Extremely high quality AlN grown on (0001) sapphire by using metal-organic vapor-phase epitaxy

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Abstract

AlN has generated much interest due to its unique properties such as its very wide direct bandgap and its very high thermal conductivity. High-quality AlN epitaxial layers are used in AlGaN-based ultra-violet (UV) light-emitting diodes (LEDs), which are strongly impacting applications such as fluorescence-based biological agent detection, water purification, sterilization, decontamination, and non-line-of-sight communications. At the same time, deep UV photo detectors need extremely high quality AlN with low dislocation density for the reduction of noise and the dark current. Therefore, the crystalline quality of AlN must be improved particularly when used as buffer layer in UV LEDs and photo detectors. We report on very high quality AlN epitaxial layers grown by low-pressure metal-organic vapor-phase epitaxy (MOVPE) using a single-wafer horizontal-flow Aixtron 200/4-RF S reactor with radio-frequency heating. The well-known two-step growth method that includes a low-temperature nucleation layer is used to initiate the growth. A systematic study is presented on the low-temperature (LT) AlN nucleation layer and the subsequent high-temperature (HT) AlN layer. Following dedicated optimization of growth parameters, AlN epitaxial layers were investigated by atomic force microscopy (AFM), x-ray diffraction (XRD), scanning electron microscopy (SEM), and photospectrometry. Fig. 1 shows that a clear and continuously linear step-flow pattern is observed on a $5\ \mu m \times 5\ \mu m$ AFM image. Terrace edges are equidistant with the terraces displaying saw-tooth-shaped edges, as shown in Fig. 1 (b). In the triple-axis x-ray rocking curve scans show a full-width at half-maximum (FWHM) of only 11.5 arcsec for the (002) peak and 14.5 arcsec for the (004) peak, as shown in Fig. 2. In Fig. 3, the KOH etching reveals an etch-pit density (EPD) of $3 \times 10^6\ cm^{-2}$ from SEM measurement and $2 \times 10^7\ cm^{-2}$ from AFM measurement. The SEM result is smaller than AFM measurement since the spatial resolution of AFM is better and micron-scale etch-pits can be observed. The optical transmission spectrum shows a very sharp drop of the transmittance at 6.1 eV. AlN with such high crystalline quality has great potential in UV LEDs and UV photodetectors.

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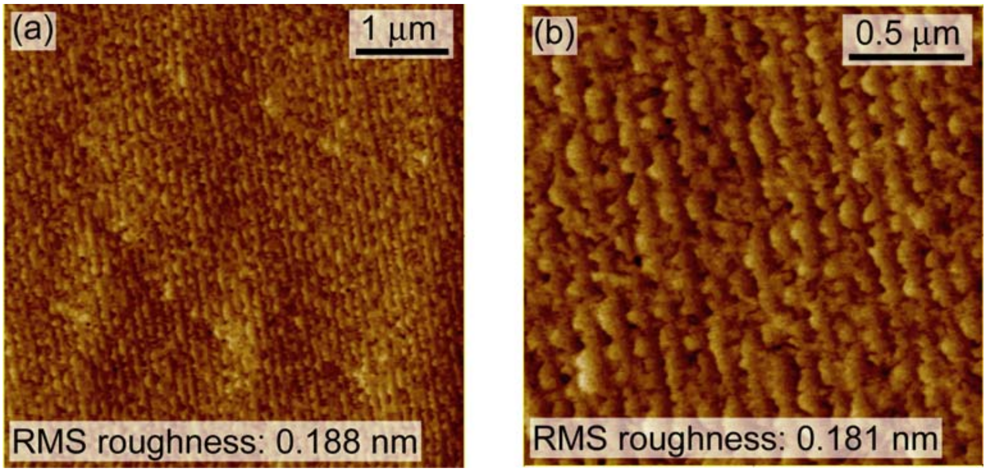

Fig. 1 AFM images of HT AlN surface grown on (0001) sapphire.

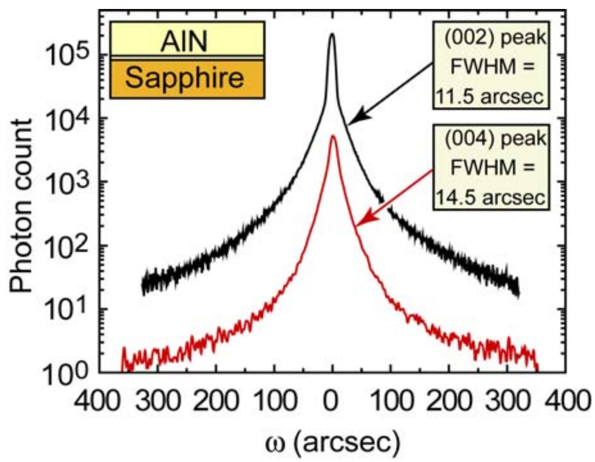

Fig. 2 X-ray rocking curves of (002) and (004) peaks of AlN by using tri-axis optics.

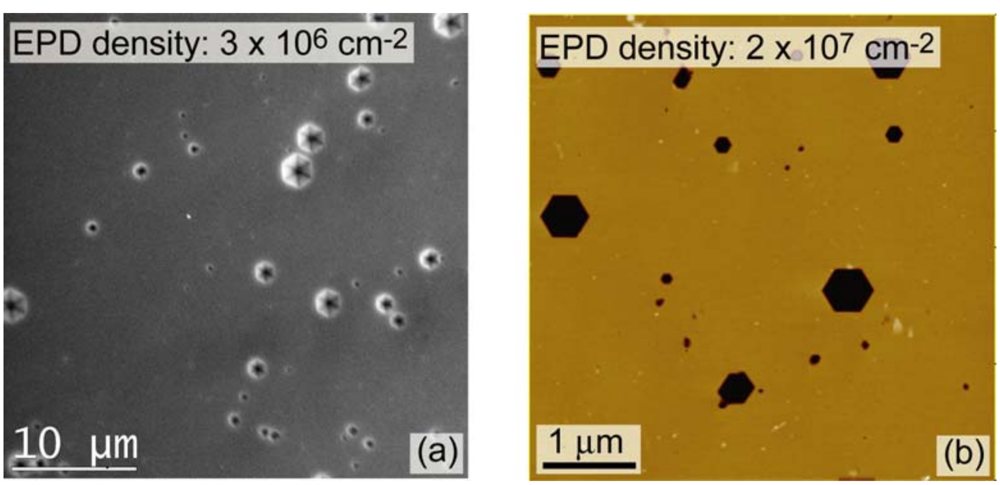

Fig. 3 a) SEM image and b) AFM image of etch-pit density of KOH etched AlN.