JULY 2013

k-Space

kSA Blue BandiT

Direct, Repeatable GaN Temperature Measurement!

WHAT kSA BLUE BANDIT PROVIDES IN REAL-TIME:

- **Direct, True GaN Film Temperature During InGaN MQW Growth**
- **Control your MOCVD process for targeted LED emission wavelength and yield!**
- **Auto-Calibrated Wafer Pocket Temperature—even with Patterned Sapphire Substrates (PSS)**
- **Film Thickness and Surface Roughness**
- **Multi-wafer and Multi-ring Capabilities**
- **Full platen scanning capability for 2D Mapping with slit viewport access**

Introduction

Standard kSA Blue BandiT Optical Head for Aixtron G series MOCVD

For over 10 years, kSA BandiT™ has proven itself to be an invaluable tool for non-contact, non-invasive, real-time, absolute wafer temperature monitoring of semiconductor materials used in today's optoelectronic and electronic devices. Now we have tailored this technology specifically for GaN HBLED deposition monitoring, offering the kSA Blue BandiT in-situ metrology tool. Blue BandiT provides critical wafer and film temperature information that standard NIR/ECP pyrometers cannot measure. This is due to the substrate (e.g. sapphire) and growing film (e.g. GaN, InGaN, AlGaN) being transparent in the infrared regime, where standard pyrometers/ECP's detect radiation. For pyrometers attempting to collect radiation in the absorbing region of these materials (<450nm), they are starved for signal due to low emission at such short wavelengths.

The kSA Blue BandiT tool offers TWO temperature measurements: 1) Direct GaN film temperature via band-edge thermometry (BET), and 2) Wafer pocket/carrier temperature via blackbody radiation analysis of the NIR radiation signal. The BET technique yields absolute film temperature measurement during the crucial InGaN/GaN MQW growth, with resolution of +/- 0.4°C and unparalleled run-to-run and tool-to-tool reproducibility of +/- 0.1 °C.

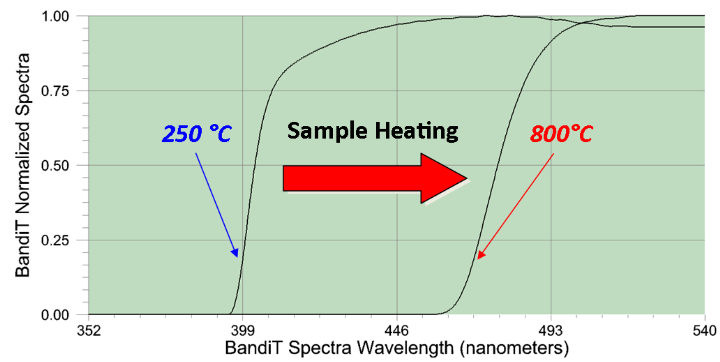
kSA Blue BandiT has been validated for use on most MOCVD reactor platforms which have slit viewport style access to the wafer. Blue BandiT provides real-time monitoring of GaN/InGaN film temperature, wafer pocket temperature, film thickness, and surface roughness. High speed triggering electronics and laser supplied with Blue BandiT easily handle the fast rotation speeds used by some MOCVD systems (up to 2000 RPM) by synchronizing directly to the wafer carrier rotation via reflectivity changes, both for symmetric and asymmetric carriers. Slower rotation MOCVD systems are synchronized by a standard trigger module placed on the rotating shaft.

In addition, a linear scanning stage has been implemented to provide full scanning capability across the slit viewport available on some MOCVD systems, yielding full carrier/wafer mapping with high spatial resolution. In short, kSA Blue BandiT provides a turn-key in-situ metrology solution with unparalleled control of the crucial InGaN/GaN MQW layers, resulting in better PL uniformity and increased yield for Production MOCVD reactors.

