

Connected metrology

Full 2D characterization of
HEMT device structure epi-wafers

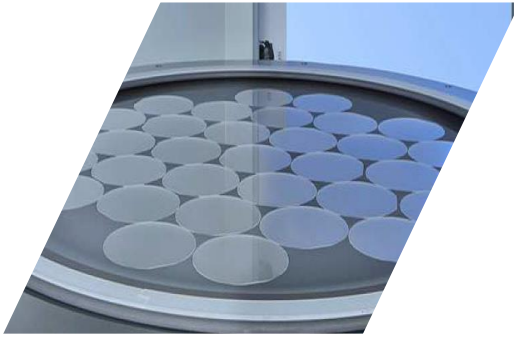
Dr. Johannes Zettler

LayTec AG

CS International 2024

- **“Epitaxy is the lithography of CS technology.”**

Rodney Pelzel, IQE (CS Mantech, 2023)



- **“Metrology is the navigation system of your epitaxy.”**

LayTec, 2000s

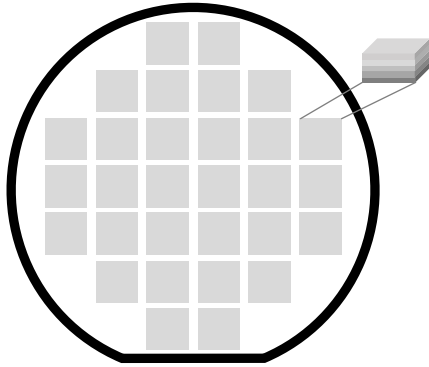
- **“Meanwhile, metrology is the navigation system of your entire frontend processes.”**

LayTec, 2020s

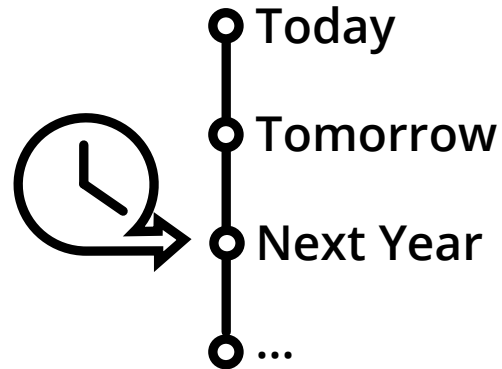
Why do you need metrology?

The ideal process would be uniform ...

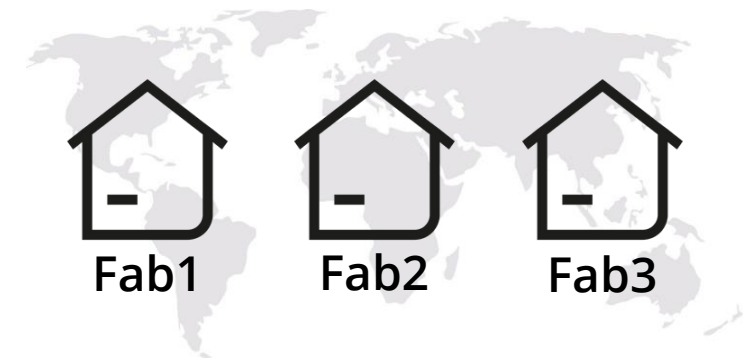
on wafer
chip-to-chip



in time
run-to-run



in space
system-to-system & fab-to-fab



- In an ideal world, you would not need metrology!
- Luckily, ideal is boring and we don't live in an ideal world.



Optical Metrology Company founded 1999 in Berlin

- › 25 years old
- › Spin-off of TU Berlin
- › 90+ employees
- › > 3500 systems sold

- › Operating worldwide
- › Member of Nynomic group

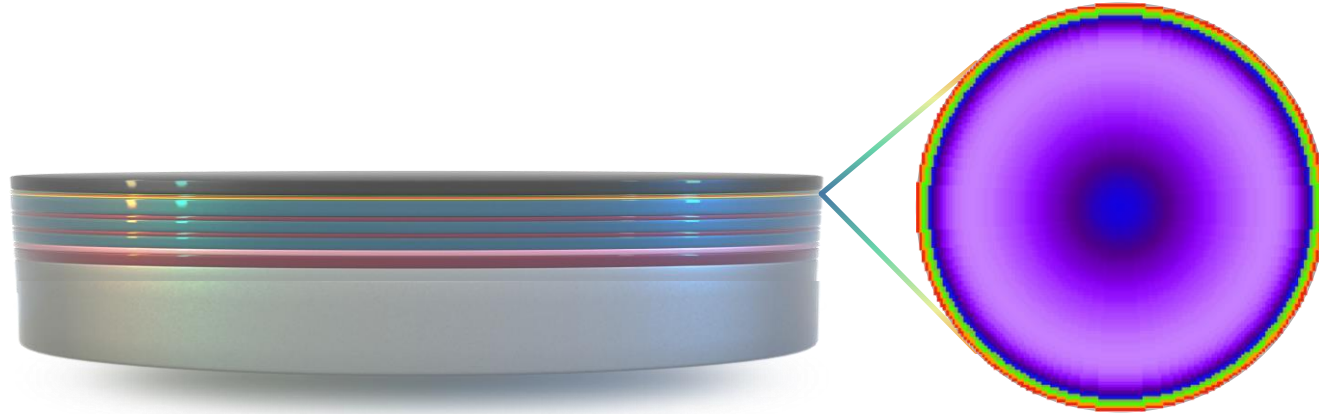


Our business: Process-integrated optical metrology
Our markets: Semiconductor and thin-film industry & academia
incl. lighting, laser, PV, glass coating ...



