In-situ growth control during MOVPE of far-UV-C LED structures with optical metrology

K. Haberland[1], T. Kolbe[2], A. Knauer[2], I. Claussen[1], T. Brand[1], M. Weyers[2]

[1]LayTec AG

[2]Ferdinand-Braun-Institut (FBH)

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Outline

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- Motivation and Introduction
- In-situ temperature measurement
- In-situ curvature measurement
- In-situ reflectance measurement
- Summary and Conclusions

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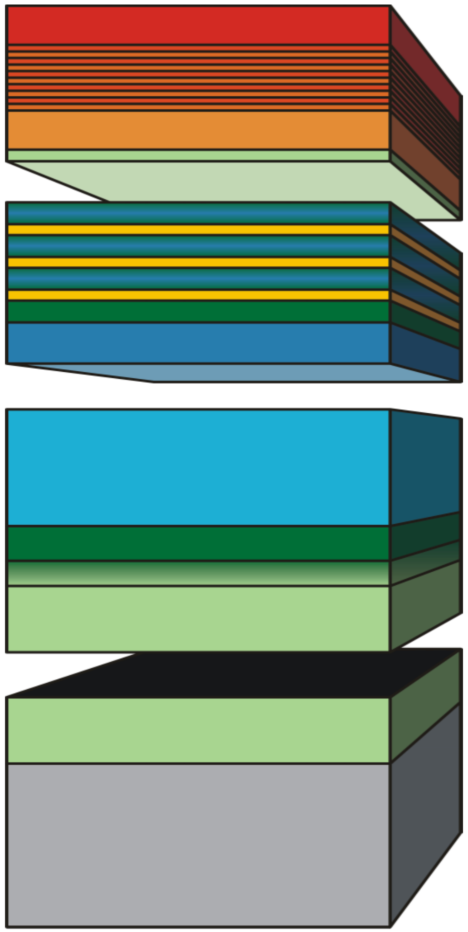
Challenges for deep UV LEDs



schematic courtesy of M. Kneissl, TU Berlin

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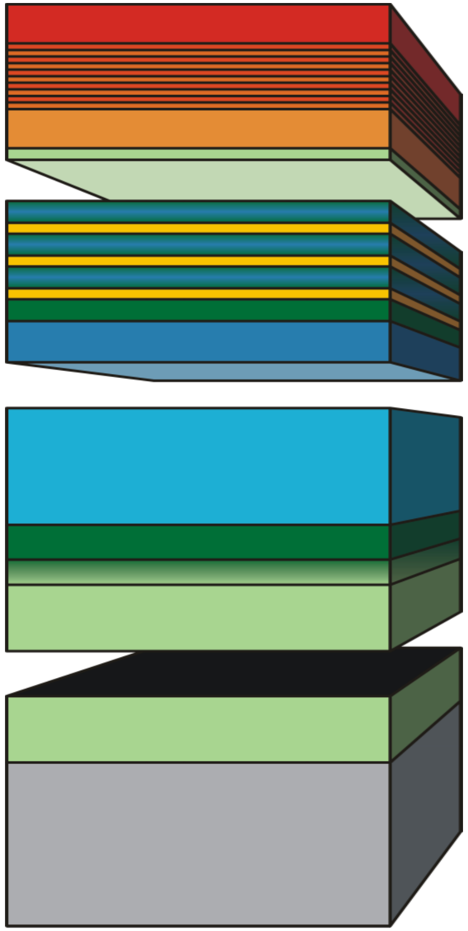
Challenges for deep UV LEDs – some translate into epi growth challenges



schematic courtesy of M. Kneissl, TU Berlin

- Growth of transparent n-$Al_xGa_{1-x}N$ layers with high Al content ($x \geq 0.8$) - control of AlGaN composition
- High p-doping at high Al contents (transparent p-contact)
- Growth at high temperature: small temperature deviations cause large changes in x and conductivity
- Active zone: precise control of growth temperature necessary to prevent Ga desorption
- Run-2-Run temperature control - setpoint corrections may be needed during run
- Curvature control to prevent cracking and subsequent wafer rejects
- Detection and control of surface roughness

