DOI 10.5162/iCCC2026/P44

In-situ-Ätzkontrolle für vertikale GaN-basierte Leistungsbauelemente unter Verwendung von Mehrwellenlängen-Interferometrie

In-situ etch control for vertical GaN-based power devices using multi-wavelength interferometry

Ralph-Stephan Unger[1]*, Frank Brunner[1], Enrico Brusaterra[1], Kolja Haberland[2], Sven Peters[3], Olaf Krüger[1]

[1] Ferdinand-Braun-Institut (FBH), Berlin, Germany
[2] LayTec AG, Seesener Str. 10-13, 10709 Berlin, Germany
[3] SENTECH Instruments GmbH, Berlin, Germany

* E-mail: ralph-stephan.unger@fbh-berlin.de

Kurzfassung

Für die Herstellung vertikaler Leistungsschaltbauelemente auf GaN-Basis sind präzise Endpunktdetektionsverfahren für die verwendeten Trockenätzprozesse erforderlich. Eine besondere Herausforderung ist hierbei der geringe Materialkontrast der homoepitaktischen Schichtstapel in den optischen Parametern n und k für verschieden dotierte GaN-Epitaxiestrukturen, die beim Durchätzen nur geringe Unterschiede in den gemessenen Reflektivitäten erwarten lassen. Um das elektronische Verhalten der Driftzone und des p-n-Übergangs in vertikalen GaN-Transistoren zu untersuchen, wurden GaN-Schichten mit unterschiedlichen Dotierkonzentrationen mittels MOVPE (Metalorganic Vapor Phase Epitaxy) gewachsen. Mit Hilfe eines LayTec TRIton in-situ Messsystems mit einer Detektionswellenlänge von 365 nm ist es beim Durchätzen gelungen, Übergänge von unterschiedlich dotierten Bereichen im Epitaxie-Stapel zu erkennen. Die beobachteten Ätztransienten lassen sich qualitativ durch das temperaturabhängige Absorptionsverhalten an der GaN-Bandlücke und den gemessenen Exzitonen-Peak in spektroskopischen Ellipsometermessungen erklären.

Abstract

For the fabrication of vertical GaN-based power switching devices, sensitive endpoint detection methods during dry etching processes are needed. One challenge here is the low material contrast of the homo-epitaxial layer stacks in the optical parameters n and k for differently doped GaN epitaxial structures, which are expected to show only minor differences in the measured reflectance during etching, especially for homo-epitaxial structures on bulk GaN substrates. To investigate the electronic behavior of the drift layers and the p-n junction in vertical GaN transistors GaN layers with different doping concentrations were grown by MOVPE (Metalorganic Vapor Phase Epitaxy). Using a LayTec TRIton in-situ metrology system during patterning of the layer stack by plasma etching with a detection wavelength of 365 nm transitions between differently doped regions in the epitaxial stack could be measured. The observed etching transients can be explained qualitatively by the temperature-dependent absorption behavior at the GaN band gap and by the measured exciton peak in spectroscopic ellipsometer measurements.

1 Motivation

Recently, vertical GaN-based power switching devices on bulk GaN substrates have been developed at FBH for high power density and high switching speed applications [1]. For this purpose, various doped epitaxial layers were grown by MOVPE (Metalorganic Vapor Phase Epitaxy) on 2-inch high-conductivity GaN substrates deploying in-situ monitoring of the reflectance.

The epitaxial structure of a vertical trench MISFET consists in a n^+ doped GaN:Si drain layer, a thick n^- doped GaN:Si drift layer, a p^+ doped GaN:Mg channel layer and a n^+ doped GaN:Si source layer. Further details are described in [2].

For the device fabrication of vertical GaN trench MISFETs, various dry etching steps are needed to etch the recess for the body diode contacts through the top n^+ GaN stopping on the channel layer, to etch the gate trench through the n^+ and p^+ GaN stopping on the drift layer and to etch the mesa edge termination through the three n^+, p^+ and the thick n^- GaN stopping on the n^+ drain layer. All of these etching steps must be done under controlled conditions with in-situ monitoring and precise depth control.

The GaN layers grown on the GaN substrate differ only in terms of their doping concentration and dopant. Due to the small differences in the dopant concentrations only a low contrast in the refractive index can be seen. Additionally, the high absorption of GaN on GaN epitaxial structures makes measurement wavelengths above 600 nm useless to detect layers by standard interferometry.

In this work, we demonstrate for the first time the detection of differently doped GaN layers during etching through the entire epitaxial stack, controlled by in-situ interferometry using a LayTec TRIton multi-wavelength in-situ metrology system.

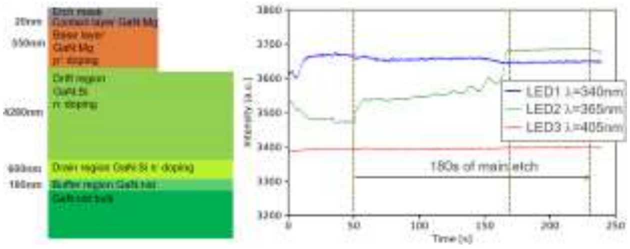

Figure 1 Schematic of the epitaxial test stack (left) used for the gate trench etch process of a vertical GaN trench MISFET. The observed etching transients using a LayTec TRIton multi-wavelength in-situ metrology system are shown on the right.

