GT Advanced Technologies Thought Leadership Series

Case Study

SEPTEMBER 27, 2011

Yields Matter: A Case Study Looking at the Impact of Sapphire Material Quality on the LED Wafering Process

Part of GT Advanced Technologies' Characterization of Sapphire Material Project

GT Material Delivers Highest Yields in LED Wafer Manufacturing

For this evaluation, 25 two-inch sapphire cores were selected. The cores were selected from material grown with different sapphire crystal growth technologies, including GT Advanced Technologies' ASF Heat Exchanger Method (HEM) based furnace, Kyropoulos and another "HEM-like" growth method. For the GT ASF cores, a sample matrix was selected based on properties including crystallographic quality, color, gas content, etc. For the purposes of this study, of the 13 GT ASF samples, five were non-LED grade material. This ratio of LED to non-LED grade ASF material is not typical of ongoing GT ASF LED quality yields, but was purposely selected to assure an effective methodology for understanding the impact of crystal defects on LED manufacturing yields. For the other material, GT used market-available cores that were rated LED grade by the core supplier. The crystal defect levels of each sapphire core were quantified and graded using GT's Optical Homogeneity Technique (OHT). The choice of cores was based on an experiment design and included a wide range of material properties to show the relationship between epi-wafer yields and output variables, including growth technology, suppliers, and various material properties.

In addition to the conclusions detailed in the Executive Summary (right), the study also determined that although the sapphire material in this study had a wide range of Etch Pit Density (EPD) results, EPD measurements were found to have a low correlation to overall wafering performance. In fact, the study concluded that the material with the lowest EPD count, performed poorly during slicing and had the largest rejected wafer ratio.

Executive Summary

This document presents the results of a study performed by GT Advanced Technologies (GT) that summarizes the effects of sapphire material quality on the epi-ready wafer manufacturing process. This wafer study is part of a larger comprehensive material characterization project which was initiated by GT to study the effects of sapphire material properties on the entire manufacturing processes in the High Brightness (HB) LED value chain.

The wafer evaluation presented in this study concluded that sapphire material quality has a direct impact on yields in wafer manufacturing of substrates for HB LEDs and that GT sapphire material that was grown in GT's Advanced Sapphire Furnace (ASF™) produced wafers with the most consistent geometry (Ra, TTV, Bow, Warp) and the lowest wafer rejection rate during the wafer manufacturing process. Rejected wafer ratio, which is inversely proportional to wafer yields, has a direct impact on wafer manufacturing profitability and consistent wafer geometry is a requirement of downstream epitaxial growth and device fabrication. GT's overall performance ranked first in this study, making it the preferred choice when considering the economics affecting the wafering process for epi-ready wafers in the HB LED value chain.

Sapphire Material Qualification

Blind study designed to cover entire LED manufacturing value chain.

Background

On July 29, 2010, GT Advanced Technologies acquired Crystal Systems Inc. (CSI). During its 40-year history, CSI established a leadership position in the growth of the world's highest quality sapphire and was supplying high quality material to the LED industry for over 12 years.

GT operates a state-of-art sapphire production facility in Salem, Massachusetts. The facility produces high quality boules and cores and functions as a technology development center and a training facility for its ASF customers. Following the acquisition, GT tripled the capacity of its crystal growth facility. GT also commercialized the ASF furnace, to enable new entrants to develop sapphire substrate businesses in order to meet the LED industry's growing demand for sapphire substrates.

In the beginning of 2011, GT initiated an extensive sapphire material qualification project to determine the sapphire material "Metrics that Matter" in the manufacturing processes of HB LED devices. A significant component of this project included an analytical study of the fundamental properties of sapphire by engaging third party analytical laboratories and material science experts.

The project was designed to cover the entire LED manufacturing value chain, from crystal growth to the final LED device, and beyond to the light bulb proof-of-concept (Figure 1). The project was structured to obtain unbiased data by working through reputable laboratories and leading manufacturers and keeping blind all material sources and parameters.

The goals of this study were to 1) identify critical metrics that had a direct impact on the wafer manufacturer's yields as well as LED device performance and 2) determine if the different sapphire growth technologies resulted in specific material properties that had an impact on LED performance.

