Characterization of crack-free and relaxed bulk-like GaN grown on 2´´ sapphire

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→ Outline

We demonstrate the growth of high-quality and stress-free bulk-like (300-μm-thick) GaN by hydride vapor phase epitaxy (HVPE) in a vertical atmospheric-pressure reactor.

The crystalline quality and the residual stress in the 2´´ GaN wafer are investigated by various characterization techniques.

The lateral homogeneity of the wafer is monitored by low-temperature photoluminescence mapping. Precise μ-Raman scattering profiling measurements provide the vertical strain distribution and the evolution of the crystalline quality with increasing film thickness.

The high crystalline quality on the Ga-terminated surface is proved by high-resolution X-ray diffraction and photoluminescence measurements.

The position of the main near-band-gap photoluminescence line and the phonon spectra obtained by infrared spectroscopic ellipsometry show consistently that the 2´´ crack-free GaN wafer is virtually stress-free over a diameter of approximately 4 cm.

→ Sample preparation

- ► Vertical hydride vapor phase epitaxy growth process
- ► ~2 μm thick MOCVD-GaN buffer layer on 2´´ c-plane sapphire substrate
- ► Growth temperature = 1090 °C; V:III ratio = 12
- ► Average growth rate = 75 μm/h

300 μm	c-plane GaN
330 μm	c-plane Al_2O_3

→ Structural characteristics

SIMS

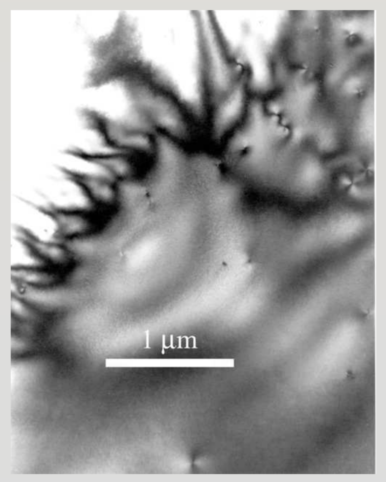
[O]	2×10^{18} cm^{-3}
[Mg]	3×10^{15} cm^{-3}
[C]	3×10^{17} cm^{-3}

X-ray diffraction

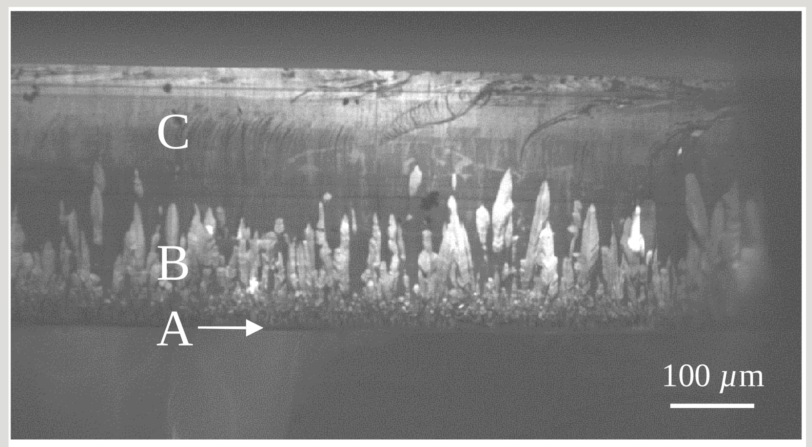
reflection	ω-scans	2θ-ω scans
(1 0 –1 4)	377 arcsec	140 arcsec
(0 0 0 2)	450 arcsec	58 arcsec

