In-situ Metrology during homoepitaxial growth of GaN

What is possible and what is not

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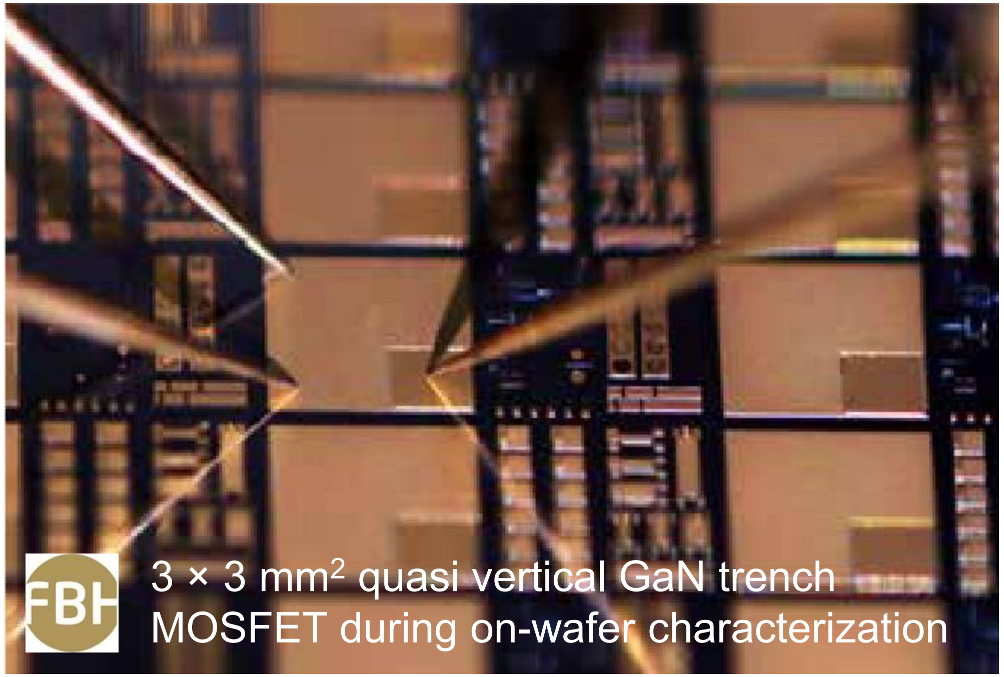
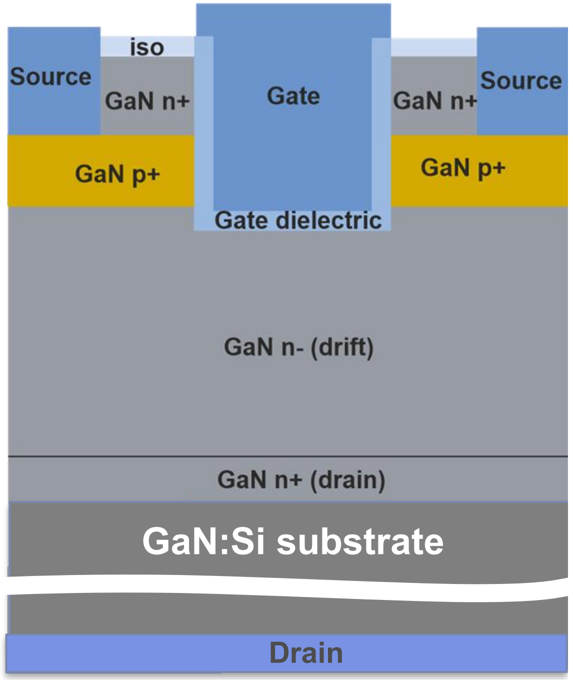
ICMOVPE XXII, in-situ Seminar, 14.07.2026

Motivation

- III-Nitride homoepitaxial growth of device layers mandatory in optoelectronics and emerging in electronics
- Low dislocation density in active layers enhances radiative recombination, reduces leakage currents and improves efficiency
- Low wafer bow promotes processability and device yield





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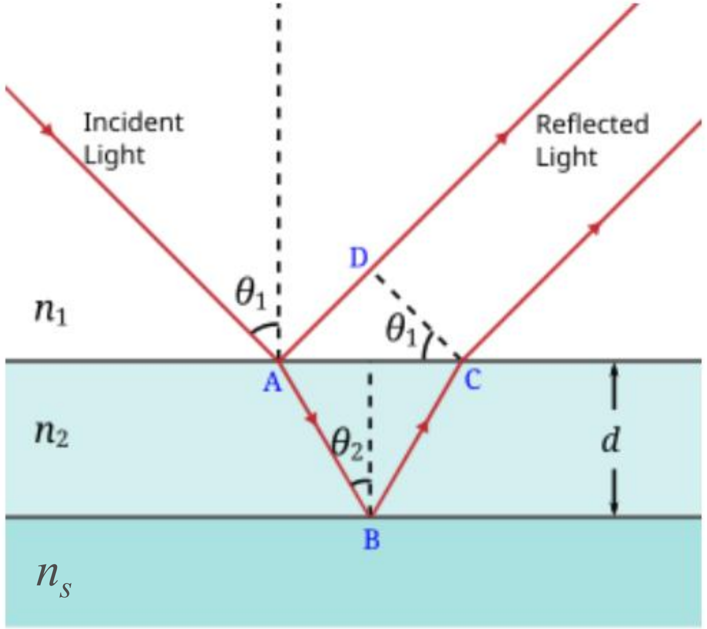
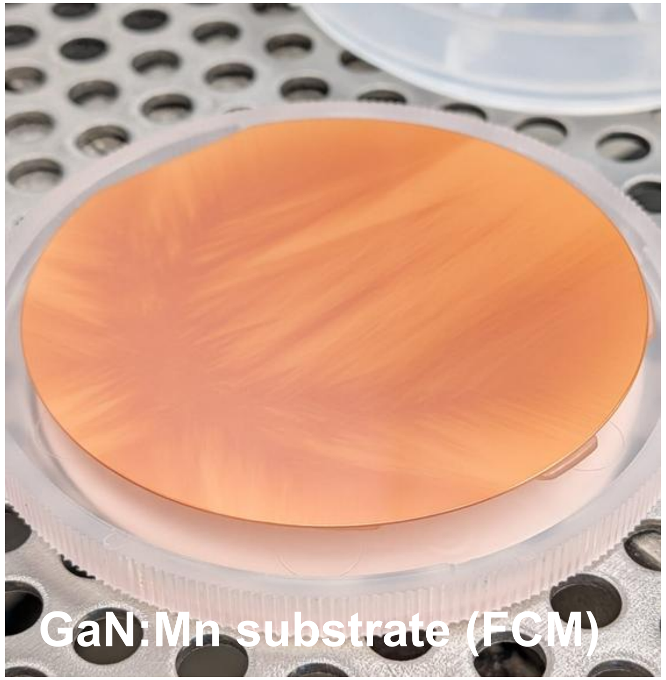
Specific features of in-situ metrology during homoepitaxy

- In-situ reflectometry suffers from nearly zero refractive index contrast ($n_2 \approx n_s$)
- GaN substrates from different vendors have individual properties (i.e. lattice bow)
- Dopant and impurity concentration of substrate influences optical and thermal properties