Direct GaN Film Temperature Capability: Control Of InGaN MQW Temperature for Ultimate LED Emission Wavelength Control

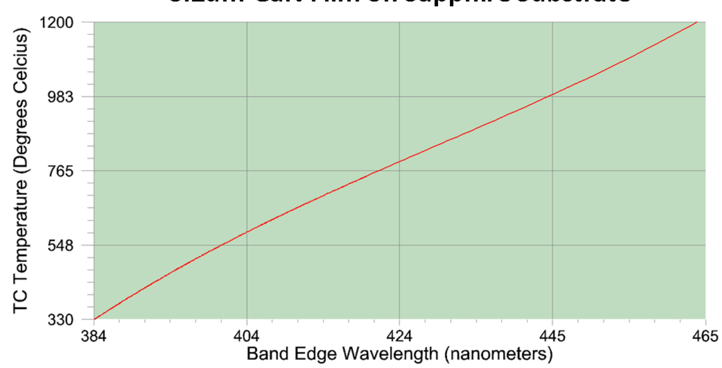
kSA BandiT's patented, band-edge based temperature measurement technology relies on the shift in band gap energy with change in material temperature. Blue BandiT uses a high-resolution solid-state spectrometer to measure the optical absorption edge of the semiconductor in real time. The measured absorption edge is used to determine the absolute film temperature via a GaN calibration file, which maps band edge to temperature. The calibration file is generated using calibrated vacuum heating chambers at k-Space to ensure the highest possible temperature accuracy. As a result, direct, accurate, and repeatable measurement of the GaN film temperature is guaranteed with kSA Blue BandiT, and unmatched by any other optical temperature monitoring technique. Temperature resolution during MQW growth is +/- 0.2°C or better. Because BandiT's technology is insensitive to changing viewport transmission, stray heater radiation, and sample wobble, Blue BandiT is the most accurate and repeatable optical method available for measuring true GaN temperature during InGaN MQW growth.

GaN Substrate Absorption Edge Shift During Heating from 250°C to 800°C



kSA BandiT Calibration File:

3.2um GaN Film on Sapphire Substrate

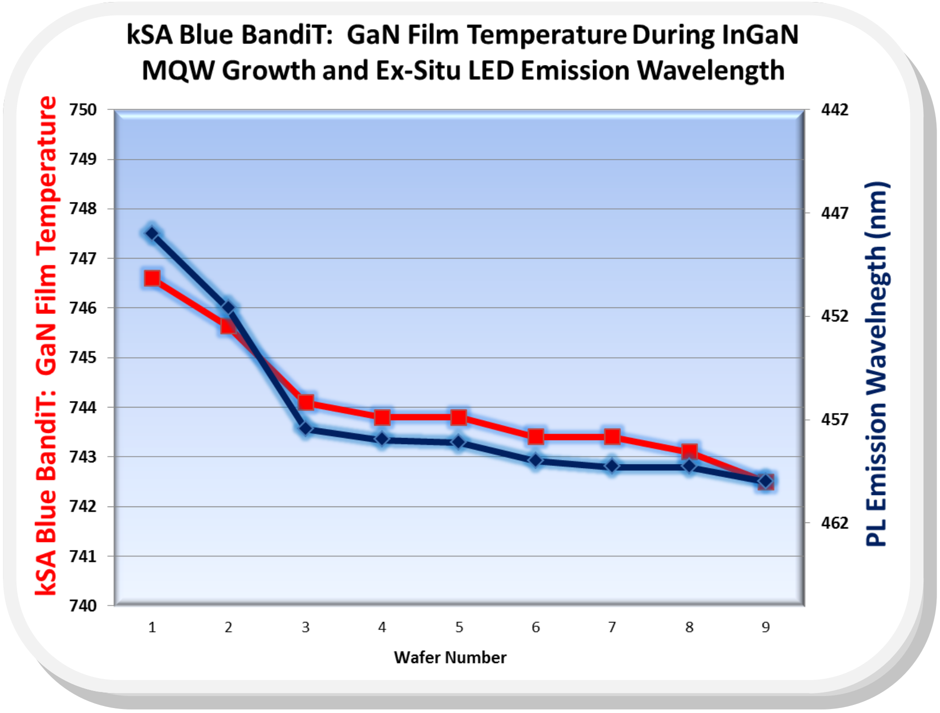


kSA Blue BandiT uses Band-edge Thermometry (BET) to directly determine GaN Film Temperature

