Defects in AlN bulk crystal substrates for UV LEDs and lasers

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Deep-UV LEDs, laser diodes, and sensors typically consist of $Al_xGa_{1-x}N$ epitaxial layers with high Al content where dislocations have a detrimental effect on device operation. Their concentration is minimized by growing pseudomorphically strained layers on bulk AlN substrates of high crystalline perfection. Additionally, electrical and optical properties of these AlN substrates are important, e.g. for efficient deep-UV light out-coupling. Thus, recognition and imaging of point and structural defects in the grown AlN bulk crystals are key for understanding the AlN substrate properties as well as for improving the process of bulk AlN crystal growth.

Bulk AlN crystals are prepared by physical vapor transport (PVT) at temperatures exceeding 2000°C [1]. Growth is performed in a hot-zone set-up consisting of TaC, graphite and tungsten parts with AlN powder as feedstock and AlN substrates as seeds. The crystal growth mainly appears on the N-polar (000-1) surface, while a diameter increase is established by m-plane (10-10) growth, see Fig. 1. Wet chemical etching, X-ray topographs and laser scattering tomographs reveal a threading dislocation density in the 10^2–10^3 cm^{-2} range in the main area; in some cases, they are complemented by a few dislocations clusters [2]. At the perimeter, a pronounced dislocation formation and polygonization appears (Fig. 2a). The observed structures and their potential origins are briefly discussed.

Main impurities in AlN bulk growth are carbon and oxygen from the hot-zone materials and gas residues. Their incorporation in the growing crystal changes with growth time (source depletion), growth temperature and surface faceting. They govern the optical and electrical properties of AlN substrates, but the underlying causalities are still under discussion. For example, optical absorption peaking at 265 nm is quenched (but near-UV absorption rises) when the concentration of oxygen [O] exceeds the concentration of carbon [C] by $[O] > 3[C]$, see Fig. 3. Based on intentionally doped samples and irradiation experiments, we explain this behavior by a fermi-level effect. Using low growth temperatures and employing getter materials to reach $([C] + [O]) < 10^{19}$ cm^{-3}, deep-UV transparent AlN crystals with $\alpha_{265nm} < 20$ cm^{-1} can be obtained (Fig. 2b) [3]. Further information about compensation mechanisms and electrical properties are provided by temperature-dependent resistivity measurements and spatially resolved free carrier absorption in the near-IR range.

References

[1] M. Bickermann (2016), III-Nitride Ultraviolet Emitters - Technology and applications, ISBN: 978-3-319-24098-5, Chapter 2

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

[3] C. Hartmann, J. Wollweber, S. Sintonen et al. (2016), CrystEngComm 18, 3488-3497

Figure 1. AlN bulk crystal, Ø 10 mm. N-polar [000-1] growth direction is upwards.

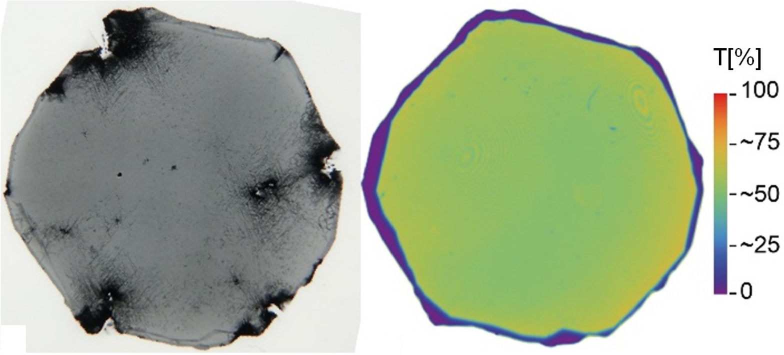

Figure 2. (a) X-ray transmission topograph and (b) map of optical transmission at 254 nm of a 140 μm thick AlN substrate with Ø 10 mm.

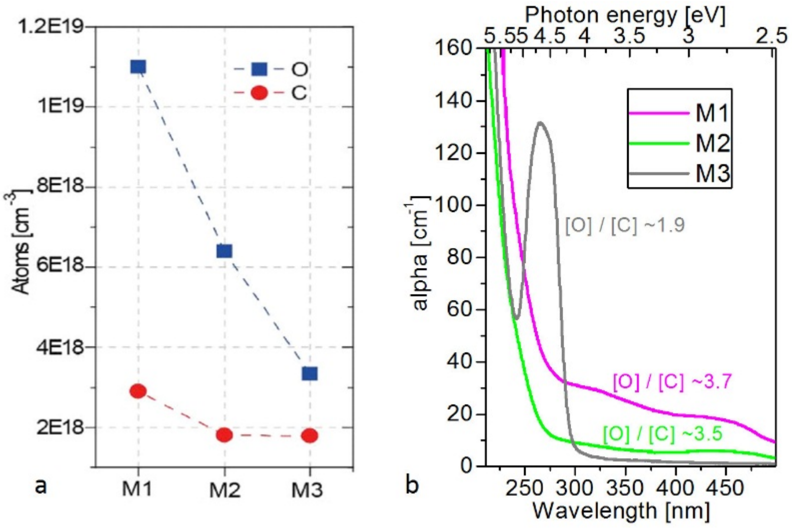

Figure 3. (a) Oxygen and carbon concentrations (measured by SIMS) in three AlN samples; (b) optical absorption spectra of these samples (thickness about 240 μm)