Sapphire Quality Metrics that Matter

Frequently Asked Questions

What are the metrics that *do* matter when evaluating sapphire quality?
There are several potential defects in bulk sapphire cores that can have a significant impact on important downstream LED processes including epitaxial growth and wafering yields. These defects include the presence of bubbles (exclusion zones) and low angle grain boundaries. GT's ASF™ growth process dramatically minimizes these defects during crystal growth. GT developed a method called OHT, or Optical Homogeneity Technique, which is proven to detect these critical defects, bubbles and low angle grain boundaries. GT's ASF customers can adopt this method for grading ASF material. This ensures that GT and its' ASF customers ship only the highest quality cores, maximizing our customer's yields.

A true measure of the quality of sapphire is how sapphire performs on key LED wafering parameters such as surface roughness (Ra), total thickness variation (TTV), warp and bow. The rate of wafer rejections and ultimately wafer yields are critical measures for wafer manufacturers as wafer yields directly impact their economics. GT recently completed a blind study to evaluate the impact of sapphire material on LED wafering. This study demonstrated that the quality and characteristics of the sapphire material source has a direct impact on LED wafer yields and that, of the materials from four suppliers that were blindly tested by an independent LED wafering manufacturer, GT ASF grown sapphire material delivers the highest wafer yields. GT ASF sapphire also ranked the best on overall performance, which was based on Rejected Wafer Ratio, EPD results and wafering geometry. (*See Yields Matter: A Case Study on the Impact of Sapphire Material on LED Wafering Yields – http://www.gtat.com/resources-casestudies.htm)*

This LED wafering analysis is part of a larger comprehensive material characterization project initiated by GT to study the effects of sapphire material properties on the entire High Brightness (HB) LED value chain and identify a comprehensive set of the metrics that matter in assessing sapphire quality and yields at each step of the LED supply chain. GT intends to publish additional papers reporting the findings from its ongoing and future studies.

Is color a "metric that matters" in determining the quality of GT ASF sapphire?
No, there is no evidence that the pink color of GT ASF sapphire is a relevant measure of quality nor that the color in GT ASF sapphire negatively impacts any manufacturing processes or HB LED device performance. Although color has been correlated to contamination in some sapphire, GT has conducted extensive GDMS research that proves that the pink hue of ASF sapphire is not indicative of any contamination or impurities. GT ASF sapphire is also proven to meet and exceed the wafer standards for 99.9995% purity. In addition, the color in GT ASF sapphire is proven to be annealed out during the standard epi-wafer manufacturing process which calls for post-annealing of sapphire at the wafer level for any and all sapphire wafers because of the stress induced by the polishing and lapping processes this step eliminates any traces of color from sapphire wafers, regardless of the sapphire source. GT has conducted extensive research to evaluate the impact of sapphire color on LED manufacturing and has published the results of this color analyses in a case study titled *The Impact of Sapphire Color on HB LED Manufacturing (http://www.gtat.com/resources-casestudies.htm).*

GT has performed a transmission analysis called PCI, or Photo-thermal Common Path Interferometry developed to study absorption for high end LIGO optics (Laser Interferometric Gravitational Observatory), at Stamford University. The study had shown that the absorption of GT ASF pink material was the lowest, meaning that transmission of light was higher as compared to two suppliers of KY and one of "HEM-like" grown sapphire.

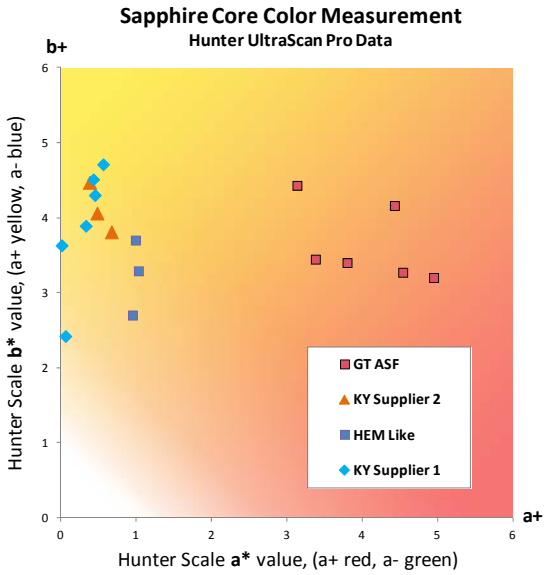
Is GT sapphire pink? What is the pink caused by?
Yes, sapphire grown using GT's ASF technology can have a pink hue. The pink hue in ASF sapphire is a result of an engineered growth process that optimizes material for LED applications, improving the yield of high quality

LED sapphire. The pink hue is not an indication of impurities or contamination in GT ASF. It is with the knowledge that GT's sapphire color does not matter, that GT has chosen to grow boules with this high yield process that optimizes production costs.