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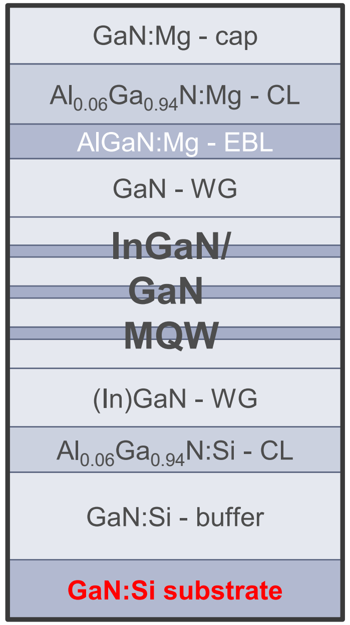
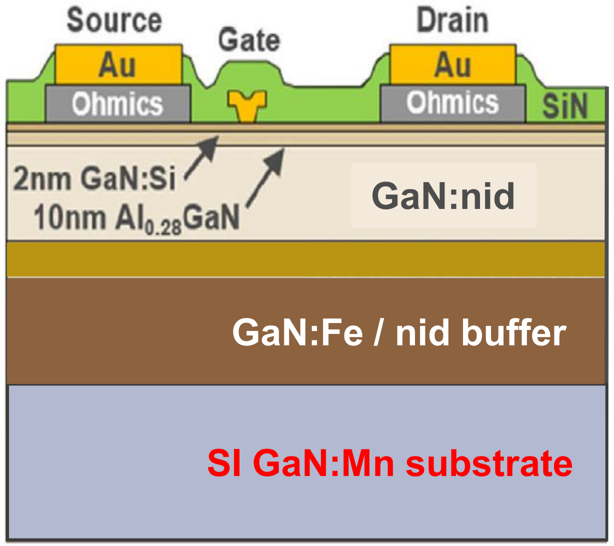
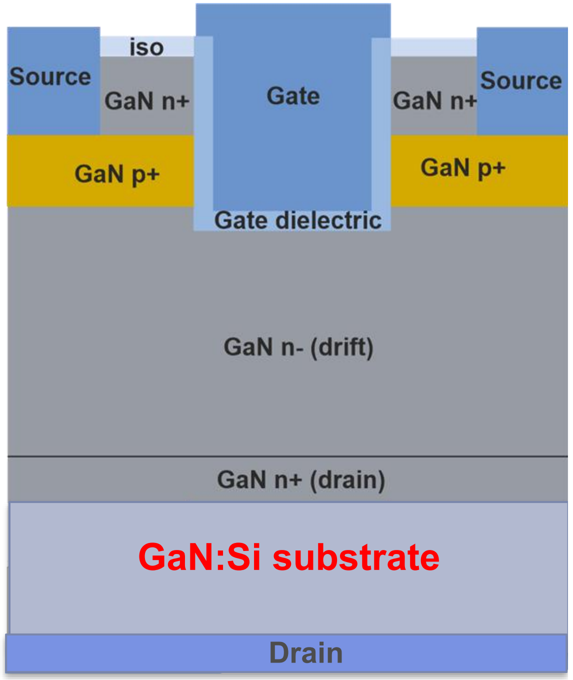
- **Dopant and impurity concentration of substrate influences optical and thermal properties**
- **Layer structures for different applications have its own special features:**



LD heterostructure



Lateral HFET



Vertical Power Transistor

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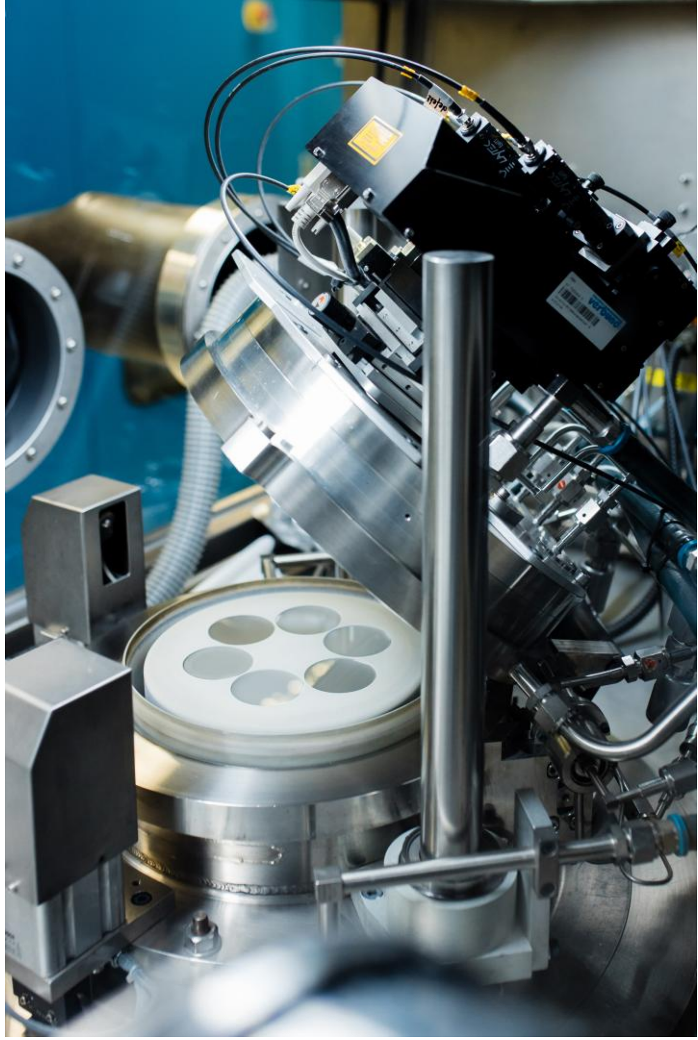
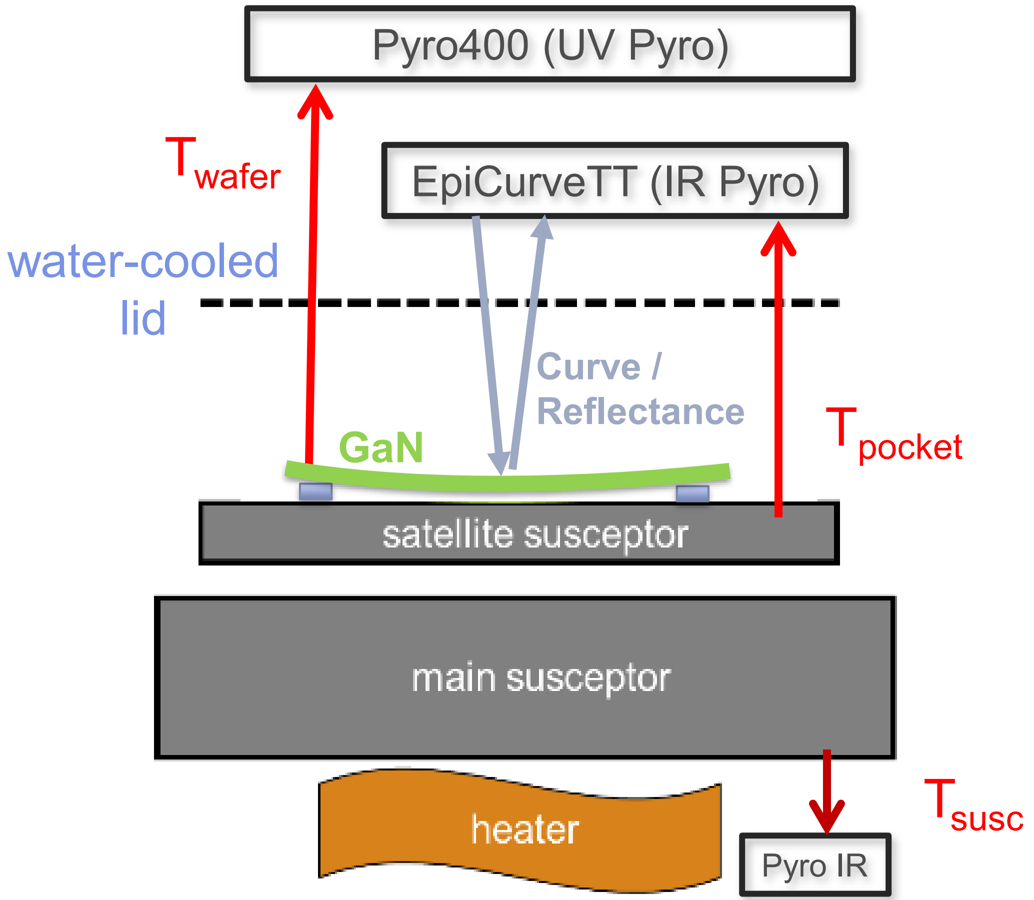
MOVPE Growth / In-situ Characterization



