
LAYTEC
Knowledge is key
LEDs and laser diodes

Why choose LayTec?

- We are the leading manufacturer of integrated optical metrology systems for all thin-film processes: LayTec systems can be customized for every specific process.
- Since more than a decade LayTec metrology defines the performance and quality standards.
- The majority of global LED producers have chosen LayTec metrology.
- We offer cutting-edge technology made in Germany through a worldwide distribution and service network.

Challenges

To be commercially successful in a highly competitive market, LED and laser manufacturers work hard to further improve device performance and reduce their total costs. The most effective way of cost reduction is optimizing the epitaxial growth process, because epitaxy of complex multilayers structures sometimes causes significant yield losses.

SUBSTRATE	EPITAXY	DIES ON WAFERS	LED PACKAGING
Substrate yield loss: – Particles – Stains – Scratches	Epi yield loss: – Pits & cracks – Composition deviations – Film thickness deviations – Epi non-uniformity – Topography defects	Front-end yield loss: – Patterning defects – Patterning overlay errors – Film uniformity	Back-end yield loss: – Dicing defects – Probe marks – Residues, peeling, contamination – Pad damage

Tight in-situ monitoring during the epitaxial growth process will help enhance yield and improve color uniformity by optimizing your processes and thereby turning every run into a “GOLDEN RUN”.

IN-SITU MONITORING

- Reflectance at 3 wavelengths
- Pocket temperature
- GaN surface temperature
- Wafer curvature

→

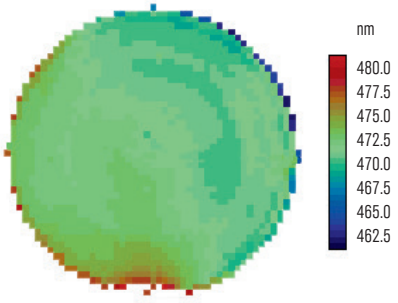
- Process optimization
- Fast failure analysis
- Prevention of spec deviations
- Wavelength uniformity control
- Process reproducibility tuning

All in real time!

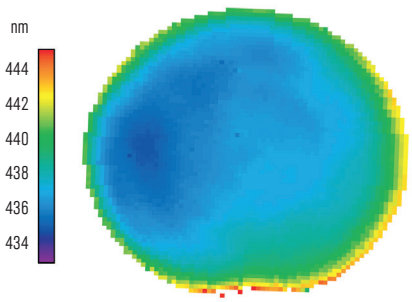
→

- Epitaxy yield improvement
- Quantum well emission uniformity
- Cost reduction

LayTec’s in-situ metrology systems are powerful tools in your hand – they provide you with real-time information on what is happening in your growth system. By tightly controlling epi-conditions for every single wafer you will be able to optimize your growth processes and achieve the best device performance and uniformity.



4” Wavelength uniformity ±1.5 nm



6” Wavelength uniformity ±3 nm

Photoluminescence (PL) uniformity map of LED wafers as achieved after in-situ process optimization and quality control with LayTec metrology.

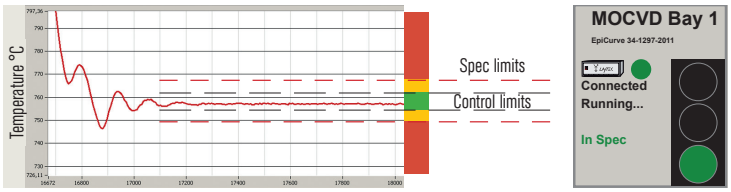
Solutions

Monitoring every step of epitaxy

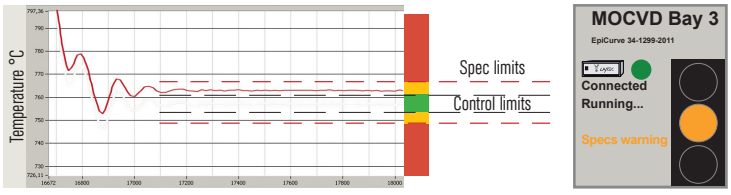
In-situ monitoring helps you predict and control your final device properties. With in-situ tools you can also identify defect wafers, avoid processing them and identify the root causes for process deviations.

EPI GROWTH (blue LED, blue laser diode UV LED)	LAYTEC'S REAL-TIME MONITORING	PROPERTIES OF YOUR FINAL DEVICE
Step 0: Nucleation layer, Substrate	Step 0: Nucleation layer quality: – Recovery time – Surface morphology – Growth rate homogeneity	Step 0: Defect density
Step 1: Buffer, Nucleation layer, Substrate	Step 1: GaN buffer quality: – Surface morphology – Thickness, growth rate – Film thickness homogeneity – Film strain	Step 1: Emission intensity
Step 2: Active layer (MQW), Buffer, Nucleation layer, Substrate	Step 2: MQW – Thickness – Ternary homogeneity – Growth rate homogeneity	Step 2: Emission wavelength Emission intensity
Step 3: Cap layer, Active layer (MQW), Buffer, Nucleation layer, Substrate	Step 3: Cap layer – Thickness – Morphology – Final bow	Step 3: Outcoupling efficiency

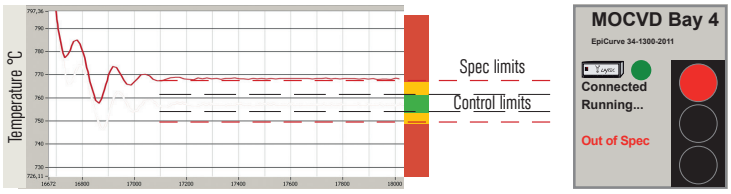
The traffic lights in LayTec's EpiNet software will ensure that your operators make the right decisions.



