Deposition control during GaN MOVPE

D. Fahle[1], R. Puesche[2], M. Mukinovic[2], M. Dauelsberg[2], R. Schreiner[2],
H. Kalisch[1], M. Heuken[1, 2], A. Vescan[1]

[1] GaN Device Technology, RWTH Aachen University, 52074 Aachen, Germany
[2] AIXTRON SE, Kaiserstr. 98, 52134 Herzogenrath, Germany
e-mail: dirk.fahle@gan.rwth-aachen.de, phone: +49-2418909105

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Abstract

First we report on the growth of GaN on 200 mm silicon (111) substrates using horizontal flow production MOVPE equipment. After optimizing and fine-tuning the system for growth on large silicon wafers, excellent thickness and PL uniformities on 200 mm silicon, as requested by LED chip manufacturers, are demonstrated.

Secondly, results from separate investigations on the influence of HCl-assisted growth impact on parasitic deposits will be presented. This approach opens the door for the application of an *in-situ* clean after growth process. Adding HCl during growth of GaN significantly reduced parasitic growth on reactor walls, which can in turn lead to significant uptime of the MOVPE reactor.

INTRODUCTION

Group III nitride based devices, such as white light emitting diodes (LED) and heterostructure field effect transistors (HFET), have recently gained a lot of attraction. Due to the unique features of group III nitrides, these devices are considered to play an important role for energy saving, e.g. replacing incandescent light bulbs by LEDs or enabling more efficient power converters.

In comparison to the conventionally used sapphire substrate, Si offers both, lower costs for those wafer sizes of up to 150 mm available from both materials as well as existence of up to 450 mm in diameter. The growth of group III nitrides on Si enables to reduce costs and to use existing 150 mm and 200 mm processing infrastructure and therefore to outperform existing technologies.

Since multi-wafer MOVPE deposition tools for 200 mm also become available, a transition from 150 mm to 200 mm is taking place. For the growth of GaN on Si, due to different lattice parameters and thermal expansion coefficients, special care has to be taken for bow and strain management during deposition. By scaling up wafer size, these issues are scaled up in importance as well.

To master this challenge, a lot of progress has been made to optimize the epitaxial structure by using AlGaN transition buffers [1-3].

The most critical step for heteroepitaxy is surface preparation and the growth of a nucleation layer. Therefore, to avoid a gallium contamination of the surface and the so called gallium melt back etching [4], cleaning of the reactor before every run is essential. Although, an efficient cleaning of reactor parts is necessary to provide a highly reproducible process, not much has been reported in literature about this topic for group III nitrides.

First we will report on the results of a modified metal-organic vapor phase epitaxy (MOVPE) reactor for 200 mm of GaN on Si deposition.

Additionally we will describe a new method to minimize the amount of parasitic deposits during growth, by adding HCl to the gas phase of a conventional GaN MOVPE process.

GROWTH OF GAN ON 200 MM SI (111)

To establish most appropriate process conditions for the growth of five times 200 mm wafers using the existing horizontal flow AIX G5 production tool, the existing MOVPE platform was further upgraded by some features. The probably most important one is the transition from a triple-inlet injector towards a penta injector. This injector features five injection levels instead of three so far. Taking this approach vey good uniformities all over the 200 mm radius are achieved. A comparison of a triple and penta injector is shown in Fig.1. As an example the ammonia distribution is shown for both types of injectors.

Further, the heating system, gas mixing and reactor furniture was redesigned. For distinction purposes, this reactor revision is being labelled as, AIX G5+.

With this new setup, GaN was grown on 200 mm Si (111) wafers. A reference HFET structure was deposited on SEMI-standard wafers with a thickness of 725 µm. After further tweaking process conditions with support from simulation calculations, as displayed in Fig. 2, a homogeneous thickness distribution is achieved, without cracking of the layer, exhibiting a unique axis-symmetric profile.