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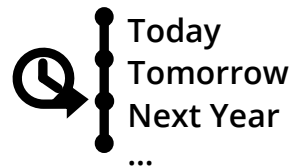
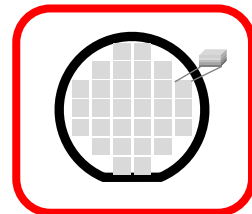
Metrology's job as your navigation system ...



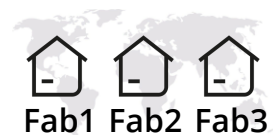
Focus today: 2D Wafer uniformity

- full quantification of critical layer structure
 - layer thicknesses
 - layer compositions
 - layer strain / relaxation ...

... is to help you reach, improve and maintain uniformity in all dimensions.



Today
Tomorrow
Next Year
...



Optical metrology along the semiconductor manufacturing chain

costs
value
risks



high costs

high value
generation

temperature
thickness
composition

maintain or
destroy value

unknown
uniformity

wrong
etch stop

Substrate

Front-end
Level 0 - Epitaxy

Epi-wafer

Front-end
Level 1 - Device Production

Dies-on-wafer

Inspection, masking/
lithography, etching,
metallization ... etc.

systems & applications

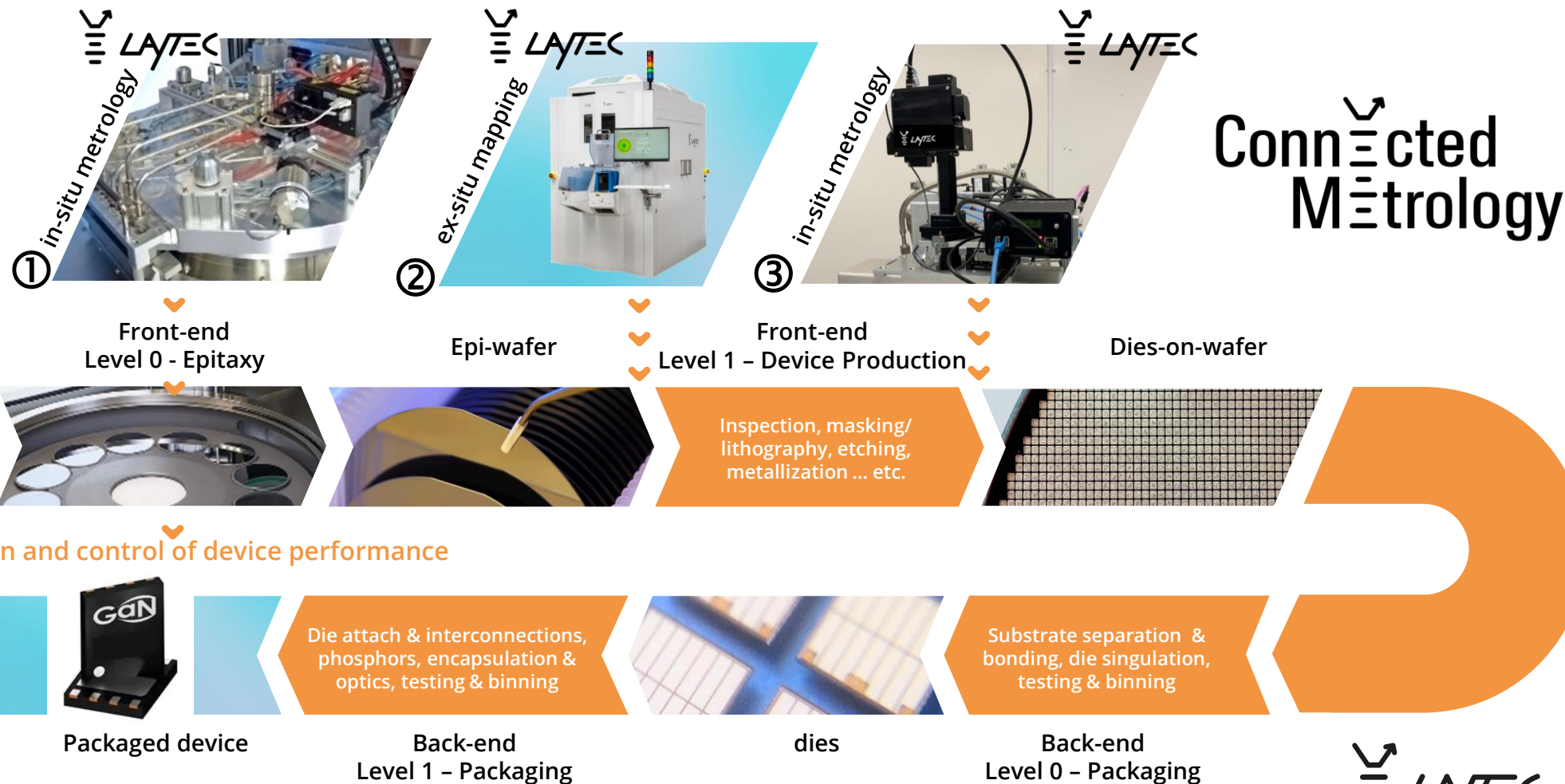
Packaged device

Back-end
Level 1 - Packaging

dies

Back-end
Level 0 - Packaging

Optical metrology along the semiconductor manufacturing chain

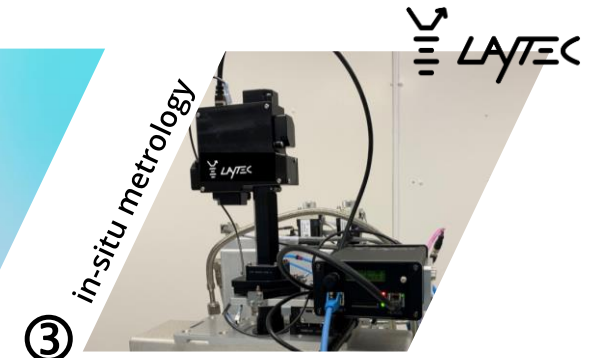
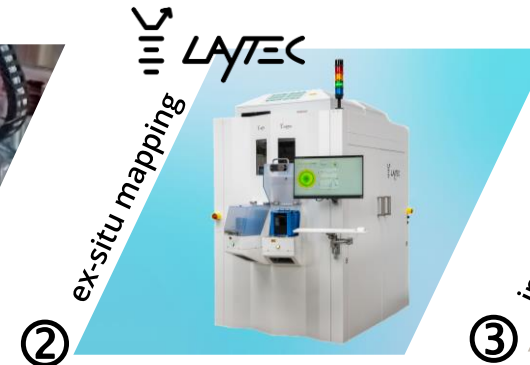
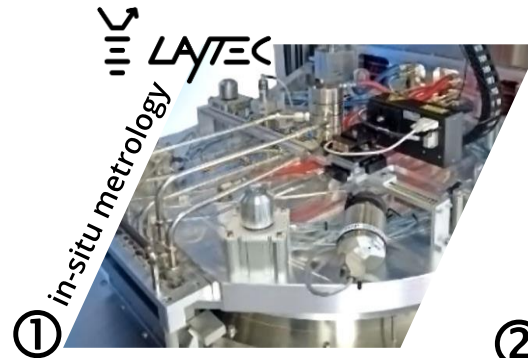


GaN/Si HEMT production – film thickness control during MOCVD and Etching

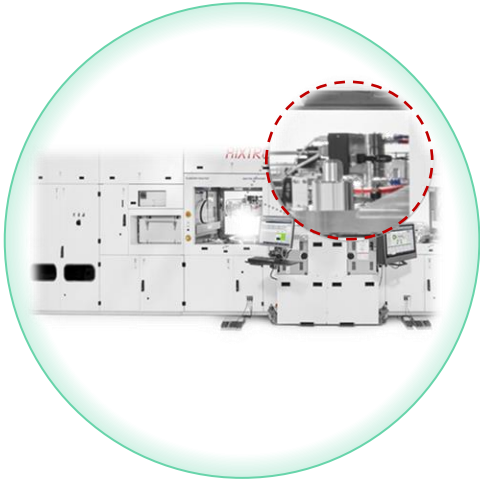
Typical E-Mode HEMT device stacks

p-GaN 10 nm ... 100 nm
AlGaIn 10 nm ... 30 nm
i-GaN channel layer 100 nm ... 200 nm
GaN/AlGaIn buffer (various patented designs) complex strain-engineering 2-6 μm

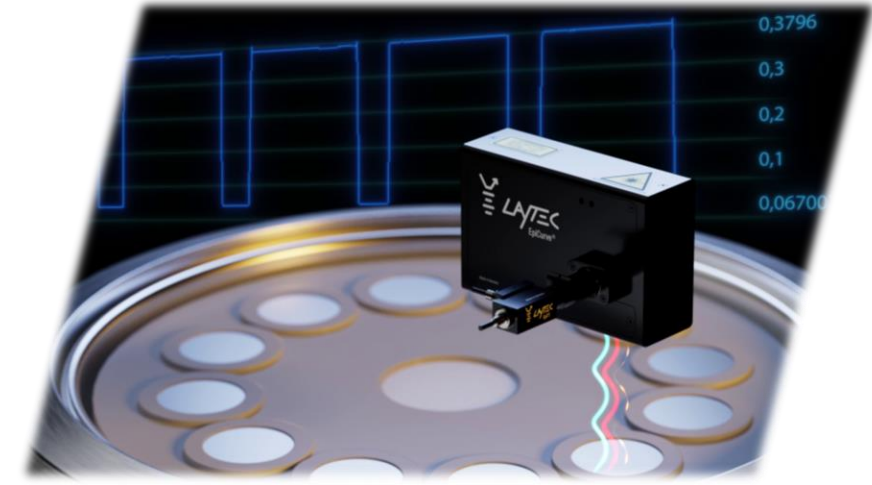
- for cost reasons: large 200 mm & 300 mm silicon wafers and extreme uniform epi and etching is required
- optical in-situ control on the level of 0.5 nm (~1 atomic monolayer) is a must