Case 1:
When all run data are within the pre-defined control limits, e.g., wafer surface temperature measured by Pyro 400, the traffic light is green.



Case 2:
When the value exceeds the control limits, but is still within the spec limits, the traffic light turns yellow.

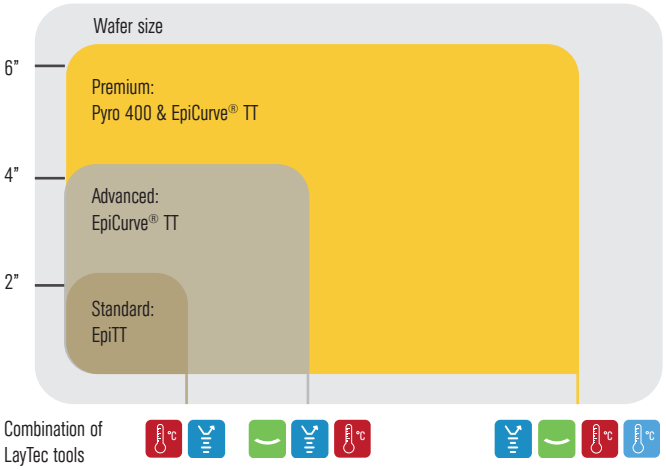


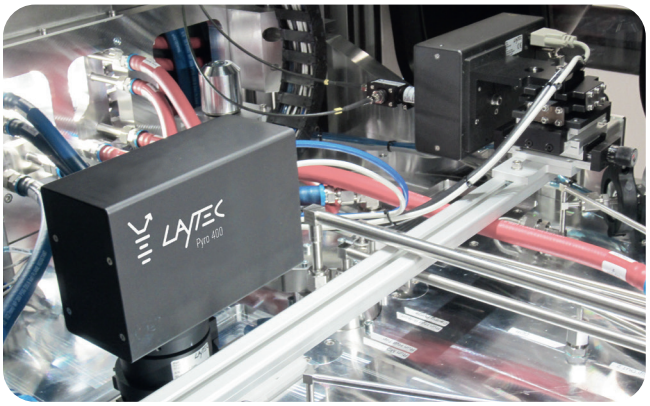
Case 3:
When the value has exceeded, both control and spec limits the traffic light turns red. This is a signal for the operator to stop the run and re-adjust the growth conditions.

Products

Standardized metrology systems for your individual demands

Thanks to our modular in-situ metrology concept, we can offer you the perfect combination of tools for your particular process, growth system and wafer size.





Pyro 400 and EpiCurve® TT

For small wafers, e.g., 2”, LayTec’s EpiTT family of products is the standard solution providing temperature and reflectance measurements.

To overcome the challenges that occur with larger wafers, you need the advanced EpiCurve® TT system which includes wafer curvature measurements and all features of EpiTT. This will help you avoid cracks, achieve flat wafers and control temperature homogeneity. Every curvature tool can be equipped with Advanced Resolution (AR) curvature measurements for wafer bow asphericity control (EpiCurve® TT AR).

Our premium package combines Pyro 400 and EpiCurve® TT and is essential for monitoring InGaN growth on transparent substrates. Pyro 400 measures the temperature of GaN layers during the growth on sapphire and SiC wafers, enabling to control directly the growth temperature of InGaN MQW layers. EpiCurve® TT adds curvature, emissivity corrected pyrometry and reflectance measurements.

Find the tool for your needs:

Substrate	Pocket temperature	Reflectance: growth rate & morphology	Wafer curvature	Wafer surface temperature	Product family	Package
Transparent: GaN on sapphire, SiC	✓	✓			EpiTT	Standard
	✓	✓	✓		EpiCurve® TT	Advanced
	✓	✓		✓	Pyro 400 & EpiTT	Premium
	✓	✓	✓	✓	Pyro 400 & EpiCurve® TT	Premium
Opaque: GaN on Si, III-Vs on III-Vs		✓		✓	EpiTT	Standard
		✓	✓	✓	EpiCurve® TT	Advanced

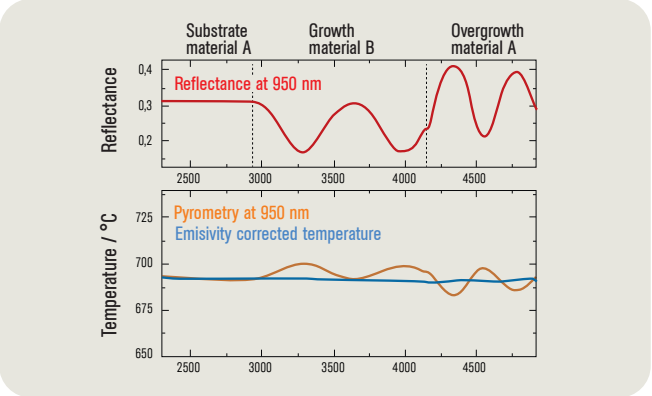
Standard

EpiTT – Yield improvement through temperature uniformity

During epitaxial deposition conventional pyrometry without emissivity correction would show oscillations due to interference. To see the true temperature (TT) we combine two methods:

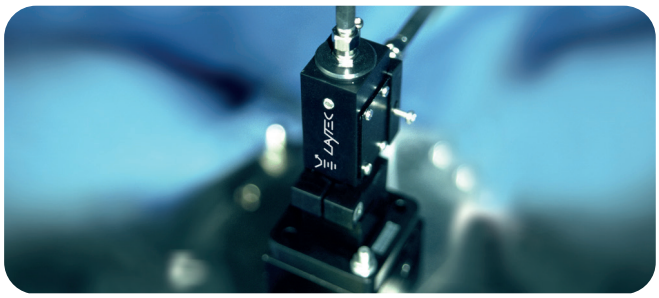
- Intensity measurement of thermally emitted light (950 nm pyrometry)
- Normal incidence reflectometry at 950 nm

This Emissivity Corrected Pyrometry (ECP) is combined with growth rate measurements in LayTec's EpiTT system.



