LED Structures Grown on 200 mm Diameter Sapphire and Silicon Substrates

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Abstract

This paper reviews results from growing LED structures on 200 mm sapphire and (111) silicon in a single wafer configuration Crius® Close Coupled Showerhead (CCS) reactor. By maintaining good temperature uniformity throughout the process state of the art uniformities were achieved on both substrate materials, including a PL peak wavelength at ~470 nm with standard deviation of σ ~1 nm for an MQW grown on (111) Silicon.

Introduction

Cost reduction of MOCVD processes in a mass production environment can be achieved by increasing the total deposited wafer area per process run. This is possible by increasing the number of wafers or by increasing the wafer diameter. Using 200 mm or 300 mm diameter wafers may provide an additional cost advantage to the wafer post growth processing due to compatibility with standard silicon processing tools.

Maintaining yield is the main challenge of moving to larger wafers, requiring comparable gas delivery uniformity and temperature uniformity across the larger wafer to achieve a comparable uniformity of properties. In CCS systems, uniformity of gas phase delivery is defined by the uniform injection over array of group III and group V delivery injectors and the narrow chamber height (~10 mm).

Uniformity of the growth temperature is often a key aspect of the uniformity of layer properties. For the growth of ternary GaInN temperature uniformity is key to growing uniform compositional layers, as the In incorporation is highly temperature dependent,. The In incorporation reduction with increased growth temperature results in an approximately -1.5 nm wavelength shift with a growth temperature variation of +1°C for material emitting in the blue spectral range. Throughout the process the wafer will bow due to strain from the mismatched epitaxial growth, differences in coefficients of thermal expansion, the vertical temperature gradient through the wafer, and the lateral temperature gradient across the wafer. This in turn may lead to a lateral temperature gradient due to thermal contact with a heated susceptor. Achieving good temperature uniformity for both the high temperature buffer structure and for the InGaN / GaN active region is a significant challenge which increases with wafer diameter. For example a curvature of 40 Km^{-1} corresponds to 50 µm on a 100 mm diameter wafer but 200 µm on 200 mm diameter.

MOCVD System and Temperature Profile Measurement

The Crius® CCS reactor was developed to meet these requirements. The heating unit of the MOCVD system was set up in three concentric zones. The relative power of the three zones was adjusted for each step in the process to compensate for the change in thermal contact due to the wafer bow. For single layer growth these ratios could be tuned based on post growth analysis of previous growth if a known correlation temperature between temperature and properties exist, such as for bulk InGaN, but to maintain uniformity during the entire growth of a complex structure in-situ surface temperature profile measurements are required. With this in mind, and the requirement not to interfere with the showerhead geometry, the Argus® dual wavelength pyrometer was developed (see fig. 1). 24 dual wavelength detectors scan the entire radius of the susceptor and provide a complete scan of the temperature profile as the susceptor rotates. The use of Argus® has previously been demonstrated as a valuable tool in the tuning of temperature uniformity of GaN on (111) Silicon processes [1], [2].

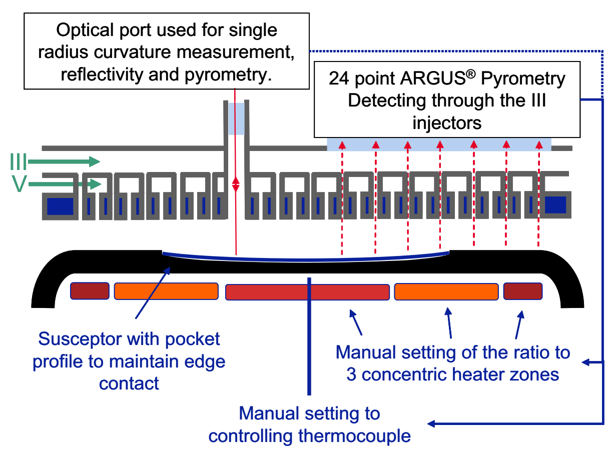

Figure 1: Schematic of the Crius® reactor with in-situ monitoring. The 200 mm wafer sits on a susceptor heated by 3 concentric radial heater zones, which are adjusted throughout the process to optimize the temperature profile on the wafer based on in-situ measurements by Argus®.