Slit width 1 mm

TEM



CL

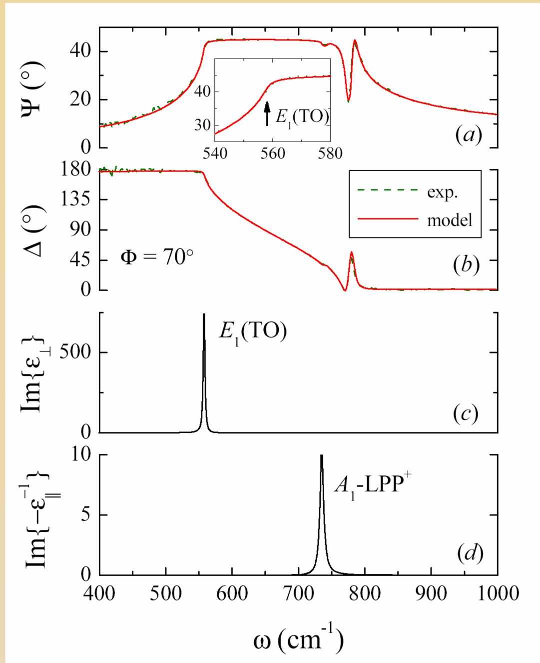


Panchromatic CL image of the sample cross-section, revealing three different structural areas of the GaN:

(A) non-radiative, ~2 μm thick MOCVD-grown nucleation layer,
(B) columnar, bright-emission, ~100 μm thick region,
(C) high-quality zone of the HVPE-grown material.

→ Optical characteristics

IR-Ellipsometry



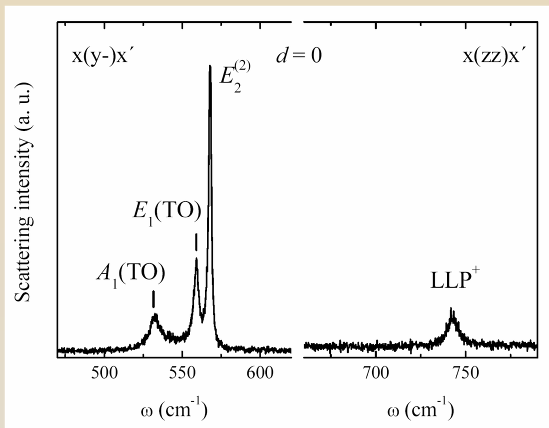
Measured (dashed lines) and modelled (solid lines) mid-infrared ellipsometric Ψ (a) and Δ (b) spectra at 70° angle of incidence. The inset enlarges the Ψ spectra in the range of the E_1(TO) phonon, which marks the onset of the material´s reststrahlen range.

Imaginary part of the GaN dielectric function perpendicular to the c-axis (c) and dielectric loss function parallel to the c-axis (d), both deduced from the IR data analysis.

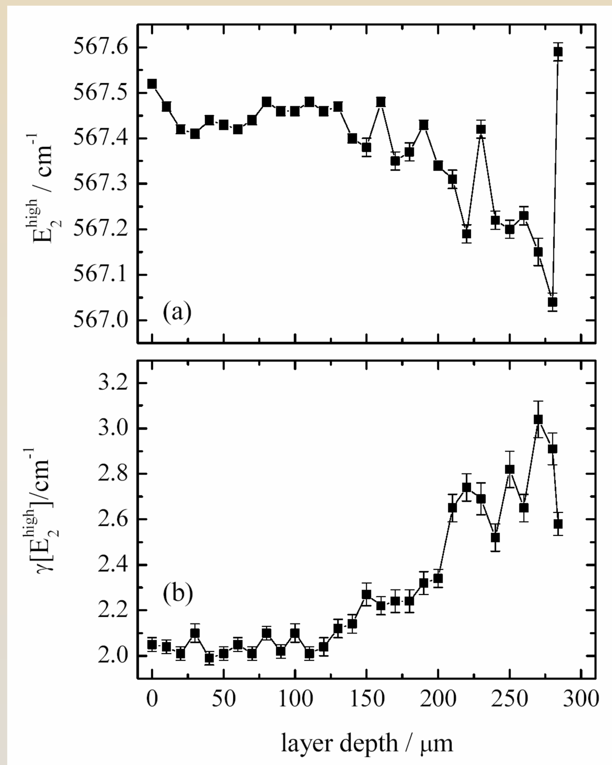
From the position of the LPP⁺ mode, the free-electron concentration in the material is determined to be 1.3×10^{17} cm^{-3}.