Pyrometer features:

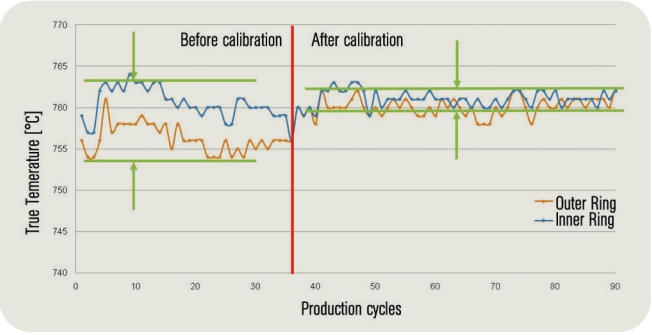
- Temperature range 450°C-1400°C
- Accuracy better than 1 K
- Wafer and area selective measurements
- True wafer temperature for opaque semiconductors such as III-Vs on Si or III-Vs on III-V
- Pocket temperature for GaN on sapphire or for SiC
- Multi-head options: EpiTwin TT, EpiTriple TT



EpiTwin TT - the twin brother of EpiTT containing two measurement heads

AbsoluT – Temperature calibration

LayTec's AbsoluT is a convenient handheld device for on-site temperature calibration. In a few minutes, your engineer will be able to set up exactly the same absolute temperature reference point for pyrometry measurements on different rings and in different reactors and runs (ring-to ring, reactor-to-reactor and run-to-run calibration).



Temperature measurement with EpiTwin TT before and after calibration with AbsoluT

The benefits:

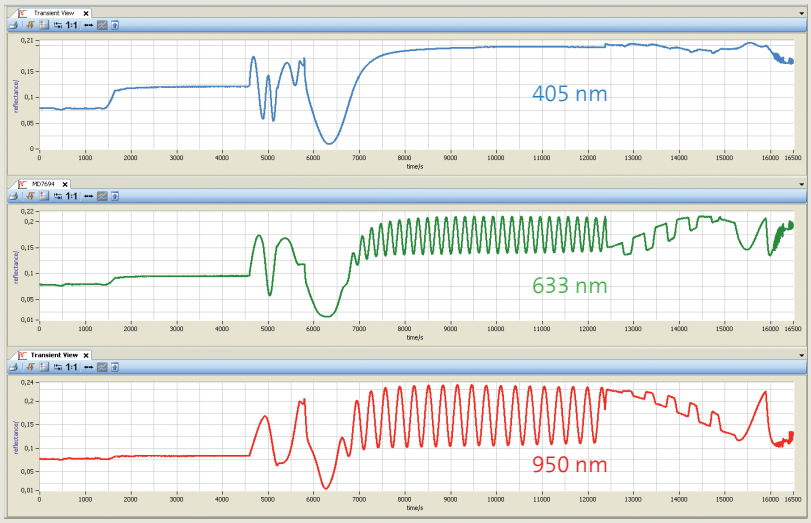
- Exact absolute growth temperature calibration
- Stability & accuracy of LED growth temperature
- Precise GaN buffer and quantum wells (MQW) temperature measurement
- Stable MQW growth temperature for many production cycles

AbsoluT used by engineer for temperature calibration

Standard

EpiTT – Growth rate, thickness and morphology

Three wavelengths reflectance makes it possible to monitor all essential properties of the growing layers, such as growth rate, layer thickness, surface roughness and others. In addition, LayTec uses 950 nm reflectance for emissivity corrections of the pyrometry measurement.



405 nm - for MQW thin layers
- Comparison of quantum wells (MQW)
- Growth rate of thin layers
- Interface quality
- Roughness

633 nm - for GaN buffer layers
- Growth rate and thickness analysis

950 nm
- Correction for emissivity changes (True Temperature)
- Growth rate and thickness analysis for high growth rate

Other wavelengths are available on request.

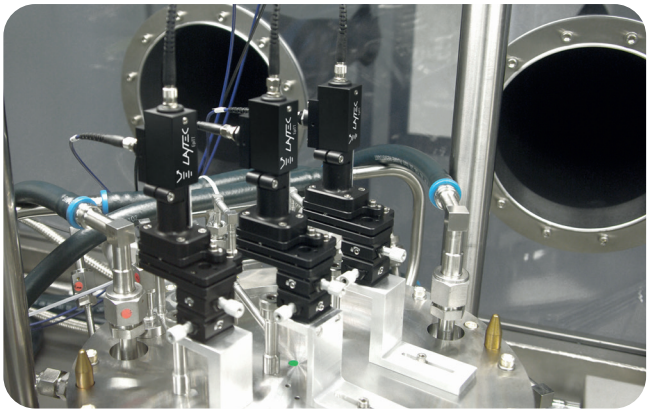
By courtesy of Otto von Guericke University Magdeburg, Germany

LayTec systems for temperature and reflectance

Both emissivity corrected temperature monitoring and reflectance measurement at 3 wavelengths are included in all products of EpiTT family and all systems that include EpiTT features. EpiTT offers industry-standard metrology for any kind of epi-growth systems and is compatible with different main rotation frequencies in the range from 0 up to 1500 rpm.