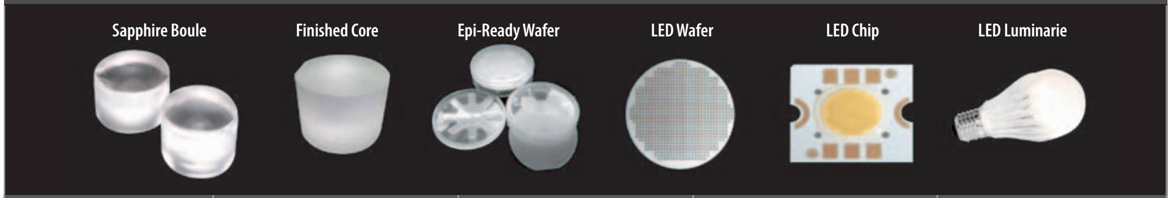
This case study focuses on the blind wafer study and the impact of sapphire quality specific to the wafering process. GT has obtained additional data and analysis results beyond what is reported in this case study from numerous third-party analytical laboratories and leading wafer and LED process metrology experts. This includes data confirming the purity and superior crystal homogeneity of ASF material. GT is in the final stages of the device fabrication analysis, working with a top MOCVD OEM, as well as reputable LED device manufacturers on 2", 4", and 6" substrate processes.

Figure 2 - Epi-Wafer Fabrication Process

INPUTS: Measurable Fundamental Properties of Sapphire

OHT (metrology of low angle grain boundaries, crystal structure, bubbles)	Interferometry Transmission (200-800 nm) GDMS (elemental analysis)	Color Analysis of Materials (color measurement) X-Ray (crystallographic analysis)	Laser Inspection and LED Surface Metrology (pre- and post-epi automated laser wafer inspection)	X-Ray Diffraction (crystal micro-structure) Physical Properties

PROCESS: LED Process Variables and Macroscopic Interactions



(GT Advanced Technologies)	Wafering Study (3rd party)	MOCVD Study (3rd party)	LED Device Fab (3rd party)	LED Luminarie (3rd party)
Crystal Growth (yields, process) Finishing of Cores (process)	Wafering of Cores (process and performance) Epi-Wafer Analysis (wafer yields, Ra, TTV, Bow Warp) Wafer EPD Analysis (pits/cm^2)	Epitaxial Growth (process and performance) Photo Luminescence (LED light metrology, wavelength, color brightness) Leading LED Metrology Co. (post-epi automated laser wafer inspection)	LED Fabrication (process and performance) Electrical Performance (forward voltage, reverse leakage, etc.) LED Light Performance (peak wavelength, brightness, binning)	LED Lamp (proof of concept)

OUTPUTS: Yields, Device Perfromance, Economics

LED Material Yields (mm, quality, cost)	LED Wafer Yields and Quality (wafer yields, wafer geometrics, cost per wafer)	Epitaxial Yields and Performance (epitaxial efficiency, low defects, performance)	LED Device Yields (device color binning, brightness, electrical performance)	Luminarie (esthetics, performance, brightness, life)

Figure 1 - Characterization Study Overview

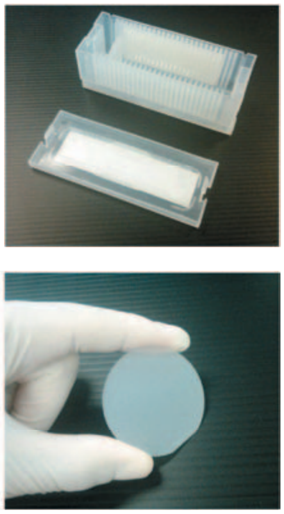


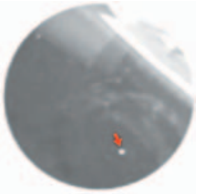
Figure 3 - Process Single Side Polish 2" Wafers

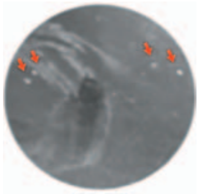
Blind Wafering Study

This evaluation focused on a critical aspect of the LED manufacturing value chain; epi-wafer sapphire substrate manufacturing (Figure 2). In order to determine how different material parameters as well as growth techniques impacted epi-wafer manufacturing, a reputable wafer manufacturer was identified and secured to process the material. For this experiment 2" cores were selected primarily driven by their broad availability and standardization across manufacturers. Material was obtained from four sapphire manufacturers, including GT, that produce material using the different growth technologies identified on page 1. Statistically significant core lengths of each material were obtained. The complete sample library for this experiment included 25 2" cores, totaling approximately 1,500mm of material (Figure 3).

