Recent Advances in Growth of Bulk GaN

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GaN crystals of high structural quality are very much required for expanding applications in full color light sources and high power -high frequency electronics. However due to its extreme melting conditions GaN cannot be grown from stoichiometric GaN liquid. New melting data coming from very high pressure (up to 10.0GPa) and temperature (up to 3400K) experiments will be discussed in the context of theoretical simulations of GaN melting by Quantum Dielectric Theory of Electronegativity in Covalent Systems [1] and Molecular Dynamics [2]. It is shown that experimentally evaluated melting temperature of GaN and its pressure dependence is much higher than it was reported in [3] and in very good agreement with theoretical predictions by Molecular Dynamics [2].

GaN bulk crystals are therefore grown at pressures much lower than the one expected for melting. The lowest dislocation density ($10^{-2}cm^{-2}$) crystals were grown by High Nitrogen Pressure Solution method however too small for applications. The only method supplying GaN substrates for industry is Hydride Vapor Phase Deposition (HVPE). Its main advantage is high growth rate exceeding 100 μm/h. Sophisticated approaches (A-DEEP, VAS) based on HVPE on foreign substrates have been developed for obtaining free standing GaN wafers with quality and size sufficient for laser applications. Real bulk GaN crystals of very high structural quality are grown by ammonothermal method at moderate pressures of 0.1-0.3GPa and low temperatures of about 400-600^{o}C. Development of this technology is limited by discouragingly low grow rate of about 1 μm/h. This can be improved by increasing both pressure and temperature of the process. Higher rate of about 20 μm/h can be also achieved in Na-flux system where pressures lower than 100MPa and temperature of about 850^{o}C are used. The existing methods and their current state will be discussed.

A new approach to GaN bulk crystallization based on growth by HVPE on Ammono-GaN seeds will be also presented. It will be shown that thick (d>2mm) GaN crystals with structural quality as good as the quality of the seeds can be grown with a rate exceeding 200 μm/h. Moreover these new crystals are of the highest purity comparable to epitaxial material. Their excellent optical and electrical properties will be discussed. These studies are crucial for establishing physical limitations of real bulk GaN crystallization by HVPE.

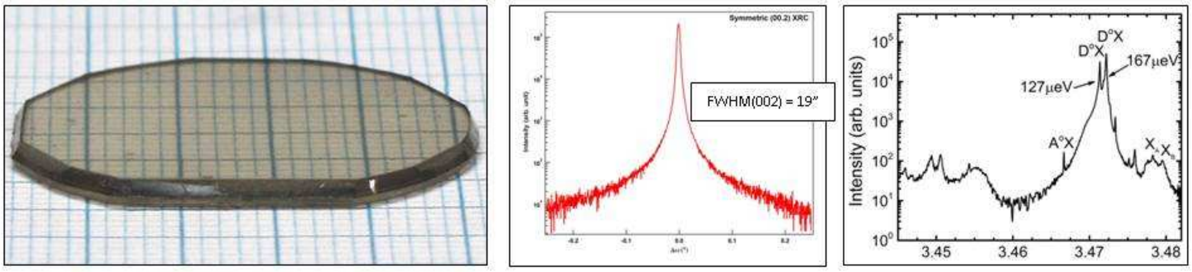

Fig. 1 GaN crystal grown by HVPE on ammonothermally grown GaN substrate. From the left: habit of 2.5mm thick crystal, its X-ray rocking curve and low temperature PL spectrum.

[1] J. A. Van Vechten, *Phys. Rev. B* 7:1479-507, 1973.
[2] K. Harafuji et al. *J. Appl. Phys*. 96, 2501 (2004);
[3] W. Utsumi et al. *Nature Materials* **2**, 735 (2003).