# (HR)TEM study of the interface region between semi-polar GaN and m-plane sapphire

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GaN is the basis for development and production of LEDs emitting light from green over blue to the UV spectrum. Typically, c-plane GaN is grown on c-plane sapphire substrates. However, this growth direction has the disadvantage that in quantum wells an additional electric field is induced due to pseudomorphic growth. These fields effectively deform the quantum well band structure resulting in the quantum-confined Stark effect (QCSE) and thus reducing the quantum efficiency of such devices. To minimize this effect, current research has the goal to grow GaN e.g. in semi-polar direction on m-plane sapphire using MOVPE.

Knowing from growth on c-plane sapphire, it is necessary to nitrate the substrates surface first for achieving good crystalline quality of GaN [1, 2]. For a better understanding of the nano structure especially of the interface region of semi-polar grown GaN, cross sectional high resolution transmission electron microscopy (TEM) is used [3].

In this study, TEM investigations on the interface between semi-polar GaN and m-plane sapphire are performed. The cross-sectionally prepared specimen was mechanically grinded, polished and followed by both side dimpling. The final thinning process was accomplished by Ar-ionmilling. An image $C_s$-corrected FEI Titan 80-300 TEM operated at 300 kV acceleration voltage was used for this study. Microscopy was done in $[\underline{1}100]_{\mathrm{GaN}}$ zone-axis direction.

An overview image shows a high amount of basal stacking faults (BSF) (Figure 1), while the high-resolution image reveals a strong contrast between sapphire, interface region and GaN (Figure 2). The thickness of the nitrated layer is approximately (3 ± 1) nm. Using the reflections $\pm(1\underline{2}10)_{\mathrm{GaN}}$, $\pm(20\underline{24})_{\mathrm{Al2O3}}$ together with the zero beam, the reconstruction in the light of these reflections reveals a high amount of dislocations, especially directly at the beginning of the interface layer (Figure 3c). These defects are caused by the lattice mismatch of these planes by about 12%. Therefore, the above grown material can be assumed being nearly relaxed and hence an analysis of the lattice constants can be done.

A Python based program was used to determine the lattice constant $a_0$ in multiple 0.7 nm by 0.7 nm areas of the image by fitting periodic structures along the $[1\underline{2}10]_{\mathrm{GaN}}$ direction [4]. The standard deviation of the $a_0$ fit within GaN is 1 pm which shows the high precision of this method. This analysis reveals a significant change of the lattice constant $a_0/2$ in the area of the interface (Figure 3b), while the mean value of $a_{\mathrm{interface}}/2 = (0.156 \pm 0.001)$ nm is in fact the same as of AlN [5]. Because of the crystallographic structure being the same like GaN, it can be deduced that the interface consist of AlN. For the grown GaN, an equivalent measurement results in $a_{\mathrm{GaN}}/2 = (0.159 \pm 0.001)$ nm showing a lattice mismatch of $(1\underline{2}10)_{\mathrm{AlN}}$ and $(1\underline{2}10)_{\mathrm{GaN}}$ planes only by 2%. This result is very close to the theoretical value of 2.5%, since $a_0/2$ for relaxed GaN is 0.160 nm [5].

Using this fit procedure it is possible to directly measure lattice constants with high precision of small areas. Therefore, this study allows verifying that the nitration of the m-plane sapphire wafer surface results in the formation of an AlN interface layer. [6]

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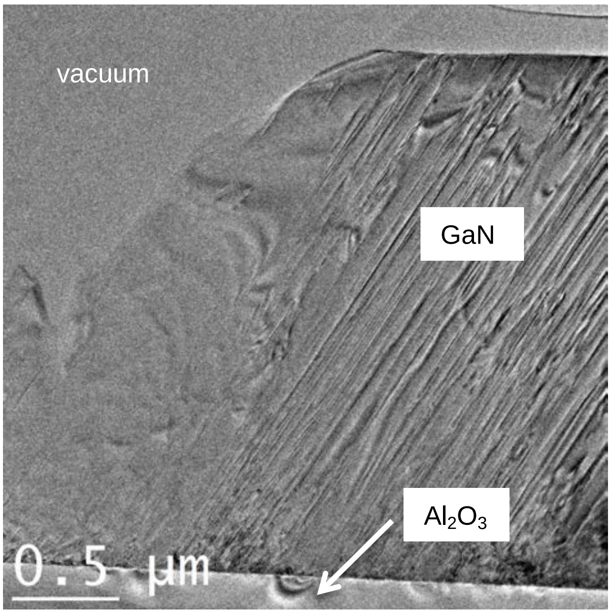