To ensure that the data remained unbiased, all samples delivered to the wafer manufacturer were independently labeled to mask their origin. Prior to delivery all material sent was inspected and the quality was graded according to GT's Optical Homogeneity Technique (OHT) method. Also, an additional EPD analysis was performed on the wafers manufactured during the study.

The manufacturer processed all 25 cores into single side polished wafers. The run schedule was randomized to minimize process drift effects and ensure that the data reflects differences in material properties. Data was collected at many of the critical stages of the manufacturing process, including wafer geometry parameters (Ra, TTV, Warp, and Bow) and the Rejected Wafer Ratio.


Single bubble in crystal


Moderate bubbles


Severe bubbles

Figure 4 - Bubble Defects in Sapphire

Evaluation Procedure

OHT Procedure

Before sending the material to the wafering facility, all cores were graded using OHT. The OHT method developed by CSI and refined over the last 40 years. OHT is used to grade sapphire material produced for many different sapphire markets including HB LED. The OHT procedure includes the inspection of material under a high intensity light to detect cracks, bubbles and inclusions followed by an inspection under a polarized light for crystal lattice defects and low angle grain boundaries (lineages).

High Intensity Light Inspection Procedure

High intensity light inspection is an efficient inspection method that provides very accurate analysis of bulk material for defects that are significant to the LED wafer manufacturing and GaN growth MOVCD processes. These include bubbles, inclusions and gas in sapphire material. Bubble defects that are visible to 1X magnification can lower Epi-ready wafer yields. Proper inspection for these defects ensures optimal material usage for high yields.

Required Equipment

- High intensity light source (laboratory illuminator with focusing lens and fiber optic light guide)
- Index matching fluid

Procedure

An index matching fluid is applied to the surface of the core to improve visibility into the bulk material at the boule or core level. The material is then inspected visually while moving the high intensity light source across the entire boule or core. The trained technician then identifies and marks the bubble, crack and inclusion locations on the core.

Grading Procedure

Bubbles are trapped gasses or vacuum holes inside a crystal. These defects can impact Epi wafer yields by creating localized defects in the GaN growth if the bubbles end up at or near the Epi surface rather than in the bulk material. Figure 4 shows trapped bubbles in sapphire. The OHT method grades the material based on frequency and size distribution of bubbles.

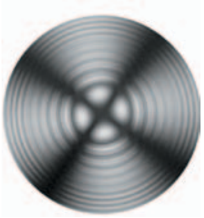
Bubbles may not affect the LED manufacturing process if they are small enough, or if they end up deep inside the Epi-ready wafer instead of at the surface. Only surface defects are responsible for negatively impacting GaN growth quality and downstream LED yields.

Polarized Light Inspection Procedure

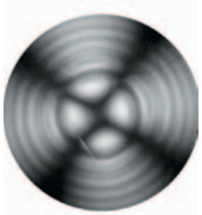
Polarized inspection is done at GT for all outgoing LED substrate sapphire cores. Polarized inspection allows for grading of material crystal lattice quality.