- AIXTRON G3 planetary system with 8x4 inch configuration (electronics)
- CCS FT 6x2 inch (optoelectronics)
- EpiCurve Blue TT incl. 5λ wavelength reflectometry
- Pyro400 on 2nd viewport (planetary system only)

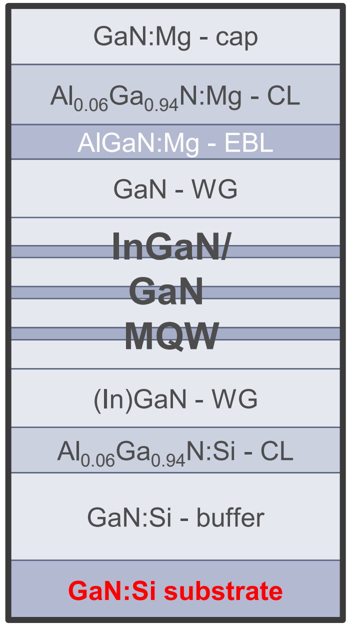
In-situ Measurement Setup (Planetary Reactor)



- Growth on wafer elevation elements (100 µm sapphire) to avoid GaN decomposition at substrate backside
- Curvature measurement in CCS reactor in ARS mode
- $T_{susc} > T_{pocket} > T_{wafer}$: determination of GaN wafer temperature requires pyrometry at UV wavelength

Case 1: Laser diode structure ~430 nm

- **CCS FT 6x2 inch with ARGUS top temperature control and EpiCurveTT in ARS mode**
- **Substrate: 2 inch GaN:Si (HVPE), vendor: MCC**



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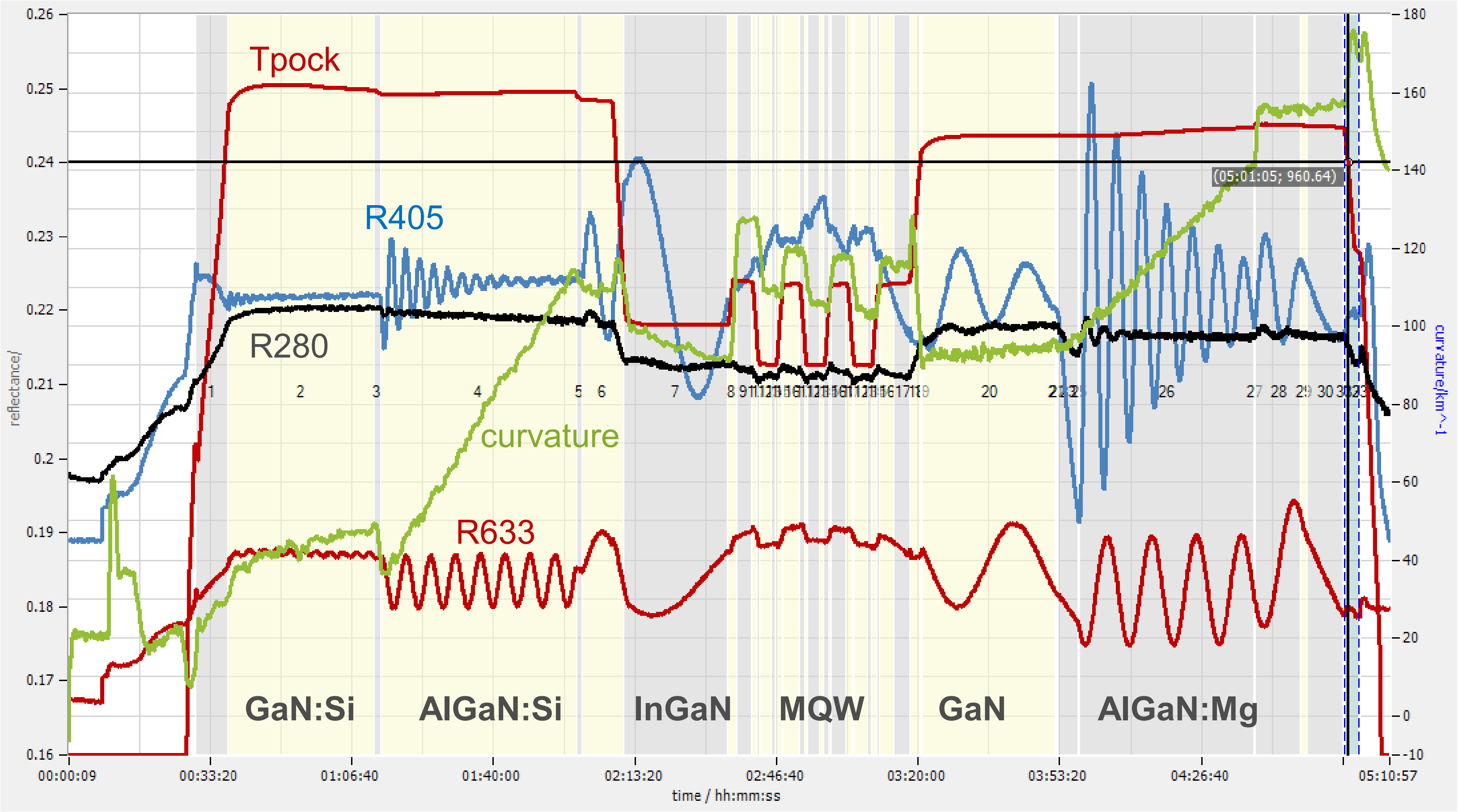

- LD device heterostructure features a wide variety of information accessible in-situ