① MOCVD: in-situ measurement and control of growth parameters

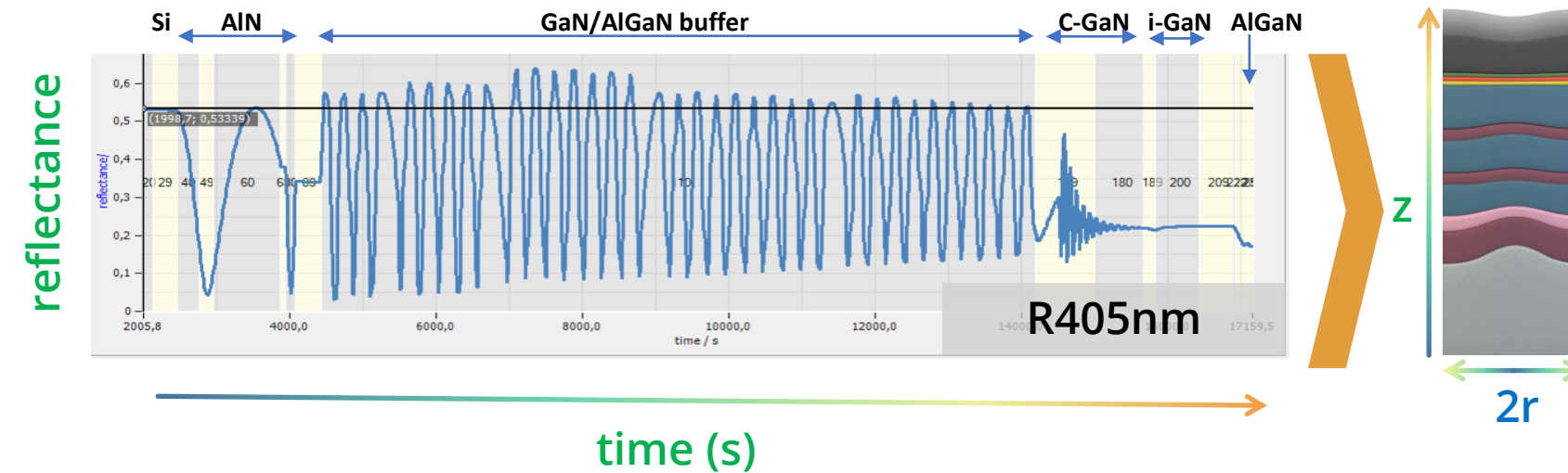


- › metrology tool: **LayTec EpiCurveTT**
- › every ~2 s measurement of
 - › temperature
 - › multi- λ reflectance
 - › local curvature
- › at center of specific wafer
- › plus radial scan across wafer
- › typical growth time: few hours
- › sensitivity of in-situ measurement unchanged from first to last layer
- › layer-specific deviations can be detected in real-time early in the process
- › state-of-the-art: used for advanced process control



slow-motion visualization of reflectance measurement

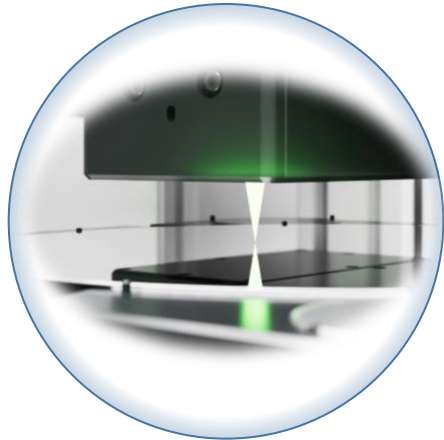
① MOCVD growth analysis of E-Mode HEMT structures



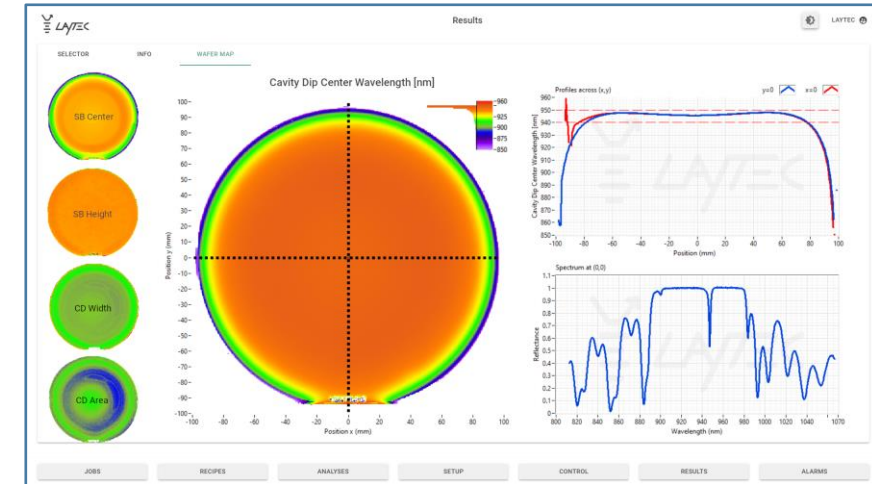
- thickness of most critical layers can be determined from in-situ data
- increasing complexity of devices requires continuous enhancements of individual measurement methods

- Limits of in-situ growth monitoring during epitaxy
 - accuracy limited for very thin, ternary layers
 - radial information only, no full 2D XY results
- E-Mode HEMT Structure – barrier layer
 - for most critical layer, simultaneous measurement of thickness and composition not always possible