The ability to directly measure and control the actual GaN temperature during InGaN MQW growth becomes critical to control the emission wavelength of the LED. The amount of Indium incorporation within the quantum wells determines the overall LED emission wavelength and is very sensitive to temperature. For every 1°C change in temperature, a corresponding 1.3 nm shift in LED PL emission is expected. In order to control the LED device yield to within a typical 2 nm bin size, temperature control of better than 1°C must be obtained during the InGaN MQW growth. kSA Blue BandiT provides this level of measurement resolution, accuracy, and repeatability across all MQW growth temperature ranges. When growing GaN films on bare sapphire substrates, kSA BandiT can determine the material band edge with as little as 500 Å of material. However, since the GaN layer is thin, the optical absorption characteristics of the GaN are still changing and need to be accounted for to properly determine the actual band edge and corresponding temperature. kSA BandiT uses a patent-pending approach to compensate for the dynamic growth of GaN on sapphire, whereby the measured band edge of the GaN film is adjusted based upon the film's thickness, which is also measured by Blue BandiT in real time. With this new approach, repeatability of the band-edge measurements can be maintained to within +/- 0.5°C after the initial GaN buffer layer is complete. This level of repeatability becomes extremely important during the growth of layers which are critical to overall device performance and yield, such as during the InGaN MQW step during HBLED layer growth. This novel band-edge temperature measurement of the GaN film provides a means for accurate temperature measurement during the critical InGaN MQW growth steps.

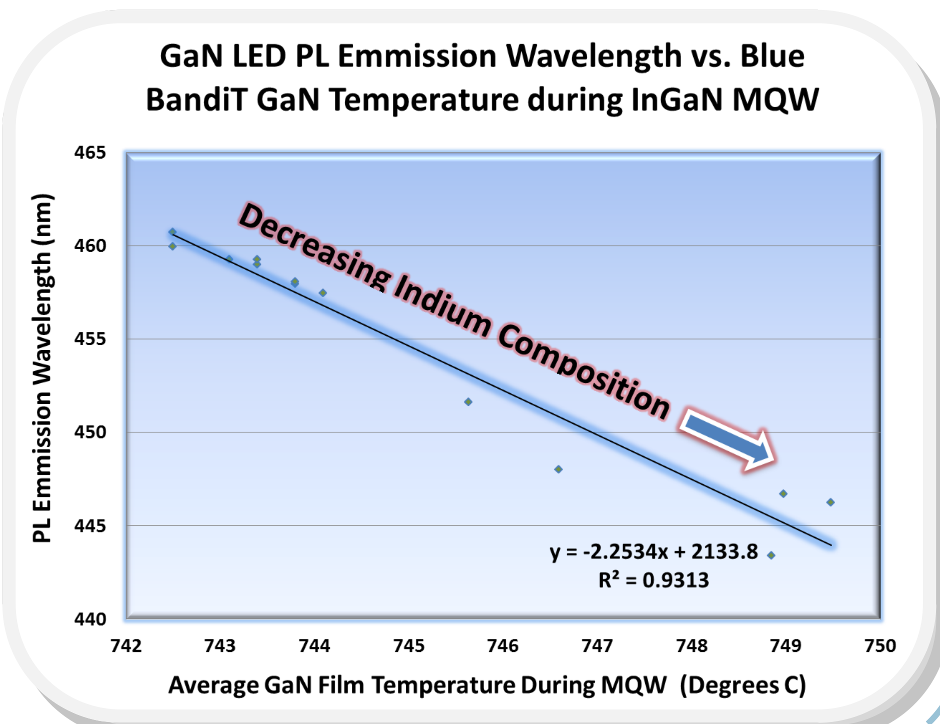
Repeatable GaN Film Temperature: Control LED PL Emission Wavelength

Validation of the direct temperature measurement technique offered by Blue BandiT comes in comparing MQW BET with photoluminescence (PL) data from the as-grown epiwafers prior to LED processing. While not used in control mode, multiple growth runs were performed over several MOCVD reactors to understand the average GaN film temperature measured by Blue BandiT during the well layers and the resulting LED emission wavelength as measured by photoluminescence. Typical temperature and PL vs. wafer plots are shown to the right and below.