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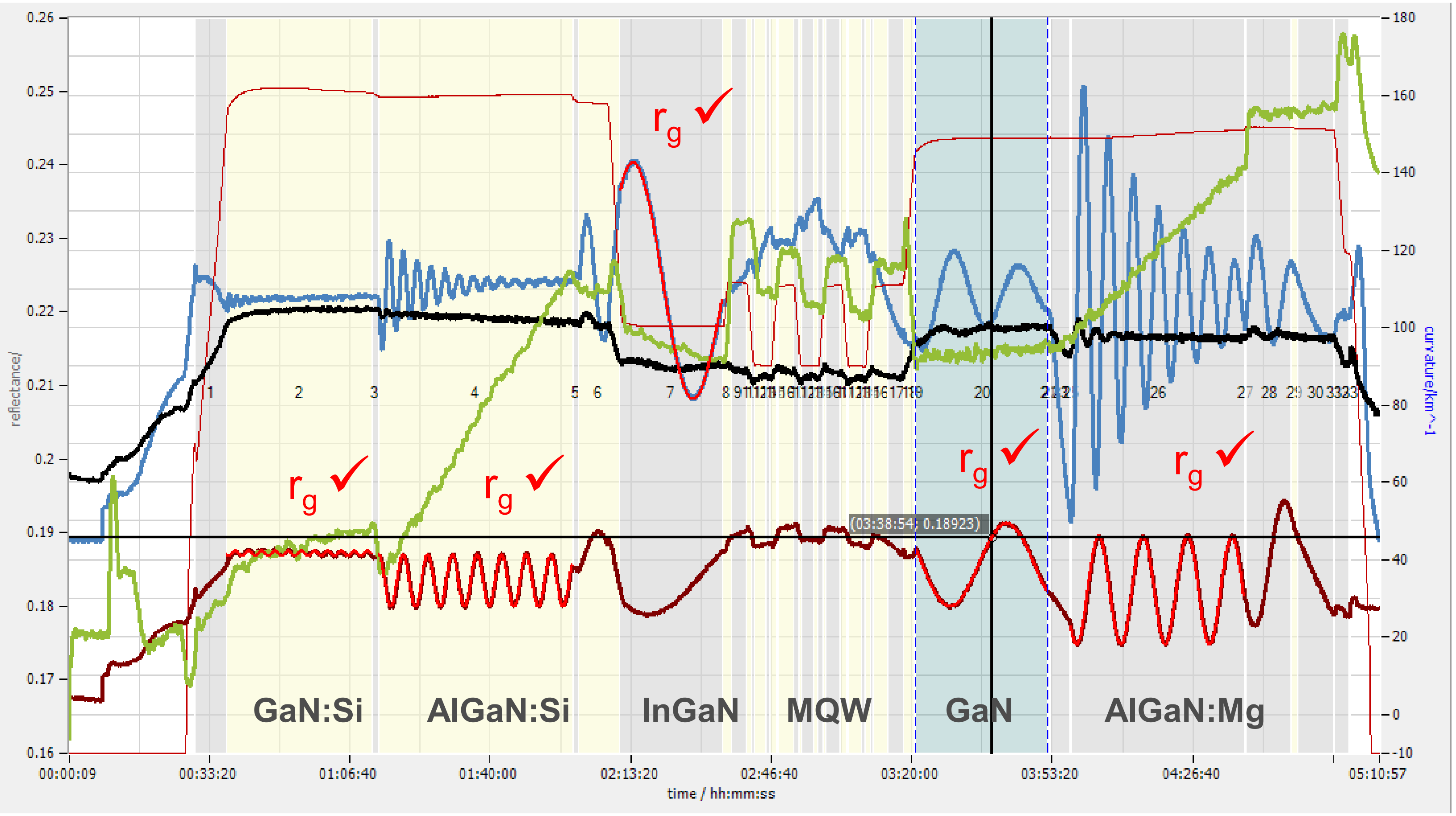

- r_g fit of cladding and waveguide layers possible (GaN / AlGaN)
- InGaN layer fitting with restrictions (no InGaN material in EpiNet included)
- 280 nm damping during AlGaN growth indicates roughening

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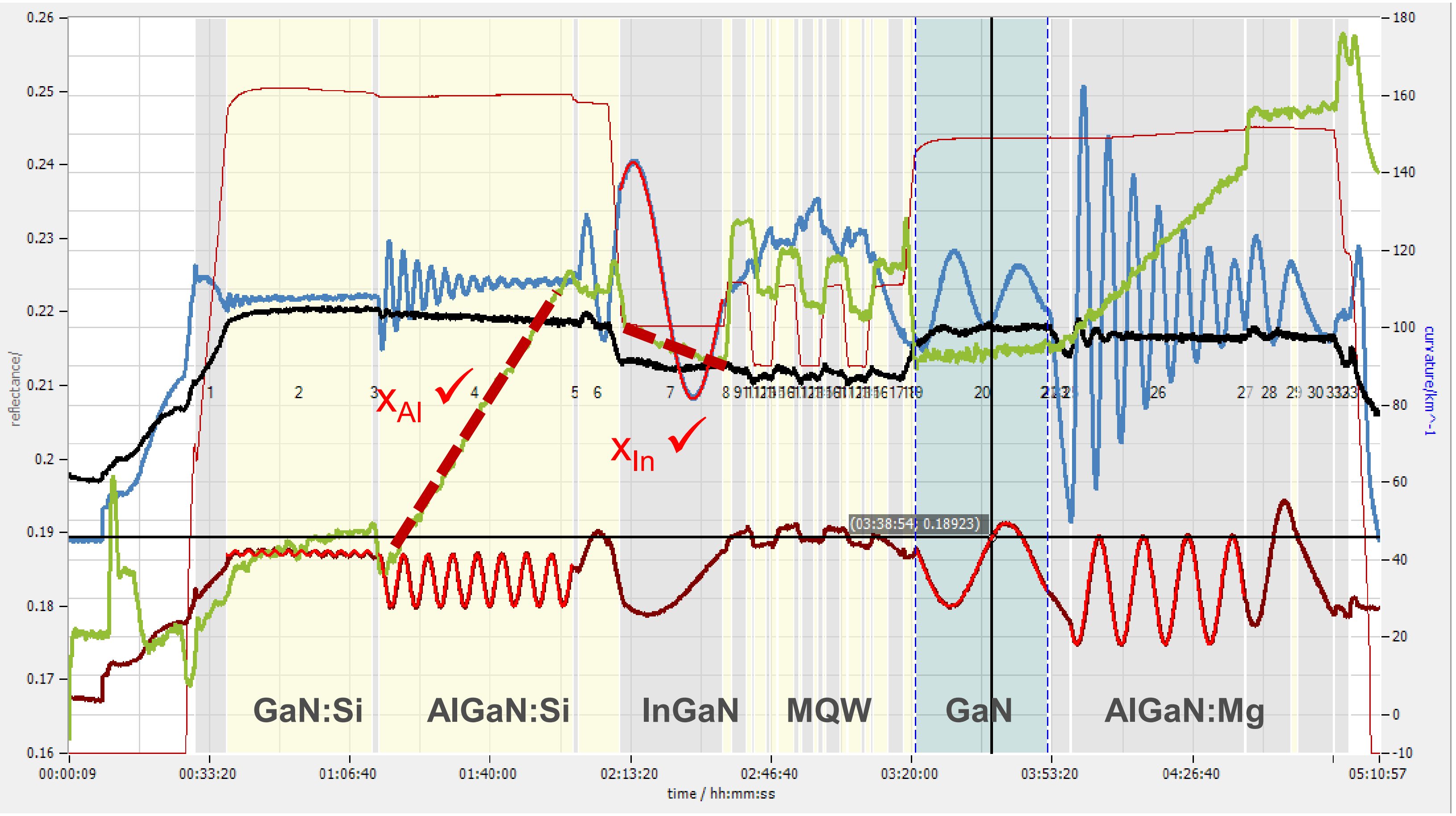
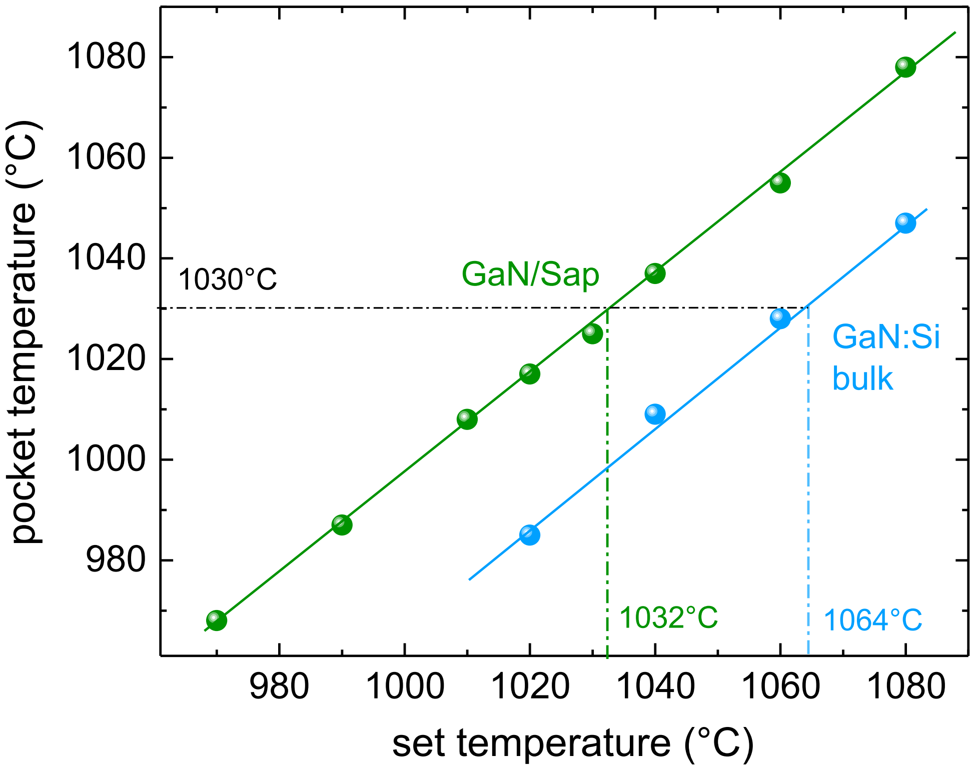
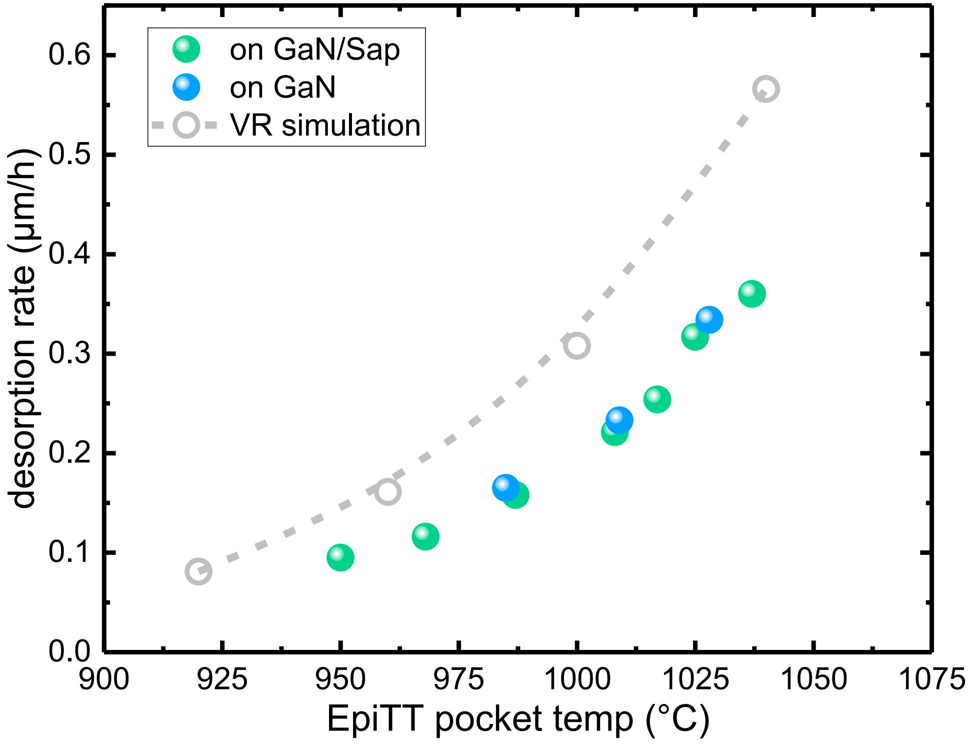


