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Rapid Threading Dislocation Typing in GaN Using STEM

STEM provides images of dislocations with greatly simplified contrast, allowing rapid dislocation typing in both cross section and plan view samples.

Introduction

Compound semiconductor GaN and its alloys have wide applications in electronic and opto-electronic devices such as light emitting diodes and laser diodes. However, the lack of lattice-matched substrates from its growth results in high density of vertical threading dislocations (VTDs). Research has shown that the VTD type (edge, screw, or mixed) has a strong influence on the device performance. As such, there is a strong need to effectively determine VTD type and density.

Discussion

Traditionally, dislocation typing in various materials is carried out by extensive conventional transmission electron microscopy (TEM) analysis of cross-section samples. However, TEM images are complicated by thickness fringes and bend contours as is shown in the left image in Figure 1. A corresponding scanning transmission electron microscope (STEM) image from the same cross section sample is shown in the right side. As compared to the TEM, the scanning convergent electron beam of the STEM provides images of dislocations with greatly simplified contrast, allowing rapid observation of all dislocation types simultaneously.

Figure 1: Comparison of VTD in GaN imaged with conventional TEM bright field (left) and STEM bright field (right)

The VTDs type (edge, screw, or mixed) can be characterized in either cross section (XS) or plan view (PV) samples. XS-STEM has the advantage of showing dislocation behavior in the whole depth of EPI layers, while PV-STEM provides better statistics on dislocation density calculation due to its larger sampling area.

By utilizing specific sample tilts in the STEM, threading dislocations in cross-sections can be characterized using **g.b** contrast criterion. Figure 2 is an example of the sample tilted to show

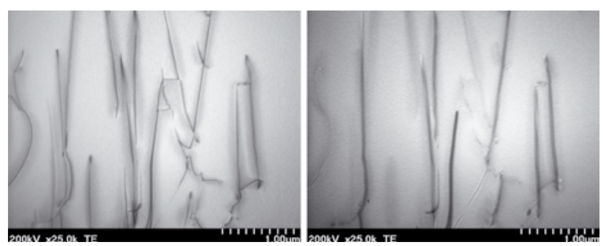

Figure 2: XS-STEM images acquired at the conditions to show dislocations with edge character (left) and with screw character (right)

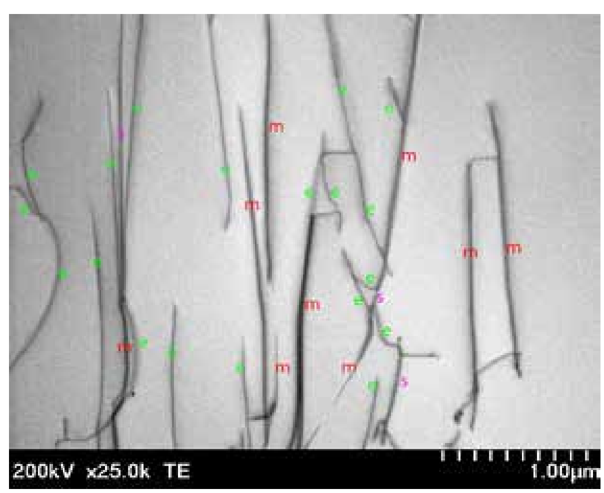

Figure 3: XS-STEM dislocation typing to pure edge (e), pure screw (s) and mixed (m) according to the visibility in figure 2.

dislocations with edge character (left image) and dislocations with screw character (right image). Dislocations shown in figure 2 (left) solely exhibit edge character (e), those shown in figure 2 (right) solely exhibit screw character (s). If dislocations show contrast in both tilting conditions, they are considered to have mixed character (m). Dislocations are then labelled according to type (edge, screw and mixed) as in figure 3.

In PV-STEM with (0001) GaN, VTDs can be characterized by tilting the sample >10º from zone axis with **g**=(11-20). In this tilt condition, dislocations with edge character show a short line according to **g.b** contrast criterion, while dislocations with screw character show two dots at spots where VTDs intersect the top and bottom of the TEM specimen. The dots are from the strain contrast produced when a screw dislocation encounters a free surface of the lamella and the stressed material near the core relaxes causing scattering of the e-beam. Thus, dislocations having a line only are pure edge, those having a pair of dots only are pure screw, and those having pairs of dots connected by a line are mixed. In order to confirm the result, it is a wise practice to image the same area with at least two different tilting directions, as shown in figure 4 (left and right). Dislocation types (edge, screw and mixed) are labeled in figure 5 according to the criteria above.

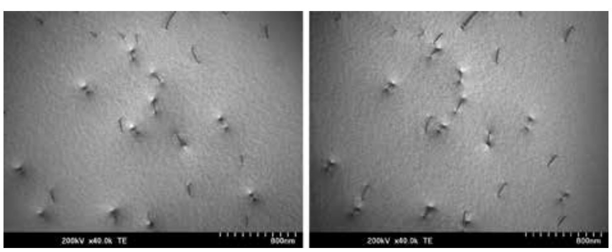

Figure 4: PV-STEM images acquired by tilting sample >10º from zone axis with two tilting directions: (left) to g=(11-20) and (right) to g-=(-2110)

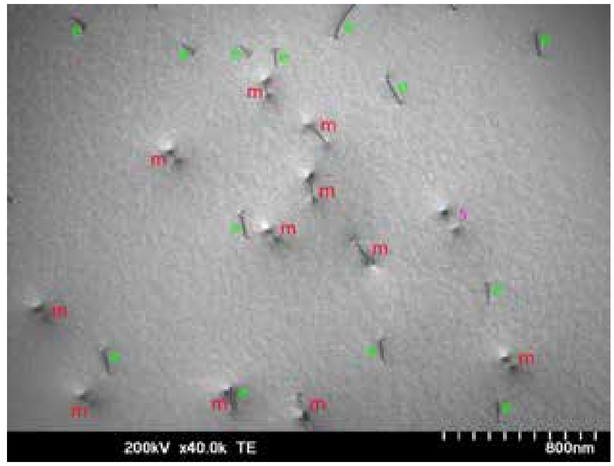

Figure 5: PV-STEM dislocation typing to pure edge (e) with a line only, pure screw (s) with dots only and mixed (m) with dots connected by a line

Conclusion

Rapid STEM characterization of VTDs in GaN meets the strong need to effectively determine VTD type and density. VTD types and density can be characterized with both XS-STEM and PV-STEM. XS-STEM has the advantage of providing dislocation behavior in each layer, while PV-STEM had better statistics on dislocation density of each type.

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