Required Supplies

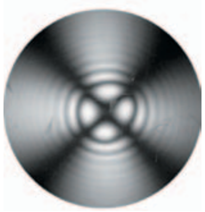
- Polarized light source (light box with polarized film) or (polarized light table)
- Polarized glasses
- Index matching fluid
- Gloves for handling



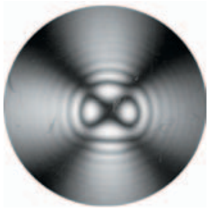
Nearly perfect crystal lattice structure



Minor crystal lattice deformation



Moderate level of crystal lattice deformation



Heavy crystal lattice distortion

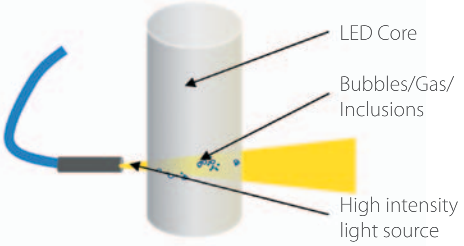
Figure 6 - Crystal Lattice Defects in Sapphire

Procedure

- The core is placed in front of polarized light source
- The surface is then wiped with an index matching fluid to improve the clarity of the image
- The core is then inspected with polarized glasses for bulk material defects

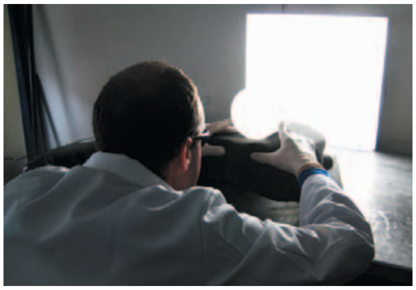
See Figure 5 - OHT Procedure below for details.

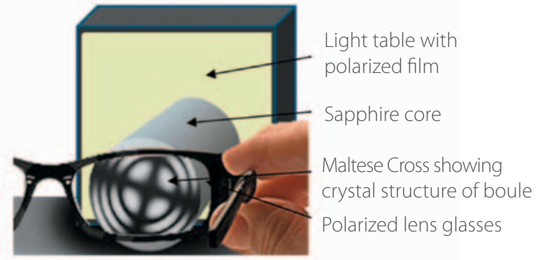
High Intensity Light Inspection of Sapphire Cores for Bubbles and Inclusions



Visual inspection for gas, scatter, inclusions under a high intensity white light. Inspection under high intensity light at core level provides a very accurate reflection of gas content in the material. Gas or bubbles can be marked up on core, removed or wafered depending on size and distribution.

Polarized Light Inspection of Cores for Crystalline Structure Quality





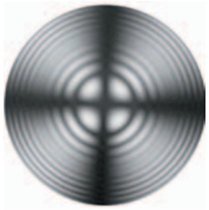
Polarized light inspection of boule using a light table with polarized film and polarized lens glasses. The crystal "Maltese Cross" can be observed. At core level, the crystalline structure can be analyzed accurately for defects, including: low angle grain boundaries (lineages), twins, lattice distortions.

Figure 5 - OHT Procedure

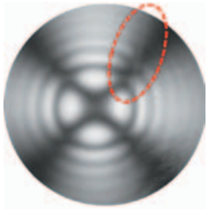
Grading Process

Grading of the material is done based on a number of variables, including: crystal lattice distortion, low angle grain boundaries (lineages), twins, and inclusions. Twins and inclusion are extremely rare and are therefore not discussed in this report.

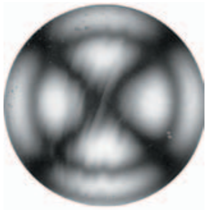
Lattice Distortion – Crystal lattice distortions occur where there is a localized or global discontinuity in the atomic pattern of the crystal molecules. Severity of lattice dislocation can vary and can be detected using cross-polarized light. Figure 6 shows four examples of progressively worsening crystal lattice distortion.



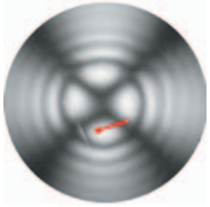
Lineage free crystal



Soft low angle grain boundary ("lineage")



Acceptable LED production level of low angle grain boundaries ("soft linages")



Sharp low angle grain boundaries can effect GaN growth ("sharp lineage")

Figure 7 - Low Angle Grain Boundary "Lineage" Defects

Low Angle Grain Boundary – A low angle grain boundary occurs when two different crystal orientations of the same material come together. The level of severity of low angle grain boundaries is influenced by the level of crystal lattice mismatch. This is the defect that sometimes is referred to as a lineage in the crystal. Figure 7 shows a low angle grain boundary in a localized part of the wafer.

