Deep UV transparent AlN substrates with high crystalline perfection for optoelectronic devices

Carsten Hartmann*, J. Wollweber, S. Kollowa, A. Dittmar, T. Schulz, A. Kwasniewski,
F. Langhans, U. Juda, K. Irmscher, M. Albrecht, M. Bickermann
Leibniz-Institute for Crystal Growth, Berlin, Germany
*Email: carsten.hartmann@ikz-berlin.de

Deep UV transparent bulk AlN crystals with high crystalline perfection are considered as the most promising substrate material for UV-C LEDs based on $Al_xGa_{1-x}N$ layers with high Al content. The use of native AlN substrates permits dislocation densities (DD) less than 10^6 cm^{-2} in the EPI layers which results in higher internal quantum efficiencies (IQE) compared to LEDs grown on sapphire substrates. Beside the crystalline perfection two further key features of the AlN substrates are essential for current UV-C LED designs. First, one needs a high deep UV transparency since the light extraction is carried out through the AlN substrate. Second, the usability of Al-polar surfaces for MOCVD layer deposition must be ensured by a qualified CMP (chemo-mechanical polishing) process.

In this work, we will present the preparation of deep UV transparent AlN substrates with high crystalline perfection which are exceedingly suitable for deep UV-C LEDs. Particular attention is paid (i) on the control of the main impurities O and C during the homoepitaxial growth of AlN single crystals via physical vapor transport (PVT), and (ii) on the characterization of chemo-mechanical polished (0001) surfaces.

The incorporation amounts of O and C in the PVT grown AlN crystals depend on the growth temperatures, on the growth orientations, and on the crucible (getter) materials. We will show that AlN crystals with high deep UV transparency ($\alpha_{265nm} < 15$ cm^{-1}) can be prepared when $3[C] < [O]$ and $([C] + [O]) < 10^{19}$ cm^{-3}. These conditions are met for the growth on the N-polar facet at seed temperatures $T_{Seed} \sim 2040$ °C using a TaC crucible with W parts. TaC helps to reduce the amount of O by forming volatile CO ($2TaC + O \rightarrow Ta_2C + CO$) and W getters C by forming W_2C ($2W + C \rightarrow W_2C$).

The crystalline perfection of the seed wafers, evaluated by rocking curves (FWHM 11-18 arcsec [1]), X-ray Lang topography, and defect-selective wet chemical etching can be preserved over several growth runs of deep UV transparent AlN single crystals.

The CMP finishing of the (0001) substrate surfaces (10x10 mm) is evaluated by TEM, AFM, and X-ray reciprocal space maps. The CMP polished surfaces achieved by process optimization led to low defect interfaces when used in subsequent MOCVD homoepitaxy.

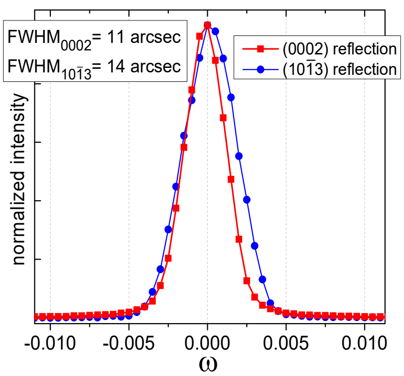

Fig.1: Rocking curves (open detector) measured with 4-bounce Ge220 monochromator

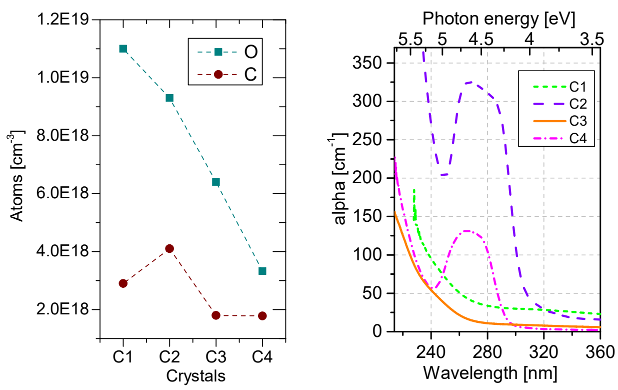

Fig.2: SIMS values (a) and UV-VIS absorption spectra (b) of AlN crystals grown under different conditions. Crystal C3 reveals $3[C] < [O]$ and $([C] + [O]) < 10^{19}$ cm^{-3} which results in $\alpha_{(265nm)} = 14$ cm^{-1}

[1] C. Hartmann, A. Dittmar, J. Wollweber, M. Bickermann, Semicond. Sci. Technol. 29 (2014) 084002.