2 Experiment

A typical GaN epitaxial structure, as shown in Figure 1 on the left, was grown using MOVPE on 2-inch GaN substrates from various suppliers.

To investigate the in-situ measurement capabilities for detecting various doping layers we used a LayTec TRIton in-situ metrology system, equipped with 3 different measurement wavelengths at 340 nm, 365 nm and 405 nm, mounted on top of a SENTECH SI 500 ICP etch chamber. Before starting the etching process, the motorized measuring head was positioned on the unmasked wafer surface inside the chamber. The three wavelengths of the TRIton are focused onto a spot with a diameter of approximately 200 µm, allowing all reflected intensities from the etched wafer surface to be measured simultaneously via an optical path in the chamber.

2.1 Monitoring trench etching

A multi-step chlorine-based ICP process with an etch time of 180 seconds in the main step was used to etch the GaN without surface roughness.

Figure 1 shows the recorded transients of the reflected light from the three LEDs of the TRIton system during etching through the p-n junction.

Due to significant oscillations accompanied by an intensity jump of the etch transient at 365 nm, we determined the boundary between Mg-doped (p~$3x10^{19}$ cm^{-3}) and Si-doped (n~$1x10^{16}$ cm^{-3}) GaN.

2.2 Deep etch at different temperatures

Deeper etching processes through the drift zone are required to etch the mesa edge terminations and form quasi-vertical drain contacts for the transistors. To demonstrate the feasibility of the in-situ measurement system, a complete etch down to the GaN substrate was performed. The result is shown in Figure 2. The reflected intensities at 365 nm wavelength (top curves) show clear transitions depending on the doping concentration. Strongly increasing Fabry-Perot oscillations were observed during transition to the GaN substrate, which can be explained by the decrease in absorption as the layer becomes thinner due to etching. This behavior is temperature-dependent and related to the band gap absorption of GaN [3], which can be observed when etching similar samples at different etching temperatures (see Figure 2).

Neglecting minor changes in etching rate due to temperature, a clear difference in absorption behavior can be observed when similar samples are etched at different etching temperatures (see Figure 3). At an etching temperature of 20 °C, more Fabry-Perot oscillations can be observed, which, compared to etching at 150 °C, is due to a lower extinction coefficient. This is in accordance with the assumption that the GaN band gap absorption shifts to longer wavelengths with increasing temperatures.

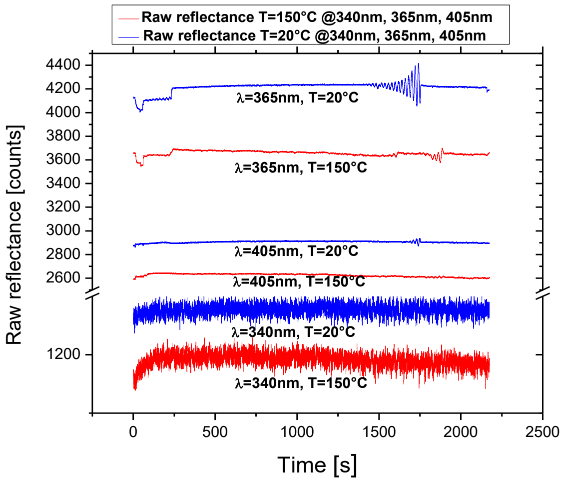

Figure 2 Raw data of etching transients recorded at different etching temperatures on samples from the same epitaxial run.

3 Results and Discussion

To understand the observed features of the measured transients, simulations were performed to predict layer boundaries at a defined etch depth. However, to do so, the knowledge of the optical parameters of the epitaxial layer described with refractive index n and the extinction coefficient k for the used measurement wavelength is the key to simulate the reflectivity vs etch depth.

A spectroscopic SENresearch ellipsometer from SENTECH was used to determine the n and k values based on a describing model. In Figure 3 we compare the refractive index and the extinction coefficient for an etched and the unetched sample.

DOI 10.5162/iCCC2026/P44

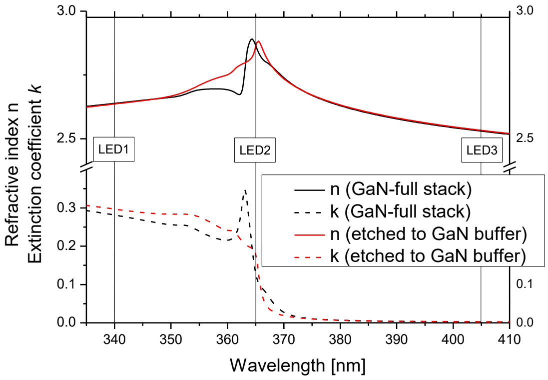

Figure 3 Comparison of optical dispersion based on n and k for an etched and an unetched sample, derived from spectroscopic ellipsometer measurements.