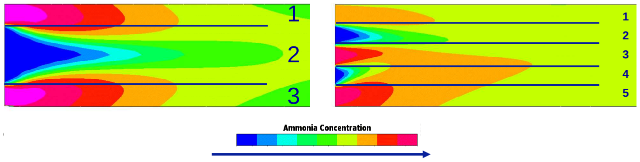
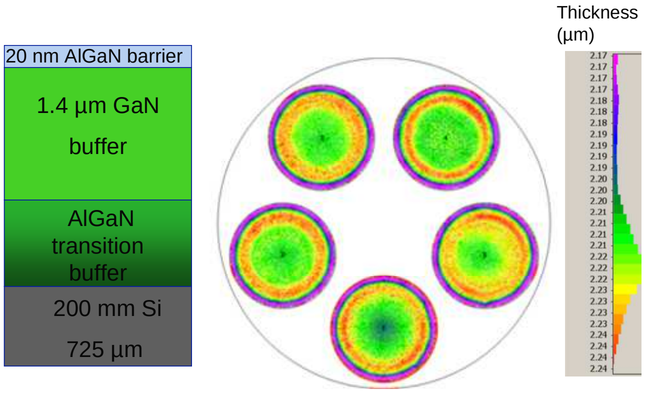


Figure 1: Calculated ammonia distribution for a triple (left picture) and a penta (right picture) injector.

Further, the composition of the AlGaN transition buffer was investigated by HRXRD. 2Theta /Omega scans of the (0002) peaks for two consecutive runs (Fig. 3) reveal exactly the same AlGaN compositions for different spots on the substrate, confirming the composition uniformity.



	Sat 1	Sat 2	Sat 3	Sat 4	Sat 5
Thickness / µm	2.21	2.22	2.21	2.22	2.21
Std. dev. / %	0.90	0.90	0.90	0.90	0.81

Figure 2: Thickness homogeneity of a reference HFET structure.

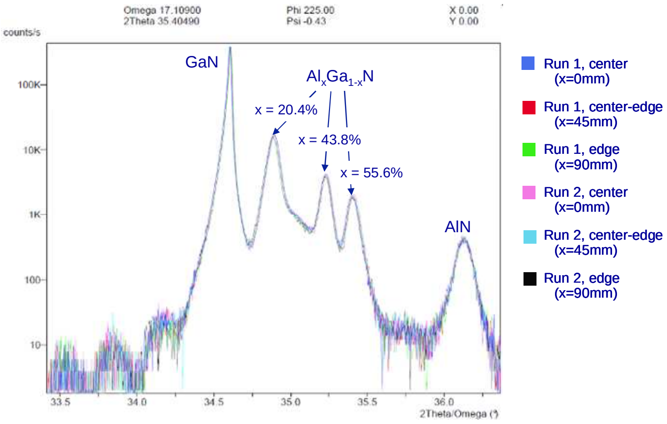


Figure 3: 2Theta /Omega scans of the AlGaN transition buffer at the center, half radius and the wafer edge for two consecutive runs. No variation in composition is observed on wafer and run-to-run.

To show the capability to grow an LED on 200 mm Si, a 5 µm thick GaN layer was grown on 1.15 mm thick substrates. On top, a five-fold InGaN/GaN quantum well structure was deposited, which gave excellent PL homogeneity with a standard deviation of σ=1.3 nm (Fig. 4). By this, 95% of the area was in a 5 nm bin or 99.75% in 10 nm bin ("bin" demonstrating a common classification together with related values serving as quality criteria between LED manufacturers and their customers).

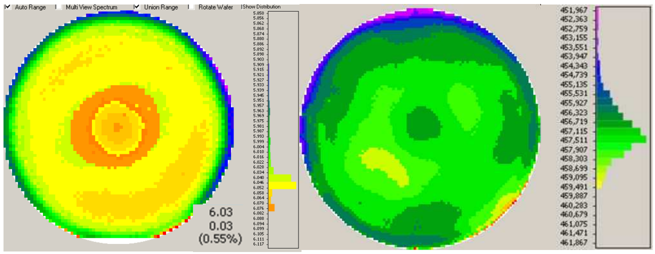


Figure 4: Thickness profile of a 5 µm GaN layer (with AlGaN transition layer 6 µm) on 1.15 mm thick substrates (left picture). In the right picture, a MQW structure on top of this buffer resulted in a homogeneous PL distribution (σ=1.3 nm without edge exclusion).

IMPACT OF HCL DURING GROWTH ON PARASITIC DEPOSITS

As motivated in the introduction, the growth of GaN on Si is sensitive to gallium contamination before or during nucleation. Sources for this contamination are parasitic deposits on reactor walls.