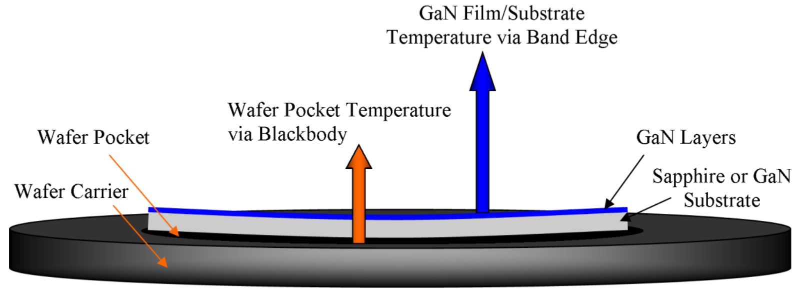
Average GaN film temperature measured during InGaN MQW vs. PL emission wavelength on multiple wafers and MOCVD tools

There is a direct and strong correlation between measured MQW temperature and PL wavelength and is expected to increase further when Blue BandiT is used in full temperature control mode. An increase in well growth temperature means increased In content in the InGaN well layer, which shifts the PL wavelength to shorter wavelengths. Initial data suggests that a closed loop control of the well and barrier temperature via Blue BandiT will result in tighter LED emission wavelength range, and hence increased yields. In addition, since BET technology is a diffuse measurement and does not require a reflectivity signal for compensation, any sample curvature or bow near the wafer edges will not impact the measurement viability or accuracy. kSA Blue BandiT is also compatible with most Polished Sapphire Substrates (PSS) and requires no external calibration due to use of the known GaN band edge vs. temperature relationship.

