ICP-etching of GaN HFET structures: real time statistical process control of nm-thick GaN layers by means of end point detection

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Outline

- Introduction
- GaN based HFET and challenges in Plasma Etch
- Endpointing with ICP
- Connected metrology
- Summary

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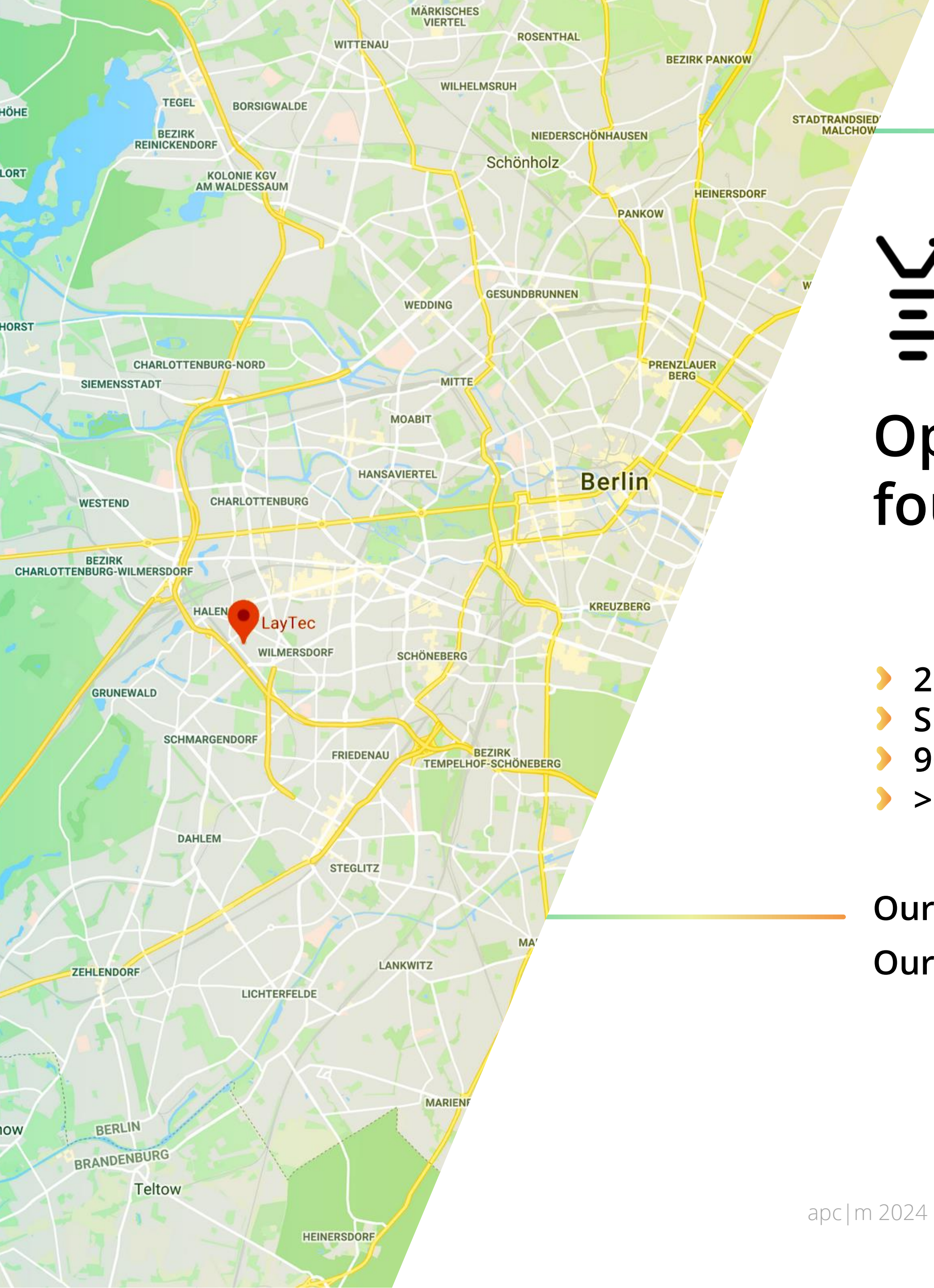

LAYTEC

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

NYNOMIC
THE PHOTONICS 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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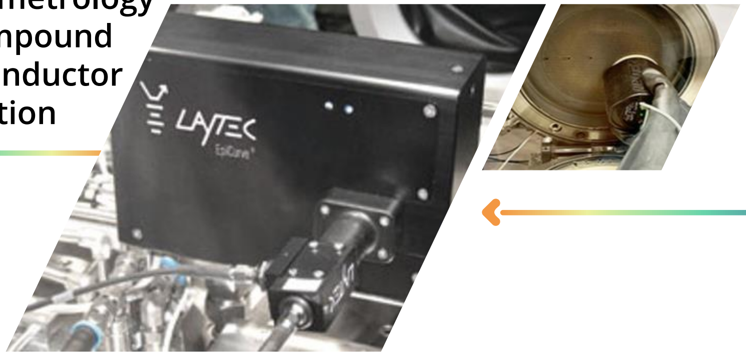
LayTec – expertise and applications in optical metrology for …

Epitaxy / MOCVD

In-situ metrology for Compound Semiconductor Deposition



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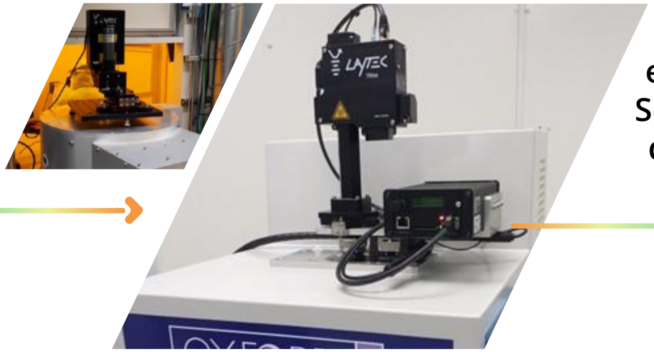
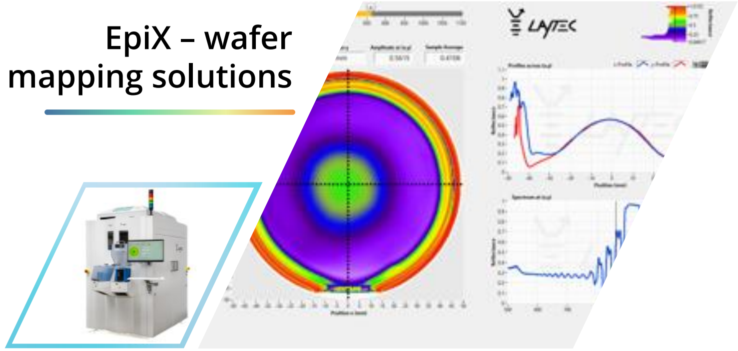
Etch



