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Characterization of GaN crystals with the X-ray topography

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Introduction

Semiconductor, GaN is expected that it can save energy by half if we use it as an electronic power device. But due to a number of crystal defects, it is difficult to become reality now. About recent GaN crystal, the measurement of strain field in a broad area around a defect is important to improve crystalline quality. Recent GaN crystal needs measurement method of crystalline quality (local variations in orientation ($\Delta\theta$) and spacing ($\Delta d/d$)).[1,2]

In this study, we captured X-ray topography images of GaN crystals using a CCD camera.

Experimental principle and samples

Measurements of symmetric 004 and asymmetric 116 reflections for GaN (001) crystals were performed at beamlines 20B and 14B. The obtained topographic images were cropped and quantified using ImageJ, and the diffraction intensities were subjected to Gaussian fitting in Igor Pro. From these results, we calculated the FWHM, lattice tilt ($\Delta\theta$), and variation in lattice spacing ($\Delta d/d$) to generate color maps.

The samples used in this experiment were grown by the ammonothermal method (Samples #1 and #2).

Results & Discussion

1. Analysis of Wavelength Dependence: Depth-Dependent Crystallinity

Using beamline 20B, X-ray topography images were captured at wavelengths of 1.2398 Å and 0.9 Å. In this measurement, the 116 reflection was analyzed to observe the structural differences between the crystal interior and the surface through FWHM color mapping.

Figures 1 and 2 show the topographs and corresponding FWHM color maps for samples #1 and #2 at both 1.2398 Å and 0.9 Å wavelengths.

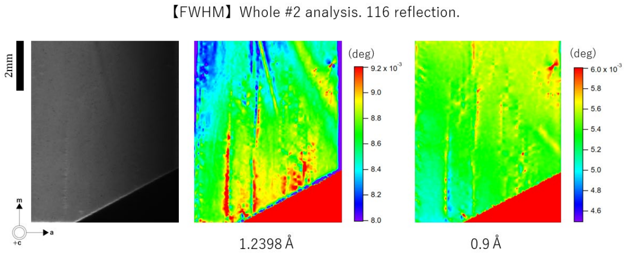

Figure 1: Comparison of FWHM for #1 at 1.2398 Å and 0.9 Å

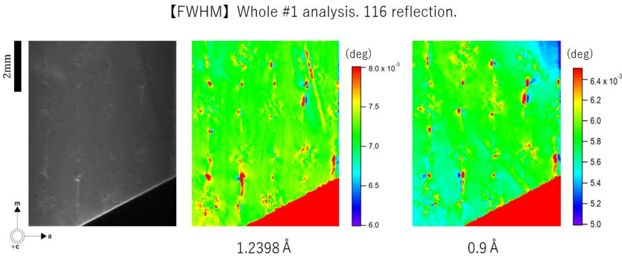

Figure 2: Comparison of FWHM for #2 at 1.2398 Å and 0.9 Å

For both samples #1 and #2, the FWHM distribution and average values in the 0.9 Å color maps showed noticeable changes compared to those at 1.2398 Å. This is likely because the X-ray extinction distance (penetration depth) varies with wavelength, incorporating more information from the near-surface region. These results suggest that the defect structures may differ between the near-surface and the interior of the GaN thin film.

Therefore, based on the FWHM distribution and averages, it is considered that the crystallinity near the surface is superior to that of the interior for both samples.

Furthermore, comparing #1 and #2, sample #1 shows a smaller area of high FWHM values and a lower overall average. These results indicate that #1 has fewer defects and higher crystal quality than #2.

2. Local Analysis: Reflection Plane Dependence

Using beamline 14B, topographs of the 004 reflection were captured for the same samples to perform local analysis. To facilitate comparison with the 116 reflection results from Section 1, the specific areas of interest are indicated on the original color maps. The resulting FWHM, $\Delta\theta$, and $\Delta d/d$ analysis for the 004 reflection are presented in Figures 3 and 4.

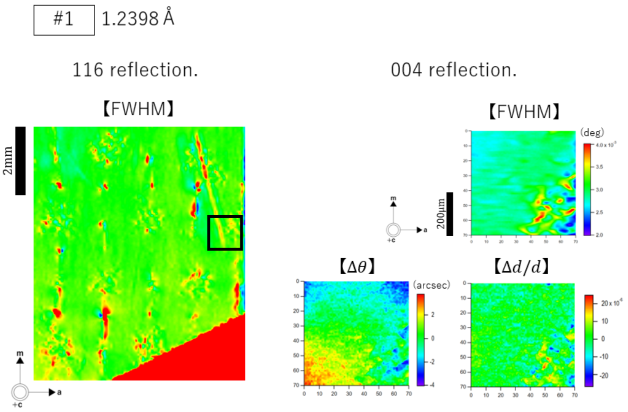

Figure 3: Local Analysis of #1

Comparing Figure 3 with the 116 reflection results, the line-like FWHM distribution extending from the upper left to the lower center was not observed. This suggests that the linear defects in this region are edge dislocations.

Furthermore, the FWHM and $\Delta d/d$ distributions in the local analysis are remarkably similar, suggesting that the defects in these areas are attributed to the expansion or contraction of lattice spacing.

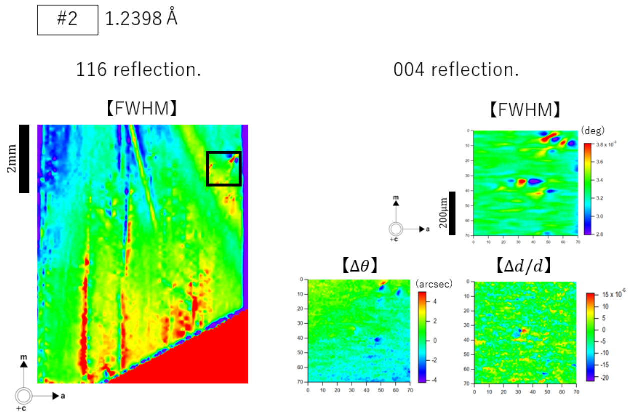

Figure 4: Local Analysis of #2

Comparing Figure 4 with the 116 reflection results, the FWHM distribution spreading to the lower left was not observed. This suggests that the defects in the lower-left region are highly likely to be edge dislocations.

Furthermore, in the local analysis, the upper-right portion of the FWHM map corresponds with the $\Delta\theta$ contrast. Additionally, the central FWHM region aligns with the $\Delta d/d$ contrast, suggesting that the defects in these respective areas are attributed to lattice tilting and the expansion or contraction of lattice spacing.

Acknowledgement

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References

[1] K. Mochiki *et al.*, Photon Factory Activity Report 2010 #28 B, 179, (2011).
[2] Y. Kitano et al., Photon Factory Activity Report 2015 #33 B, 222, (2016)

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