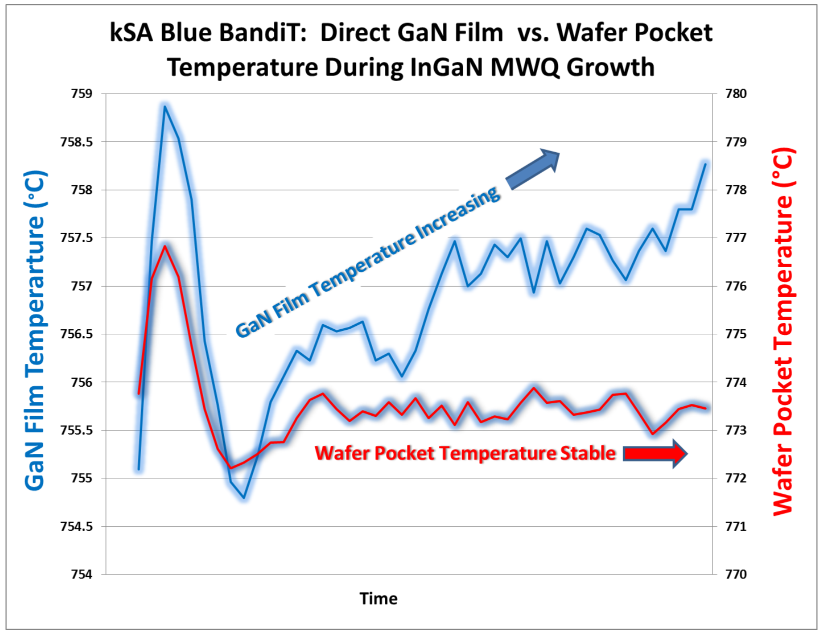


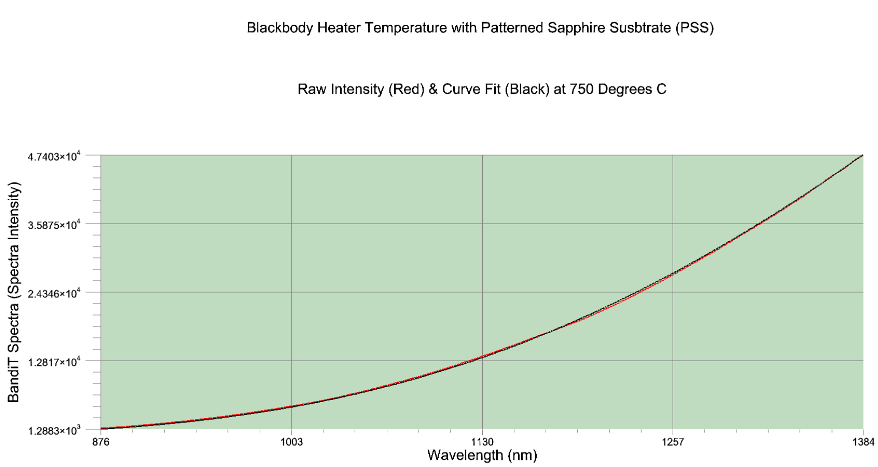
Wafer Pocket vs. Direct GaN Film Temperature

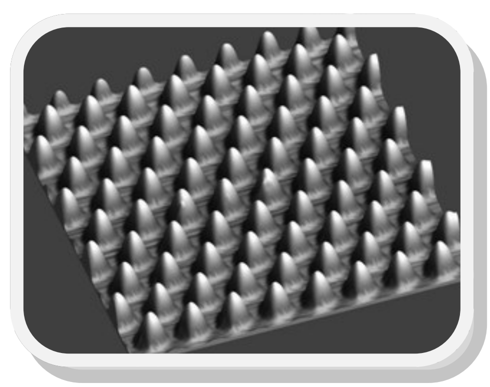
kSA Blue BandiT also combines a new, patented blackbody emission fitting technology. The spectral radiation intensity from the pocket is collected via a solid state spectrometer and is fit in real time to Planck's equation to determine temperature. This novel technique provides a direct measurement of the underlying graphite wafer carrier or pocket. Automated in-situ calibration via blackbody radiation curve fitting ensures run-to-run repeatability and unmatched resolution (better than 0.1°C). kSA Blue BandiT band edge and blackbody methods can be used simultaneously for direct temperature monitoring of both the GaN film/substrate and underlying graphite wafer carrier to help minimize temperature non-uniformities and completely characterize both temperatures during growth. Differences in thermal mass, gas flow influences to surface temperature, and wafer bow can be readily monitored and compensated for to ensure process temperatures used for control lead to accurate uniformity profiles and correct temperatures during each step in the LED growth process. Since kSA Blackbody curve fitting does not rely on intensity or emissivity changes for temperature determination, carrier and/or pocket temperature monitoring during the entire LED growth process. This is even the case with Patterned Sapphire Substrates (PSS) which pose a great challenge for Emissivity Corrected Pyrometry (ECP) due to the large and unpredictable interface diffraction that changes the amount of signal entering the pyrometer and reflectance detectors.



GaN film temperature (BET) and wafer pocket temperature (Blackbody) measured simultaneously. Note differences in absolute temperature and stability during initial InGaN MQW well growth.