Models for multiple wafer ring reactors

LayTec offers multi-head configurations of EpiTT and EpiCurve® TT families which are specifically designed for multiple wafer ring reactors. These models have two (EpiTwin TT) or three (EpiTriple TT) optical heads for temperature and reflectance measurements at independent positions. Virtually all LayTec systems can be upgraded to multi-head systems.



EpiTriple TT

Advanced

EpiCurve® TT – Flat wafers by strain engineering

Challenges of 4”, 6” and larger wafers

Wafer bowing → Different distance from pocket surface to wafer in the center and at the edges of the wafer → Temperature deviations across wafer → Composition inhomogeneity reduces yield

See the difference

Accurate in-situ control → Minimization of bowing-related wafer temperature inhomogeneities → Better photoluminescence (PL) uniformity, higher yield

LayTec systems for curvature, temperature and reflectance

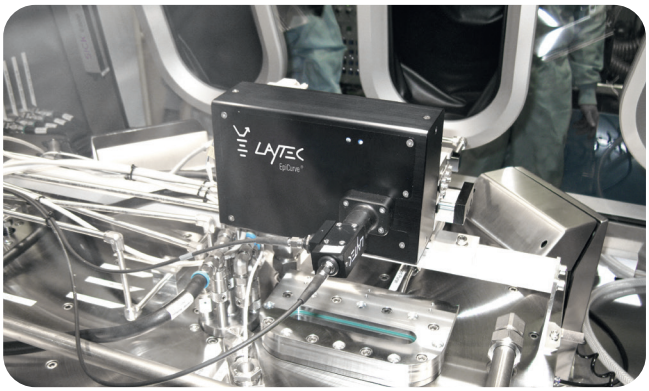
EpiCurve® TT includes:

- Wafer selective curvature measurements
- Curvature range from -7000 km^{-1} (convex) to +800 km^{-1} (concave)
- EpiCurve® TT versions with a blue laser provide measurements on double-sided polished and patterned transparent substrates
- Aspherical bowing curvature measurements with Advanced Resolution (AR) option
- All features of EpiTT: emissivity corrected pyrometry and growth rate / thickness measurements by 3 wavelength reflectance

Fields of application:

- GaN LED and laser diode production
- GaAs / AlGaInP / InP laser diode production
- Triple-junction solar cell production on GaAs, Ge, Si
- R&D for new materials and devices and many others

For multiple wafer ring reactors, a combination with one or two additional EpiTT heads is recommended: EpiCurve®Twin TT, EpiCurve®Triple TT.



EpiCurve® TT

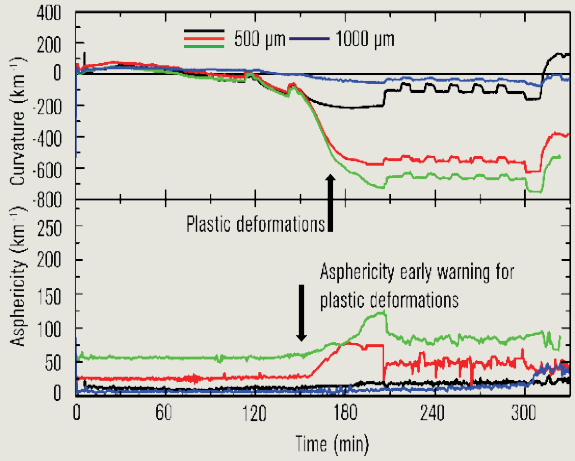
EpiCurve®Twin TT

Advanced

EpiCurve® TT – For III-Nitride growth on silicon

When substrates and epi-layers have a large lattice mismatch and a large mismatch of thermal expansion coefficient, high dislocation density and high tensile stress cause critical wafer bowing and, finally, cracking. Therefore, complex devices such as GaN-based structures on silicon require precise strain engineering to achieve a high quality material. LayTec's in-situ metrology systems provide direct monitoring of the critical growth parameters for stress compensation and strain engineering.

The screenshot shows in-situ curvature measurements by EpiCurve® TT of four different InGaN / GaN LED structures on silicon with step-by-step optimized engineering interlayers. In addition, the substrate thickness was increased from 500 µm to 1000 µm to compensate curvature caused by thermal and lattice mismatch. As a result, after the cool-down process the wafer is flat (0 km^{-1}).



- Compensation of large difference in thermal expansion coefficients by advanced strain engineering
- Goal: flat wafer at room temperature - by introduction of strain compensating interlayers
- Introduction of compressive strain (LT - AlN)
- Strain engineering requires precise curvature control to avoid overcompensation leading to plastic deformations
- Additional balancing of strain by thicker substrates thickness (500 µm→1000 µm) or pocket shaping

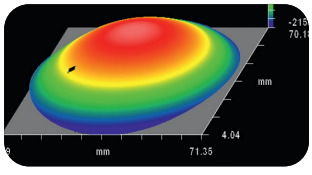
By courtesy of Otto von Guericke University Magdeburg, Germany, Dep. Semiconductor Epitaxy

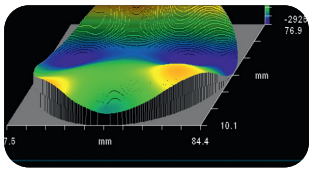
EpiCurve® TT AR – Asphericity monitoring with advanced resolution

One of the challenges during buffer growth is the increasing asphericity of the wafer. For processes potentially causing aspherical wafer curvature, we offer the EpiCurve® TT with the Advanced Resolution (AR) option.