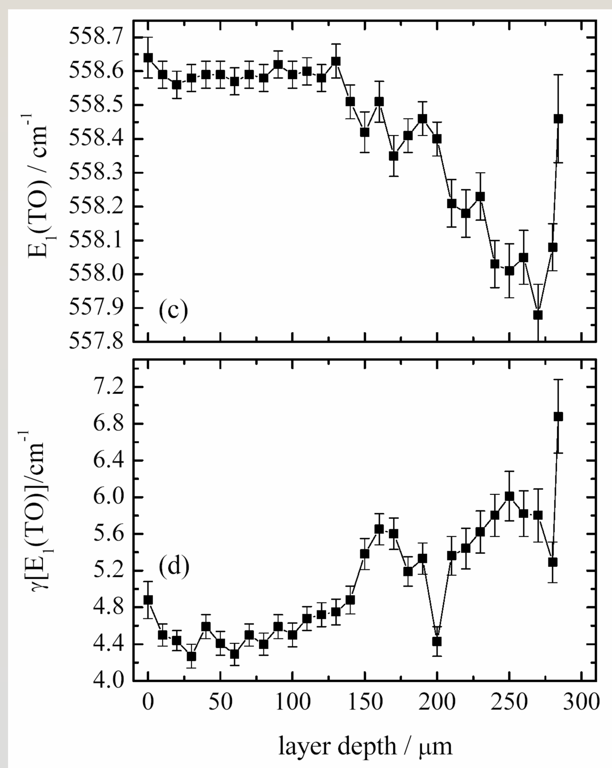
μ-Raman scattering

(after laser-induced lift-off from substrate)



Above: μ-Raman scattering spectra taken in $x(y,-)\bar{x}$ and $x(z,z)\bar{x}$ geometries at the Ga-terminated surface (d = 0).



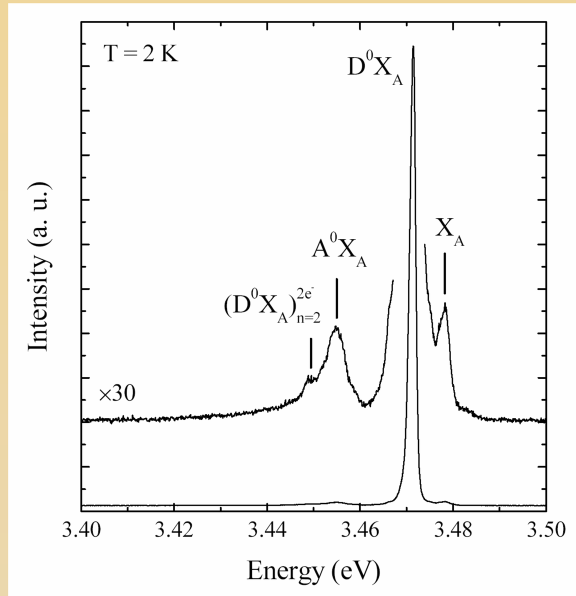


Right: Frequency and linewidth of the $E_2^{(2)}$ phonon (a and b) and E_1(TO) phonon (c and d) modes vs.. distance d from the Ga-face. Both modes exhibit similar dependences.

The systematic error for the phonon frequency is estimated to be ~0.5 cm^{-1}.

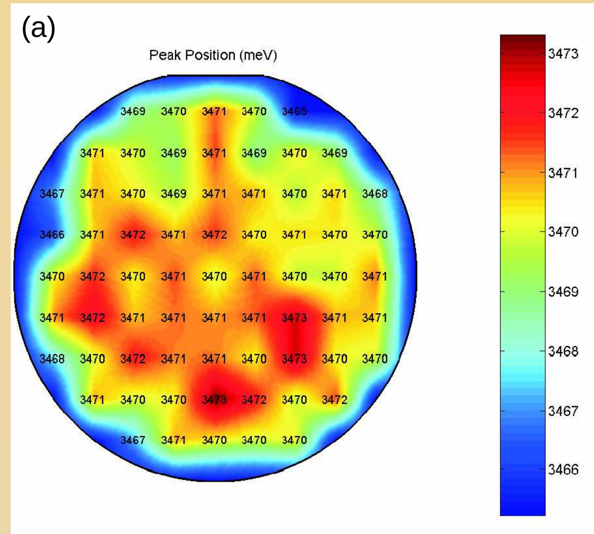
The linewidth profiles reveal a homogeneous crystalline quality for the upper ~150 μm, followed by gradual deterioration towards the interface to the substrate.