A fine abrasive ground finish on the material face significantly improves visibility of bulk crystal material at the boule or core level.

There is no such thing as a perfect crystal and a trained operator can distinguish between different levels of crystal defects. GT has identified an acceptable level of defect severity; however, some LED manufacturing processes may be less or more flexible in using different material quality. Operators must be trained to determine an acceptable quality level, or deformation of the "Maltese Cross" and to identify grain boundaries and their severity.

Wafering Procedure

A standard two-inch process was selected for manufacturing of the epi-wafers. A leading wafering house was selected for the evaluation. All 25 cores were shipped to the wafer house and marked such that neither the source nor quality of each core was disclosed to ensure a blind evaluation, without any bias toward any particular supplier or growth method. Figure 8 shows the specification for the epi-ready wafer as provided by the wafering house.

Item	Specification
Material	High Purity and Monocrystalline Al_2O_3
Diameter	50.8 ± 0.25 mm
Thickness	430 ± 20 um
Orientation	C-plane (0001) off angle 0.20º ± 0.1º(M-axis); 0± 0.1º(A-axis)
Orientation Flat	16.0 ± 1.0 mm
Primary Flat Location	A-axis [11-20] ± 0.3º
Front Side Surface	Epi-Ready Polished
Surface Roughness	Ra < 0.3 nm
Edge Chamfering	Ground with 45 degree Chamfering
Back Side Surface	Fine Ground Ra = 1.0 ± 0.2 um
TTV	< 10 um
Bow/Wrap	+3 ~ - 10 um / < 10 um
Package	Clean Room, Nitrogen Atmosphere

Figure 8 - EPI-Wafer Spec

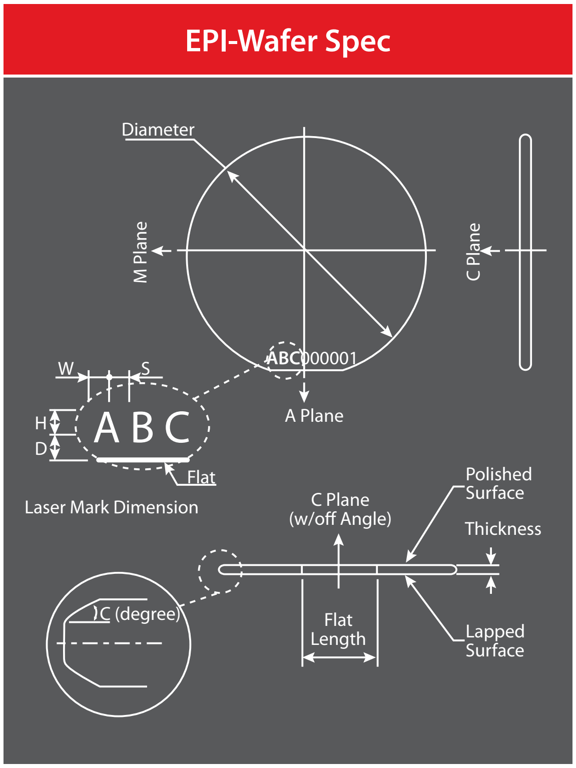


Figure 8 - EPI-Wafer Spec

EPD Procedure

The sapphire industry has been using EPD analysis as a supporting analytical inspection of sapphire material for substrate applications, which is performed at the wafer level. The EPD method is a destructive analysis and provides some insight into the crystal structure as well as surface quality of the wafers. EPD analysis provides a pit count of the surface of the wafer after chemical etching. The inspection looks at the EPD count per unit area and is linked to crystal structure as well as subsurface damage ([1]Robert T. Bondokov, 2006) induced during the wafer manufacturing process. GT performed the EPD analysis to compare it with OHT in terms of its reliability in identifying LED vs. "Non-LED" sapphire quality. After wafering was completed, two wafers were selected from each of the 25 cores, roughly 10mm deep from each side of the core. Consequently 50 wafers were submitted for EPD analysis whereby each wafer was measured in nine locations. The image in Figure 9 shows a layout of measurements taken on a sapphire wafer.