- Curvature slope fitting enables determination of AlGaN and InGaN composition

Case 1: Temperature measurement on GaN bulk vs. GaN/sapphire





- setpoint temperature needs adjustment to obtain similar pocket temp for sapphire and GaN
- similar desorption rates indicate a wafer temperature very similar to the pocket T

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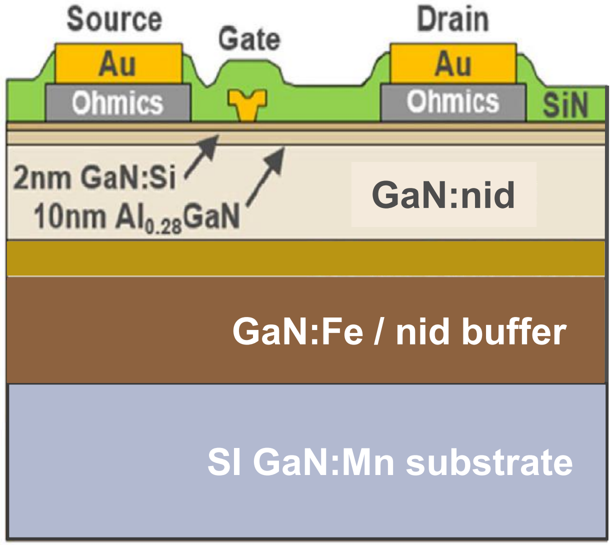
Case 2: Heterostructure Field Effect Transistor (HFET or HEMT)

- **AIXTRON G3 planetary system with Pyro400 and EpiCurveTT**
- **Substrate: 2 inch GaN:Mn (HVPE), vendor: FCM**

