Tailoring electrical and optical properties of AlN during seeded AlN bulk growth

Carsten Hartmann, Andrea Dittmar, Frank Langhans, Sandro Kollowa, Martin Naumann, Klaus Irmscher, Jürgen Wollweber, Matthias Bickermann*
Leibniz Institute for Crystal Growth (IKZ), Max-Born-Strasse 2, 12489 Berlin, Germany
*corresponding author, phone +493063923047, fax: +493063923003,
email: matthias.bickermann@ikz-berlin.de

Single-crystalline aluminum nitride (AlN) is a promising substrate material not only for AlGaN epilayers with high Al content, e.g. for solid-state deep-UV optoelectronics, but also for high temperature and high power applications. AlN bulk single crystals are grown by the physical vapor transport (PVT) method at temperatures well above 2000°C. Crystals of high structural perfection (dislocation densities < 10^4 cm^{-2}) can be grown using N-polar AlN single crystal wafers as seeds [1–3]. However, proper control of the PVT growth process is made difficult due to gradual changes of the reactor materials caused by attack of gaseous Al and unintentional incorporation of impurities (O, C, Si) into the growing crystals during growth. The latter determine the electrical, thermal, and optical properties of bulk AlN substrates. In turn, these properties can be adjusted at least partially by providing proper growth conditions or by employing doping.

We will present and discuss preparation and characterization of bulk AlN crystals and substrates with tailored properties while maintaining the high structural quality: (a) We will show that deep-UV transparent AlN single crystals with α(265 nm) < 20 cm^{-1} can be prepared even when growing in the N-polar growth direction when 3[C] < [O] and [C] + [O] < 10^{19} cm^{-3}. The possible routes to provide such material are presented. (b) Providing a suitable Si doping technique in PVT growth, bulk AlN with weak n-type conductivity even at room temperature ([Si] ≈ 1.6 x 10^{19} cm^{-3}, n = 1.2 x 10^{15} cm^{-3}, μ = 36.5 cm^2/Vs) and also reduced absorption in the deep-UV range can be prepared. (c) For high-temperature electronics and piezoelectric sensors, electrically semi-insulating bulk AlN even at temperatures beyond 1000°C is desired, which can be prepared by reducing the oxygen content in the growth atmosphere.

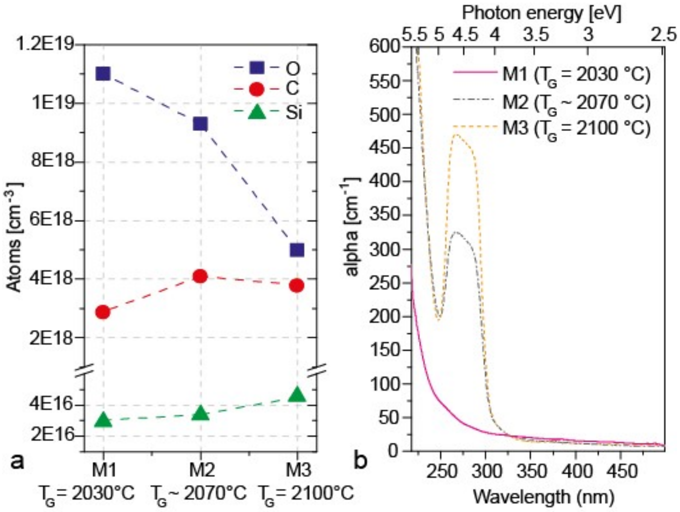

Fig. 1: Deep-UV transparent AlN bulk crystals: (a) SIMS values for different impurities and (b) optical absorption spectra in dependence of the growth temperature T_G.

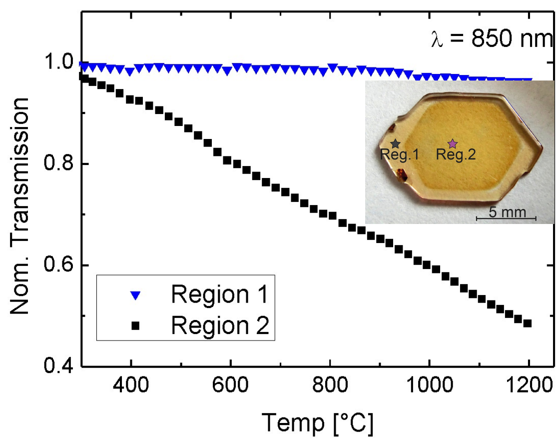

Fig. 2: Crystal regions with and without a decrease in near-IR transmission due to free carrier absorption at elevated temperatures. Region 1 is electrically semi-insulating even at temperatures exceeding 1000°C.

[1] C. Hartmann, A. Dittmar, J. Wollweber, M. Bickermann, "Bulk AlN growth by physical vapour transport", Semicond. Sci. Technol. 29 (2014) 084002.

[2] T. Paskova, M. Bickermann, “Vapor Transport Growth of Wide Bandgap Materials”, in: Handbook of Crystal Growth, Second Edition, Vol 2A: Bulk Crystal Growth - Basic Technologies, P. Rudolph (ed.), Elsevier Science Ltd. 2015, ISBN: 978-0-44463-303-3, Chapter 16.

[3] R. Dalmau, Z. Sitar, “AlN Bulk Crystal Growth by Physical Vapor Transport”, in: Springer Handbook of Crystal Growth, G. Dhanaraj, K. Byrappa, V. Prasad, M. Dudley (eds.), Springer-Verlag Berlin Heidelberg 2010, ISBN: 978-3-540-74182-4, Chapter 24.