Optical endpointing Solutions for dry and wet Etching

EpiX – wafer mapping solutions



Mapping

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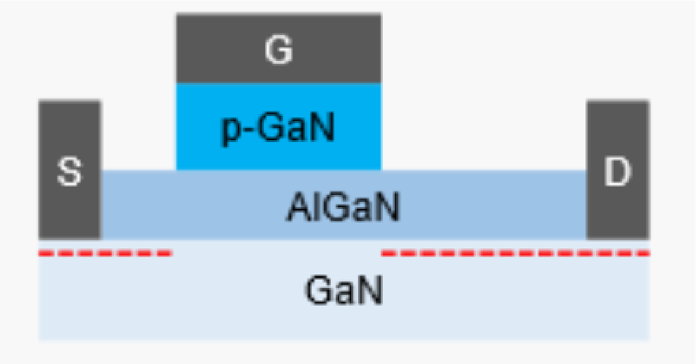
Challenges in GaN Power Device Fabrication

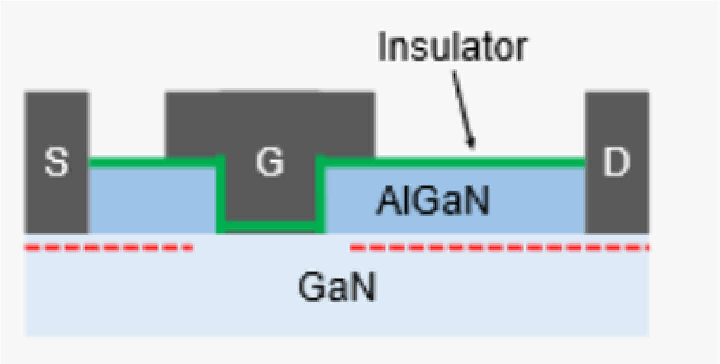
- Normally-OFF GaN HFET concepts

(a) p-GaN gate HFET



- High gate leakage
- Lower breakdown voltage
- Easier manufacturing

(b) MIS-HFET



- Low gate leakage
- Large gate voltage swing
- Manufacturing challenges: stop 5 nm before GaN interface without contrast layer!

Challenges in Plasma Etching

- Time based etching has limitations
- End Point Detection (EPD) offers advantages

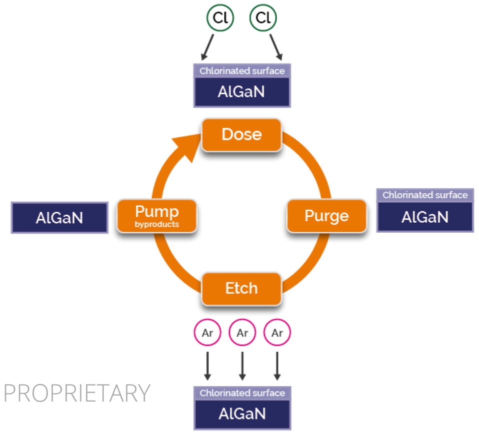
EPD Method	Monitors
Optical Emission Spectroscopy (OES)	Plasma
White Light reflectance	Wafer
Interferometry	

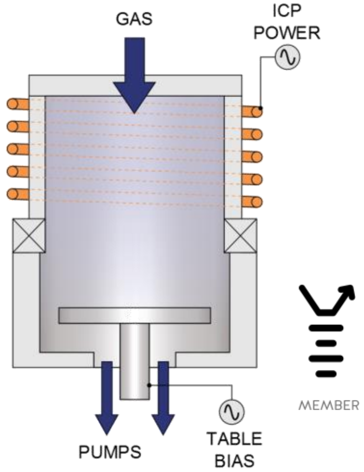
APCM 2023

APCM 2024 !

Processes	Atomic Layer Etching (ALE)	Inductively Coupled Plasma (ICP)
Profiles	Anisotropic	Isotropic/Anisotropic
Etch Rate	Slow ~ 0.1 nm/sec	Slow to fast ~ 1-10 nm/sec
Selectivity	Very good	Very good

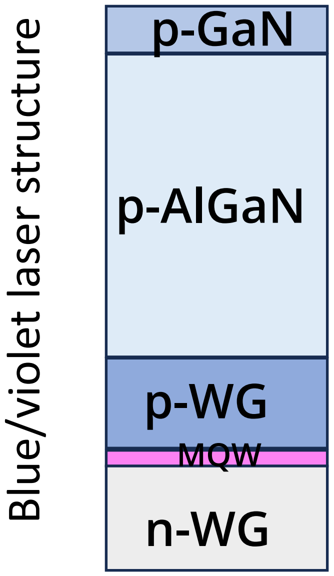
- Is interferometry based EPD also suitable for AlGaN etch thickness control using ICP ?