GT ASF material was found to have more red hue intensity, correlating to the pink appearance of the ASF grown boules. While GT ASF sapphire has a pink hue, all sapphire from other suppliers has color and as measured during our material characterization efforts. Other growth technologies material was shown to have more yellow hue, which is less apparent under typical lighting conditions.

If the pink color is not caused by impurities, what then causes the distinctive pink hue?
No crystal is perfect. Thermodynamics dictates that a certain amount of crystal imperfections, even at extremely small levels, will occur in all crystals including sapphire. Imperfections such as vacancies (where an atom is missing from the lattice) or interstitials (where an extra atom occurs in the wrong location) are known to cause color, and it has been suggested in the literature that this may be the cause of pink in sapphire. As the findings of our recent case studies have shown, the pink hue observed in our ASF-grown material causes no downstream issues with HB LED wafer manufacturing.

How do you know that all sapphire has color?
GT has performed extensive studies evaluating wafer samples from GT and other sapphire suppliers using a Hunter UltrascanPro tool, which is a leading metrology tool for measuring color and color intensity. As illustrated in the chart below, this evaluation has shown that all sapphire has color. GT ASF material was found to have more red hue intensity, correlating to the pink appearance of the ASF grown boules. Material from other suppliers was tested and measured a yellow hue. Yellow color under typical lighting conditions is less noticeable to the human eye than red.



Is the pink color in ASF sapphire an indication of poor quality or contamination?
No. The "pink" of GT ASF sapphire is not indicative of impurities, contamination or poor quality. This is demonstrated by third party analyses as well as direct feedback from long standing LED customers, and their customers many of who are the leading wafer manufacturers and players in MOCVD growth, as well as leaders in industrial markets where very high quality sapphire material is required. This includes:

GDMS analysis has proven that pink-hued ASF sapphire is not indicative of impurities or contamination. Working with an independent laboratory, GDMS analysis of GT's ASF sapphire material has shown that it is as pure as or more pure than competitor's sapphire. ASF crystal growth has very low concentrations of V, Cr, Mo, Fe, Ti, and Mg, elements that have been linked to color in sapphire. This analysis has shown that the level of elements in the raw aluminum oxide are the same as the levels of contamination after the sapphire growth process proving that the ASF process does not add any contamination. (See *The Impact of Sapphire Color on HB LED Manufacturing - http://www.gtat.com/resources-casestudies.htm).*

Blind studies have demonstrated that GT ASF sapphire is a leader in quality and yields. GT has conducted a blind study with an independent wafering house to analyze the performance of sapphire from various sapphire suppliers in the critical epi-ready wafering step. Of the material tested from four suppliers, GT ASF grown sapphire material was shown to deliver the highest wafer yields and ranked best on overall performance, which was based on Rejected Wafer Ratio, EPD results and wafer geometry. (*See Yields Matter: A Case Study on the Impact of Sapphire Material on LED Wafering Yields – http://www.gtat.com/resources-casestudies.htm)*

Customer feedback has validated that GT ASF sapphire is of the highest quality. GT's proprietary ASF process builds on the 40-year legacy of innovation and quality pioneered by Crystal Systems, which was acquired by GT in July 2010. For over 12 years GT has supplied sapphire to the LED industry, today supplies sapphire material to six of the top 10 LED wafer makers and GT ASF material has been qualified by a leading high brightness device maker. In addition, GT supplies sapphire materials to other industrial markets including the optical market that has much higher quality standards than the LED market. GT's customers across all markets have consistently provided positive observations on the superior quality of the ASF grown sapphire material.

Are there incremental steps or costs associated with removing the pink from GT sapphire? Does sapphire with color like GT's require special treatment to retain the original purity chemicals or costs?
No. GT ASF sapphire gets treated exactly the same as any other sapphire source through the entire LED manufacturing process and no extra steps or incremental costs are required to treat GT ASF material. We have received direct confirmation of this from our LED wafering customers as well as their customers.