② Post epi wafer mapping

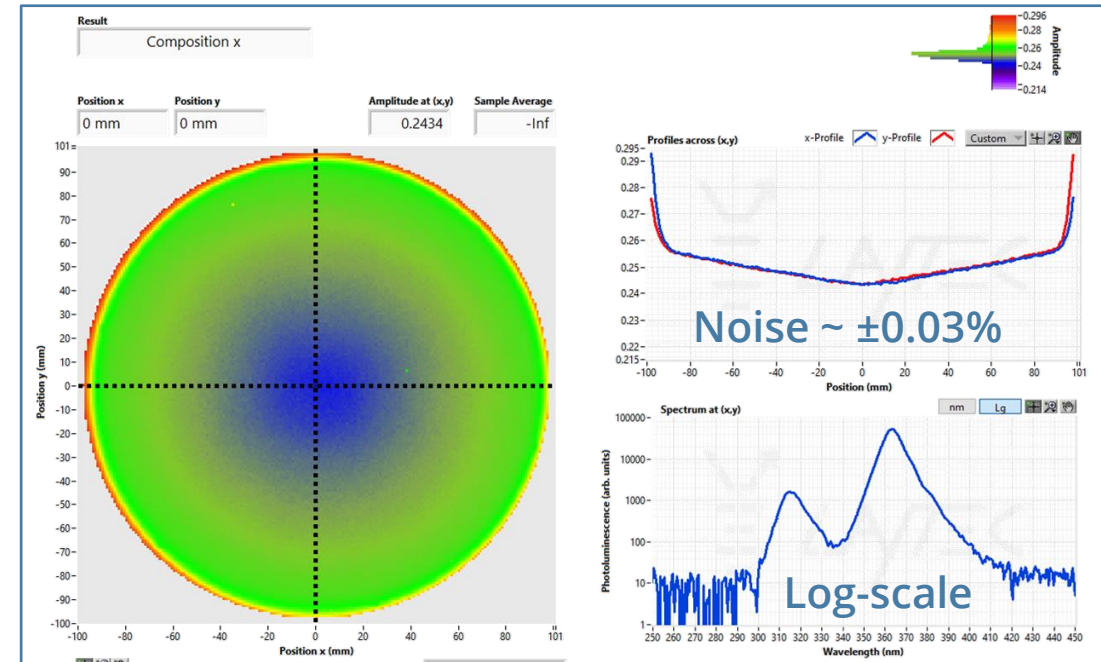


- › metrology tool: **LayTec EpiX**
- › ex-situ wafer mapping
- › white light reflectance and photoluminescence
- › x,y mapping @ 250-2400 nm
- › best-in-class measurement performance and accuracy
 - › low spectral noise
 - › superior absolute accuracy
 - › superior 2D measurement uniformity
- › advanced analysis algorithms



② HEMT Epiwafers - Standard Approach: UV-PL Mapping

- UV-PL of D-Mode reference structures
- determination of AlGaN barrier composition
 - very low signal for thin layers
- for E-Mode structures, excitation laser blocked by p-GaN
 - Al-composition measurement not possible
- limitations:
 - no quantification of barrier thickness etc.
 - probing rather minimum AlGaN composition rather than average AlGaN composition
 - not applicable for complex barrier designs with varying AlGaN composition

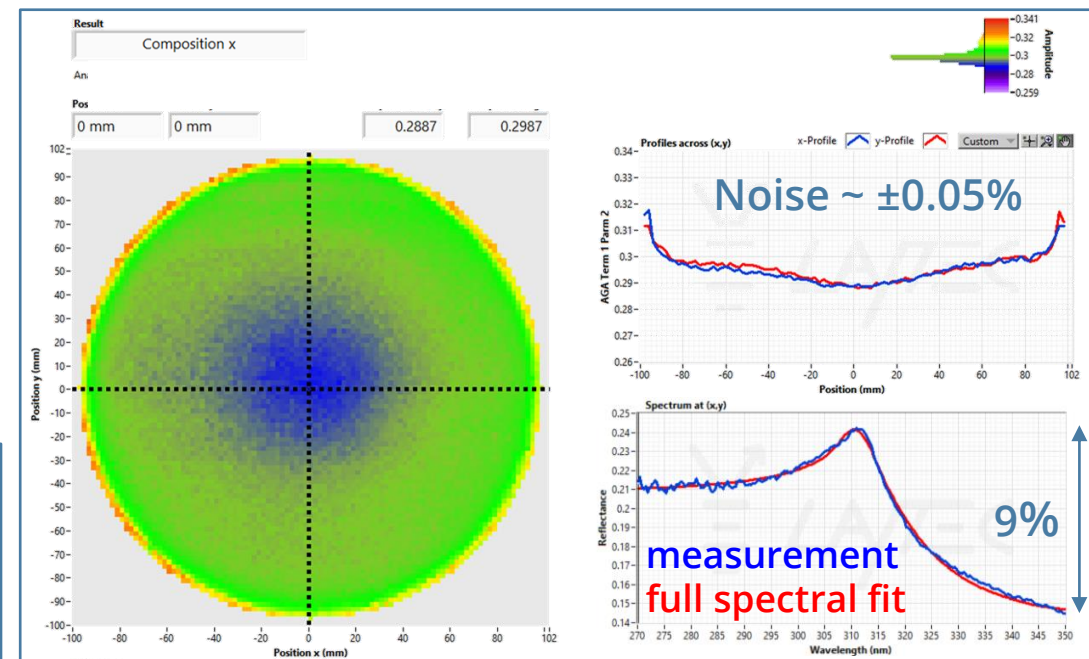
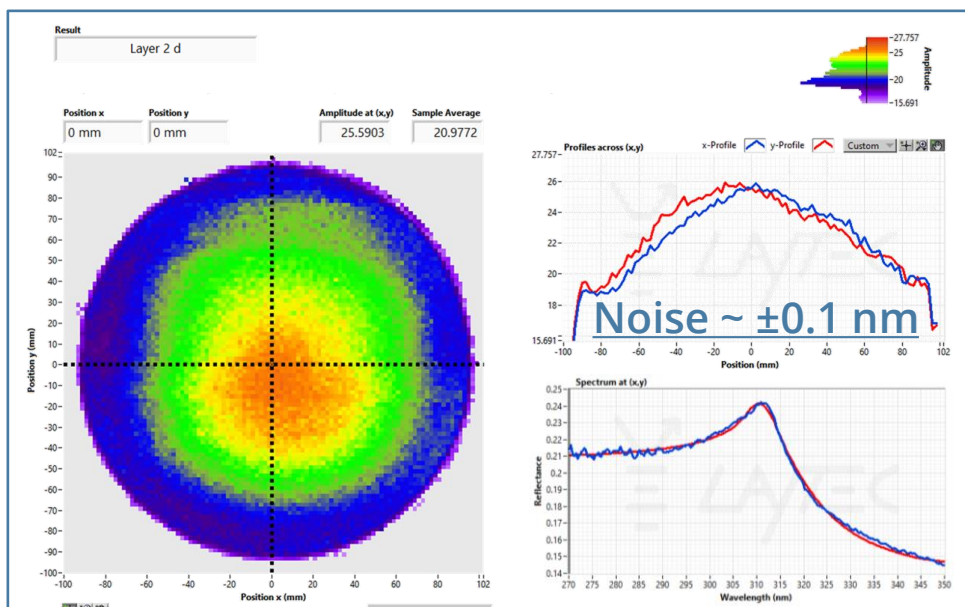