The advantages of the AR option:

- Provides information on wafer curvature along two perpendicular directions: radial and azimuthal
- Measures quantity of the aspheric of the curvature component and gives access to information on layer formation
- Detects relaxation at an early stage
- Reduces signal fluctuations in the main (spherical) bow measurement caused by aspherical effects



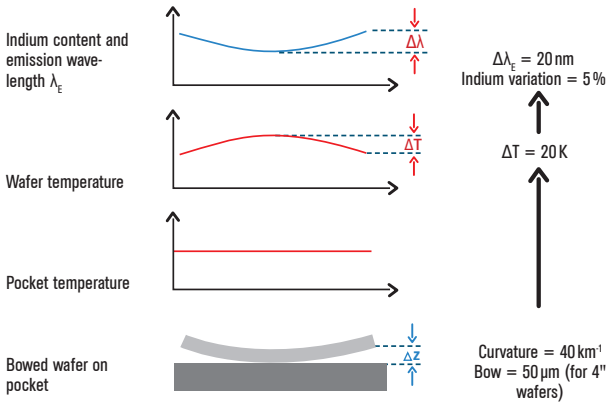


Premium

Pyro 400 – Wafer surface temperature for transparent substrates

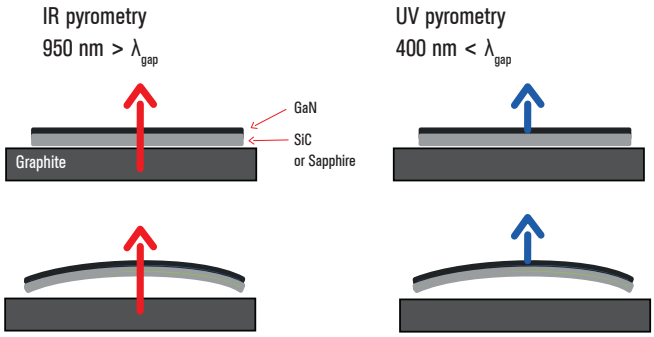
Why wafer surface temperature?

Real GaN surface temperature is the most critical parameter of the epitaxial process. According to the Solid State Lighting (SSL) road map, a wavelength variation across wafer of approx. 1 nm is required. This equals a temperature variation of less than 1 K. When the wafer bows, the deviation between wafer surface temperature and pocket temperature increases e.g., for a 4" sapphire substrate up to 20 K or more. This results in a significant indium content variation in the InGaN / GaN multiple quantum wells (MQW) and, thereby, in a strong variation of the emission wavelength. In other words, surface temperature is fundamental for the homogeneous growth of the active layers and the performance of the final device.



Transparent substrates: GaN growth on sapphire or SiC

When it comes to bowed transparent substrates like sapphire or SiC, a conventional infrared (IR) pyrometer can measure only the pocket temperature. The GaN surface temperature can only be measured by an ultraviolet (UV) pyrometer, because GaN absorbs and thermally emits only below 400 nm.

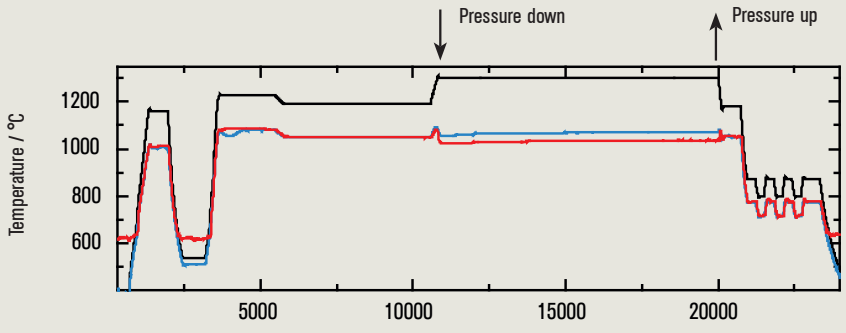


Suface temperature variations during LED laser growth

In this example the conventional pyrometer does not "notice" the drop in wafer temperature by 20 K after changing the reactor pressure. But Pyro 400 does! The red curve in the screenshot shows the exact wafer surface temperature as measured by Pyro 400.

Black - Process temperature
Red - Wafer temperature measured by Pyro 400
Blue - Pocket temperature measured by conventional pyrometer

Two critical changes of reactor pressure (p) are indicated.