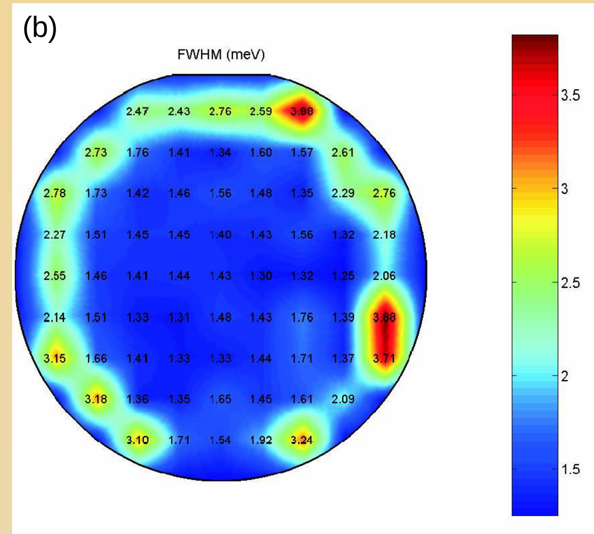
PL

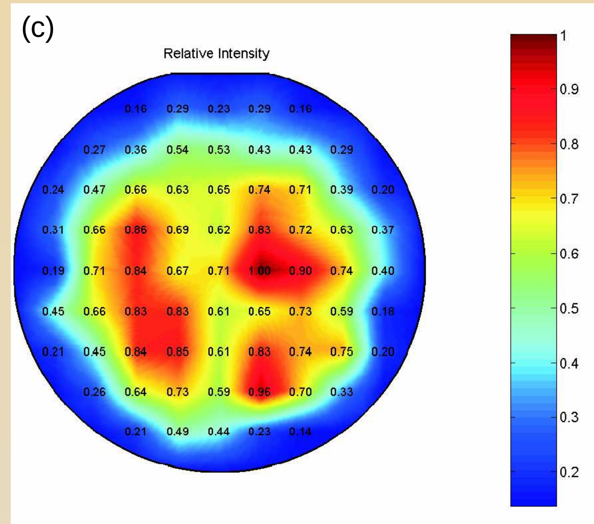


Above: Low-temperature near-band-gap PL spectrum taken in the centre of the wafer.

The main peak, which is due excitons bound to neutral shallow donors (D^0X_A), is accompanied by the free-A-exciton line X_A, a broad, probably C_N acceptor related line (A^0X_A), and a weak feature likely arising from a two-electron transition, $(D^0X_A)_{n=2}^{2e}$.







Right: Planar PL maps of the D^0X_A peak energy (a), the peak broadening (b), and the relative intensity (c) over the 2" wafer.

The position of the D^0X_A emission varies with no more than ±2 meV around 3.471 eV over a diameter of approximately 4 cm. At the wafer edges the D^0X_A peak position is partly lower than the stress-free value, indicating a small amount of tensile stress of ~0.3 GPa at maximum.

The D^0X_A line width as well as the relative line intensity are essentially constant over the 2" wafer and degrade to some extent at the edges only.

Obviously, the HVPE-grown material possesses excellent optical properties and structural homogeneity over nearly the entire wafer.

→ Results & Conclusions

► **Bulk-like GaN** with a thickness of 300 μm was grown on c-plane sapphire substrate, buffered with an Aixtron MOCVD-GaN layer, by **hydride vapor phase epitaxy** in a vertical atmospheric-pressure reactor with a bottom-fed design.

► Using a slit width of 1 mm, the FWHM values of the (1 0 –1 4) and (0 0 0 2) diffraction peaks in the XRD ω-scans are 377 and 450 arcsec, respectively, indicating **high crystalline quality**.
Low-temperature PL spectra taken in the wafer centre show the main donor bound exciton peak at 3.470 eV with a FWHM of 1.4 meV, confirming the high crystalline quality of the GaN.

► The stress-analysis of the position of the main donor bound exciton peak, and the E_1(TO) phonon mode frequency at 558.1 cm^{-1} determined by Infrared Spectroscopic Ellipsometry show consistently that the 2" crack-free GaN is **virtually stress-free over almost the entire wafer**.

► The GaN material reported here is thus highly promising to **serve as a substrate for further homoepitaxial growth** of high-quality GaN needed for the fabrication of advanced electronic and optoelectronic device applications.

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