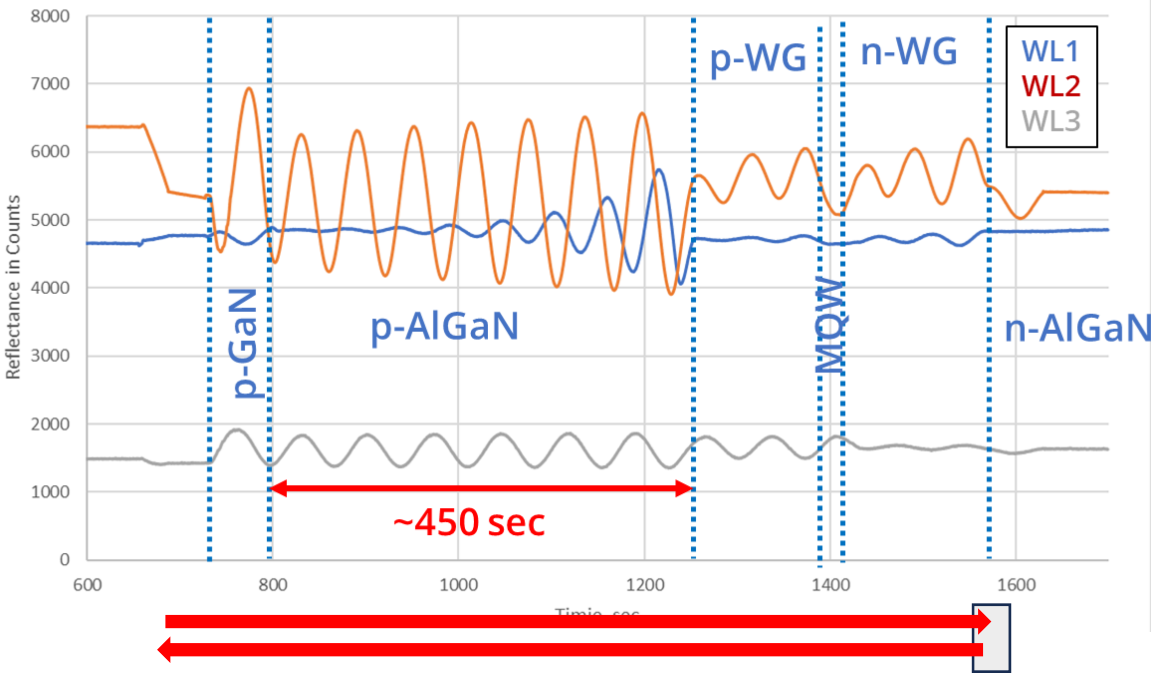


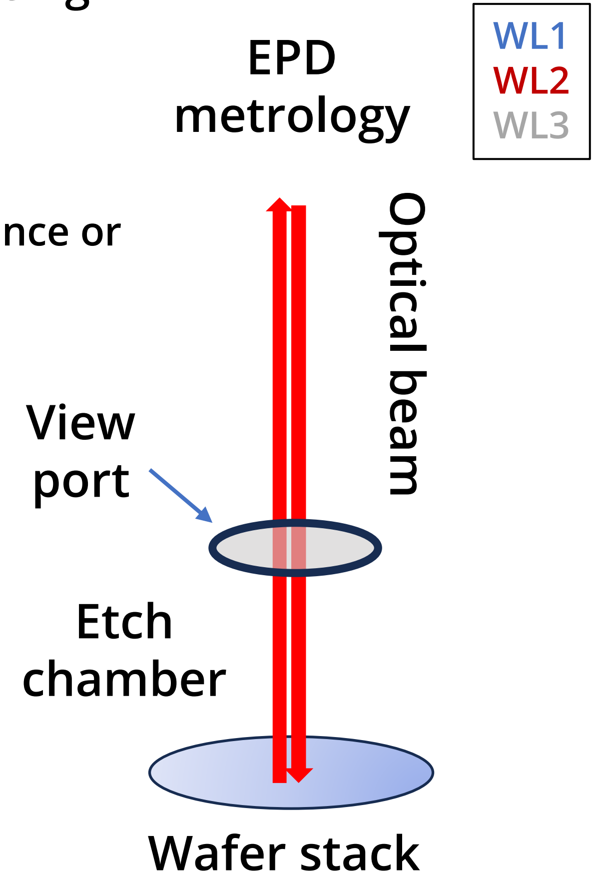


Plasma-Etch using Interferometry EPD in Compound Semiconductor

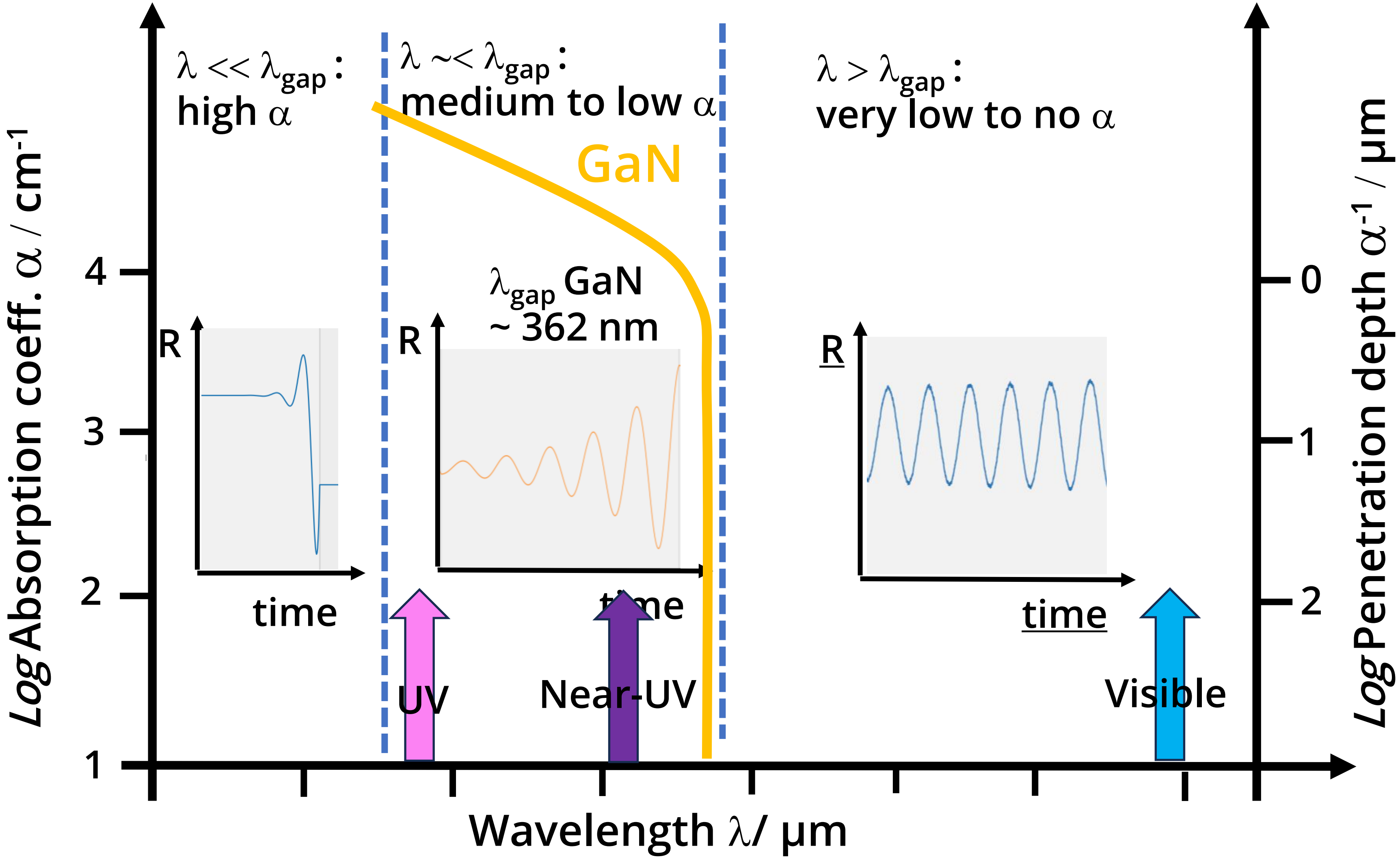
- **Real time measurements of an optical beam being reflected at a surface being etched away**
- **Principle of Operation: ‚Wafer Stack Etching‘**
  - **Signals from etching surface and every other interface of wafer stack → Reflectance or ‘Etch transient’**







