Status of AlN Bulk Crystal Growth for Use as Substrates in Deep-UV Applications

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Bulk AlN crystals are considered a promising substrate material for deep-UV LEDs, laser diodes, and sensors. Such devices consist of $Al_xGa_{1-x}N$ layers with high Al content which can be grown pseudomorphically strained on bulk AlN. But realization of efficient devices also requires the bulk AlN substrates to have deep-UV optical transmittance, high crystalline perfection, a specific off-cut, and an epi-ready surface. Furthermore, the physical vapor transport (PVT) growth technology used at the IKZ only allows incremental increase of crystal diameter/substrate size. These challenges as well as routes to their solution and remaining limitations on the way to a transfer to industry will be discussed in the presentation.

The findings can be summarized as follows:

- Deep-UV transparent AlN crystals with $\alpha_{265nm} < 25$ cm^{-1} on the full wafer area are grown reproducibly at IKZ 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]. Best values reached so far are $\alpha_{265nm} = 14$ cm^{-1}. Further reduction in the overall impurity content will be necessary to improve transparency at even lower wavelengths (< 230 nm).
- X-ray topographs of the substrates reveal a threading dislocation density in the 10^2–10^3 cm^{-2} range in the main areas, although still some dislocation clusters as well as pronounced dislocation formation and polygonization at the perimeter appear (Fig. 1). We will present models for formation of these defects. Appropriate selection of wafers used as seeds in subsequent growth runs is mandatory to maintain structural quality and enable effective diameter increase of the AlN crystals.
- Chemo-mechanical polishing is required and has been used to remove residual subsurface damage. An accurate off-orientation with respect to the c-axis of 0.1±0.05° is mandatory (and reliably achieved) to ensure step flow with monolayer terraces across the substrate when growing epitaxial layers. Maintaining a planar surface is an outstanding challenge in particular for the small substrate sizes (e.g. Ø 10 mm) currently used.
- Overgrowth of the epi-ready Al polar (0001) AlN surface by metalorganic vapor phase epitaxy at 1250°C leads to a homogenous continuation of the AlN growth. 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.
- Results and challenges of the MOCVD homoepitaxy on bulk AlN substrates are presented. Also, first deep-UV LEDs and optically pumped laser structures were grown on the bulk AlN substrates and demonstrate the potential of this technology.

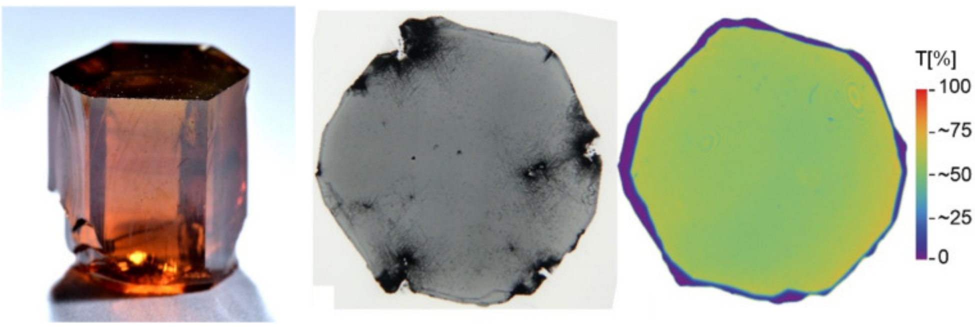

Figure 1: AlN bulk crystal, Ø 10 mm (left). X-ray transmission topograph (middle) and map of optical transmission at 254 nm (right) of a 140 µm thick AlN substrate with Ø 10 mm.

[1] C. Hartmann, J. Wollweber, S. Sintonen, A. Dittmar, L. Kirste, S. Kollowa, K. Irmscher, M. Bickermann, Preparation of deep UV transparent AlN substrates with high structural perfection for optoelectronic devices, CrystEngComm 18 (2016) 3488-3497