DEEP-UV TRANSPARENT BULK SINGLE-CRYSTALLINE ALN SUBSTRATES

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Bulk aluminium nitride (AlN) is a very promising substrate material for UV optoelectronics based on AlGaN ternary compounds. AlN single crystals exceeding 1" in diameter can now be grown by physical vapour transport (PVT). UV transparency is of high interest for UV devices designed to emit through the substrate. We report on 500 µm thick bulk AlN substrates with plain UV transmittance of 50% (i.e., absorption coefficients $< 15\ \mathrm{cm}^{-1}$) at wavelengths down to 220 nm in almost the whole wafer area. Results from optical absorption (OA) are correlated to the structural quality of the samples and compared to cathodoluminescence (CL) measurements and chemical analysis.

Polished samples from a number of seeded bulk single-crystalline AlN crystals were investigated. The samples are characterized by a homogeneous yellowish coloration in the main area. A distinctive transparent or brownish appearance of some areas is caused by basal or rhombohedral/prismatic plane faceting. OA was measured at room temperature in the visible and UV wavelength range. Despite the fact that all crystals faced similar growth conditions (growth temperature, oxygen contamination of the source material), the obtained spectra show significant differences, see Fig. 1. As a particular result, sample colour does not correlate with deep-UV absorption. All spectra are successfully deconvoluted into a similar set of broad bands of Gaussian shapes peaking at 2.8 eV, 3.6 eV, 4.25 eV, and 5.0 eV; the band at 4.25 eV is presumably a superposition of several peaks. Lowest deep-UV absorption as shown in Fig. 1b is observed in crystals grown on AlN seeds of high structural quality; main areas of such crystals are characterized by their smooth surface morphology.

CL spectra of the samples exhibit below band-gap features at 1.8 eV, 2.05 eV, 2.4 eV, 3.25–3.65 eV and 4.3 eV. The spectra can be categorized into two types which show remarkable differences in their temperature dependence as shown in Fig. 2. The differences are clearly correlated to OA results. In samples with higher deep-UV absorption, CL intensity at room temperature peaks at 3.4 eV. All CL features increase in intensity and the main band shifts to 3.25 eV when the sample is cooled down to 100 K. In comparison, samples with low deep-UV absorption generally exhibit lower below band-gap CL intensity. Typically, a broad feature at 2.05 eV dominates at room temperature while the band at 3.25 eV increases (and a new band at 2.4 eV arises) at lower temperatures. All investigated spectra of this type show a maximum at approx. 150 K below which the CL intensity decreases again, probably due to charging effects.

In the presentation, the results are interpreted in terms of our point-defect model for AlN [1] accounting for substitutional oxygen (O_N), aluminium vacancies (V_{Al}), and V_{Al}–O_N complexes. Additionally, we take different levels of Si contamination into account. Obviously, the concentration of point defects is considerably lower in AlN samples which exhibit low deep-UV absorption. The conclusion is supported by evaluation of point defect concentrations using chemical analysis, electron spin resonance [2], and positron annihilation [3].

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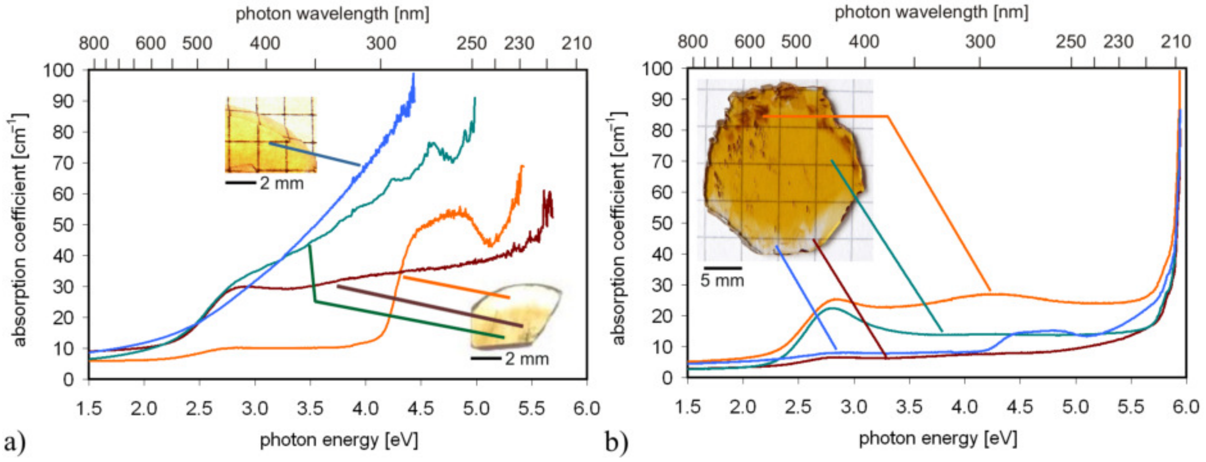

Fig. 1: Optical absorption (OA) of AlN samples (see insets) measured at room temperature. a) Different areas of crystals grown on AlN templates. b) Different areas of a crystal with smooth surface morphology grown on a high-quality AlN seed.

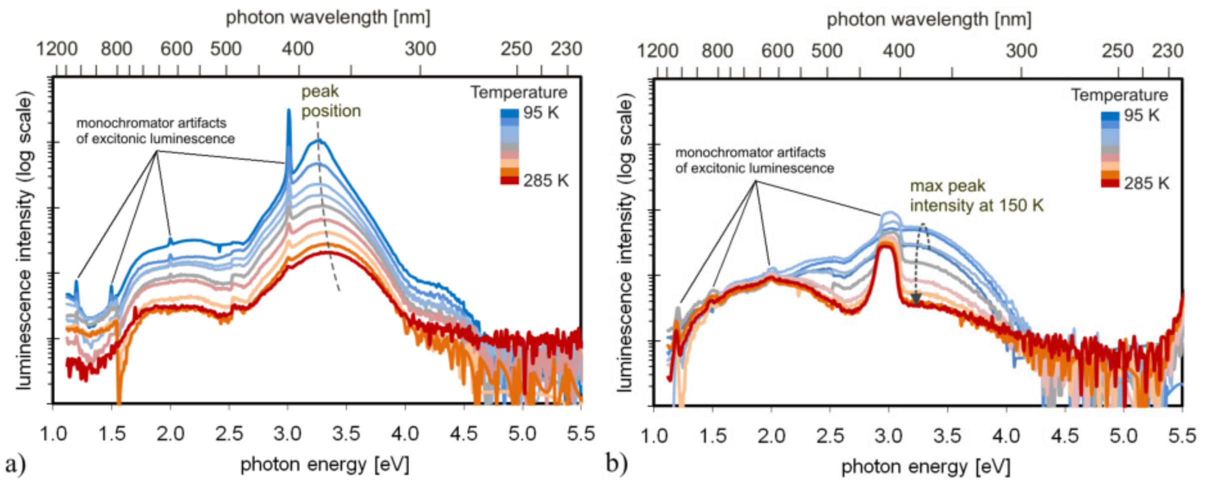

Fig. 2: Temperature-dependent cathodoluminescence (CL) spectra of main yellowish areas of AlN samples shown in Fig. 1. a) Sample grown on an AlN template. b) Sample grown on a high-quality AlN seed. Note that the intensities of the two series of spectra are not directly comparable as they were recorded using a different monochromator entrance slit (0.2 mm and 2 mm, respectively).

REFERENCES:

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