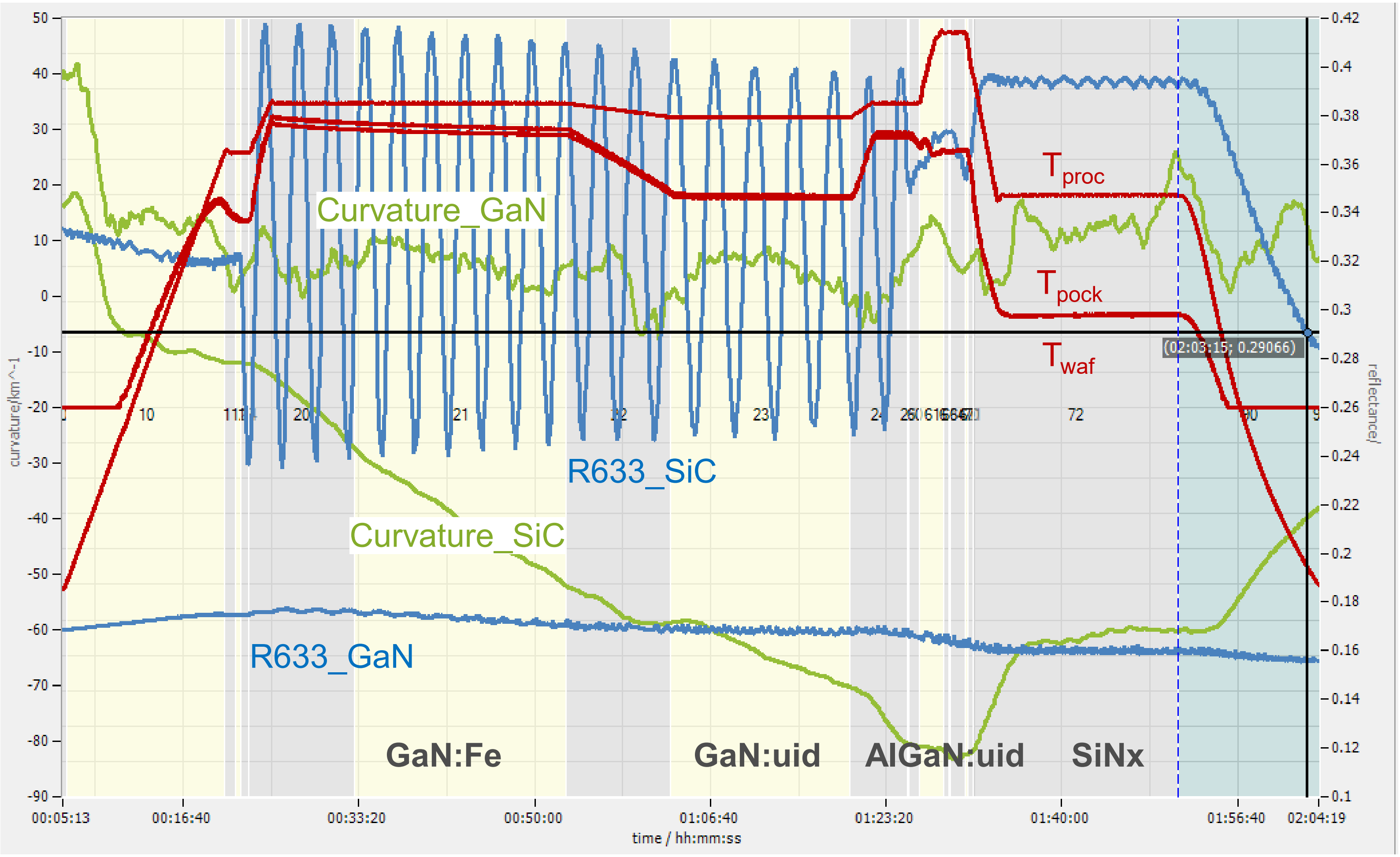
LD heterostructure



Lateral HFET

Vertical Power Transistor

HFET structure grown simultaneously on GaN:Mn and 4H-SiC/AlN



- distinct differences in curvature evolution
- $T_{proc} > T_{pock} > T_{waf}$ strongly depending on growth conditions
- SiC: double-side polished: twice the R633 intensity
- R633 nearly without oscillation for GaN-based growth

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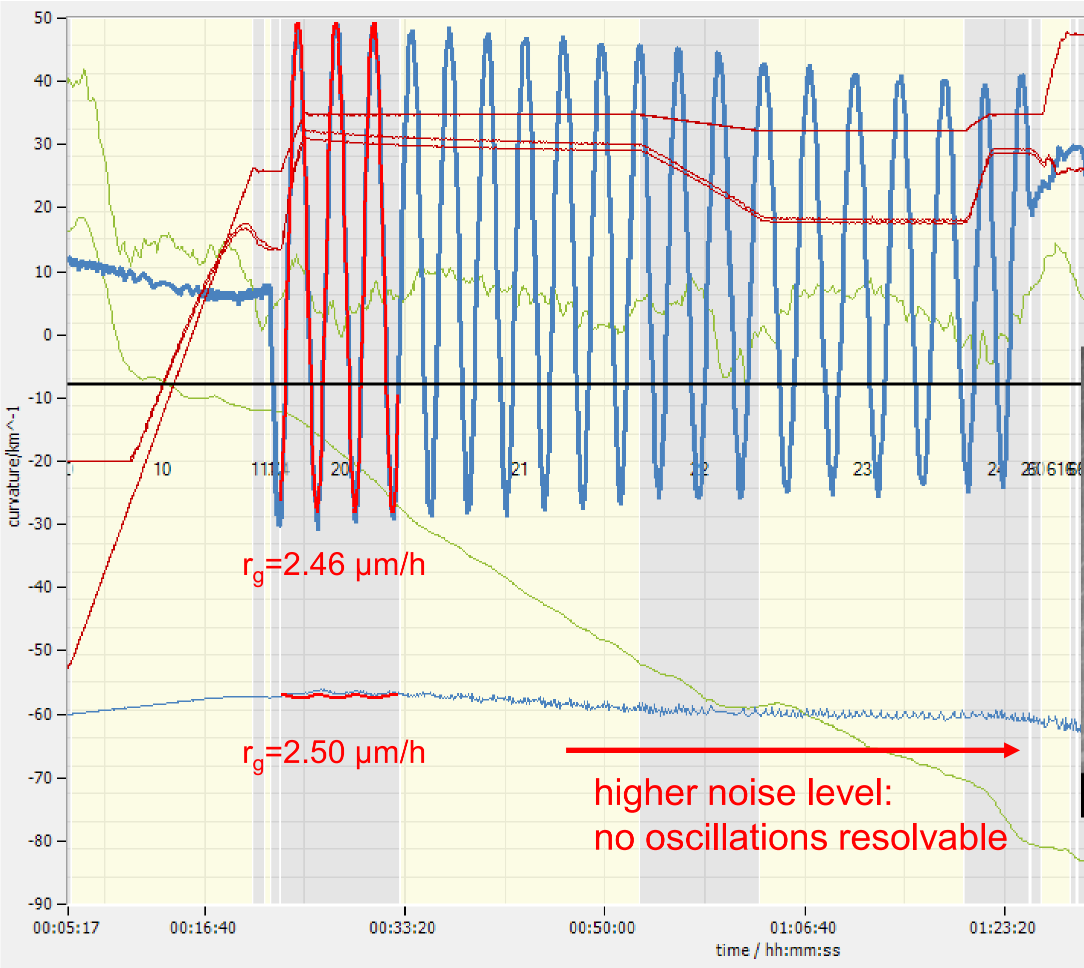
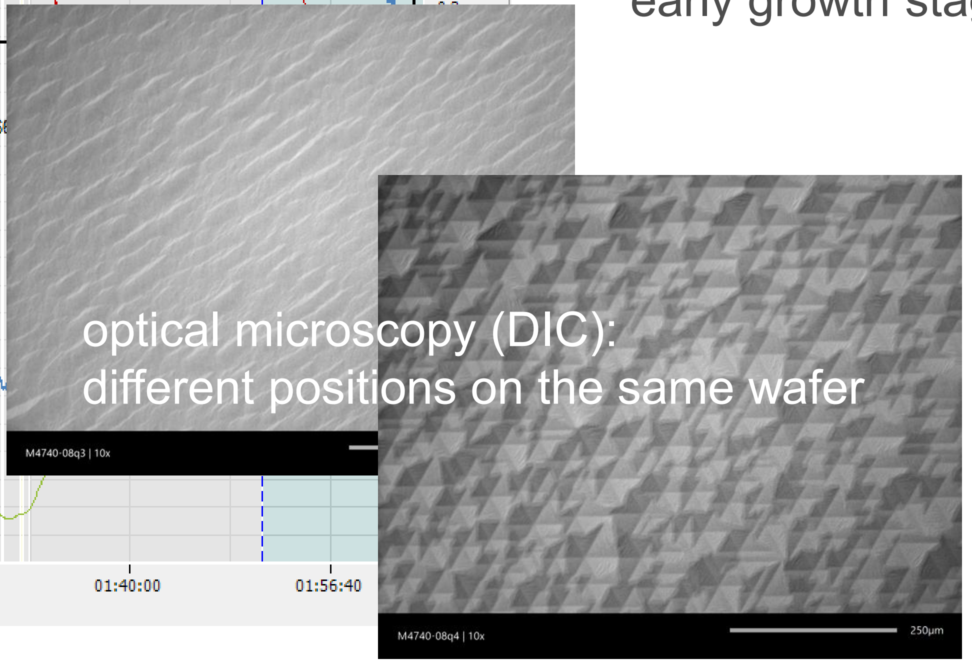
HFET structure grown simultaneously on GaN:Mn and 4H-SiC/AlN





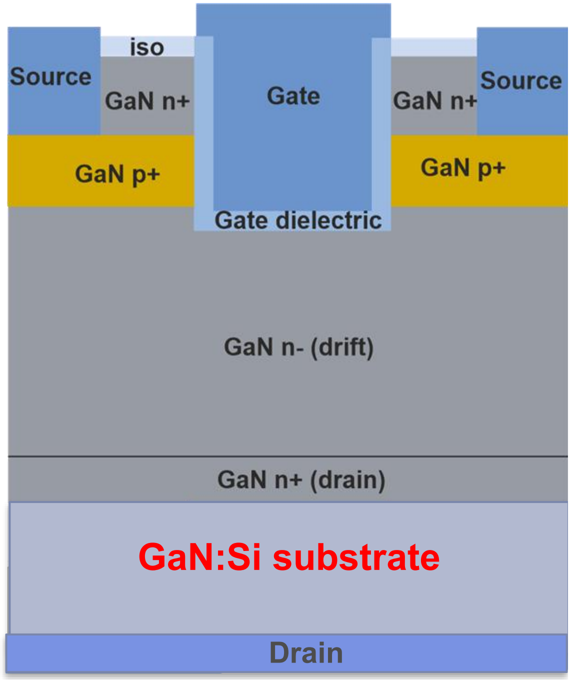
- GaN-on-GaN: R633 fitting possibe, sometimes only in early growth stages