***Figure 1.*** *Overview TEM image of semi-polar GaN on m-plane sapphire along [1100]$_{GaN}$. There is a high density of BSFs.*

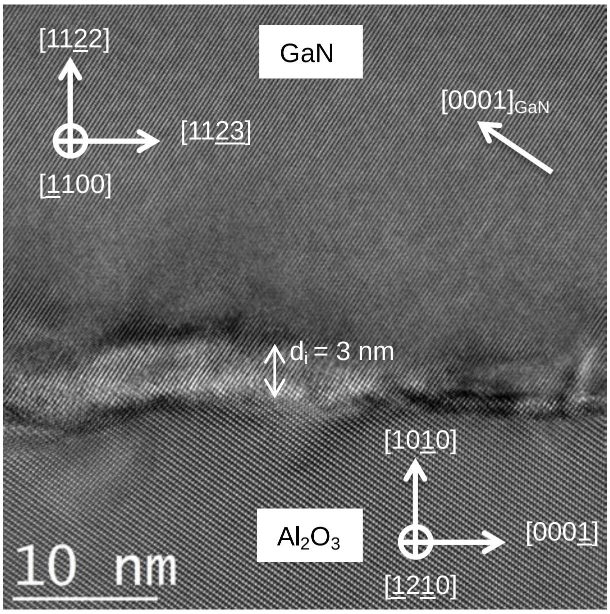


***Figure 2.*** *HRTEM image of the interface region along [1100]$_{GaN}$. A bright interface layer is visible with a thickness $d_i$ of about 3 nm.*

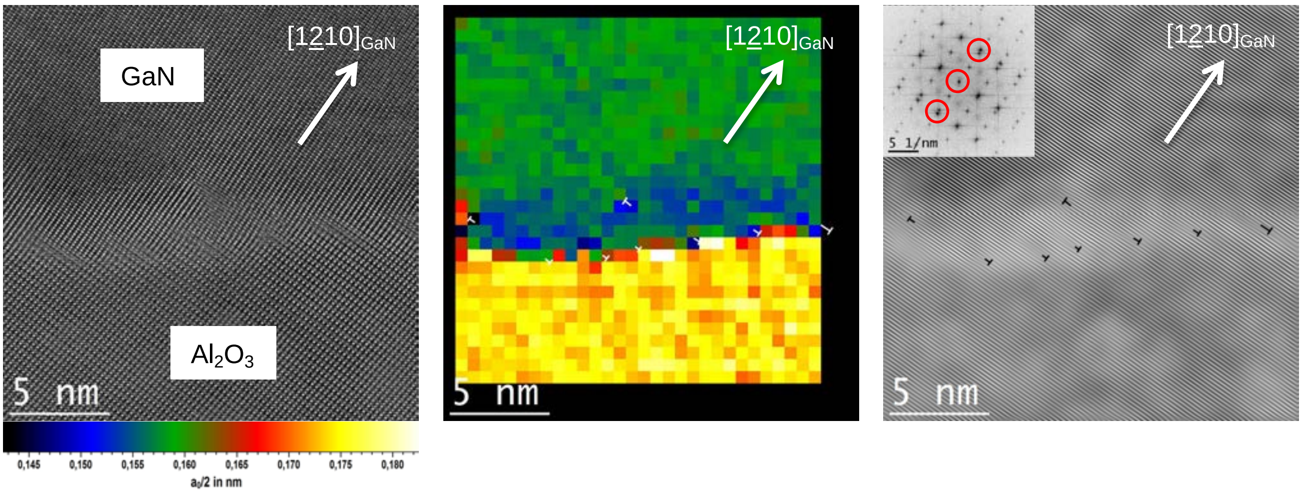


***Figure 3.*** *a) HRTEM image of the interface layer. b) Fit of the GaN lattice constant $a_0/2$ of a) in direction $_{GaN}$ c) Fourier filtered reconstruction in the light of the reflections ±(1210)$_{GaN}$ and ±(2024)$_{Al2O3}$ and the zero as indicated in the inset. The "T" show the position of dislocations.*