs

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The semiconductor material GaN is used in blue and white light emitting diodes (LEDs). It's also a promising material high power and RF electronics Traditional planar epitaxial fabrication of GaN is, however, not adequate due to the large lattice mismatch between GaN and the available substrates, such as sapphire, Si and SiC. At the strained interfaces threading dislocations (TDs) are formed, degrading efficiency, reliability and lifetime of the devices.
Nano-sized structures show the potential to be free of TDs due to their small dimensions, and morphologies such as nano-wires and nano-pyramids (grown along <0001>) have additional benefits. For instance, the quantum confined Stark effect can be reduced since these morphologies can offer non-polar and semi-polar planes, respectively.
Truncated GaN pyramids were grown by selective area metal-organic vapour phase epitaxy on a GaN substrate with high TD density. A 30 nm thick layer of amorphous Si_3N_4 (grown by low-pressure chemical vapor deposition) with openings about 100 nm in diameter, patterned by electron-beam lithography and etched by reactive ion etching, was used as the selective area mask. The mask blocks most of the TDs in the substrate from entering the pyramids, but the ones that cross through the mask are interesting to study due to their degrading impact on the device.
To clearly observe the threading dislocations, weak beam dark field (WBDF) transmission electron microscopy (TEM) was applied on focused ion beam (FIB) prepared cross sections. The images facilitate tracing of TDs through the material and how they enter the nano-structures. The FIB lamella, which was about 100 nm thick, showed a TD density of about 10 TDs/µm in projection. Six adjacent pyramids were analyzed where two was found to have TDs from the substrate coming through the mask. The WBDF technique is challenging on a high acceleration voltage microscope due to the low curvature of the Ewald sphere. WBDF condition such as 3g(9g) was found to be more suitable than the standard g(3g) since many diffraction spots are excited. By slightly defocusing the diffraction pattern and using Kikuchi lines as guide lines WBDF conditions became easier to set up.