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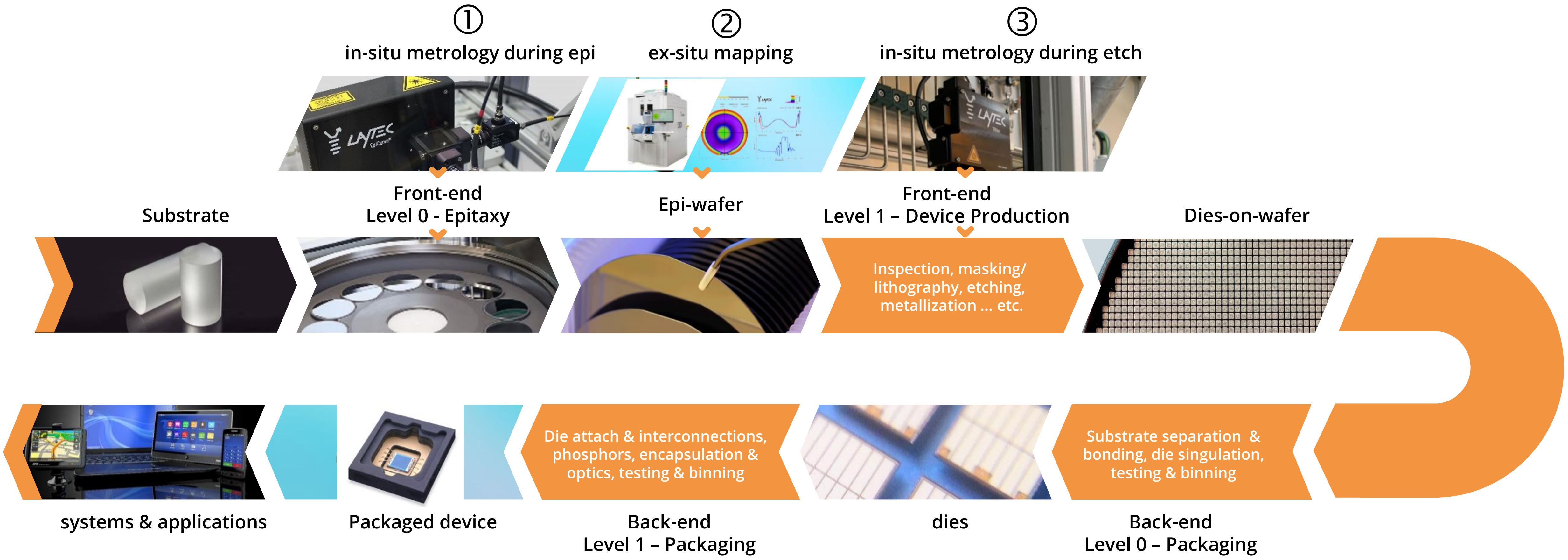
Optical metrology along the semiconductor manufacturing chain



Epi is complex and very early in the manufacturing chain – if you don‘t get the epi right…

