Status and Challenges of AlN Bulk Crystal Growth for Use as Substrates in Deep-UV Emitters

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Bulk AlN crystals are particularly interesting as substrates for deep-UV optoelectronic devices comprised of $Al_xGa_{1-x}N$ layers with high Al content which can be grown pseudomorphically strained to AlN. However, besides size and cost of AlN substrates, additional properties greatly influence the device characteristics and efficiency, e.g. deep-UV optical transmittance (for light outcoupling) and an epi-ready (chemo-mechanically polished) surface with high crystalline perfection (for low dislocation densities in the epilayers) and specific off-cut orientations (for layer-by-layer growth to prevent compositional changes in the epilayers). This presentation will discuss the challenges to satisfy the above requirements and the routes to solve them, with a focus on the bulk AlN crystal growth technology employed at IKZ, i.e., physical vapor transport (PVT) of AlN in TaC crucibles at temperatures below 2100°C, with N-polar growth direction.

Deep-UV transparent AlN crystals with $\alpha < 25\ cm^{-1}$ at 265 nm on the full wafer area are grown reproducibly with the above-mentioned technique when the concentrations of oxygen and carbon impurities [C] and [O] satisfy the inequalities 3[C] < [O] and ([C] + [O]) < $10^{19}\ cm^{-3}$ [1]. X-ray topographs of the substrates reveal a threading dislocation density of 10^2–$10^3\ cm^{-2}$ in the main area, but some dislocation clusters persist in the crystal volume, and polygonization is observed at the perimeter (Fig. 1). Overgrowth of the epi-ready Al polar (0001) AlN surface by metalorganic vapor phase epitaxy at 1160°C leads to a homogenous continuation of the AlN growth. An accurate off-orientation with respect to the c-axis of 0.05–0.2° ensures step flow with monolayer terraces across the substrate when growing epitaxial layers (Fig. 2). On the best obtained layers, XRD rocking curves do not exhibit additional or broadened peaks and no defects are observed at the interface by TEM. The morphology depends strongly on the miscut angle. Finally, deep UV light emitting diodes (LEDs) on AlN substrates are demonstrated.

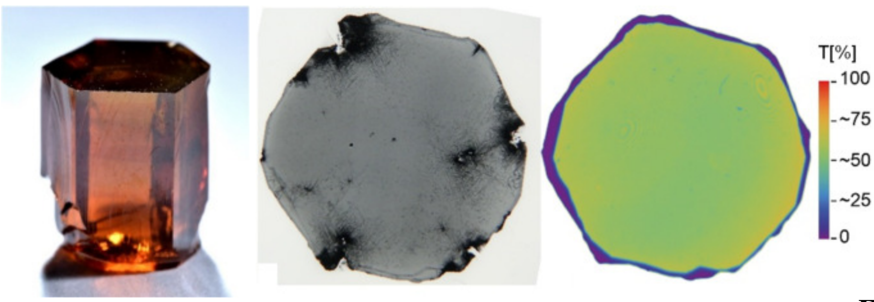

Fig. 1 AlN bulk crystal, Ø 10 mm (left). X-ray transmission topograph (middle) and map of optical transmission at 254 nm (right) of a 140 µm thick AlN substrate with Ø 10 mm.

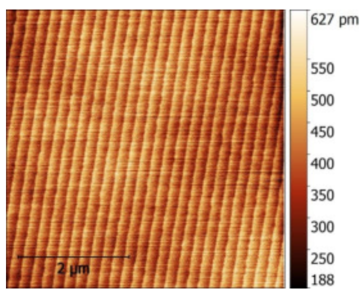

Fig. 2 AlN homoepitaxial layer grown by MOCVD on an AlN substrate with 0.06° off-cut.

[1] C. Hartmann, J. Wollweber, S. Sintonen, A. Dittmar, L. Kirste, S. Kollowa, K. Irmscher, M. Bickermann, CrystEngComm 18 (2016) 3488-3497