Case 3: Vertical Power Transistor

- **AIXTRON G3 planetary system with Pyro400 and EpiCurveTT**
- **Substrate: 2 inch GaN:Si (AT), vendor: Ammono**

LD heterostructure

Lateral HFET



Vertical Power Transistor

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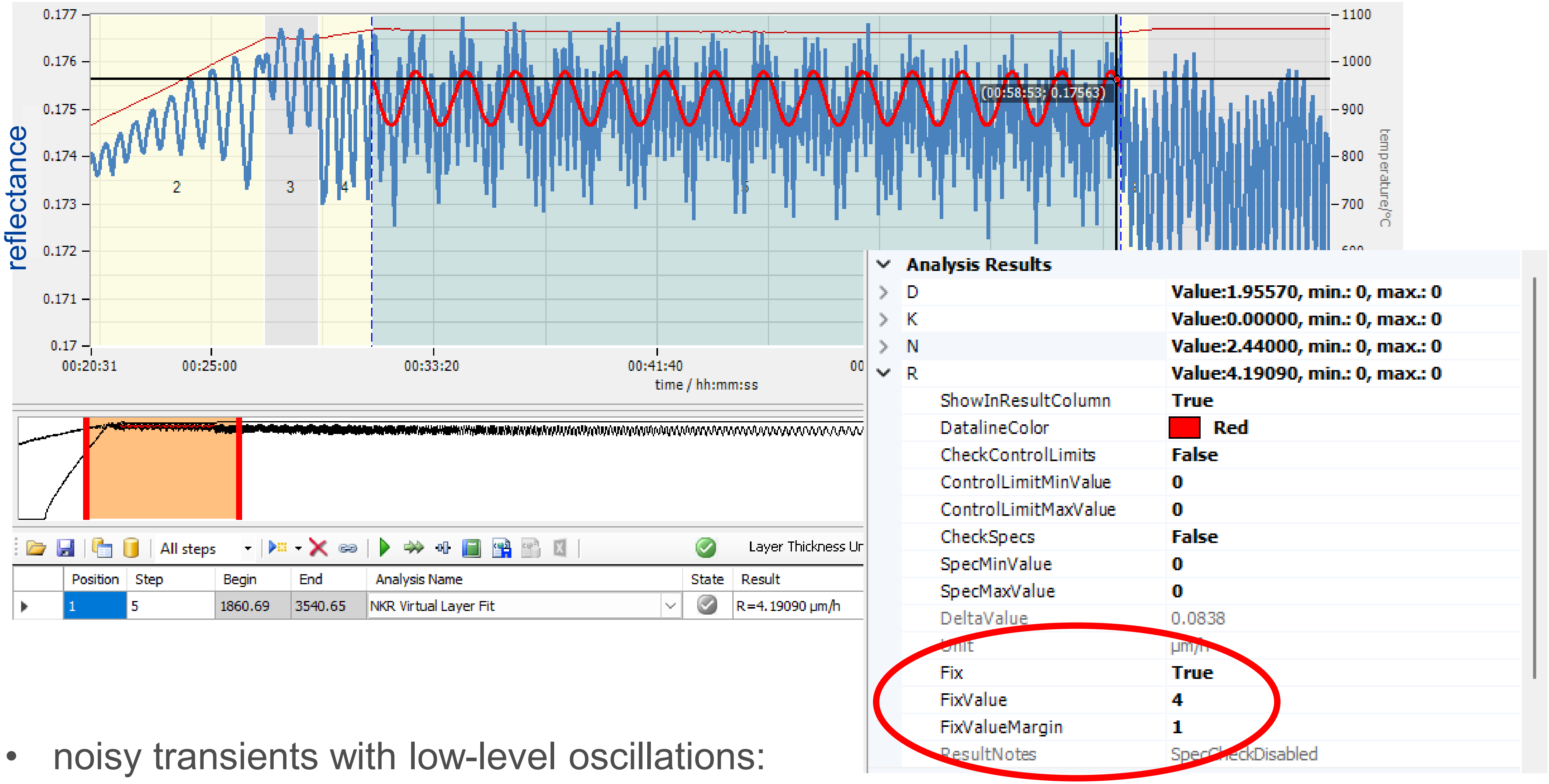
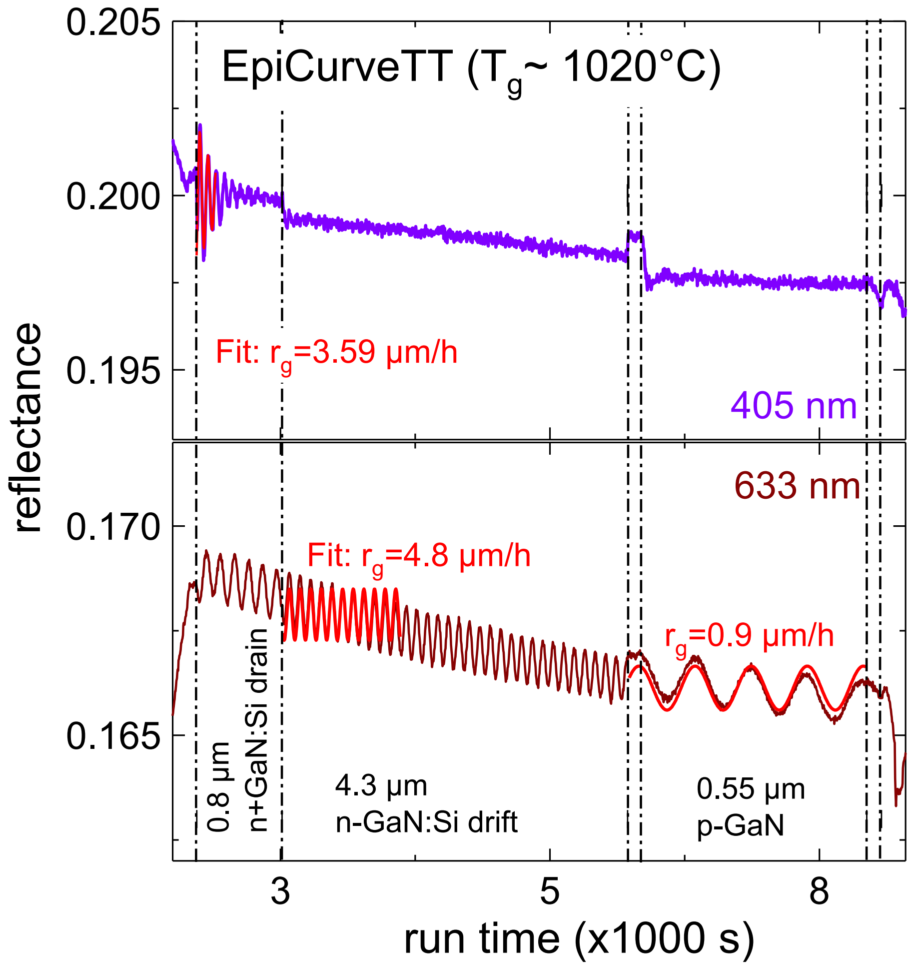
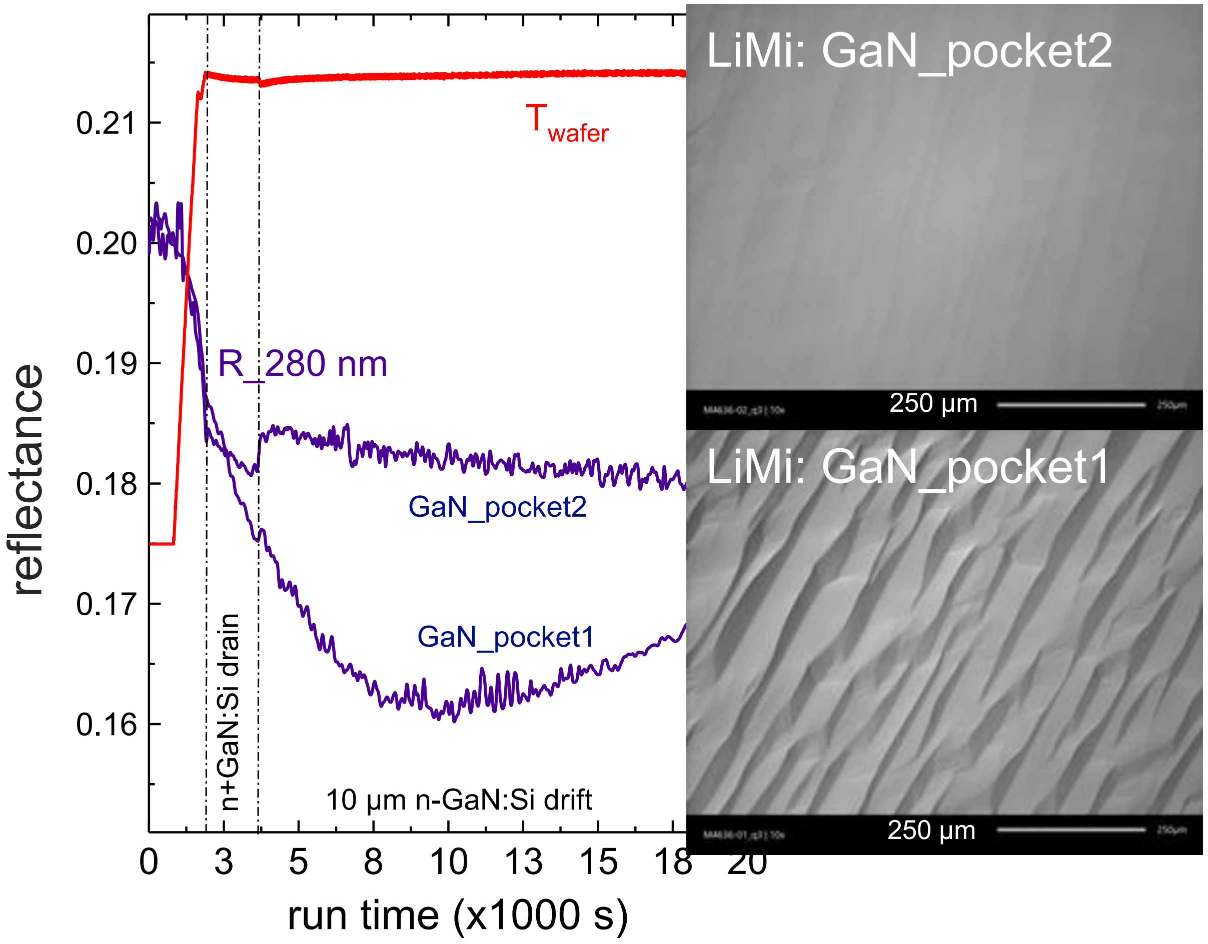
Fitting of low-level oscillations by applying a FixValueMargin