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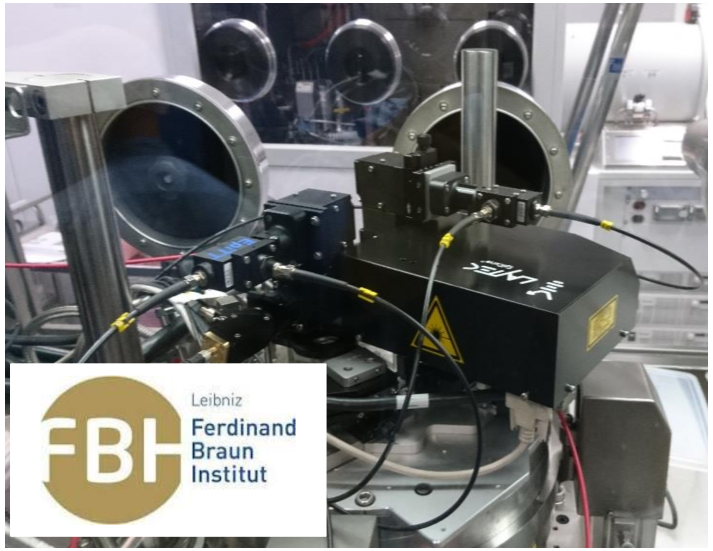
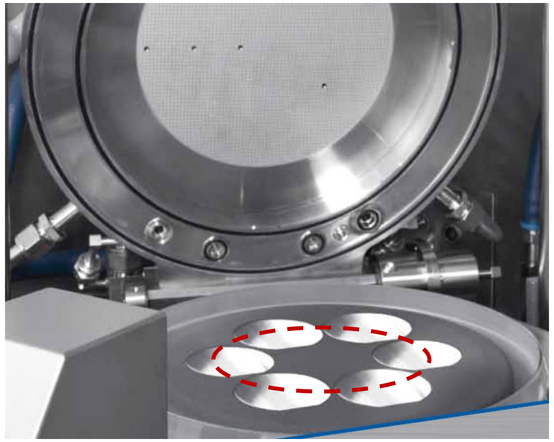
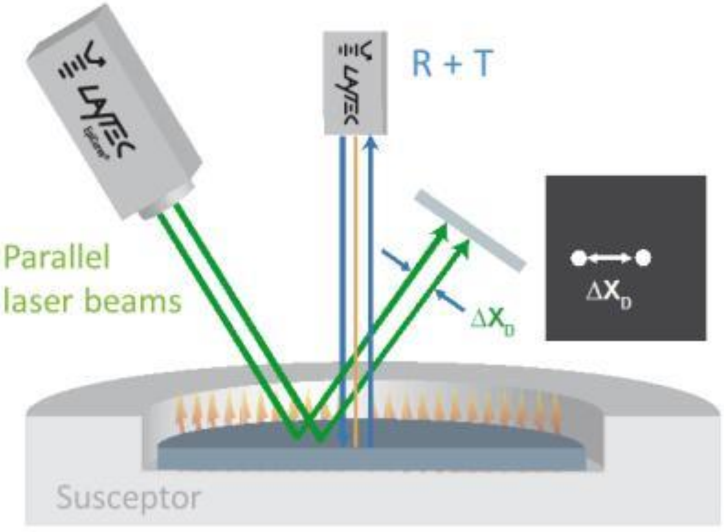
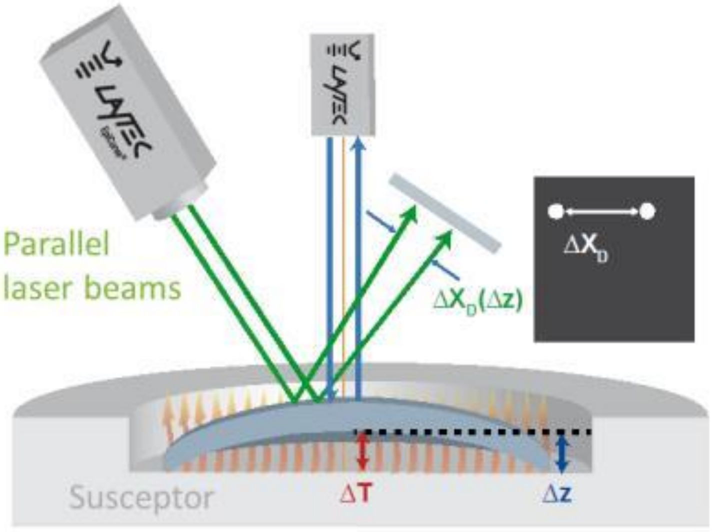
Optical in-situ metrology during MOCVD – how does it work?







Flat wafer



Bowed wafer

Pyrometry at 950nm (and 400nm)

Reflectance 280nm, 365nm, 405nm, 633nm, 950nm

Wafer Curvature (incl. asphericity detection)