Importance of wavelength: GaN & thin film reflectance



R: Reflectance between thin films

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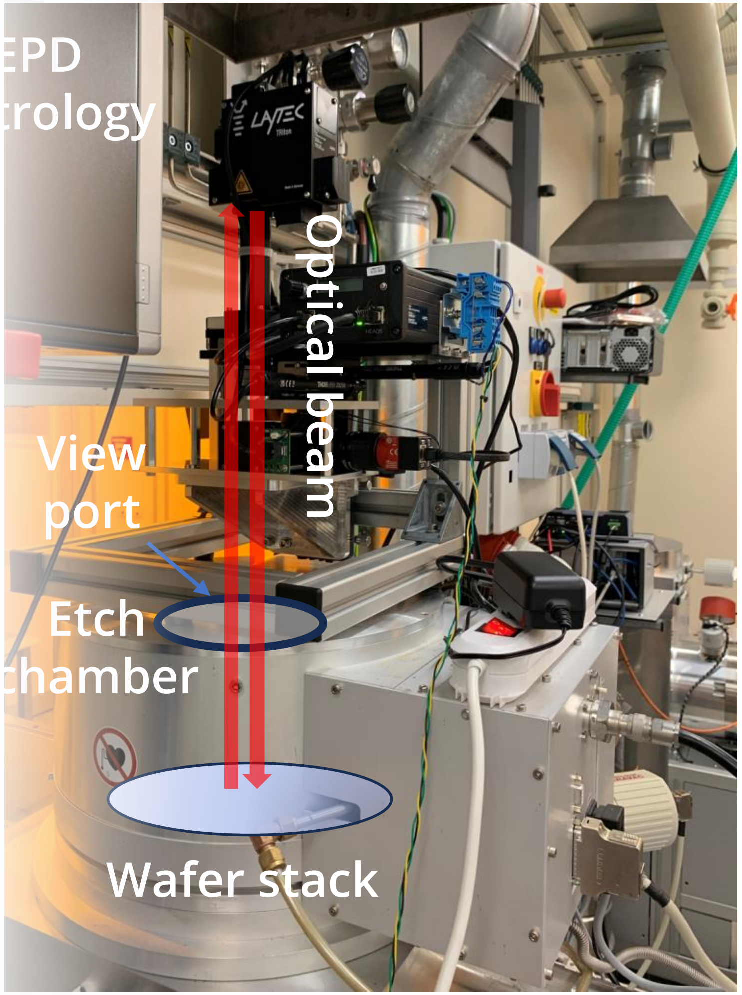
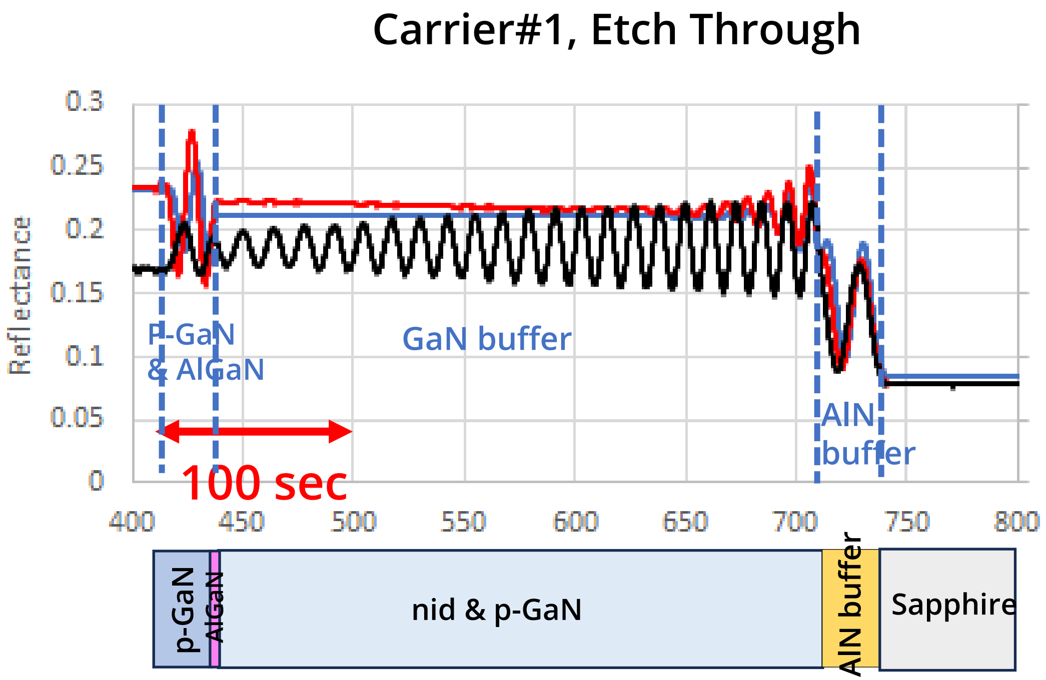
In-situ setup on an ICP etcher

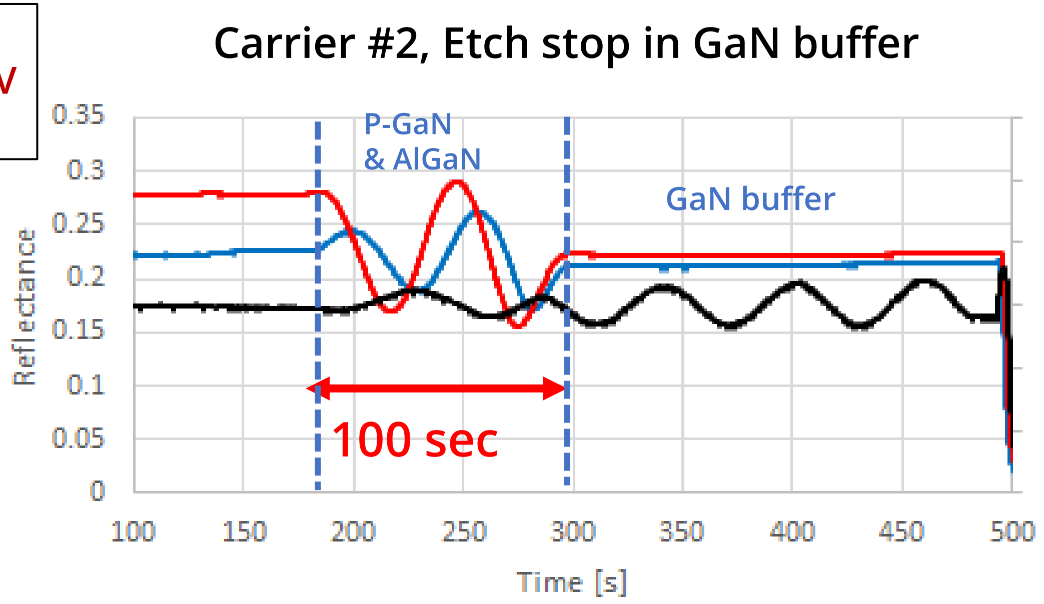
- UV and near UV wavelengths
- Camera for pattern recognition
- Communication for endpointing
- Recipe loop waits on endpointing signal
- Communication latency ~200ms
- Performed several etch runs on p-GaN HFET and UV GaN-laser structures
- Successfully demonstrated endpointing < 10nm p-GaN HFET structure