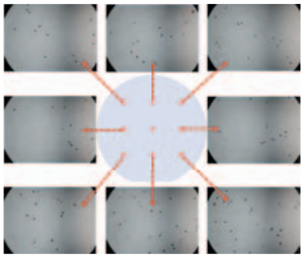


Figure 9 - EPD Sampling Diagram

Results

OHT Grading Results

The OHT process, as described above, was followed to individually inspect and grade all bulk sapphire material. For the purposes of this study, 13 GT ASF samples were used, five of which were non-LED grade material. This ratio of LED to non-LED grade for ASF material is not typical of ongoing GT ASF LED quality yields but were included to assure an effective methodology for understanding the impact of crystal defects on LED manufacturing yields. For the other material, GT used market-available cores that were rated LED grade by the core supplier.

Each anonymously unmarked core was inspected and graded by GT's trained and experienced OHT technicians. A grading code was assigned. Below is a simplified grading result, shown only as LED and Non-LED grade. In practice a higher resolution grade was assigned to each core to further differentiate subtle quality grades. In the table shown as Figure 10, the grade marked by supplier on the cores are also shown.

Supplier	Growth Method	Grade Marked by Supplier	OHT Grading Results
GT	ASF	LED	LED
GT		LED	LED
GT		LED	LED
GT		LED	LED
GT		LED	LED
GT		LED	LED
GT		LED	LED
GT		NOT LED	NOT LED
GT		NOT LED	NOT LED
GT		NOT LED	NOT LED
GT		NOT LED	NOT LED
GT		LED	LED
GT		NOT LED	NOT LED
Competitor 1	KY	LED	LED
Competitor 1		LED	LED
Competitor 1		LED	NOT LED
Competitor 1		LED	NOT LED
Competitor 1		LED	LED
Competitor 1		LED	LED
Competitor 2	HEM-like	LED	LED
Competitor 2		LED	LED
Competitor 2		LED	LED
Competitor 3	KY	LED	LED
Competitor 3		LED	LED
Competitor 3		LED	NOT LED

Figure 10 - OHT Results Table

OHT is Able to Reliably Pick Up Low Angle Grain Boundaries and Bubbles

These are known to impact epitaxial growth and consequently LED device yields.

Blind Code	Wafers Inspected	EPD			
		Average	Std Dev	Max. Avg	Min. Avg
CS-194	2	246	105	347	145
CS-499	2	285	165	559	411
CS-745	2	264	185	307	222
CS-289	2	652	411	822	482
CS--688	2	662	346	664	660
CS--933	2	721	207	950	492
CS-513	2	271	177	381	361
CS-273	2	802	572	839	765
CS-541	2	846	734	943	748
CS-919	2	3568	3218	3898	3238
CS-418	2	627	316	842	411
CS-839	2	670	188	738	603
CS-617	2	655	265	772	535
CS-628	2	140	2006	148	131
CS-377	2	1358	68	1550	1166
CS-532	2	513	169	553	472
CS-609	2	2551	1287	3417	1685
CS-181	2	111	77	142	81
CS-622	2	364	204	377	350
CS-122	2	332	151	381	283
CS-942	2	293	85	303	283
CS-936	2	268	120	270	260
CS-231	2	630	172	637	623
CS-299	2	522	212	549	495
CS-746	2	898	455	1193	603

Figure 11 - EPD Table Results

GT uses the OHT inspection method for the analysis and inspection of incoming sapphire material for LED substrates. OHT reliably picks up low angle grain boundaries and bubbles which are known to impact epitaxial growth and consequently LED device yields and device color and electrical properties.

EPD Results

In Figure 11, EPD results show that 22 of 25 cores submitted for analysis were less than 1000 pits/cm^2. Two of the samples that passed the EPD test (< 1000 pits/cm^2) were from material that was graded as "Non-LED" quality using the OHT method. This demonstrates that the OHT method is able to detect critical material defects, which the EPD method did not and supports that OHT is a more robust and reliable grading technique of "LED" grade sapphire.