measured individually on 6x2“ configuration on AIXTRON CCS

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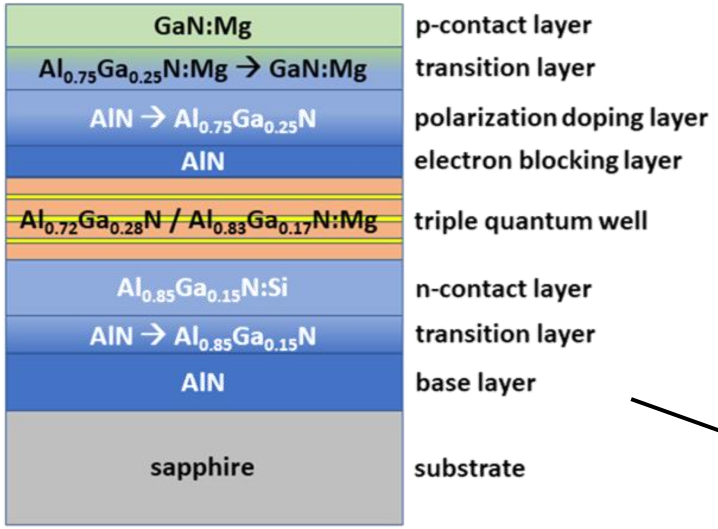
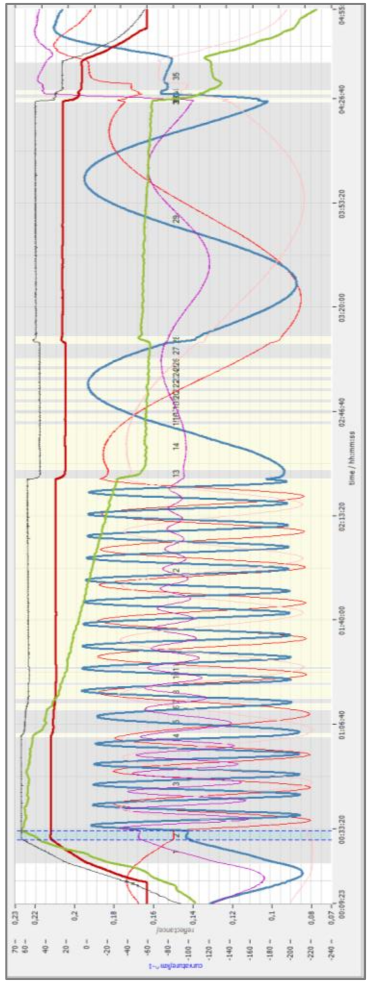
in-situ metrology for MOCVD of UV-LED structures

Schematic layer stack of UV-LED



Growth time



In-situ data

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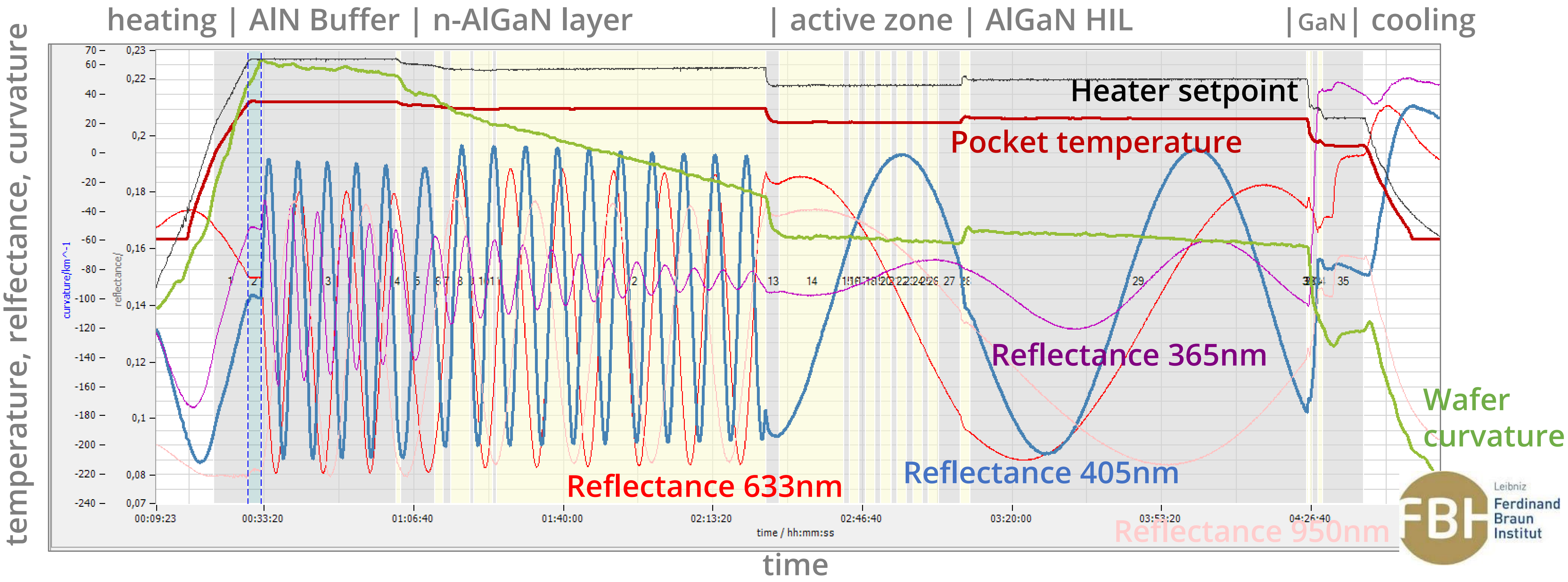
In-situ data of 230 nm UV LED (wafer #1, center)