AlGaN composition from UV-PL

UV-PL alone not sufficient for process control!

② More powerful: UV-Reflectance Mapping

- UV-Reflectance of HEMT product wafers
- full spectral fit of UV reflectance
- determination of AlGaN barrier composition + thickness
 - composition usually 3-4% above PL as UV-R is probing average composition
 - also applicable for complex barrier designs with varying composition



AlGaN composition from UV-R of D-Mode

AlGaN thickness from UV-R of D-Mode

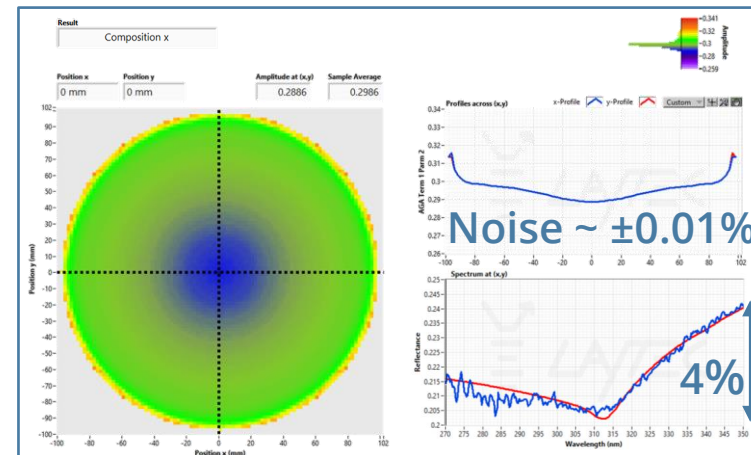
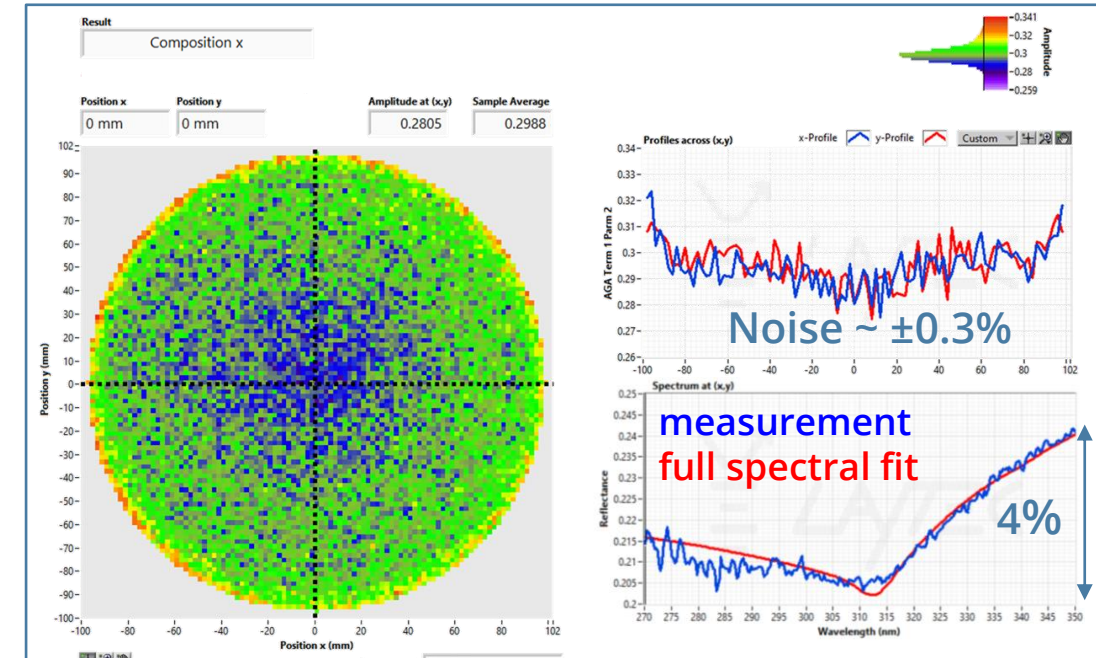


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② More powerful: UV-Reflectance Mapping