Could GT's pink sapphire have an impact on optical transparency in chip designs that do not remove the sapphire such as Flip-Chip with sapphire?
GT supplies sapphire to and is qualified at a majority of the top wafer manufacturers in the world. GT is confident that there is no negative impact on Flip-Chip and other device architectures that transmit light through GT ASF sapphire. In addition, GT has demonstrated that the color in ASF sapphire gets annealed out during the standard epi-wafer manufacturing process and that post-anneal light transmission reaches theoretical maximums.

GT has performed a transmission analysis called PCI, or Photo-thermal Common Path Interferometry developed to study absorption for high end LIGO optics (Laser Interferometric Gravitational Observatory), at Stamford University. The study had shown that the absorption of GT ASF pink material was the lowest, meaning that transmission of light was higher as compared to two suppliers of KY and one of "HEM-like" grown sapphire.

How does the pink in GT ASF sapphire impact absorption rates and transmission?
A study conducted by a third-party using Photo-thermal Common-path Interferometry or PCI recently demonstrated that wafers produced using GT ASF material do not negatively impact absorption rates or impact light transmission on devices that transmit through sapphire substrate. In fact, GT ASF material had the lowest absorption levels and the pinkest of the GT material tested actually had the lowest absorption level of all material tested.

PCI is a method developed at Stanford University for measuring the absorption of optical components. The PCI method was developed specifically for extreme sensitivity for the measurement of low absorbance materials and is a highly accurate method for measurement of the absorption of light at wavelengths from 400nm to 700nm.

The study demonstrated that wafers produced using GT material had an absorption measurement of 0.2 %/cm, significantly less than the HEM-like sample which had the highest absorption measurement at 1.6 %/cm, or 8X that of the GT material. Absorption at 455nm was calculated to be <0.1 %/cm, which is far too small to have any negative effect on devices that transmit the LED light through the sapphire substrate. This absorption is far below the 3-5% absorption levels feared by the Flip-chip HB LED industry. (*The Impact of Sapphire Color on HB LED Manufacturing - http://www.gtat.com/resources-casestudies.htm).*

Theoretically, what could a reduction in optical transparency mean in terms of loss of lumens per wafer?
GT has performed extensive analysis of transmission of light to ensure that ASF material does not impact any LED device performance. The effects of optical transparency become insignificant and are not differentiable from that of other suppliers. There is no loss of lumens for HB LED devices manufactured with GT ASF. GT material was measured using PCI (Photothermal Common-path Interferometry) to have an absorption of less than 0.1%/cm, which was lower than other suppliers tested, including KY and HEM-like sapphire. This absorption is too low to have any negative impact on optical transparency.

What is OHT?
OHT is GT's non-destructive method for grading the quality of boule or core level sapphire. OHT is designed to detect bubbles and crystal lattice defects at the boule and core level, before the start of any downstream manufacturing. OHT includes a visual inspection under a polarized light to detect low angle grain boundaries (lineages), twins, and bulk sapphire lattice distortion. Also, the sapphire is inspected under a high intensity white light for gas or bubble content in the core material.

What are the differences between ASF and Kyropolous?
GT's ASF method is based on the Heat Exchanger Method or HEM obtained by GT in the Crystal Systems acquisition. This method uses a crucible, with a seed placed in the bottom, to melt the sapphire feedstock while using a heat exchanger to cool the seed. The ASF method has the advantage of growing the sapphire crystal from the bottom, meaning the seed and crystal growth begins from the bottom of the crucible and the crystal grows up. The advantage of the ASF approach is that any defects such as bubbles in the melt are allowed to float up and away from the crystal growth front and escape out the top of the melt. This approach is different than Kyropolous (Ky) and Czochralski (Cz), which both seed and grow from the top of the liquid sapphire capturing defects and bubbles in the sapphire crystal. Additionally the ASF method has no moving parts and a low cost heat. Both Ky and Cz have moving parts in the growth and use higher cost shorter lifetime heaters.

What are the advantages C-axis vs. A-axis growth?
GT ASF makes use of A-axis for growth as it has proven to be higher yielding and more economical. A-axis grows much faster than C-axis therefore choosing larger area A-axis growth planes have proven to be an advantage of the ASF. The fact that sapphire is recyclable adds to the advantage of A-axis growth for C-axis applications leading to the Value Metric for sapphire crystal growth being defined as $/mm unlike other process where the material is not recyclable leading to a Value Metric of Mass Ingot Yield.