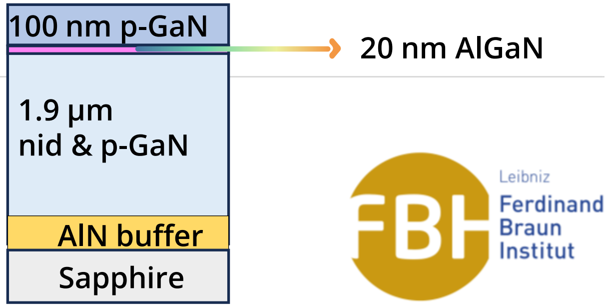


In-situ diagnostic 1: Influence of wafer carrier

UV
Near-UV
Visible







Carrier#1

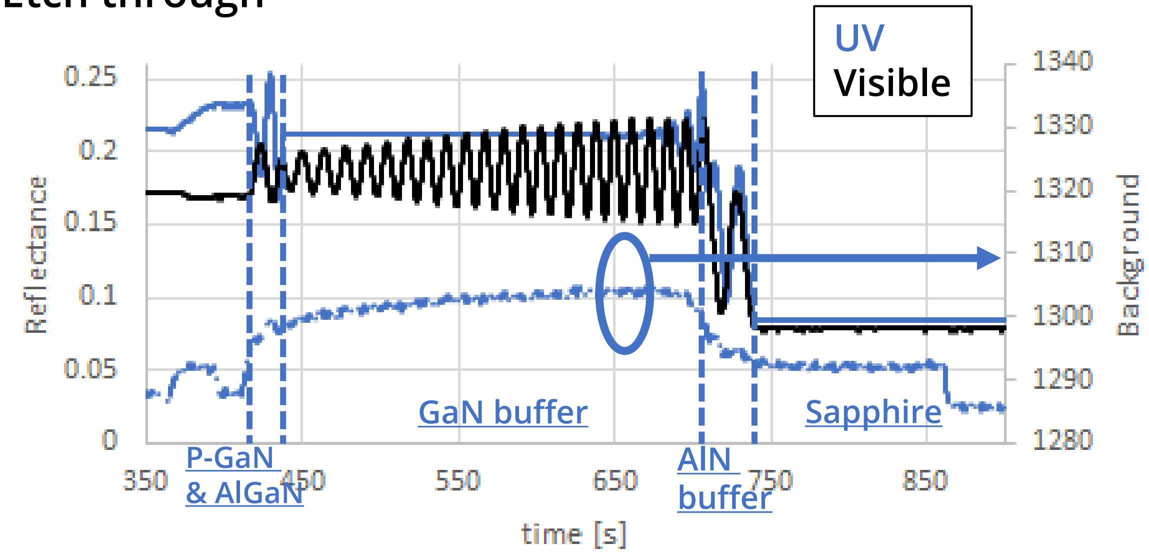
- Clearly visible Fabry Perot Oscillations/fringes in:
  - p-GaN & AlGaN barrier at all 3 wavelengths
  - Entire thickness of GaN buffer in visible
- Fast etch rate ~ 220 nm/min = 3.6 nm/sec

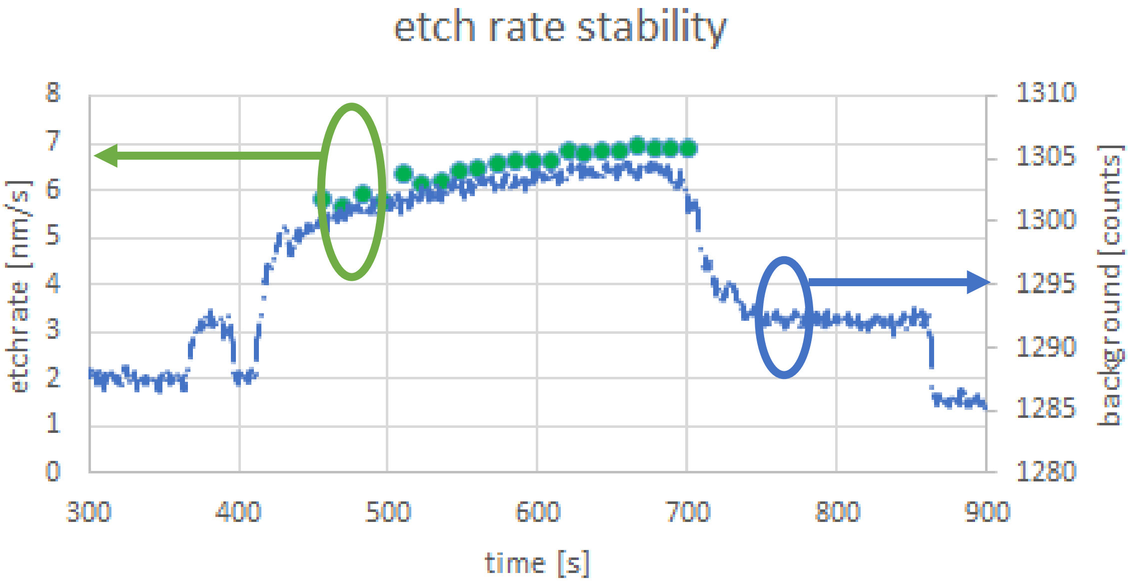
Carrier #2

- Identical features, even though etch rate much lower ~ 51 nm/min

In-situ diagnostic 2: Etch rate stability

Etch through





- Again, clearly visible FPO in p-GaN & AlGaN barrier at all 3 wavelengths
- Etching of entire GaN buffer can be monitored w/ visible wavelength
- Slight etch rate increases during etch from 6 to 7nm/s:
  - evidence of chamber warm-up effect : heat transfer Wafer → Electrode !
- In-situ measurements also enables some plasma monitoring, like with OES