A key observation of our analysis shows that GT samples that had very high EPD counts were graded as below LED Quality by the OHT method due to lineages or low angle grain boundaries that were detected. While there was a moderate correlation of EPD to OHT results, the data outliers included samples

with low EPD counts that were graded as Non-LED by OHT, due to sharp "lineages". These lineages are known critical defects in HB LED manufacturing during the epi growth process and are often rejected. This further confirmed our understanding that EPD is not a complete reflection of sapphire material quality, as it can fail to detect certain critical defects. A total of five cores were determined to be below LED grade by OHT, yet were found to be acceptable using a standard EPD evaluation (Figure 12).

Observation

EPD is not an effective means of quality measurement or quality control.

In conclusion, the study illustrated that EPD is not an effective means of quality measurement or quality control for LED material as it passed six samples that were proven by the OHT method to have critical defects that would impact LED manufacturing and wafer loss. OHT, on the other hand, was able to identify all defective material prior to wafering, which would have resulted in no lost wafers. To further verify this observation, GT will be conducting further experiments to generate additional supporting data on OHT vs. EPD reliability.

Core Sample	EPD (pits/cm^2)				EPD Grading (<1000 pits/cm^2)	OHT Grading Results	Missed Quality Problem by EPD
	Average	Std Dev	Max. Avg	Min. Avg			
1	246	105	347	145	LED	LED	
2	285	165	559	411	LED	LED	
3	264	185	307	222	LED	LED	
4	652	411	822	482	LED	LED	
5	662	346	664	660	LED	LED	
6	721	207	950	492	LED	LED	
7	271	177	381	361	LED	LED	
8	802	572	839	765	LED	NOT LED	MISSED
9	846	734	943	748	LED	NOT LED	MISSED
10	3568	3218	3898	3238	NOT LED	NOT LED	
11	627	316	842	411	LED	NOT LED	MISSED
12	670	188	738	603	LED	LED	
13	655	265	772	535	LED	NOT LED	MISSED
14	140	2006	148	131	LED	LED	
15	1358	68	1550	1166	NOT LED	LED	
16	513	169	553	472	LED	NOT LED	MISSED
17	2551	1287	3417	1685	NOT LED	NOT LED	
18	111	77	142	81	LED	LED	
19	364	204	377	350	LED	LED	
20	332	151	381	283	LED	LED	
21	293	85	303	283	LED	LED	
22	268	120	270	260	LED	LED	
23	630	172	637	623	LED	LED	
24	522	212	549	495	LED	LED	
25	898	455	1193	603	LED	NOT LED	MISSED

Figure 12 - EPD vs. OHT Table

Rejected Wafer Ratio is a Good Indicator

It shows the percentage of wafers failing epi-ready spec set forth by wafering house.

The EPD results showed that on average GT had an EPD count of 443 pits/cm^2 for all samples that were graded by OHT at or above "LED Grade". The other suppliers' material had EPDs of 934, 298, 683 pits/cm^2 (Figure 13). Looking at KY vs. ASF, KY had statistically significant greater average in EPD values. On average, KY growth had two times the amount of pits per square centimeter as material produced in GT's ASF furnace.

Supplier	Growth Technology	Average EPD Count
GT	ASF	443.00
COMPETITOR 1	KY	934.60
COMPETITOR 2	HEM-like	297.67
COMPETITOR 3	KY	683.33

Figure 13 - EPD Results

Wafering Results

Wafering results were measured by evaluating wafer quality, before and after anneal, as well as tracking the "Rejected Wafer Ratio" which measured the number of wafers that either broke or did not pass the epi-wafer spec.

One key observation from the results was the relative number of yielded (accepted specification) wafers to the amount of rejected wafers per core. This rejected wafer ratio, which is inversely proportional to wafer yields, is a critical measure of the material performance during the wafering, annealing and polishing process. In Figure 14, the rejected wafer ratio appears to be a reliable indicator of material quality, as it shows the percentage of wafers that failed to meet the epi-ready specification set forth by the wafering house. The LED grade material from GT had the lowest rejected wafer ratio in the study.

