Rapid Characterization of Vertical Threading Dislocations in GaN Using a Dedicated Scanning Transmission Electron Microscope

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Key Words: STEM, Gallium Nitride, GaN, Vertical Threading Dislocation (VTD), Dislocation Characterization

Abstract

We demonstrate that the vertical threading dislocations (VTDs) in GaN-based materials can be characterized using a dedicated Scanning Transmission Electron Microscope (STEM). Each dislocation can be readily identified as edge, screw or mixed; distribution and density of each type can be easily evaluated. Comparing to conventional TEM, STEM characterization of dislocations is rapid, simple and easy to interpret.

INTRODUCTION

Rapid development of light emitting diodes (LEDs) and laser diodes (LDs) for use in commercial applications continuously pressures manufacturers to improve the performance of their devices. The National Renewable Energy Lab has set goals for increasing the internal quantum efficiency (IQE) of GaN based LEDs to 90% by 2015 [1]. Research has shown that the threading dislocation (TD) type has a strong influence on the IQE [2] of the device. As such, there is a growing need to efficiently determine threading dislocation types in a commercial environment.

Traditionally, defect or dislocation characterization in various materials is carried out by extensive conventional transmission electron microscopy (TEM) analysis of cross-section samples.[3-5] However, TEM images are complicated by thickness fringes and bend contours, as well as Kikuchi diffraction patterns which complicate the observation of dislocations. As shown in figure 1, the scanning convergent electron beam of the STEM provides images of dislocations with greatly simplified contrast, allowing rapid observation of all vertical threading dislocation (VTD) types simultaneously, and can be further sorted into three types: edge, screw, or mixed.

EXPERIMENT

A commercially available LED with Wurtzite c-GaN grown on sapphire substrate was used for the demonstration of the characterization of dislocation types using STEM. The LED was deconstructed from the package and loaded to an FEI 200TEM focused ion beam (FIB). Cross section samples were lifted out from the die surface suing a proprietary in-situ FIB technique. The cross sections were attached to a 200 mesh copper TEM grid and thinned to electron transparency using gallium ion beam.

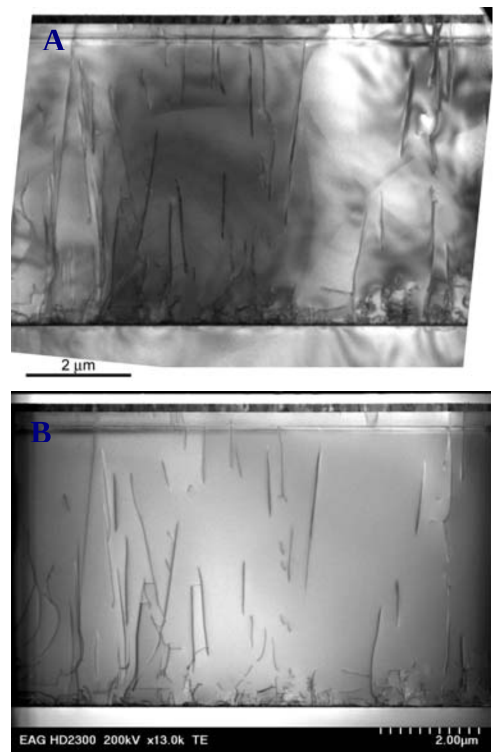

Figure 1: Comparison of TEM and STEM imaging of VTDs in GaN m-plane. (A) TEM bright field Image showing contrast form dislocations as well as thickness fringes, bend contours and Kikuchi diffraction pattern. (B) STEM bright field of the identical sample as in (A) showing simplified and uniform contrast.

A Hitachi HD2300 dedicated scanning transmission electron microscope was used to characterize threading dislocations in the cross sections of the LED. Transmitted electrons were detected by an axial bright field detector with a collector aperture. Conventional TEM images were recorded using a Hitachi HF2000.

RESULTS AND DISCUSSION

There are three possible Burgers vectors in the hexagonal close packed (hcp) lattice that are equal to the lattice translations **a**=<11-20>/3 (**b1**), **c**=<0001> (**b2**), and **a+c**=<11-23>/3 (**b3**), which correspond to edge, screw and mixed type vertical threading dislocations (VTDs) in c-GaN. In TEM characterization of the dislocations, a widely used contrast criterion is "**g.b**", which evaluates the alignment of the strain field of a dislocation with Burgers vector (**b**) passing through the specimen with the diffraction vector (**g**) producing the image contrast. [6]

Edge dislocations have three possible Burger's vectors, namely $\mathbf{b1}^{(1)}$ = [11-20]/3, $\mathbf{b1}^{(2)}$ = [-2110]/3 and $\mathbf{b1}^{(3)}$ = [1-210]/3. For an A-plane TEM foil with plane normal of [1-210], most TEM system that tilt within ±15° can only tilt to zone axis of 1-210, which has **g**-vectors that are perpendicular to plane normal. As a result, dislocations with $\mathbf{b1}^{(3)}$=[1-210] don't have image contrast. Therefore an A-plane GaN foil is not preferred for dislocation characterization in GaN using TEM. In order to overcome this difficulty, M-plane GaN is used for dislocation characterization.