It is therefore of most importance to minimize the amount of parasitic deposits formed during growth or to even completely remove these deposits. Hydrogen chloride (HCl) addition to the GaN process has been proven to play a positive role in limiting parasitic gas phase reactions [5].

To investigate the suitability of HCl, acting both as additional parameter for growth control and *in-situ* cleaning agent, we carried out the following experiments in a research multi-wafer MOVPE system – hotwall system [5, 6] in a 2 inch wafer configuration.

As described in [5], we injected HCl during the growth of GaN on sapphire.

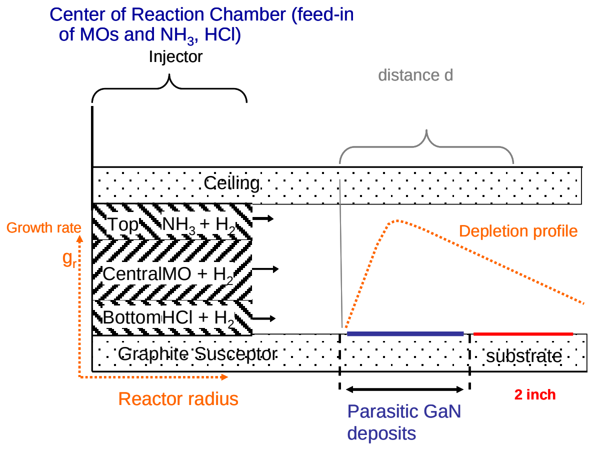


Figure 5: Experimental setup, HCl is separated from NH_3 by the central level of the injector. By introducing HCl at the bottom level, it is introduced close to the area in which the most parasitic deposits are formed. A typical depletion profile of the growth rate in a horizontal reactor is illustrated by the dotted line.

By feeding-in HCl during growth via the lower level of the injector, the highest concentration of HCl in the gas phase is obtained in the region between the location of injector and the substrate edge in which most parasitic deposits occur (see Fig. 5). Before each experiment the system is thermally cleaned by a long high temperature bake (>1200°C) under hydrogen ambient to remove the remained deposits.

Depending on the flow rate of HCl relative to that of TMGa, we observe that the etch-clean effect extends over a certain distance from above mentioned region. A visible sharp change in contrast between the cleaned and the still coated susceptor surface further downstream was observed, as illustrated in Fig. 6.

As reference, a run without HCl was performed, during which we measured the size of parasitic deposits to be 5.5 cm. With increasing HCl flow, the size of the deposits is successively reduced and finally diminished to 0.1 cm for an HCl flow of 16 sccm (see Fig.7).

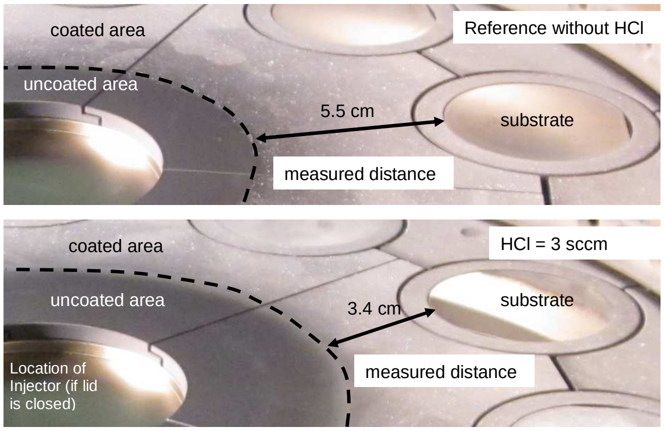


Figure 6: Pictures of the susceptor after a reference growth run without HCl (upper picture) and after a run with 3 sccm HCl (lower picture). A visible sharp change in contrast marks the abrupt transition between the cleaned and coated susceptor surface (highlighted by the dashed line). The size of parasitic deposits is reduced by flowing HCl into the reactor during growth.