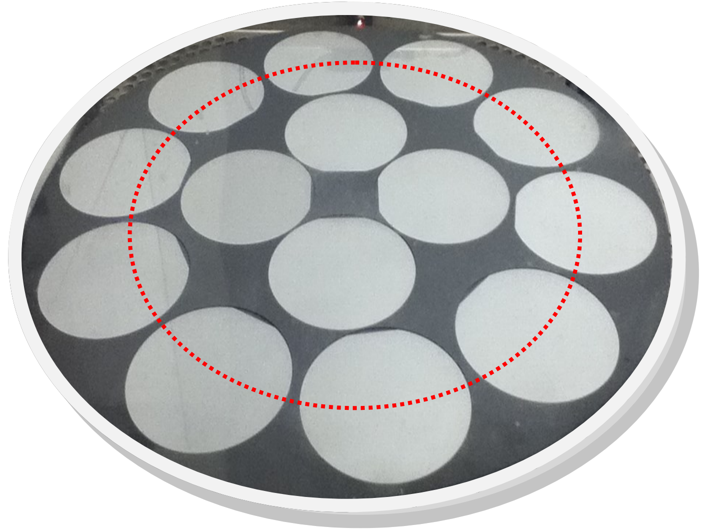




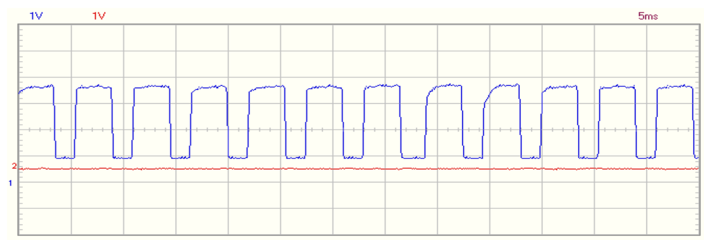
Blackbody Temperature works with Patterned Sapphire Substrate (PSS)

Laser Triggering for Rotation Synchronization

Most high speed MOCVD reactors use a spindle drive mechanism which is in contact with the wafer carrier and drives the rotation speed upwards of 1000 rpm or more. This spindle and wafer carrier system is typically a ‘friction fit’ and not mechanically coupled, which leads to unpredictable carrier slip during rotation. This slip makes wafer-sorted in-situ optical metrology a challenge. To solve this issue, k-Space developed a high speed laser and photo detector optic, coupled with a microprocessor and wafer/web identification algorithms (patent pending), to synchronize to the carrier rotation at any rotation speed, and regardless of carrier slip. Using this new setup, an internal trigger is generated via real-time analysis of the web widths as seen by the laser reflectance, and this trigger is sent to the Blue BandiT spectrometers for triggered data acquisition. In this manner, a “hard” spindle trigger is not needed, and carrier slip is no longer an issue. This new technique has been validated over many full device runs on symmetric and asymmetric carriers from multiple vendors. With this implementation, Blue BandiT is now stand-alone as it does not require any trigger or other electrical connection to the MOCVD tool.



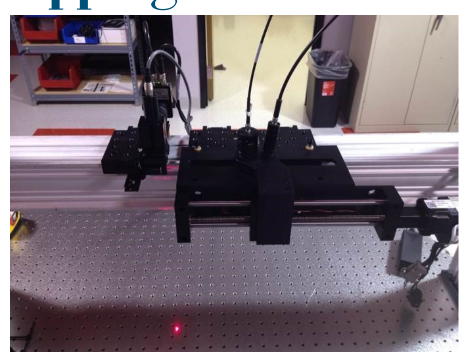
Laser reflectivity changes between substrate and web (in between wafers) are used to identify wafer positions and synchronize with rotation speed for wafer-specific real-time metrology. Trace below shows typical laser reflectance signal generated by Blue BandiT during high-speed rotation.