Based on thermal modeling and experimental data of temperature profile and curvature the susceptor design was optimized for the larger wafer size. Through this design, higher tensile stress was avoided at the rim of the wafer which is known to initiate fracture. In parallel to this development AIXTRON has developed a version of the Crius compatible with 200 mm and 300 mm cluster based cassette to cassette wafer handling.

The compatibility for the single wafer configuration was tested through the growth of a generic GaInN / GaN LED structure on 200 mm diameter, 1.3 mm thick, c-plane Sapphire substrates (see fig. 2). Additionally a uniformity demonstrator structure was developed on 200 mm diameter, 0.725 mm thick, (111) Silicon.

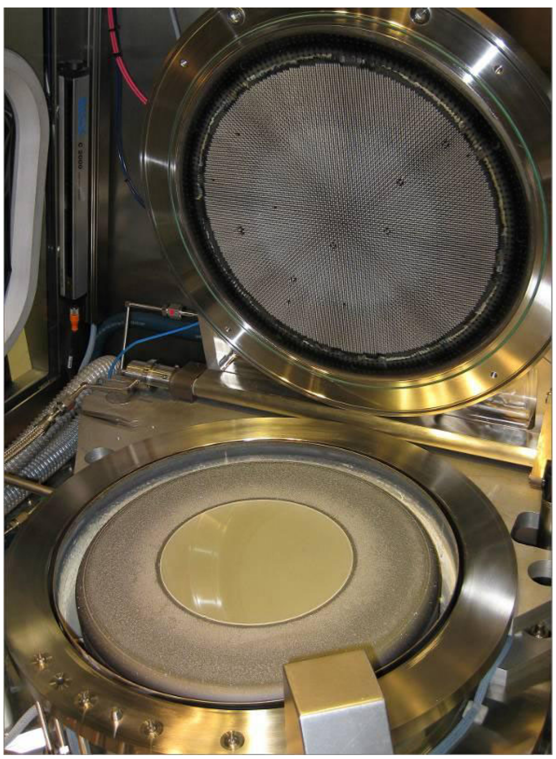

Figure 2: Photo of the Crius® Closed-Coupled-Showerhead MOCVD reactor opened after the growth of an LED structure on 200 mm sapphire.

WAFER CURVATURE DURING GROWTH

Curvature of the wafer was measured using a two-beam deflectometer at 60° intervals on the rotating wafer at a radius of 35 mm, with the two beams and thus the curvature measurement in the radial direction. Analysis of the curvature data during the process on 200 mm diameter Sapphire indicated a spherical profile until growth of the GaN buffer layer, as shown if fig. 3. A minor spread for bowing can be seen between different locations on the wafer during initial anneal in Hydrogen for surface preparation and initial low temperature GaN nucleation layer growth, with values comparable to that observed on 150 mm diameter Sapphire substrates with the same thickness[2]. The deviation between measurement points increases at the start of the GaN buffer growth which is interpreted as non-spherical bow caused by in-homogeneity of the strain in the substrate as originally delivered. The InGaN / GaN MQW growth alternates between two temperatures, ~730°C for the InGaN wells, and 850°C for the GaN barriers. The curvature is shown to change between the InGaN and GaN, from ~30 Km-1 for the InGaN to ~40 Km-1 for the GaN due to the effect of the thermal expansion coefficient difference between the structure and the underlying sapphire.

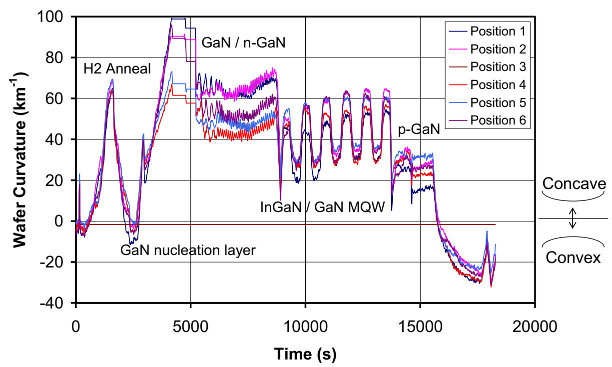

Figure 3. Wafer curvature, measured at 6 positions at 60° intervals around the circumference, during LED growth on 200 mm diameter sapphire.