- UV-Reflectance of HEMT product wafers
- full spectral fit of UV reflectance
- determination of AlGaIn barrier composition + thickness
 - composition usually 3-4% above PL as UV-R is probing average composition
 - also applicable for complex barrier designs with varying composition
- also for E-Mode structures!
 - lower signal due to absorption of p-GaN
 - higher noise of measurement results
 - improved fitting results through reduction of degrees of freedom in spectral fit by using wafer-specific in-situ analysis-results

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AlGaIn composition from UV-R of E-Mode with 100 nm p-GaN

2D-smoothed

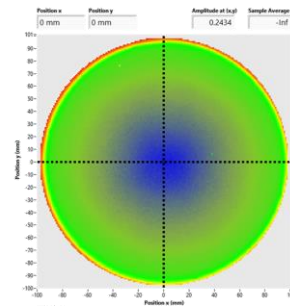


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② HEMT Epiwafers - UV-PL vs. UV-R Mapping

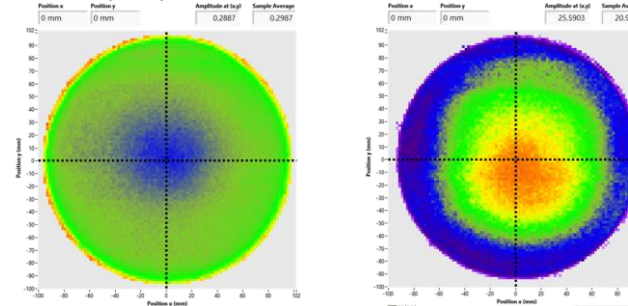
D-Mode

UV-PL
LayTec and Competition



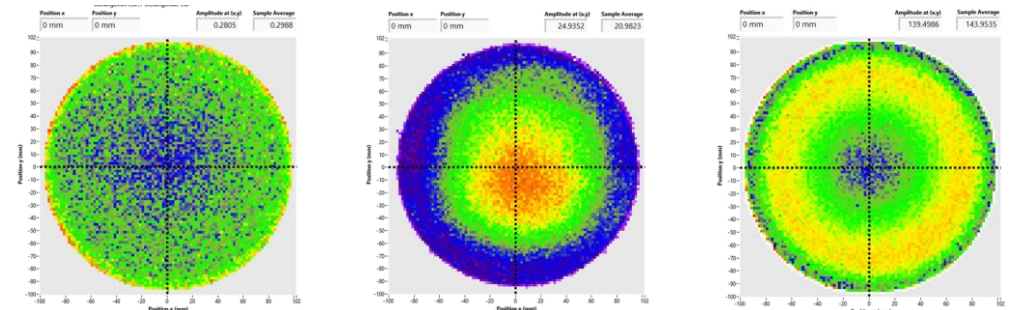
AlGaN composition (local minimum)

UV reflectance
LayTec only



AlGaN composition (average+more) & AlGaN thickness

E-Mode



AlGaN composition (average) & AlGaN thickness & p-GaN thickness

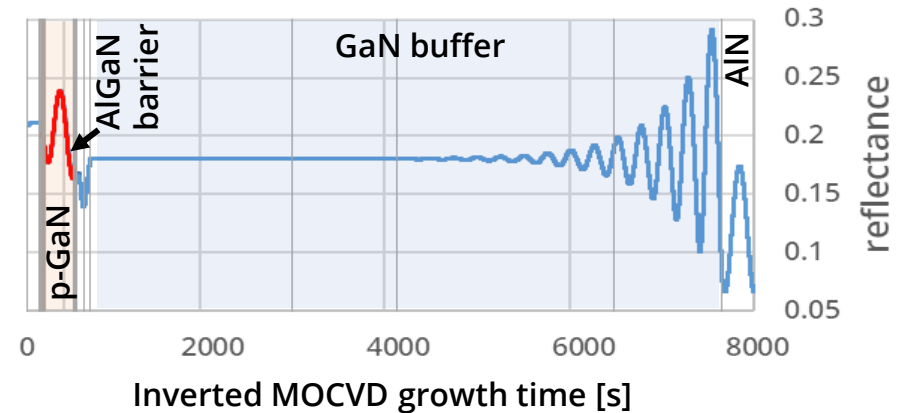
③ Etching – Standard: End-Pointing using Optical Emission Spectroscopy