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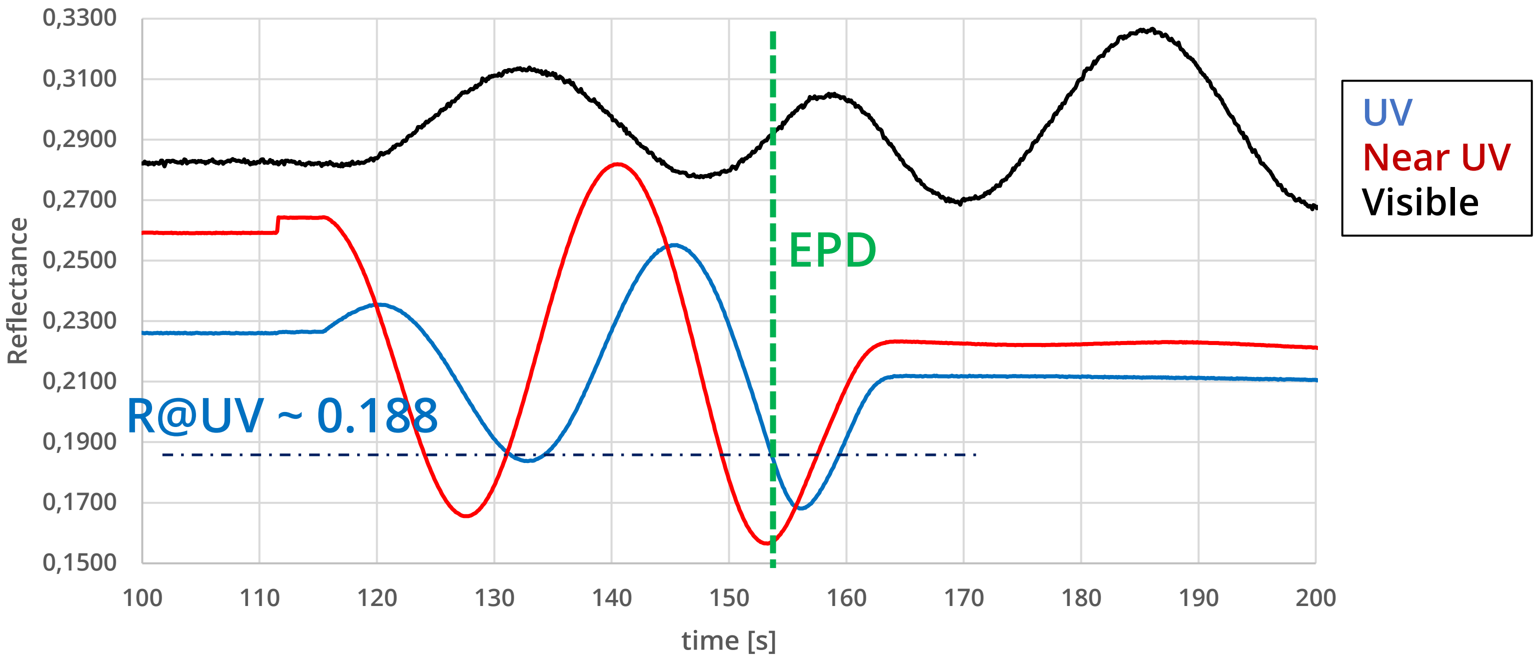
Calibration prior to systematic EPD: Time ←→ Etch Depth

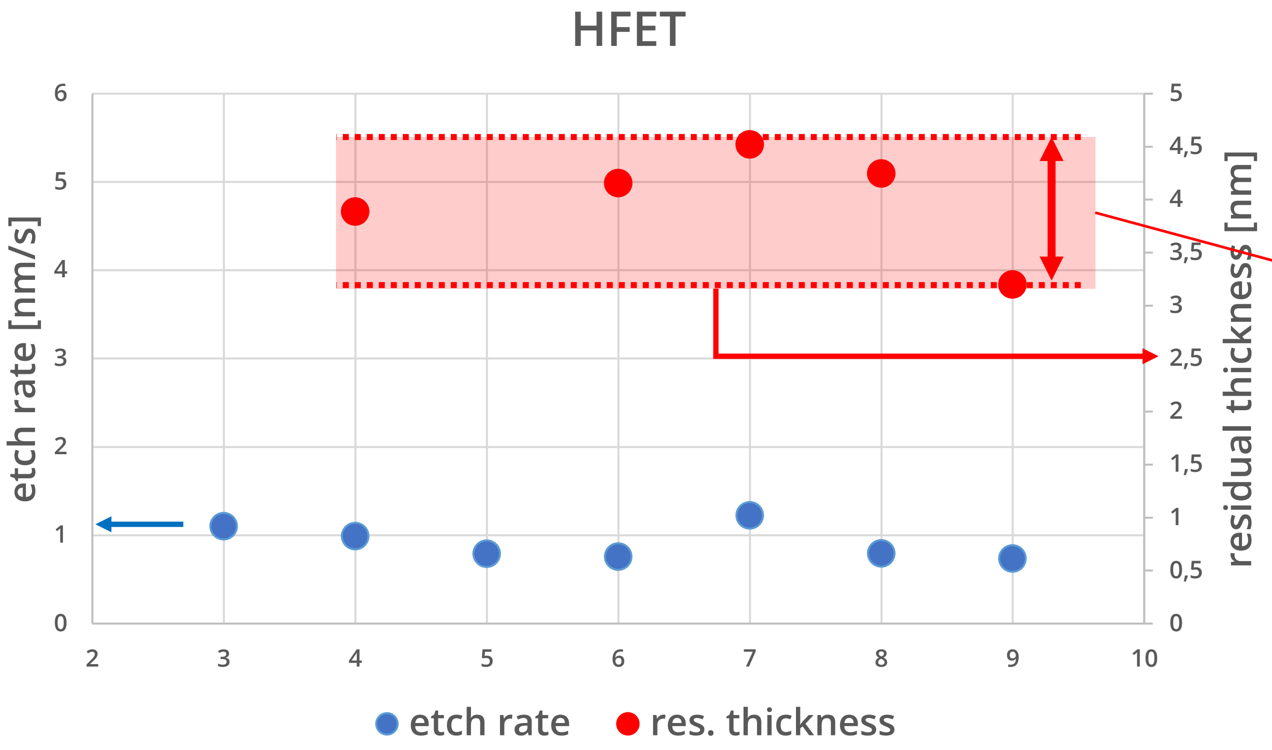
Carrier #2

Etch stop in GaN buffer



- **EPD requirement : remaining AlGaN thickness < 10 nm**
- **Algorithm derived from targeted Reflectance @ UV wavelength**

