Growth of Aluminum Nitride on Sapphire via Spatially Separated Precursor Flow Metal Organic Chemical Vapor Deposition

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Aluminum nitride (AlN) and aluminum gallium nitride ($Al_xGa_{1-x}N$) alloys are attractive for a number of applications including deep ultraviolet optoelectronic devices, such as light emitting diodes and avalanche photodiodes, as well as high power, high frequency electronics. Unfortunately, the growth of these materials via metal organic chemical vapor deposition (MOCVD) with smooth surface morphology, high crystal quality, and excellent optical properties is challenging due to the low surface mobility of the Al species and the parasitic reactions between the trimethlyaluminum (TMAl) and ammonia (NH_3) precursors[1]. As a result, significant efforts have focused on growth techniques to improve crystal quality including high temperature, greater than 1300 °C, and low pressure growth[1,2], along with pulsed-flow growth schemes[3,4]. In the case of AlN, high temperature and low pressure conditions have been effective in improving crystal quality and reducing parasitic reaction, but are not as well suited for ternary alloys, such as $Al_xGa_{1-x}N$ or $Al_xIn_{1-x}N$, due to the low sticking coefficient of Ga and In species at high temperatures. On the other hand, pulsed-flow growth techniques, in which the group III and group V precursors are alternated during growth, have also been investigated as a means to improve surface mobility of the Al species at significantly lower temperatures while also reducing parasitic gas-phase interactions by minimizing gas mixing. Typical pulsed-flow schemes involve introducing the precursors into the chamber at different times and require an evacuation period to prevent gas mixing.

In this work, we discuss a separated precursor flow MOCVD chamber with a novel gas injection scheme for the growth of AlN layers on sapphire substrates. In this design, the precursors are laterally injected into the growth chamber from individual ports around the perimeter, as shown in Figure 1. The group III and group V sources are spatially separated by a nitrogen purge to ensure minimal gas mixing. As the ~8" susceptor, which can hold up to five 2" wafers, is rotated, the substrate is exposed to each source separately. Unlike other pulsed approaches, since both the group III and group V sources are introduced into the chamber at the same time, the pulse duration is controlled by the rotation speed, which ranges from 1 rpm to 120 rpm. The strong precursor separation created by the injection port design and nitrogen purge eliminates the need for an evacuation period and ensures an abrupt transition between sources.

AlN films ranging from 200-700 nm in thickness on sapphire substrates have been grown using this technique. These films were grown by first cleaning the substrate *in situ* with hydrogen, then a moderate-temperature nucleation layer at 920 °C was grown and followed by the main layer growth at 1080 °C. The nucleation and main layer growth used nitrogen as the carrier gas, 50 μmol/min of TMAl, and 1.5 standard liters per minute of ammonia. These growth conditions result in a growth rate of approximately 3 nm/min. These films have smooth surface morphology with an RMS roughness of ~1.0 nm, as shown in the atomic force microscopy image in Figure 2, which is quite smooth considering the relatively low growth temperature employed. High-resolution x-ray diffraction using a four-circle diffractometer equipped with a four-bounce Ge 220 monochromator shows the full-width half maximum of the symmetric (002) rocking curve is around 35 arcsec, as shown in Figure 3, indicating well oriented films with minimal screw dislocation density. The asymmetric (105) rocking curve has a FWHM of 232 arcsec suggesting minimal tilt. The influence of this novel gas injection scheme on growth conditions and resulting crystal quality of AlN films will be further discussed.

References

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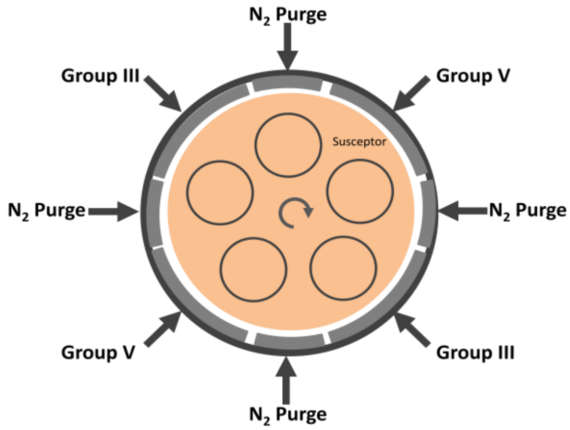

Figure 1. Schematic of MOCVD chamber showing spatially separated group III and group V injection ports.

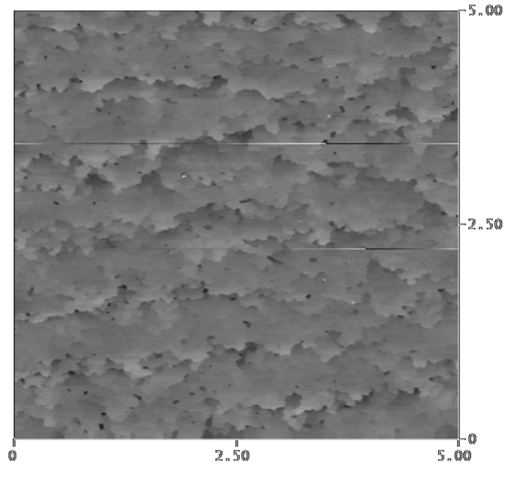

Figure 2. Atomic force microscopy image of AlN on sapphire. RMS surface roughness is 1.021 nm. Z-scale is 20 nm.

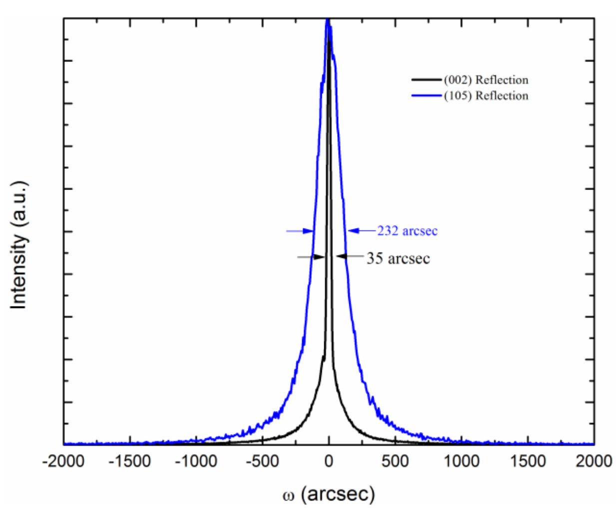

Figure 3. High resolution x-ray diffraction rocking curves of the (002) and (105) reflection.