BL24XU
Hyogo ID

1. Introduction

BL24XU is known as the Hyogo ID beamline. It is a contract beamline designed by Hyogo prefecture for industrial applications. BL24XU is a branched beamline employing a figure-8 undulator light source, a diamond (220) beam-splitting monochromator for branched line A, and a Si (111) double-crystal monochromator (DCM) for mainstream B. The end-station is specialized for high-resolution structural characterization by microbeams and imaging (Table 1).

Recently, we have begun actively promoting the use of data-driven science and engineering such as applying machine learning to analysis utilizing synchrotron radiation. The informatics approach has the potential to rapidly derive the relationship among the structure, physical properties, and manufacturing processes by analyzing a number of specimens under different conditions. In addition, it may extract useful features from massive amounts of data, such as two-dimensional spectrum mappings.

Efforts continue in the development of new measurement methods. Bright-field X-ray topography, which was developed in recent years, is now available to industrial users. Here, we report its developments.

Table 1. Specifications of the measurement techniques in BL24XU.

Measurement technique	Structural information	Spatial resolution
Projection / imaging microscope / coherent diffraction CT	2D/3D image Field of view: 1 μm–1 mm Absorption, refraction contrast (projection / imaging microscope) Absorption, phase contrast (coherent diffraction)	10 nm–0.33 μm
Microbeam SAXS / WAXD / XRF	Periodic / aggregation structures from angstrom scale to several hundred nm in size Distribution of crystal grains Elemental mapping	0.5–5 μm
Bonse–Hart USAXS	Periodic / aggregation structures 16 nm–6.5 μm in size	Bulk
Highly parallel microfocus diffraction, bright-field topography	Local strain, dislocation	0.5–30 μm (diffraction), 0.65 μm (topography)
Near-ambient-pressure HAXPES	Chemical state	30 μm

2. Bright-field X-ray Topography

In recent years, bright-field X-ray topography has been established and then developed into topography using the Borrmann and Super Borrmann effects [1, 2]. These methods have also been made available to industrial users. As an example, we report here the results of using bright-field X-ray topography to evaluate GaN substrates.

GaN has excellent physical properties, such as thermal conductivity and electron saturation velocity, and is expected to be a material for next-generation power-device semiconductors. However, there are many lattice defects such as dislocations in the crystal, which may degrade the performance of semiconductor devices. The heteroepitaxial growth of GaN crystals on heterogeneous substrates such as sapphire is commonly used. However, the difference in lattice constants and thermal expansion coefficients between the two can be a cause of dislocations. Therefore, we attempted to reduce dislocations by using homoepitaxially grown GaN substrates as seed crystals.

In this study, we evaluated dislocations in GaN crystals grown by the Na-flux method using GaN prepared by the ammonothermal method as seed crystals and examined the usefulness of homoepitaxial growth.

Experiments were performed at SPring-8 BL24XU Hutch B2 using bright-field X-ray topography with a 10 keV synchrotron X-ray beam. Dislocation images were observed by capturing X-rays transmitted by the sample using a CMOS camera. Figure 1 shows a crystal of GaN grown by the Na-flux method on a sapphire substrate, and Fig. 2 shows a GaN crystal grown by the Na-flux method on a GaN crystal prepared by the ammonothermal method. The dislocation densities of Figs. 1 and 2 were measured to be about $2\times10^5/\mathrm{cm}^2$ and $8\times10^3/\mathrm{cm}^2$, respectively. The Burgers vector ($\boldsymbol{b}$) in the crystal was identified as a-type ($\boldsymbol{b}_{a1}$, $\boldsymbol{b}_{a2}$, $\boldsymbol{b}_{a3}$) on the basis of the condition that the dislocation contrast disappears ($\boldsymbol{g}\cdot\boldsymbol{b}=0$).

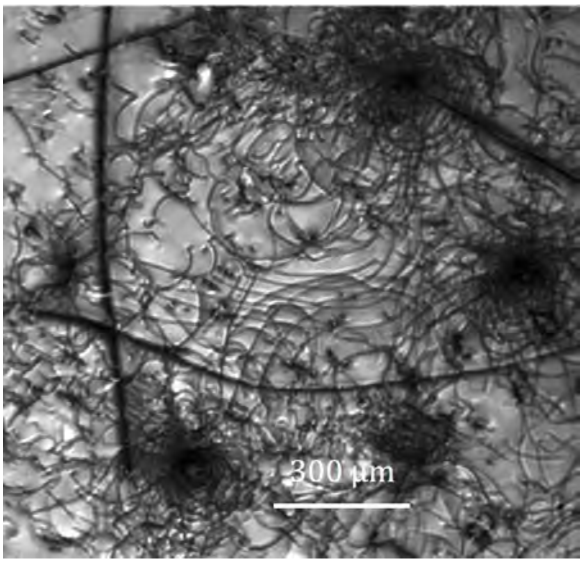

Fig. 1. Topographic image of GaN crystal grown by the Na-flux method on a sapphire substrate.

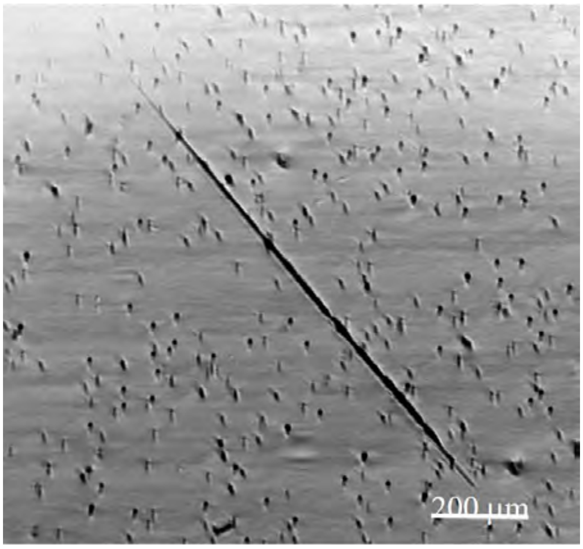

Fig. 2. Topographic image of GaN crystal grown by the Na-flux method on a GaN crystal prepared by the ammonothermal method.

Regarding the operation of the experimental stations for user access, we would like to express our gratitude for the cooperation of JASRI.

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