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# AlGaN/GaN heterostructure grown on 1°-tilt sapphire substrate by MOCVD

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**Abstract**

AlGaN/GaN epitaxial layers were grown on 0°-tilt and 1°-tilt sapphire substrates by metalorganic chemical vapor deposition (MOCVD). With exactly the same growth conditions, it was found that dislocation density was smaller and crystal quality was better for the AlGaN/GaN epitaxial layers prepared on 1°-tilt sapphire substrate. We also found that AlGaN/GaN epitaxial layers on 1°-tilt sapphire substrate were grown with step growth mode while those on 0°-tilt substrate were grown with two-dimensional island growth. From the temperature-dependent mobility, it was found that crystal quality of the AlGaN/GaN epitaxial layer prepared on 1°-tilt sapphire substrate is better.


*Keywords:* Vicinal-cut sapphire; AlGaN/GaN; MOCVD; XRD; AFM; Hall measurement

## 1. Introduction

In recent years, much progress has been achieved in GaN-based optical devices such as light emitting diodes (LEDs) [1–4] and laser diodes (LDs). However, poor material quality in III-nitride films still has a negative impact on device performance [1–5]. Conventional GaN-based

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devices are usually grown on exactly *c*-face (0001) sapphire substrate. Even though incorporating a low temperature GaN or AlN nucleation layer could improve crystal quality of the GaN epitaxial layer [6,7], nevertheless, the lowest threading dislocation density of these samples was still of the order of $10^9$–$10^{12}$ $cm^{-2}$ due to the large differences in lattice constant and thermal expansion coefficient between the epitaxial layer and the underneath sapphire substrate. Therefore, it is necessary to further reduce threading dislocation density in the epitaxial layers.

The use of tilted substrates in semiconductor epitaxy has been acknowledged for a long time. In metalorganic chemical vapor deposition (MOCVD) of GaN, Grudowski et al. [8] reported an improvement in the photoluminescence (PL) properties by using (0001) sapphire substrates tilted towards $(11\bar{2}0)$. Generally speaking, moving away from the nominal (0001) orientation imposes a step-flow growth mode, which is less sensitive to surface singularities compared to the nucleation growth of two-dimensional islands [9]. Growth on properly tiled substrates may therefore be used to improve the crystal quality and reduce dislocation density [10–12] of semiconductor epitaxial layers.

GaN-based materials are potentially useful for applications in high speed, and high power electronic devices due to their advantageous material properties such as wide bandgap (AlInGaN varies from 0.78 to 6.2 eV) [13], high breakdown fields ($\sim 10^6$ V/cm) [14] and high saturated electron drift velocity ($\sim 10^7$ cm/s) [15]. The existence of AlGaN/GaN heterojunction with high conduction band offset and high piezoelectricity can also result in high sheet carrier densities and high room temperature mobilities. Similar to the well-known AlGaAs/GaAs system, AlGaN/GaN also forms two-dimensional electron gas (2DEG) as the operating basis of high mobility devices, such as heterostructure field effect transistors (HFETs). The high mobility and high sheet carrier densities render AlGaN/GaN HFETs with high saturation currents [16–20]. However, these GaN-based devices still have not reached their full potential as far as the extent of the aforementioned achievement is concerned. To fully exploit the potential of GaN-based HFETs, the crystal quality of AlGaN/GaN heterostructure must be improved accordingly. As mentioned earlier, one possible way to reduce threading dislocations and also to improve crystal quality of III-nitride epitaxial layers is to use tilted sapphire substrates. However, no report on AlGaN/GaN heterostructure prepared on tilted sapphire substrates could be found in the literature to our knowledge. Here, we report the growth of AlGaN/GaN heterostructure on 1°-tilt sapphire substrate. Physical properties of both samples grown on exactly *c*-axis oriented and 1°-tilt (0001) sapphire substrates will also be discussed.

## 2. Experiments

Samples used in this study were all grown by MOVCD on *c*-plane (0001) sapphire substrates with a vicinal-cut angle of 1° toward the *a*-plane $(11\bar{2}0)$ (i.e., 1°-tilt). Details of the growth conditions can be found elsewhere [21,22]. Prior to the growth, sapphire substrate was first heated to 1100 °C in a stream of hydrogen to clean the substrate surface. Chamber temperature was then decreased to 520 °C to grow a 25-nm-thick GaN nucleation layer. Next, a 2.2 μm-thick unintentionally doped GaN layer, a 1.1 μm-thick Mg-doped semi-insulating carrier confinement layer, a 0.25 μm-thick unintentionally doped GaN channel layer and a 17 nm-thick unintentionally doped $Al_{0.22}Ga_{0.78}N$ cap layer were subsequently grown at 1050 °C. Fig. 1 depicts schematic structure of the samples used in this study. For comparison, AlGaN/GaN heterostructures was also prepared on nominal (i.e. 0°-tilt) (0001) sapphire substrates. Notice that the identical growth conditions were used when we prepared the epitaxial layers on these two different substrates. A Bede D1 high resolution X-ray diffraction (HRXRD) system was