Significant changes in the refractive index and extinction coefficient can be observed very close to the band gap of GaN at 365 nm. This explains qualitatively the observed features in the measured in-situ etching transients only at an emission wavelength of 365 nm (LED2). An exciton peak observed at 363 nm was also found for the unetched sample that is not visible after etching down to the unintentionally doped buffer.

The band gap also depends on temperature and shifts to longer wavelengths as the temperature rises. This behavior was investigated using spectroscopic ellipsometry on a heated sample in which the entire epitaxial stack except for the GaN substrate was etched away. The measurement was performed using the same model, but at different temperatures ranging from 24 °C to 300 °C, as shown in Figure 4.

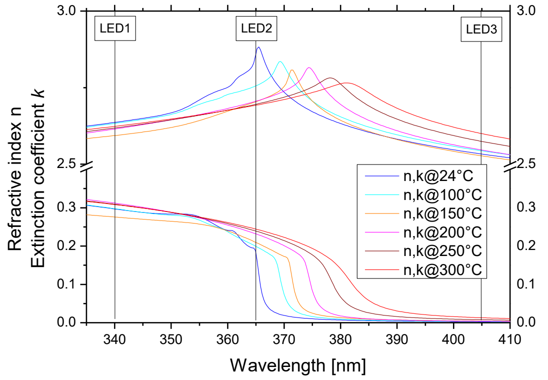

Figure 4 Measured dispersion of refractive index n and the extinction coefficient k based on temperature dependent spectroscopic ellipsometric measurements of an etched sample.

When comparing the n and k values at T = 24 °C and T = 150 °C for a wavelength of 365 nm, we found that the refractive index decreases from 2.85 to 2.70 and the extinction coefficient increases slightly. This is consistent with the observed behavior in Figure 2 and would qualitatively explain the increase in visible oscillation at 20 °C compared to the etching transition at 150 °C. Due to the low material contrast of the doped layers compared to the GaN substrate, it is difficult to separate the n and k values for each layer with a fixed thickness in the model. So, we tried a basic simulation using the transfer matrices model for epi-layers shown in Figure 5 to calculate the expected reflectivity curve in dependence of the etch depth. For the GaN-substrate the n and k values from the etched sample and for the Mg doped GaN epi-layers the n and k values of the unetched sample were used. It has also been reported that absorption increases with the doping concentration of GaN [4]. The n and k values between the top layer and the substrate were obtained by fitting the curve to the measured etch transient at 365 nm wavelength.

The layer boundaries can be predicted very accurately using forward simulation based on 365 nm wavelengths. Comparing the simulation with the data measured at room temperature in Figure 2, the Fabry-Perot oscillations for the p-n junction are more strongly suppressed, but the visible number of Fabry-Perot oscillations corresponds quite well with the two drain layers.

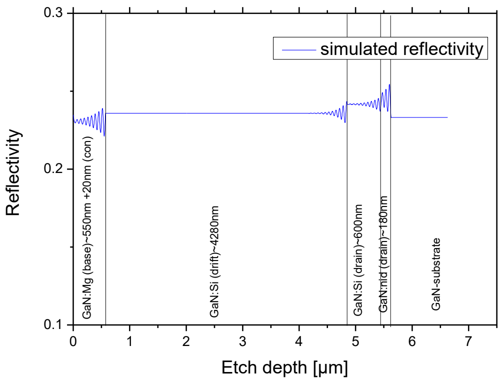

Figure 5 Simulation of reflectivity based on measured n and k values derived from ellipsometric measurements for an etched and an unetched sample.

4 Outlook

A simple simulation based on the optical material parameters n and k for the measurement wavelength of 365 nm used in the transfer matrix model [5] can be applied to qualitatively verify the boundaries between differently doped regions in an epitaxially grown GaN stack on a GaN substrate. In order to understand the change in the visible number of periods in the recorded etch transient curves, the values n and k must be determined more accurately. To do so, we plan to measure the optical parameters for each grown layer separately by etching back the sample used. A more sophisticated approach would be to fit the etch transients using LayTec's SimulyzR software, which can extract the values n and k from the etch data.

5 References

[1] E. Bahat-Treidel *et al.*, "On the Conduction Properties of Vertical GaN n-Channel Trench MISFETs," IEEE Journal of the Electron Devices Society, pp. 1–1, 2021

[2] E. Brusaterra *et al.*, "Vertical GaN Trench MOSFETs With HfO2 / Al2O3 Layered Gate Dielectric," in *IEEE Transactions on Semiconductor Manufacturing*, https://ieeexplore.ieee.org/document/11121373

[3] M. Manasreh *et al.*, "A. Temperature Dependence of the Absorption Band Gap Edge of GaN," *MRS Online Proceedings Library* 395, 553–557 (1995). https://doi.org/10.1557/PROC-395-553

[4] J. Piprek *et al.*, "Analysis of wavelength-dependent performance variations of GaN-based ultraviolet lasers." *Optoelectronic Devices: Physics, Fabrication, and Application IV*. Vol. 6766. SPIE, 2007

[5] M. Born *et al.*, "Principles of optics: electromagnetic theory of propagation, interference and diffraction of light." Oxford, Pergamon Press, 1964.