- etch-stop layers required as only sensitive to interfaces

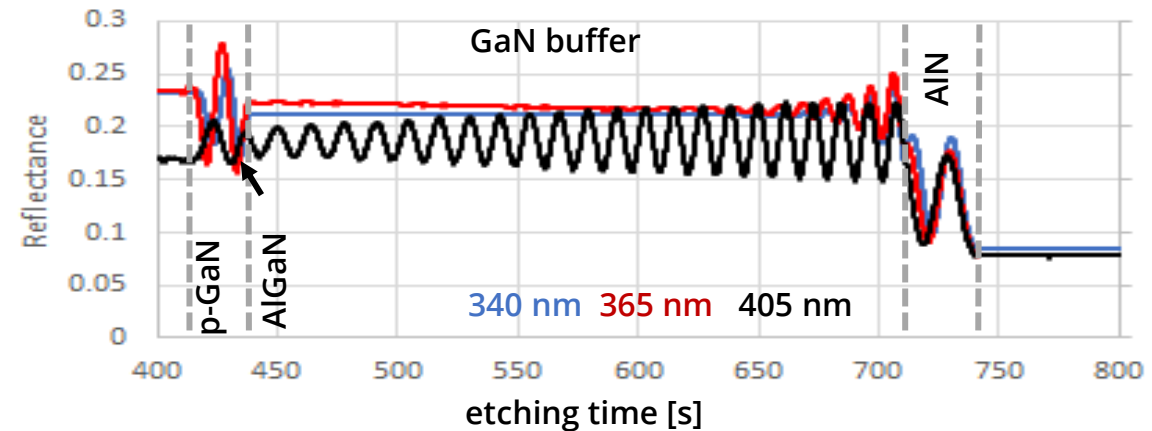
More powerful: UV-Reflectance based EPD

- example: in-situ reflectance during growth/etch of GaN/AlGaIn HFET structure
- Epi:
 - Fabry-Pérot-Oscillations (FPO) due to increasing layer thickness during epitaxial growth
 - highly accurate layer thickness measurements
 - 'time inverted' reflectance trace gives preview to etch transient measurement
- Etch:
 - FPOs due to shrinking layer thickness during etching
 - real-time analysis based on pre-existing measurements enables EPD anywhere in stack

Epi



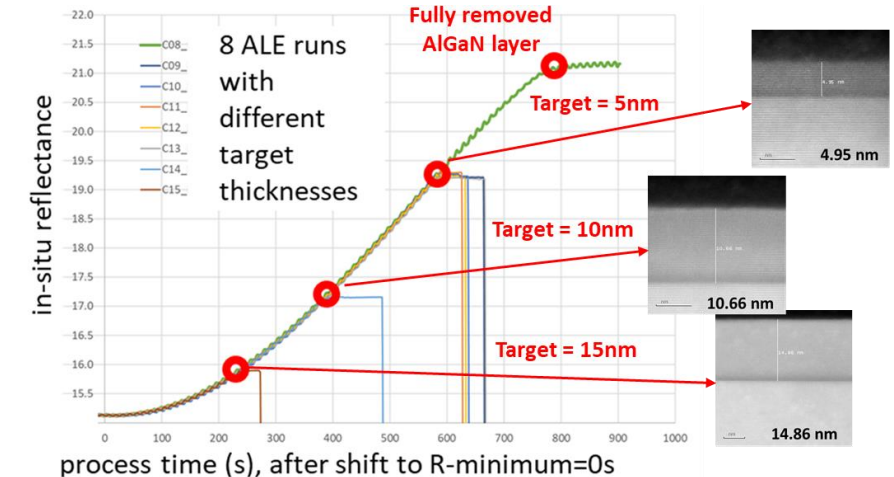
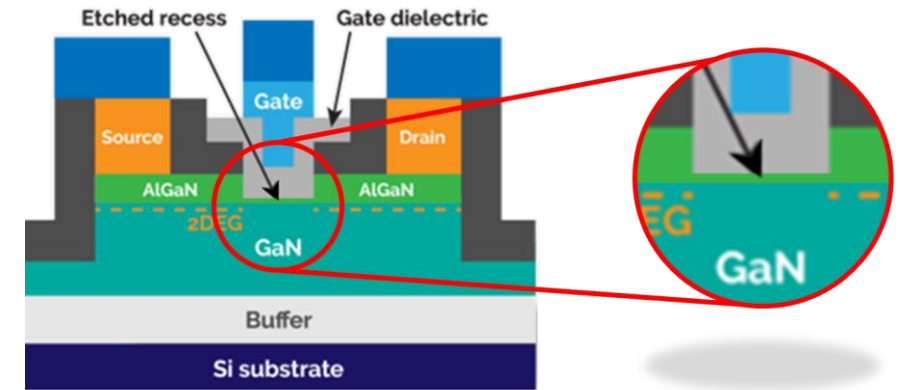
Etch



③ Plasma etching of HEMT structures

- Metrology tool: LayTec TRiton or Etchpoint
- UV-reflectance based (multiple wavelengths)
- Measurement of etch rate and remaining layer thickness
- Automated endpointing (EPD) for AlGaIn and GaN etch
- EPD at any point within stack possible when wafer was previously measured with LayTec metrology during Epi

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EPD with Etchpoint on Oxford Instruments chamber

Summary

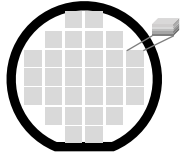
On-Wafer & Wafer-to-Wafer uniformity:

- › Suitable metrology required to fully quantify wafers
 - › UV reflectance mapping & UV reflectance endpointing methods of choice
 - › LayTec provides best-in-class measurement performance and accuracy also for mapping and etch
- › Connected metrology enables advanced wafer-specific analysis and end-pointing
 - › process also suitable for optical devices like (μ-)LEDs and other structures

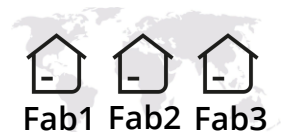
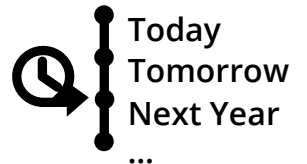
Run-to-Run, System-to-System, & Fab-to-Fab uniformity:

- › LayTec systems provide absolute results by design and come with automatic self-calibration procedure with each measurement as well as a sophisticated cross-calibration procedure

Choose LayTec metrology as your navigation system.



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Metrology



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The background features a dark blue/black area on the left with a glowing white arrow pointing up and to the right. Several horizontal light bars in green, yellow, and orange are visible on the left side. A large white diagonal band runs from the top left to the bottom right. A blue parallelogram is positioned near the top left, and an orange parallelogram is near the bottom right.

Knowledge is key

www.laytec.de