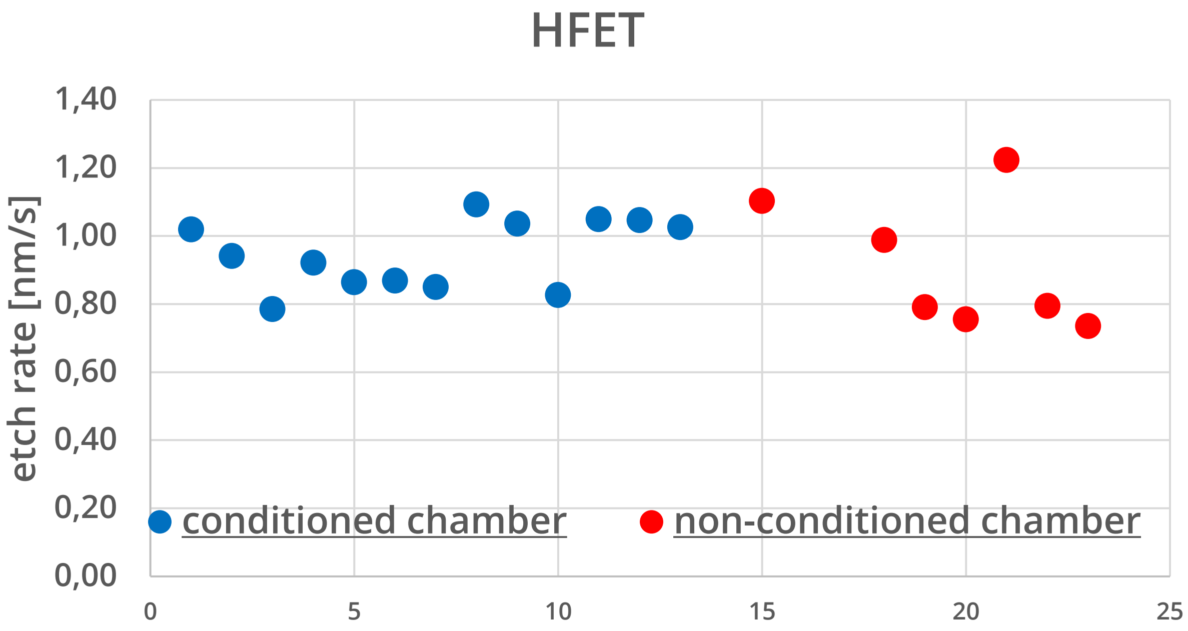
Multiple End Point Detection Trials on HFET → Suitability for Process Control

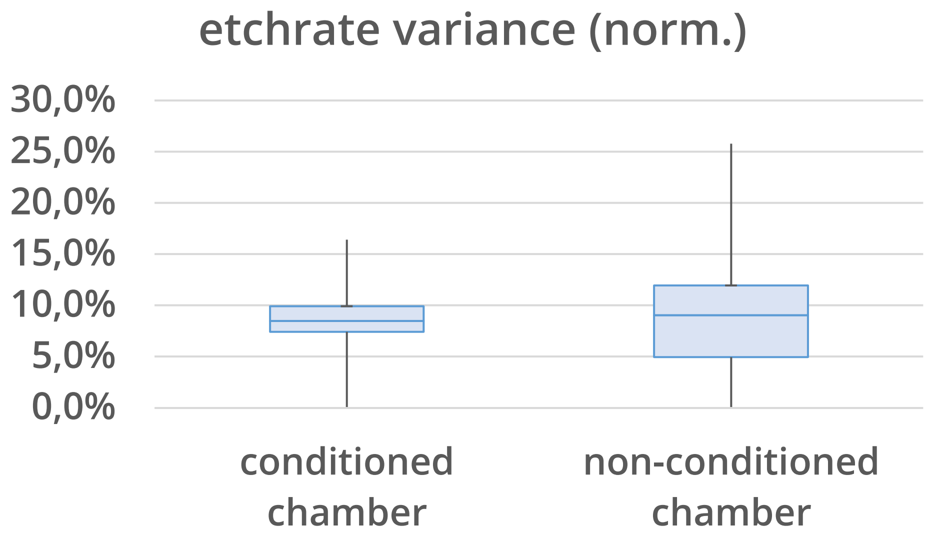


- Specifically developed EPD algorithm
- Residual AlGaN thickn. variation < 1.5 nm
- ➔ reproducibility better than 1.5 nm

- **Successful automatic EPD enabling to reach specifications:**
  - residual AlGaN of < 10 nm ! → Median ~ 4 nm
  - With a range of < 1.5 nm

Multiple End Point Detection Trials on HFET → Suitability for Process Control





- Chamber conditioning: ‚Run a regular process but with a seasoning wafer'
- Measurement system accurately determines the etchrate in situ
- Etch metrology evidences two different operating conditions of etcher

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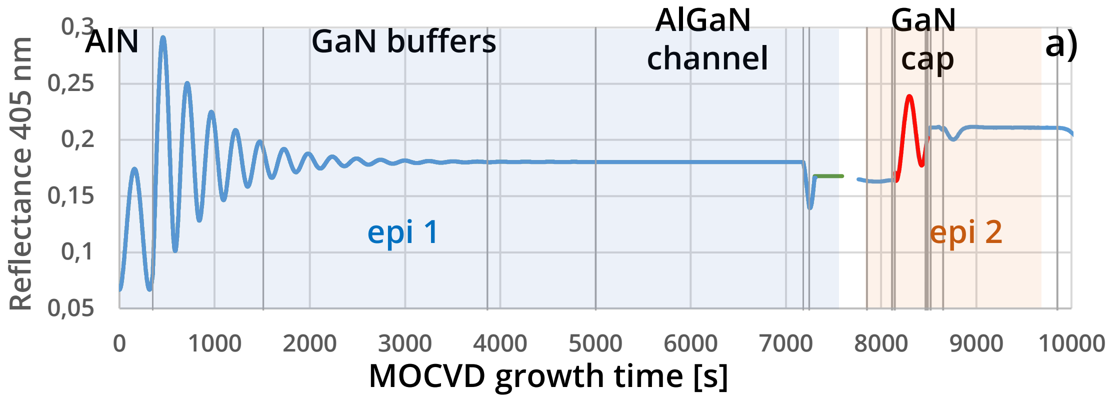
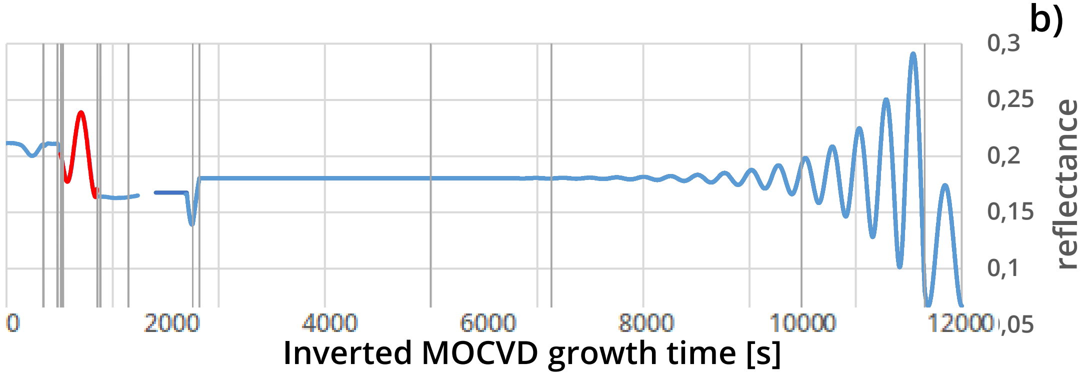
Plasma-Etch end-pointing in GaN/AlGaN-based HFET structures