The impact of HCl on the deposition profile on the substrate is shown in Fig. 8. Substrates were deliberately blocked from rotating in order to study the effect of HCl on the deposition profile along the reactor radius without averaging the profile over the wafer by rotation. Up to an HCl flow of 3 sccm, the deposition profile is not affected by HCl. No increase in growth rate was observed. Contrary, we observed a decrease in growth rate at an HCl flow of 9 sccm HCl, which did not influence the form of the deposition profile significantly. For the case of 9 sccm, not all deposits were removed upstream the substrate, but the growth rate was already reduced to 0.8 times of that of the reference. Further increasing of HCl flow made the deposits upstream the wafer disappear and only some deposits left on the area between the satellites. At these conditions, the deposition profile on the wafer were considerable affected and the growth rate was reduced by half. Once all parasitic deposits are consumed by HCl, some of the remaining HCl reaches the substrate acts as an etchant on the GaN film. Therefore, a lower growth rate is observed.

As we never observed an increase of growth rate, we conclude that gallium chlorides formed from parasitic deposits do not contribute to deposition on substrate. Experiments on the etch rate of aluminium-containing layers revealed that the etch rate is much lower and high temperatures would be needed. E.g., for etching AlN by HCl, a temperature higher than 1300°C is required but yielding a low etch rate. For these materials, a Cl_2 etch process is more suitable which also gives higher etch rates on GaN, which we will report on elsewhere.

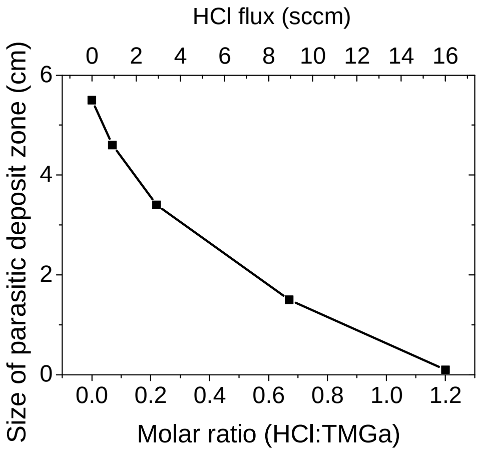


Figure 7: Reduction of the parasitic deposits. The size of parasitic deposits is measured as distance between substrate and transition between the clean susceptor surface and still coated surface. With increasing HCl flow, the amount of parasitic deposits is significantly reduced.

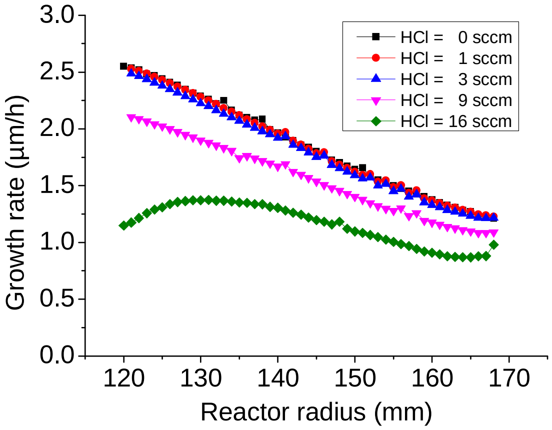


Figure 8: Deposition profiles on substrate for different HCl flows during growth. The growth rate is reduced above an HCl flow of 9 sccm. For an HCl flow of 16 sccm, the shape of the profile is affected due to surface etching.

CONCLUSIONS

We have demonstrated the growth of GaN on 200 mm Si substrates. By optimizing the design of the reactor, we enabled the deposition on SEMI-standard wafers for HFET applications. Furthermore, we demonstrated on top of a 6 µm thick crack-free GaN layer an InGaN/GaN MQW structure with excellent PL homogeneity.

For the use of HCl during growth, we observed a significantly reduced coating of the reactor entrance area, upstream of the substrate. Although for high flows of HCl, all parasitic deposits were converted to gallium chlorides, these species did not contribute to the growth on the substrate. Further, the results show the suitability of HCl for an *in-situ* clean for GaN deposits. For AlGaN- or AlN-containing parasitic deposits, a more reactive gas like Cl_2 is required to obtain reasonable etch rates.

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ACRONYMS

MO : Metal-Organic
MOVPE: Metal-Organic Chemical Vapor Epitaxy
PL: Photoluminescence
HRXRD: High Resolution X-RayDiffraction