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MOVPE growth of GaN epitaxial films on AlN/h-BN/AlN double hetero-structures

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1. Introduction

Hexagonal boron nitride (h-BN) has a graphite-like honeycomb structure (a = 2.50 Å, c = 6.66 Å). Boron and nitrogen bond with sp^2 hybridization in plane and the planes bond with van der Waals forces to each other, which brings about the cleavable nature of h-BN. Recently, we demonstrated that the h-BN layer inserted between a sapphire substrate and GaN-based device structures grown on it works as a release layer; namely, the resulting GaN-based structures can be mechanically removed from the growth substrate and transferred onto a foreign substrate [1]. The h-BN layer on (0001) sapphire substrates [2] also acts as a buffer layer for the growth of GaN-based semiconductors, in that single-crystal GaN of device quality is obtained with the help of one more buffer layer of AlN or AlGaN on the h-BN layer [1].

A growth of GaN films on an AlN/h-BN/AlN double hetero-structure may further increase the versatility of this transfer method since AlN can be grown on a wide variety of substrates. In this presentation, we report successful growth of GaN epitaxial films on the AlN/h-BN/AlN double hetero-structures prepared on sapphire substrates.

2. Experiments

Figure 1 is a schematic illustration of a GaN film grown on an AlN/h-BN/AlN double hetero-structure on a sapphire substrate. The structure is grown by low-pressure metalorganic vapor phase epitaxy (MOVPE) with hydrogen carrier gas. First, using trimethylaluminium (TMAl) and ammonia (NH_3), a low-temperature (LT) AlN buffer layer is grown on the (0001) sapphire substrate at a growth temperature of 550°C. Then, we grow the double hetero-structure

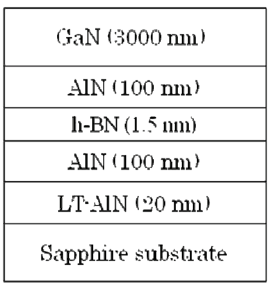

Figure 1. Schematic illustration of the structure.

at a growth temperature of 1060°C. The double hetero-structure, consisting of AlN layers with the thickness of 100 nm and h-BN layer with the thickness of 1.5 nm, is prepared using TMAl, triethylboron, and NH_3. Finally, GaN thick film is grown on the double hetero-structure using trimethylgallium and NH_3. The structural properties are investigated by high-resolution X-ray diffraction (Philips X'Pert System) with a wavelength of 1.5406 Å for a copper target and atomic force microscopy (AFM).

3. Results and discussions

Optical microscopy (Fig. 2) for the surface of the GaN shows a flat surface with measured root mean square roughness of 0.72 nm over an area of 1×1 μm^2, as seen in the AFM image (Fig. 2), indicating that a flat GaN film can be grown on the AlN/h-BN/AlN structure.

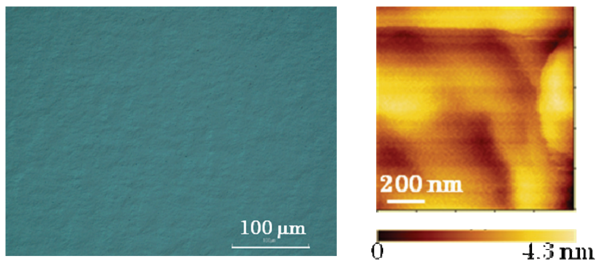

Figure 2. Optical microscopy (left) and AFM images for the GaN film grown on the double hetero-structure.

X-ray diffraction (XRD) in the $2\theta/\omega$ configuration for the GaN film exhibits only (0002) GaN and (0002) AlN diffraction peaks (Fig. 3), indicating that a (0001)-oriented single-crystal GaN film has been grown on the AlN/h-BN/AlN double hetero-structure and the orientation relationship between the substrate and AlN, GaN is $(0001)_{GaN} \| (0001)_{AlN} \| (0001)_{sapphire}$.

The crystallographic in-plane orientation relationship between the GaN film and sapphire substrate is investigated using a XRD phi scan for the $(10\bar{1}1)$ planes of the GaN film (Fig. 4). For comparison, the XRD phi scan for the $(11\bar{2}3)$ planes of the sapphire substrate is also shown in Fig. 4. The GaN film shows the six-fold azimuth symmetry, consistent with the wurtzite structure. Comparison of the XRD

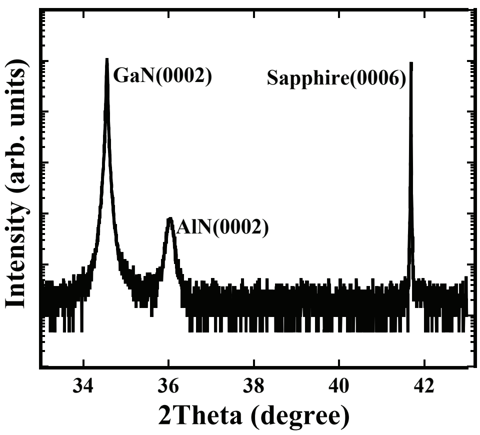

Figure 3. X-ray diffraction using 2θ/ω configuration for the GaN film.