Supplier	Growth Technology	Lost Wafer Ratio	Overall Rank
GT	ASF	2.4%	1
COMPETITOR 1	KY	6.0%	3
COMPETITOR 2	HEM-like	6.9%	4
COMPETITOR 3	KY	3.0%	2

Figure 14 - Rejected Wafer Ratio Results

The results shown in Figure 15 relate to wafering performance. In this evaluation post anneal wafer geometry data, including Ra, TTV, Warp and Bow, was measured and included in the analysis. Flat wafer geometry, indicating low Warp and absolute Bow values, results in a maximum thermal contact of the wafer to the MOCVD carrier, and thus optimizing the wafer temperature. This has a direct impact on LED wavelength uniformity maximizing LED device yields and price premiums for in-spec devices. ([2]*In situ metrology advances in MOCVD growth of GaN-based materials*, October 2004).

Supplier	Growth Technology	After Anneal				Overall Rank
		Average Ra	Average TTV	Average Warp	Average Bow	
GT	ASF	1.15	6.37	3.93	-0.76	1
COMPETITOR 1	KY	1.21	6.16	4.29	-1.12	3
COMPETITOR 2	HEM-like	1.21	8.60	6.08	1.28	4
COMPETITOR 3	KY	1.20	7.87	3.56	-1.06	2

Figure 15 - Wafering Metrology Results with Ranking

Results Summary

Wafering Analysis Ranking Results								
Supplier	Growth Technology	EPD Average Count	Wafering Performance				Wafer Yields*	Ranking
			Average Ra	Average TTV	Average Warp	Average Bow		
GT	ASF	2	1	2	2	1	1	1
COMPETITOR 1	KY	4	3	1	3	3	3	3
COMPETITOR 2	HEM-like	1	4	4	4	4	4	4
COMPETITOR 3	KY	3	2	3	1	2	2	2

Figure 16 - Results Summary Ranking

An overall ranking was based on lost wafer ratio, EPD results and wafering geometry. The ranking provides a 1-4 rank for every variable in this evaluation, with the "1" indicating the best performance and "4" indicating the worst (Figure 16). According to this analysis GT ASF material scored highest on average, against Competitors 1-3.

Other key study findings included:

- Most critically, GT ranked first according to wafering yields as determined by the wafer reject ratio described in section Wafering Results. This is significant because wafer yields have a direct impact on profits for wafer manufacturers.
- There are statistically significant and quantifiable differences between materials from different growth technologies.
- ASF-grown material has the overall best wafer geometry specifically Ra, TTV, Warp and Bow. This ensures a competitive advantage for the wafer manufacturer when working with ASF grown material, as there is a direct link in wafer geometry to downstream processing during epi growth where predictable wafer geometry is required in the MOCVD chambers.
- The study confirmed the validity of GT's OHT method, which has been used to deliver consistent LED grade quality material to the HB LED industry for over 12 years.
- A correlation was identified between material grade as determined by the OHT method and the rejected wafer ratio. This correlation validates the value of high quality bulk sapphire material to the epi-wafer manufacturing process.

The study illustrated that overall GT's ASF-grown material performed better than the alternative growth methods evaluated including Kyropulos and the "HEM-like" method. GT ASF material ranked highest for the important measure of wafering yields which has a direct impact on a wafer manufacturer's profitability and is a key Metric that Matters. In addition, GT ASF was proven to offer additional benefits such as improved wafer geometry, which will enable a highly competitive position for wafer manufacturers with downstream customers.

GT Ranked First According to Wafering Yields

This is significant because wafer yields have a direct impact on profits.

Future Characterization Project Study Work

This wafer manufacturing study is part of an ongoing, extensive effort by GT to determine the sapphire material "Metrics that Matter" in the entire manufacturing processes of a HB LED device. GT has additional efforts underway with several industry-leading partners to objectively evaluate sapphire material characteristics that matter as one moves downstream. GT is in the final stages of the device fabrication analysis, working with a top MOCVD OEM, as well as reputable LED device manufacturers on 2", 4", and 6" substrate processes. In the coming months, GT plans to publish additional information relating to the analysis and results of these additional phases of the study.

ASF Grown Material Provides Overall Best Wafer Geometry

There is a direct link in wafer geometry to downstream processing during epi growth.

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