RESULTS ON 200 mm DIAMETER SAPPHIRE

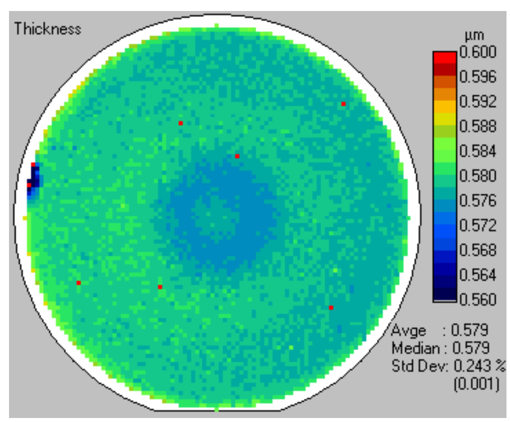

Figure 4: Thickness mapping from a GaN layer, grown on 200 mm sapphire using low temperature nucleation conditions, by post growth white-light interference (Nanometrics rpm VERTEX®). The thickness uniformity, only σ = 0.24% (with 6 mm edge excl.), indicates the uniformity of the gas phase delivery.

To first gauge the thickness uniformity of the low temperature GaN nucleation layer, usually only ~20 nm thick, a test structure was grown under these growth conditions (530°C growth temperature, 900 mbar total pressure) with the growth time increased to 1 hour. The thickness was mapped using post growth white-light interference (WLI) measurements (Nanometrics rpm VERTEX). The reference layer confirmed excellent thickness uniformity by a standard deviation of σ = 0.25% (see fig. 4). This thickness uniformity gives an indication of the uniformity of gas phase delivery over the 200 mm diameter wafer, as the sensitivity to temperature is small at these growth conditions.

Generic LED structures were grown on 200 mm sapphire. WLI measurements yielded a total thickness of approx. 5 µm with a standard deviation of σ = 2.6% (with 4 mm edge excl.), as shown if fig. 5a. These structures are dominated by the high temperature GaN buffer growth at 1070°C and 900 mbar and the one of n-GaN at 400 mbar pressure. The first susceptor design yielded a peak wavelength uniformity of σ = 12.1 nm (with 6 mm edge exclusion) at ~500 nm as previously reported [4]. By using an improved susceptor design iteration and further tuning the heater zone ratios a standard deviation of σ = 3.3 nm at approximately 510 nm average wavelength (with 6 mm edge exclusion) was achieved, as shown in fig. 5b, whilst still maintaining the uniformity of the high temperature GaN layers. These results compare favorably with those reported on smaller sapphire wafers [3].

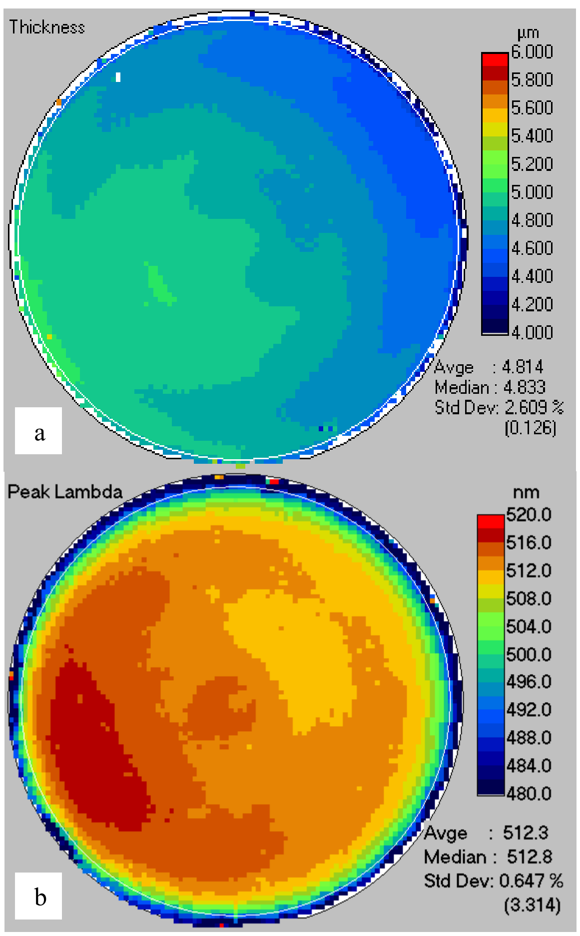

Figure 5: (a) Thickness and (b) PL peak wavelength mappings of a generic LED process run on a 200 mm diameter sapphire substrate.