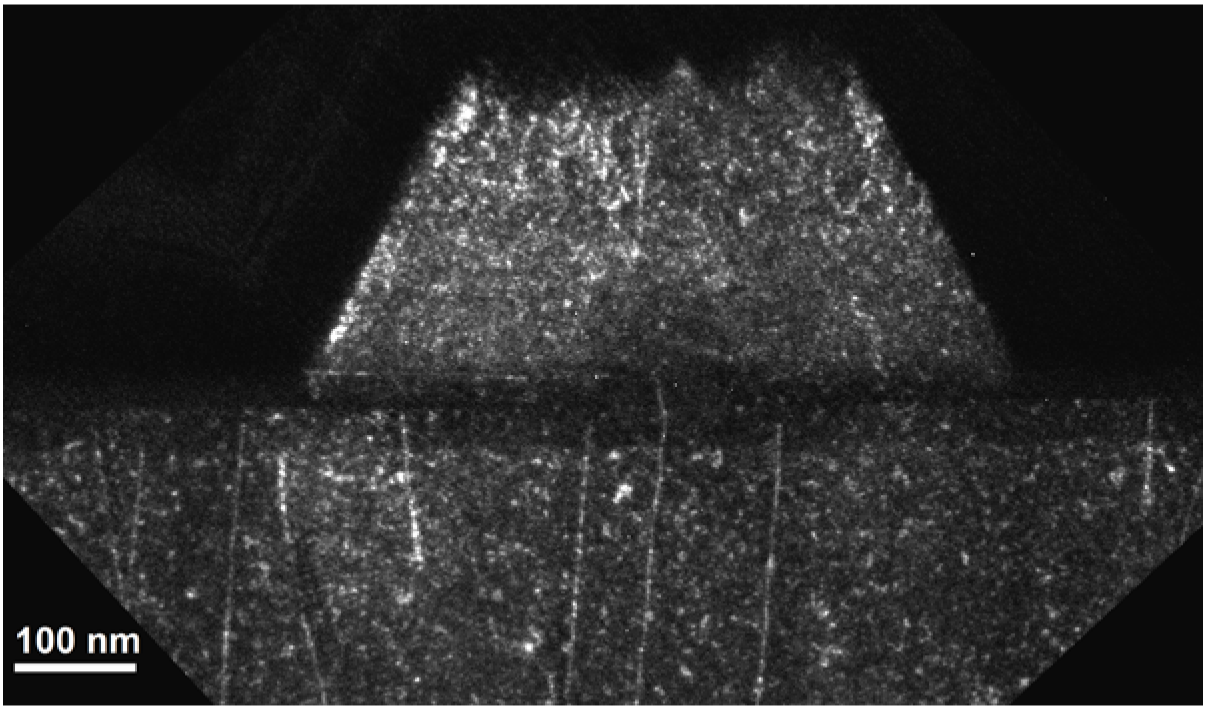

Fig. 1: 3g(9g) weak beam dark field (WBDF) TEM image of FIB prepared cross sections of truncated GaN nano-pyramid grown through small openings in Si_3N_4 mask on a GaN (0001) surface. Threading dislocations (TDs) are visible as bright lines. Two TDs marked by red arrows are blocked by the mask, while one TD marked by a green arrow enters the pyramid.

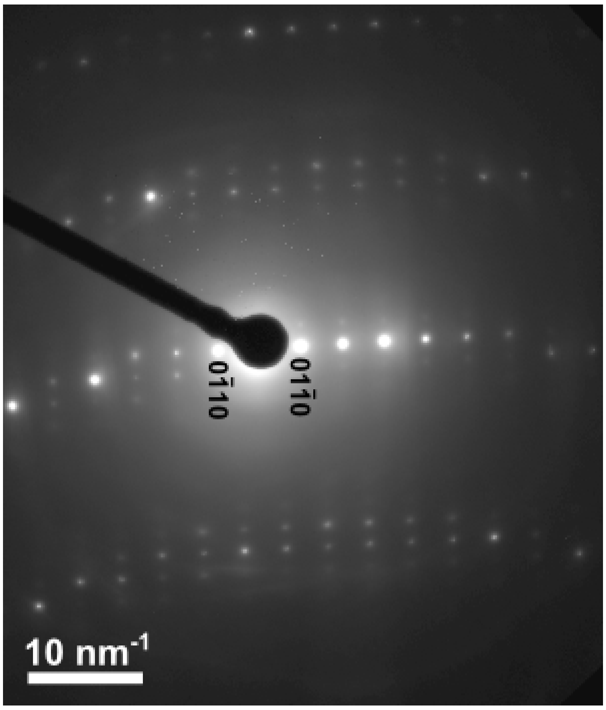

Fig. 2: The low curvature of the 300kV Ewald sphere causes a challenge to set up the WBDF conditions. Kikuchi lines, visible at slight defocus, are usable as guidelines.

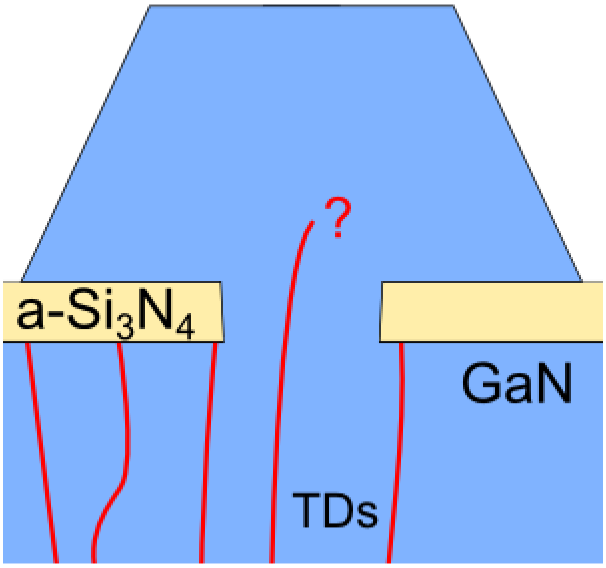

Fig. 3: Schematic illustration of one truncated GaN pyramid (grown through openings in amorphous Si_3N_4 on a GaN substrate) as seen in TEM projection. Threading dislocations (TDs) are marked as red lines. The Si_3N_4 mask acts as a filter, keeping the TDs in the substrate, but occasionally a TD pass through the opening.