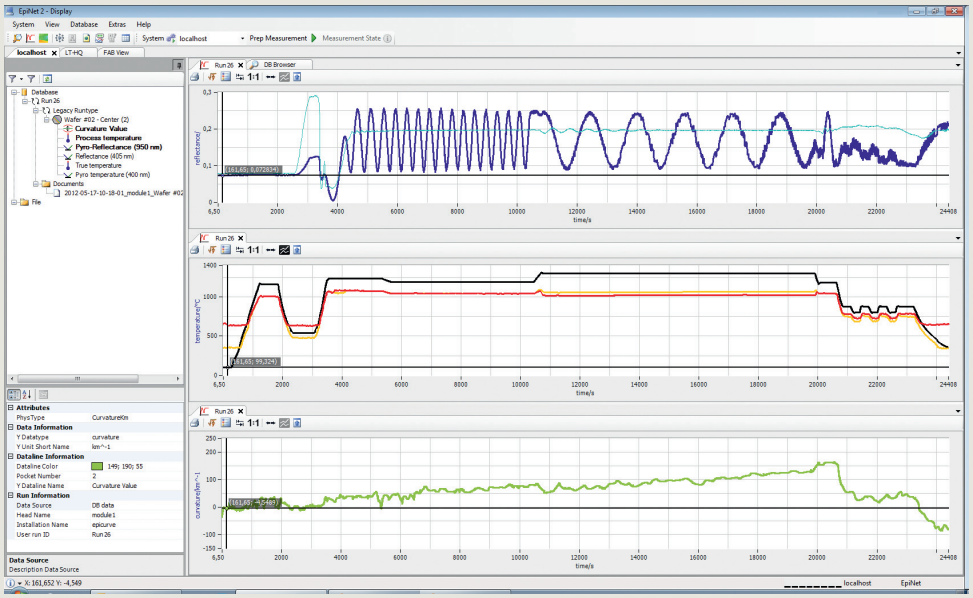
By courtesy of Ferdinand Braun Institute, Berlin, Germany

Premium

Pyro 400 & EpiCurve® TT – Maximum control for transparent substrates

LayTec's premium in-situ solution is a combination of Pyro 400 and EpiCurve® TT. These tools will give you all real-time growth parameters and the best monitoring of quantum well growth in blue and green LEDs and laser diodes.

Example: GaN / AlGaN quantum well laser



Reflectance 405 nm
Reflectance 950 nm

Reactor temperature (recipe)
Pocket temperature (950 nm)
Wafer temperature (400 nm)

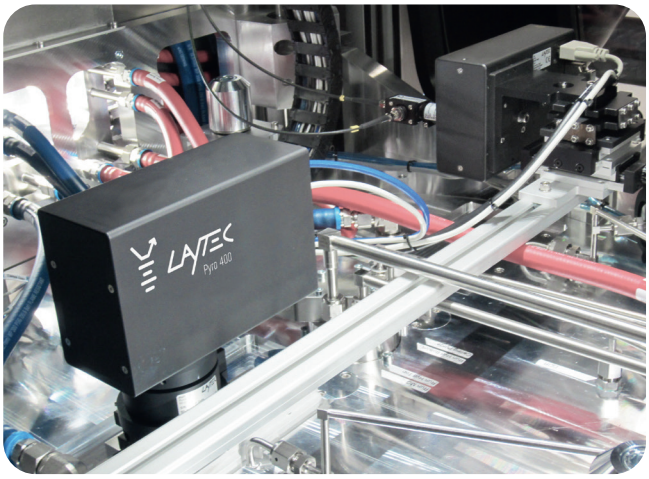
Wafer curvature

By courtesy of Ferdinand Braun Institute, Berlin, Germany

Premium package for transparent substrates

Pyro 400 and EpiCurve® TT provide:

- Measurement of the real surface temperature of GaN for the best LED wavelength uniformity on sapphire and SiC substrates, using ultraviolet pyrometry
- Emissivity corrected pyrometry at 950 nm to measure pocket temperature for root-cause failure analysis
- Correlation of reflectance at three wavelengths for growth rate, thickness analysis and pyrometry correction
- Curvature measurements for strain engineering and in-situ calibration of ternary composition

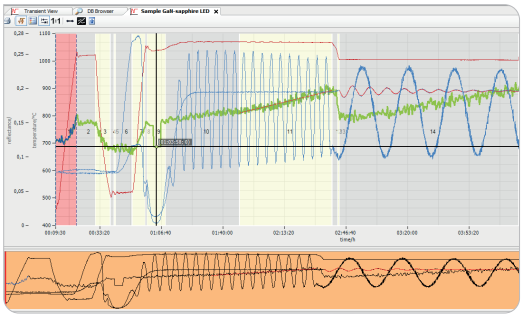


Pyro 400 and EpiCurve® TT installed on one growth system

Control and analysis software

EpiNet - Improve yield and process capacity

All LayTec in-situ systems are equipped with LayTec's EpiNet software specially developed for process optimization, analysis and control. Our software solutions can be integrated in the whole fab to monitor all runs simultaneously and support operators when making "stop or go" decisions. It lets you visualize wafer measurements, browse through previous runs and explore the rich set of information that is captured during your process. EpiNet gives you the calculation tools you need, to extract key figures about your wafers and your epitaxy. In run-to-run control and in statistical process control these key figures allow you to improve your yield and process capacity.



With EpiNet you can:

- Turn raw in-situ data into valuable information
- Drill down to single data points
- Rapid R&D analysis
- Improve your epitaxy yield
- Maximize your process capacity
- Save money with automation

Features

Measurements

- Time resolved, wafer resolved, zone resolved measurements for all LayTec in-situ products incl. emissivity corrected pyrometry, multi wavelength reflectometry and wafer curvature
- Both spherical and aspherical wafer curvature can be measured simultaneously when using EpiCurve® TT AR (Advanced Resolution)
- Full linescan capabilities included (available during run and post run)

Data handling

- Storage of all measurement and automated configuration and analysis data in SQL database for complete the accessability of results
- Run type management for easy repetition of identical or similar runs regarding zone setup and analysis recipes
- Export filters for XML, CSV, SQL and others for easy processing in upstream systems
- Comprehensive visualization and data analysis options

