Structural Analysis on OVPE GaN by Nanobeam X-ray Diffraction

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[Introduction] GaN-based devices have been indispensable for high-performance vertical power devices and reliable high-speed transistors because of appealing properties of GaN, including wide direct bandgap (~3.49 eV), high electron mobility (> 1000 $\mathrm{cm^2/V \cdot s}$). Takino *et al.* have successfully produced high-quality GaN substrates in the oxide vapor phase epitaxy (OVPE) method with low dislocation density (~ $10^4\ \mathrm{cm^{-2}}$) and low resistance (~ $10^{-4}\ \Omega \cdot \mathrm{cm}$). Vertical p-n diodes fabricated based on the OVPE GaN substrate exhibit low on-resistance ($\sim 0.08\ \mathrm{m\Omega \cdot cm^2}$) and a high breakdown voltage (1.8 kV) [1]. However, the crystal structure related to the low dislocation density and high oxygen concentration is not thoroughly investigated. So, this research tries to analyze the crystal structural characteristics of OVPE GaN prepared in three-dimensional (3D) growth modes by nanobeam X-ray diffraction (nanoXRD).

[Experiment] Figures 1(a) and 1(b) are the optical microscope image of the cross-sectional m-plane of the OVPE GaN sample, showing the area investigated in the nanoXRD experiment and the correlated multi-photon-excited photoluminescence (MPPL) image, respectively. This research focuses on the stem structure observed in Fig. 1 (a). NanoXRD measurements were conducted in SPring-8 BL13XU with a beam size around 700 (hor.)×410 (ver.) $\mathrm{nm^2}$. With the help of Gauss fitting on Intensity-2θ profile, lattice constants were extracted from 2-200 and 2-202 diffractions of the sample with an interval of 1.5 μm. A reciprocal space map (RSM) of each irradiation point was obtained.

[Results and discussion] In the MPPL image, the stem structure appears as a straight dark line through the target area. With $\{11\bar{2}2\}$ facets growing around the stem structure, dislocations are supposed to propagate toward those facets and coalesce or annihilate at the stem. Due to these converged dislocations, the c/a lattice constant ratio map shows a deformed crystal structure close to the stem structure [Fig. 1(c)]. To indicate the defects distribution around the stem structure, we obtained the full width at half maximum (FWHM) of 2θ profiles from Gauss fitting. The FWHM distribution maps for 2-200 and 2-202 diffractions are shown in Figs. 1(d) and (e), respectively, which are directly related to the lattice spacing variation in the sample [2]. Qualitatively, a large value of FWHM means a higher defect density. Interestingly, at the stem structure, larger values of FWHMs are distributed in the 2-200 diffraction map compared to those in the 2-202 diffraction map, which specifically reflects the converged distribution of dislocations with *a*-component of Burgers vector. More detailed analytical results will be shown in the presentation.

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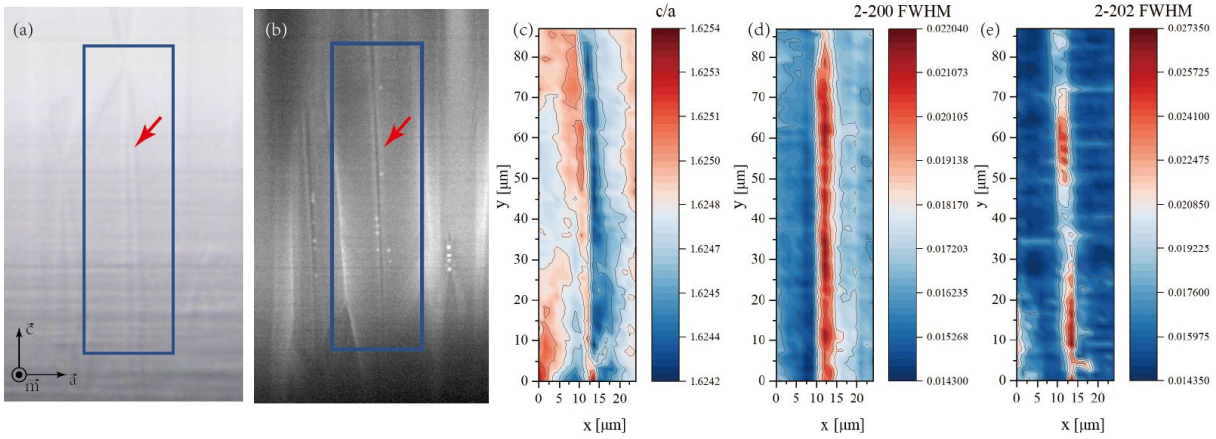

Fig. 1 (a) Optical microscope image of the sample. Red arrow marks the stem structure which is at the center of target region for nanoXRD. (b) Corresponded MPPL image. (c) c/a lattice constant ratio map. (d) and (e) FWHM maps obtained from 2θ profiles of 2-200 and 2-202 diffractions, respectively.