- noisy transients with low-level oscillations: fitting with NKR Virtual Layer Fit analysis routine (with n/k from database)

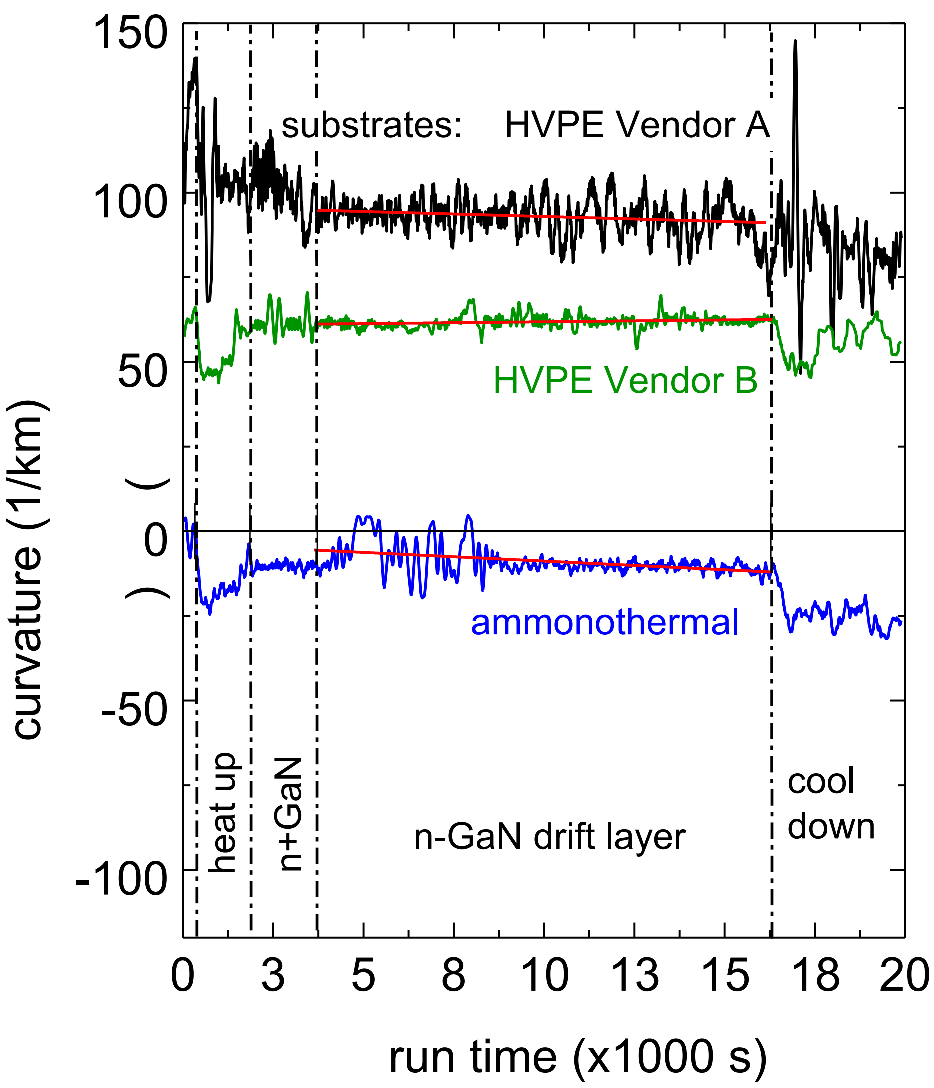
Growth rate determination and roughness evolution





- Surface sensitivity of short-wavelength reflectance reveals roughness differences

Curvature analysis on different GaN substrates



- Different initial bow for different vendors
- Stress-free GaN drift layer growth independent of substrate type

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Summary

- **In-situ measured wafer temperature, reflectance and curvature traces individual GaN substrate properties**
- Pocket and wafer temperature deviates significantly from process temperature and varies with growth conditions
- Growth rate fitting is possible even for low-level noisy reflectance traces, depending on substrate properties, partially only at early stages of growth
- UV wavelengths (e.g. 280 nm) for reflectance measurements increase sensitivity for roughness determination
- Curvature measurements show variations of initial wafer bow depending on substrate vendor

Knowledge (sharing) is key