The "**g.b**" criterion is also applied to STEM imaging with. When a sample is tilted on zone axis, dislocations with **g**-vectors in multiple directions are visible, which is equivalent to conventional TEM images taken under symmetrical multi-beam diffraction conditions. All threading dislocations are visible under this condition (Figure 2).

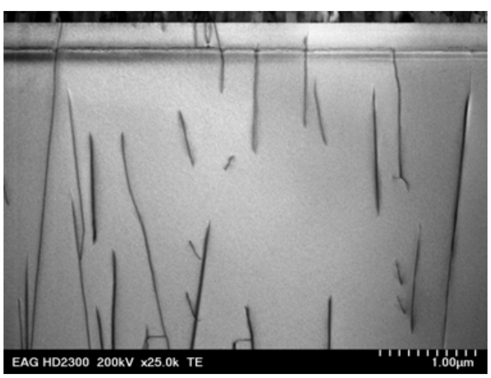

Figure 2: STEM bright field image of dislocations with all components of VTDs.

When sample is tilted perpendicular to c-axis, only dislocations with g-vectors parallel to the c-axis are visible, which is equivalent with conventional TEM images taken under two-beam diffraction conditions of **g**=<0002>. In this condition only dislocations with a screw component appear in the images (Figure 3-A). Similarly when sample is tilted parallel to c-axis, only dislocations with g-vector perpendicular to the c-axis are visible, which is equivalent to conventional TEM images taken under two-beam diffraction conditions of **g**=<11-20>. In this condition only dislocations with edge component are visible in the images (Figure 3-B).

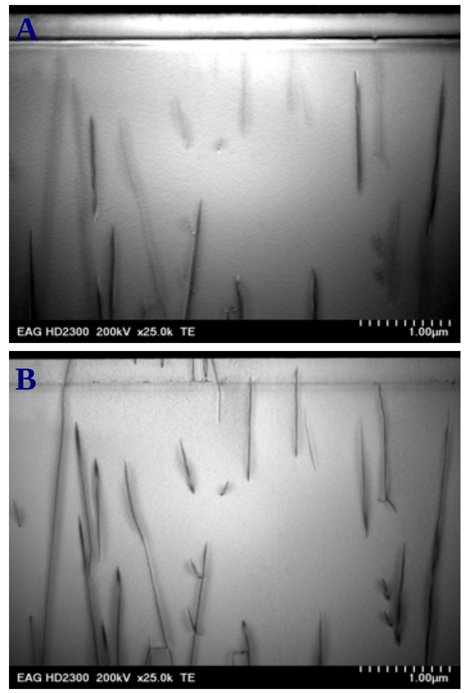

Figure 3: STEM bright field image of dislocations with screw (A-top) and edge (B-bottom) components.

With comparison of images with screw component and edge component, all the dislocation can be characterized by their types (Figure 4).

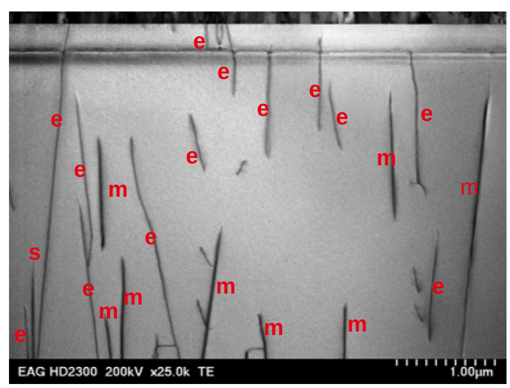

Figure 4: STEM bright field image of dislocations with screw (top) and edge (bottom) components. All dislocations are characterized by their types (e-edge, m-mixed, s-screw).

The STEM images are free from thickness fringes, bend contours and Kikuchi diffraction patterns due to the particle-like nature of scanning electron beam and incoherent imaging [7].

CONCLUSION

We have successfully demonstrated the characterization of threading dislocations in GaN based devices using dedicated STEM. The characterization is rapid, simple and easy to interpret without complications from thickness fringes, bend contours and Kikuchi diffraction patterns. The method can be extended to different materials and different dislocation types.

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ACRONYMS

STEM: Scanning Transmission Electron Microscopy
FIB: Focused Ion Beam
VTD: Vertical Threading Dislocation
LED: Light Emitting Diode
LD: Laser Diode
IQE: Internal Quantum Efficiency