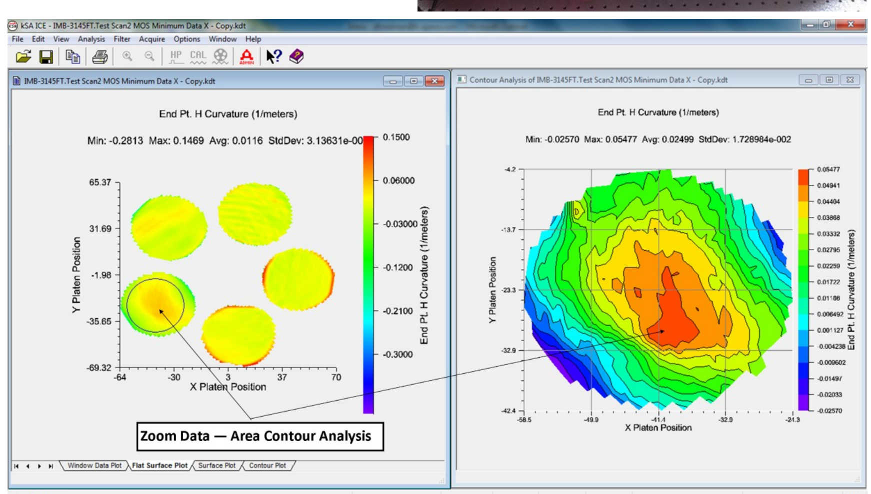


Scanning Hardware for In-Situ 2D Wafer Mapping

Some of today’s MOCVD systems incorporate a full slit style viewport which covers the full wafer carrier radius. By using the same Blue BandiT optics hardware and rotational triggering electronics mated to a linear scanning drive, a full 2D map of any parameter can be obtained during growth. The system is the only monitoring technique that can provide real-time 2-dimensional temperature (both GaN film and underlying wafer pocket), thickness, or surface roughness information of all wafers during wafer carrier rotation and growth. Thermal uniformity profiles can now be monitored and adjusted via typical multiple filament heating zones used on most production MOCVD systems. Film thickness uniformity and surface roughness profiles can also be obtained before any wafers have even left the growth chamber.

kSA BandiT hardware with linear scanning mount (Top) and 2D profiles (bottom) for all wafers on the carrier

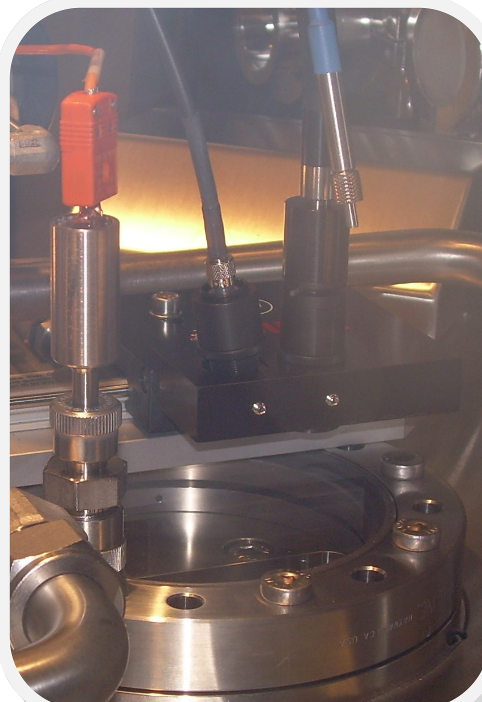




kSA Blue BandiT Performance Specifications

	kSA Technology Used	Temperature Range (°C)	Resolution (°C)	Repeatability (°C)
Direct GaN Film or Freestanding GaN Substrate	Band Edge Thermometry	300-1500	± 0.4	± 0.25
Graphite Wafer Carrier or Pocket Temperature	Blackbody Curve Shape Fitting	400-1500+	± 0.5	±0.5

kSA Blue BandiT for Direct GaN Temperature During MOCVD



Leveraging over 20 years of in-situ monitoring technology and expertise, k-Space has successfully integrated and can now offer its established real-time kSA BandiT product technology for most production MOCVD systems. The newly developed kSA Blue BandiT in-situ metrology tool can provide the following key GaN MOCVD growth parameters: 1) direct GaN film temperature during InGaN MQW growth; 2) wafer carrier and wafer pocket temperature; 3) high resolution surface roughness; 4) total film thickness and MQW thickness. In addition to providing individual wafer measurements on any wafer and wafer carrier configuration, linear scanning hardware now allows for full 2D wafer profile maps to obtain important yield information even before the wafers have exited the MOCVD reactor.

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k-Space Associates, Inc., is a leading supplier to the semiconductor, surface science, and thin-film technology industries. Since 1992, we've delivered the most advanced thin-film characterization tools and software, thanks to close collaboration with our worldwide customer base. We realize the best products are developed with our customers' input, so we're good listeners. For your real-time surface analysis, curvature/stress, temperature, deposition rate, or custom project, we look forward to helping you with your thin-film characterization needs.

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