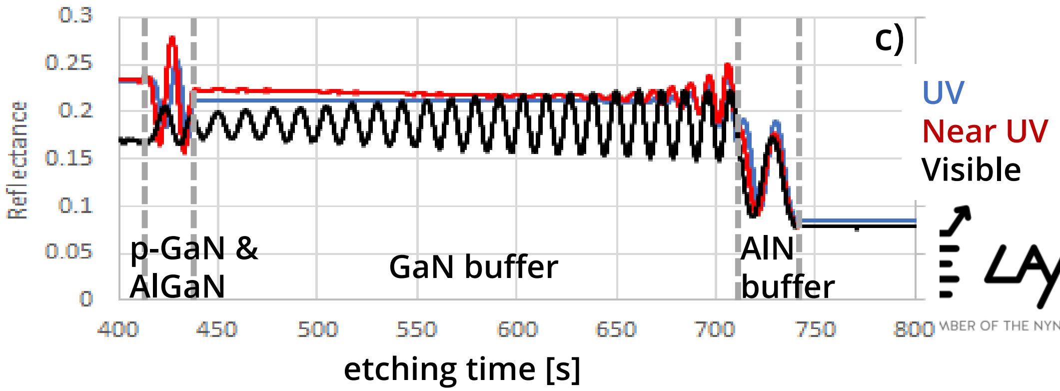
- **a) Real-time reflectance measurement during MOVPE**
- **layer thickness measurements with accuracy in ±1 nm range**



- **b) 'Time inverted' reflectance trace**
- **Preview to etch transient measurement**



- **c) Real-time reflectance measurement during plasma etching**
- **Analysis simplified by previous knowledge**



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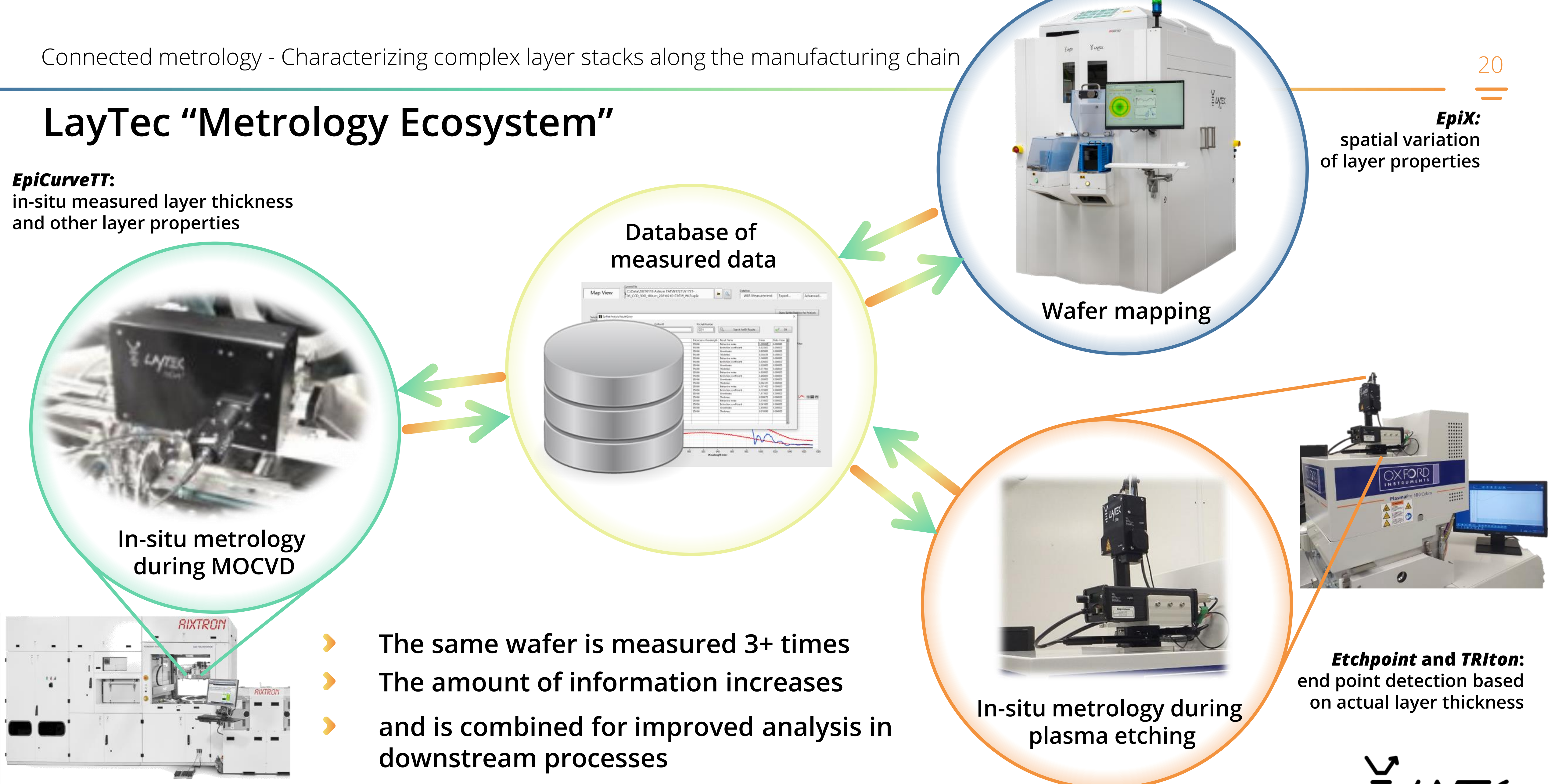

***EpiCurveTT*:**
in-situ measured layer thickness
and other layer properties

In-situ metrology
during MOCVD

Database of
measured data

***EpiX*:**
spatial variation
of layer properties

Wafer mapping

In-situ metrology during
plasma etching

***Etchpoint* and *TRIton*:**
end point detection based
on actual layer thickness

- The same wafer is measured 3+ times
- The amount of information increases
- and is combined for improved analysis in downstream processes

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Conclusion

- End pointing is demonstrated for ICP etch of GaN HFET
- Reproducibility and accuracy of end pointing is also demonstrated
- End pointing enables process control :
  - residual AlGaN thickness ~ 4 nm
  - with range < 1.5 nm
- Accurate real time etch rate variation :
  - Evidence of different etcher operating conditions
- Similarly end-pointig is possible for ICP dry etch of GaN, InP and GaAs
- Combination of in-situ deposition control, post-epi mapping and in-situ etch control offers potential for even tighter process control and maximum yield

Knowledge is key

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