Advanced analysis

- Analysis recipe for synchronized step-by-step analysis of the growth process
- Fast determination of growth rate, layer thickness and optical constants even for very thin layers
- Extensive data base of optical constans of numerous material (e.g., GaN, AlN, AlGaAs)
- Statistical analysis: average, maximum, minimum, standard deviation and determination of the slope (e.g., temperature, curvature...)
- Dedicated analyses for specialized applications (e.g., GaN 3D - recorvery time)

Easy control

Fast and easy growth analysis on PSS

Patterned Sapphire Substrates (PSS) are becoming indispensable in GaN LED production. LEDs grown on PSS typically have larger light output and better crystal quality. To take MOCVD processes on PSS under tight in-situ control, some additional efforts are needed. Every kind of patterned substrate, e.g., cone, dome (Fig. 1) or spherical pattern, requires individual calibration of the reflectance signal before the process. This document describes an easy automated way to meet this challenge.

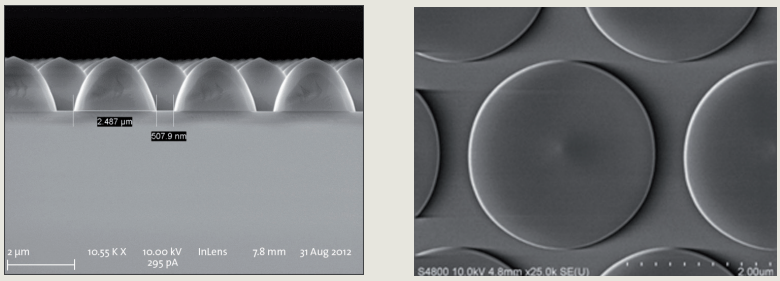


Fig. 1: REM images of PSS with domes (left) and cones (right) as pattern.

Fig. 2 shows the reflectance signals measured during the growth of GaN on PSS. The initial reflectance of the bare PSS substrates is typically lower than that of standard single-side polished sapphire. In addition, the inital reflectance of the three wavelengths (405 / 633 / 950 nm) is very different because the interaction of light with the 3 dimensional nano-/micro-pattern (scattering, diffraction, interference) strongly depends on the wavelength. In the screenshot (Fig. 2), the increasing reflectance amplitude (after ~4000 s of the growth process) shows the coalescence process of GaN. After ~8050 s, the 405 nm reflectance stabilizes at 15.5%, indicating the improvement of the GaN surface quality. The 633 nm and 950 nm reflectance signals have well developed interference patterns.

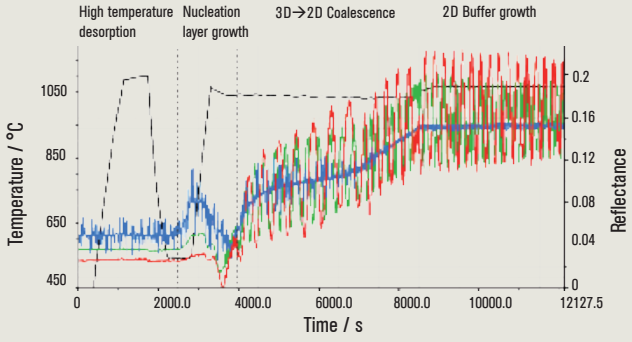


Fig. 2: GaN growth on PSS measured by LayTec's EpiCurve® TT installed on AIXTRON PLanetary® G3 reactor at Ferdinand Braun Institute, Berlin, Germany.
Screenshot of EpiNet software: reflectance at 405 nm (blue), 633 nm (green), 950 nm (red); True Temperature (black).

Interestingly, some lateral non-uniformity of the PSS structures across the wafer obviously shows up in these data. The initial 405 nm reflectance on the bare PSS substrate (0... ~4000 s) is noisy, while 633 nm and 950 nm reflectance is rather smooth. The 405 nm wavelength is in resonance with some geometric parameters of the pattern's structure, which is non-uniform. As soon as the GaN buffer is thick enough, the 405 nm light does not reach the pattern anymore because of the absorption in the GaN. Hence, the 405 nm reflectance „noise" reduces because the GaN surface is rather smooth. However, the interference patterns of the 633 / 950 nm reflectance look "noisy" during 2 D buffer growth. Obviously, the initial non-uniformity of the PSS structure causes a certain non-uniformity in the GaN thickness.

LayTec's EpiNet software makes it easy to take LED growth processes on PSS under tight in-situ control. It quickly identifies even quality deviations and non-uniformities of the PSS substrates. Furthermore, the software also contains fitting of thin layers, wafer bow calculation and many further features indispensable for growth on PSS.

Economics

Return on Investment (ROI) after a few months

- Real-time access to process data
- Guidance for setting up efficient GOLDEN RUN definitions
- Detection of LED process defects at the earliest possible stage

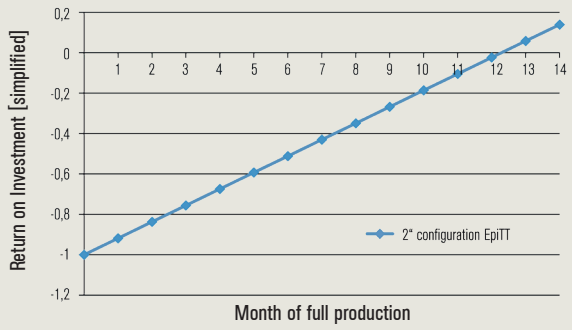
- Increased manufacturing stability
- Accurate run-to-run reproducibility
- Reduced operational costs