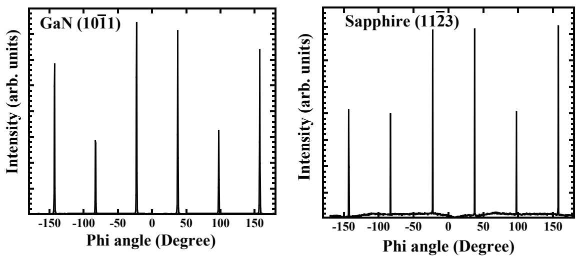

Figure 4. X-ray diffraction phi-scan profiles of a GaN/AlN/h-BN/AlN/sapphire structure: the (10$\bar{1}$1) planes of GaN (left) and the (11$\bar{2}$3) planes of sapphire (right).

patterns between sapphire and GaN (Fig. 4) indicates that the in-plane orientation of GaN on the double hetero-structure grown on the sapphire is $[10\bar{1}0]_{GaN} \parallel [10\bar{1}0]_{AlN} \parallel [11\bar{2}0]_{sapphire}$. The in-plane and out-of-plane orientation relationships between the GaN and sapphire are identical to the relationships for GaN film grown on AlN/h-BN/sapphire [1]. This confirms that the h-BN acts as a buffer layer also on the AlN layer.

We performed X-ray rocking curve measurements (ω scan) of symmetric (0002), (0004), and (0006) reflections for the GaN films grown on the double hetero-structure. In Fig. 5, the values of $\beta_\omega(\sin\theta)/\lambda$ are plotted against $(\sin\theta)/\lambda$, where θ, λ, and β_ω are the Bragg reflection angle, X-ray wavelength, and the integral breadth of the measured profile, respectively.

The slope of the fitted line is the tilt angle α_ω, which can be used to estimate the screw dislocation ($\boldsymbol{b}_{sc}$=[0001]) density (N_{sc}) [3] by

$$N_{sc} = \alpha_\omega^2/(4.35|\boldsymbol{b}_{sc}|^2).$$

From the Williamson-Hall plots in Fig. 5, the estimated screw dislocation density is 5.9×10^9 cm^{-2}. The screw dislocation density for the GaN grown on the AlN/h-BN/AlN is slightly higher than that for the GaN film grown on AlN/h-BN/sapphire [1], indicating that the h-BN can be used as a good buffer layer also on the AlN layer as well as directly on the sapphire substrate. In Fig. 5, the values of $\beta_\omega(\sin\theta)/\lambda$ are fitted by a straight line, whose y-intersection y_0 can be used to estimate the lateral coherent length $L_\parallel$ [3] by

$$L_\parallel = 0.9/(2y_0).$$

Using this formula, we estimate the lateral coherence length to be 0.409 μm.

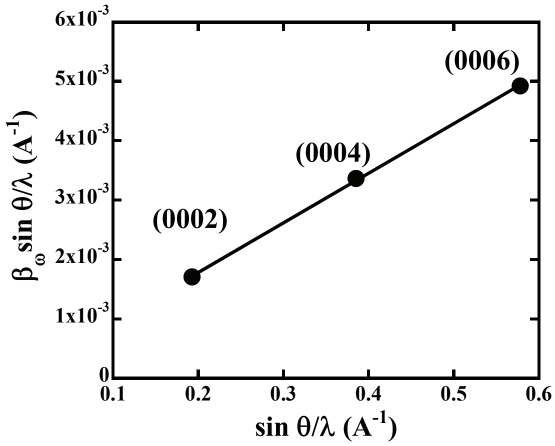

Figure 5. Williamson-Hall plot for GaN film grown on AlN/h-BN/AlN/sapphire.

3. Conclusions

We successfully grow epitaxial GaN films on AlN/h-BN/AlN structures on sapphire substrates. XRD measurements in the $2\theta/\omega$ configuration and phi scan reveal the h-BN acts as a good buffer layer on the AlN layer and the orientation relationships between the GaN and sapphire are $(0001)_{GaN} \parallel (0001)_{AlN} \parallel (0001)_{sapphire}$ and $[10\bar{1}0]_{GaN} \parallel [10\bar{1}0]_{AlN} \parallel [11\bar{2}0]_{sapphire}$.

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