RESULTS ON 200 mm DIAMETER (111) SILICON

To quantify the potential uniformity of LED structures on (111) Silicon, the structure previously demonstrated for GaN on 200 mm Silicon [1] was further developed. 1.3 µm GaN:Si(3.3x$10^{18}$$cm^{-3}$) crack free (except outer 9 mm) was achieved, with a final bow of <100 µm and Full Widths at half maximum of 550 arcsec and 1000 arcsec for the 002 and 102 reflexes respectively. Further optimization of the structure is expected to further improve these values. Based on ex-situ WLI a state of the art thickness uniformity of σ ~ 1.2% was achieved as shown in Figure 6. Upon this structure a 5 period InGaN / GaN MQW was grown using 750ºC for the InGaN Wells and 850ºC for the GaN barriers which yielded a PL uniformity of σ ~ 1 nm (with 4 mm edge exclusion) at 467 nm peak wavelength, as shown in fig. 7.

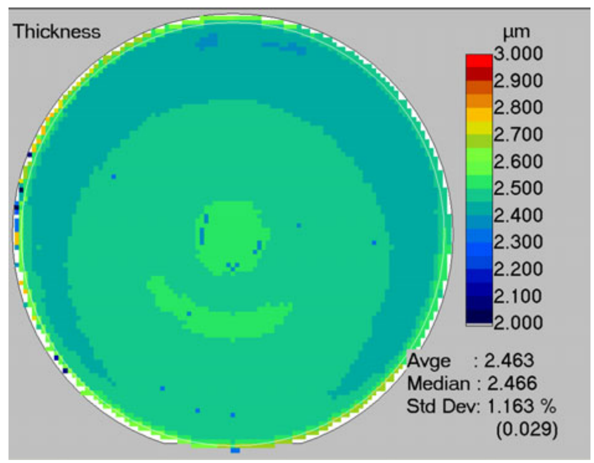

Figure 6: Post growth thickness mapping of an LED structure including 1.3 µm GaN:Si grown on a 200 mm diameter (111) Silicon substrate.

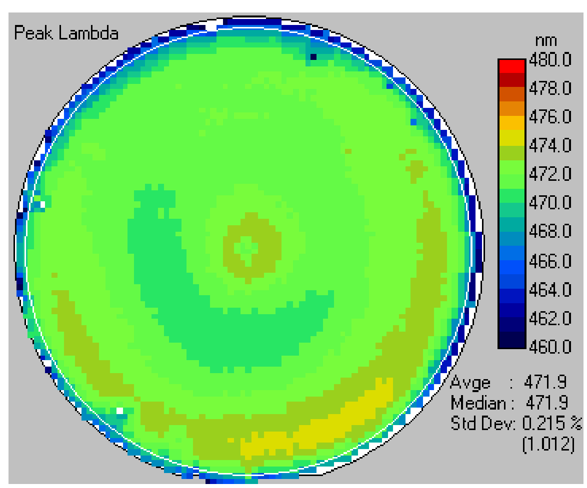

Figure 7: Post growth PL peak wavelength mapping of an MQW grown on a 200 mm diameter (111) Silicon substrate.

CONCLUSIONS

MOCVD growth of GaN-related materials on 200 mm diameter Sapphire and (111) Silicon in a Crius® CCS system have been investigated using in-situ measurement tools for both wafer curvature and precise temperature profile across the susceptor. The results are promising with uniformities on sapphire approaching those achieved on smaller wafers and state of the art uniformities on (111) Silicon.

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ACRONYMS

LED: Light Emitting Diode
CCS: Close Coupled Showerhead
PL: Photo-Luminescence
MOCVD: Metal Organic Chemical Vapour Deposition
WLI: White Light Interference
MQW: Multiple Quantum Well