- Yield enhancement
- Quality optimization
- Cost reduction

With a reasonable investment in LayTec metrology, LED manufacturers achieve astonishing increases in yield and productivity. Here are two examples calculated by our industrial customers:

Process optimization with standard package: EpiTT example

- Repeatable, stable emissivity-corrected temperature measurement by AbsoluT calibration (±1 K repeatability)
- Three reflectance wavelengths, incl. MQW detection
- Online reproducibility (GOLDEN RUN)

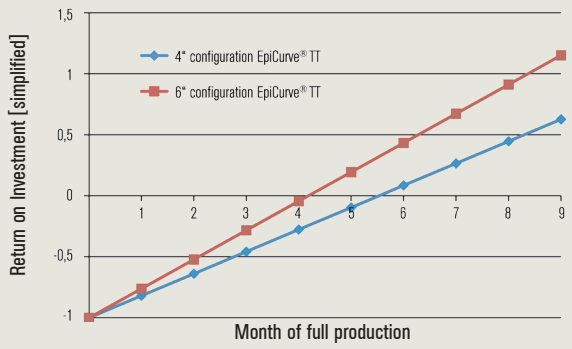


ROI: 12 months for 2” GaN LED

- EpiTT on AIXTRON G5 HT
- Incl. 3 mm edge exclusion
- 2” wafer configuration
- Full production month: 24 / 7 / 4
- Based on simplified ROI calculation for metrology investment

Process optimization with advanced package: Example EpiCurve® TT AR

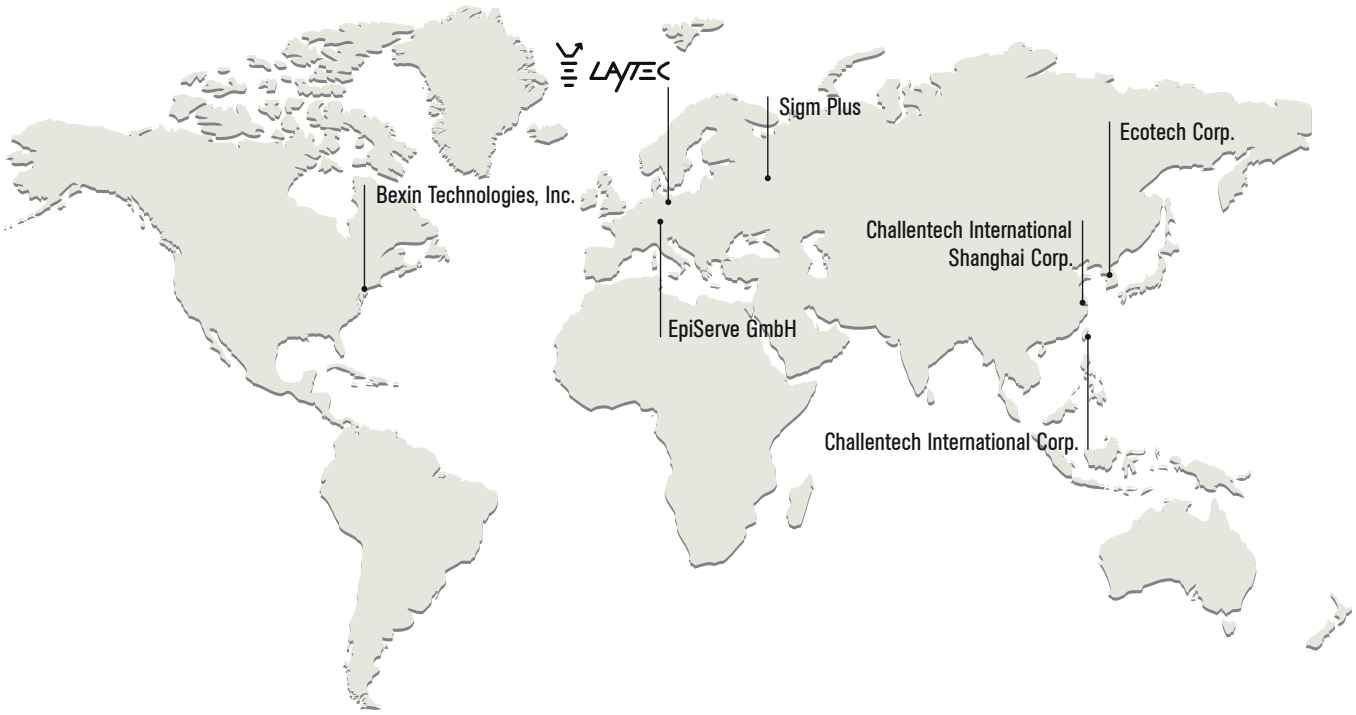
- Bow control and, therefore, process transfer to larger wafers
- 20% less runs required for epi R&D process development saves three months of R&D time
- Faster strain engineering during pre-production phase saves one month of optimization time
- Precise bow tuning and process control improves yield by 10% with respect to number of epi wafers and by further 5% due to edge exclusion optimization
- Early detection and elimination of slip lines improves epi wafer yield by 5% with respect to number of epi wafers



ROI: 4 months for 6” GaN LED

- EpiCurve® TT AR on AIXTRON G5 HT
- Incl. 3 mm edge exclusion
- 4” vs 6” wafer configuration
- Full production month: 24 / 7 / 4
- Based on simplified ROI calculation for metrology investment

Global Network



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