- In-situ data: a treasure trove of information about each layer and each wafer

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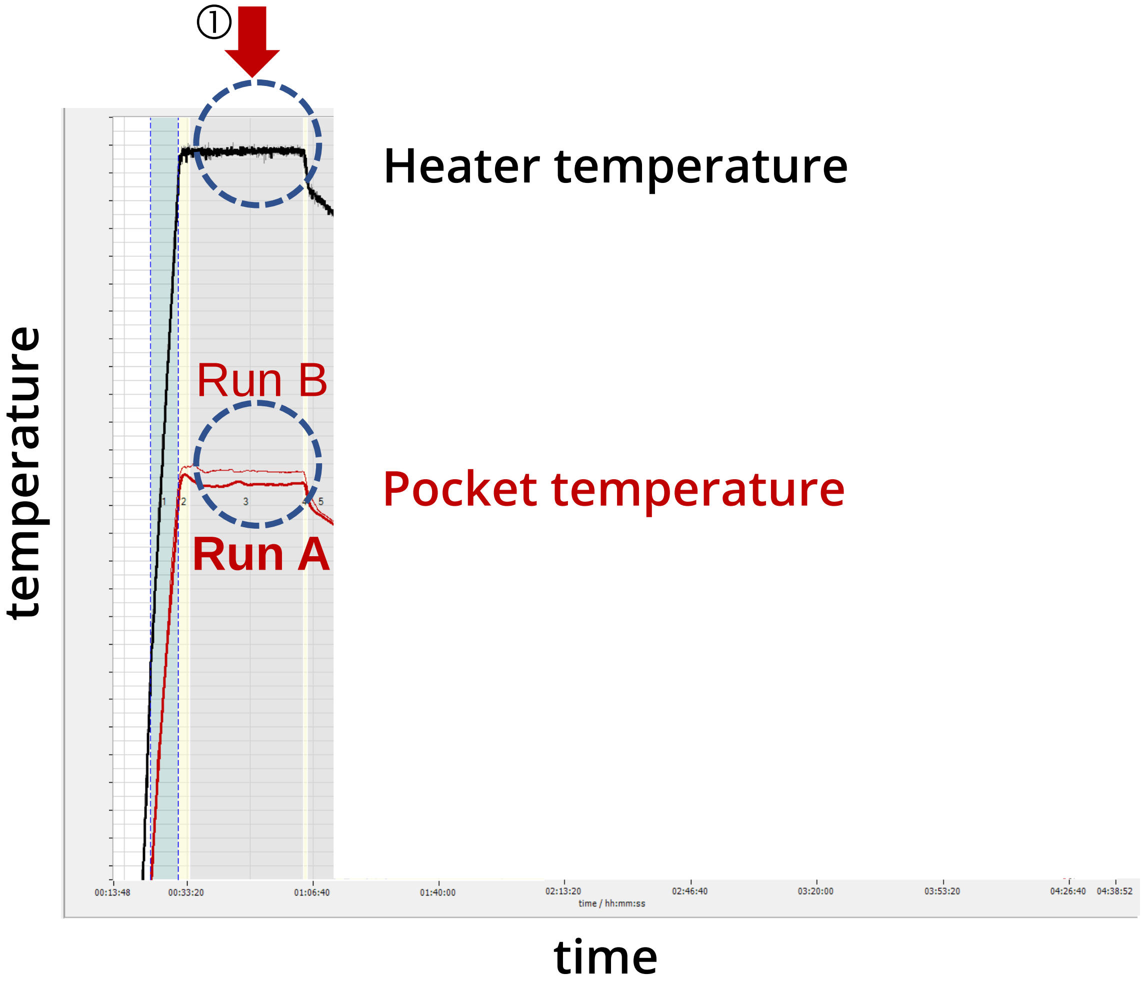
Interactive feed-back control for pocket temperature



- Run A and B (identical recipe):
- ①: Same heater temperature
- Run B shows higher pocket temperature

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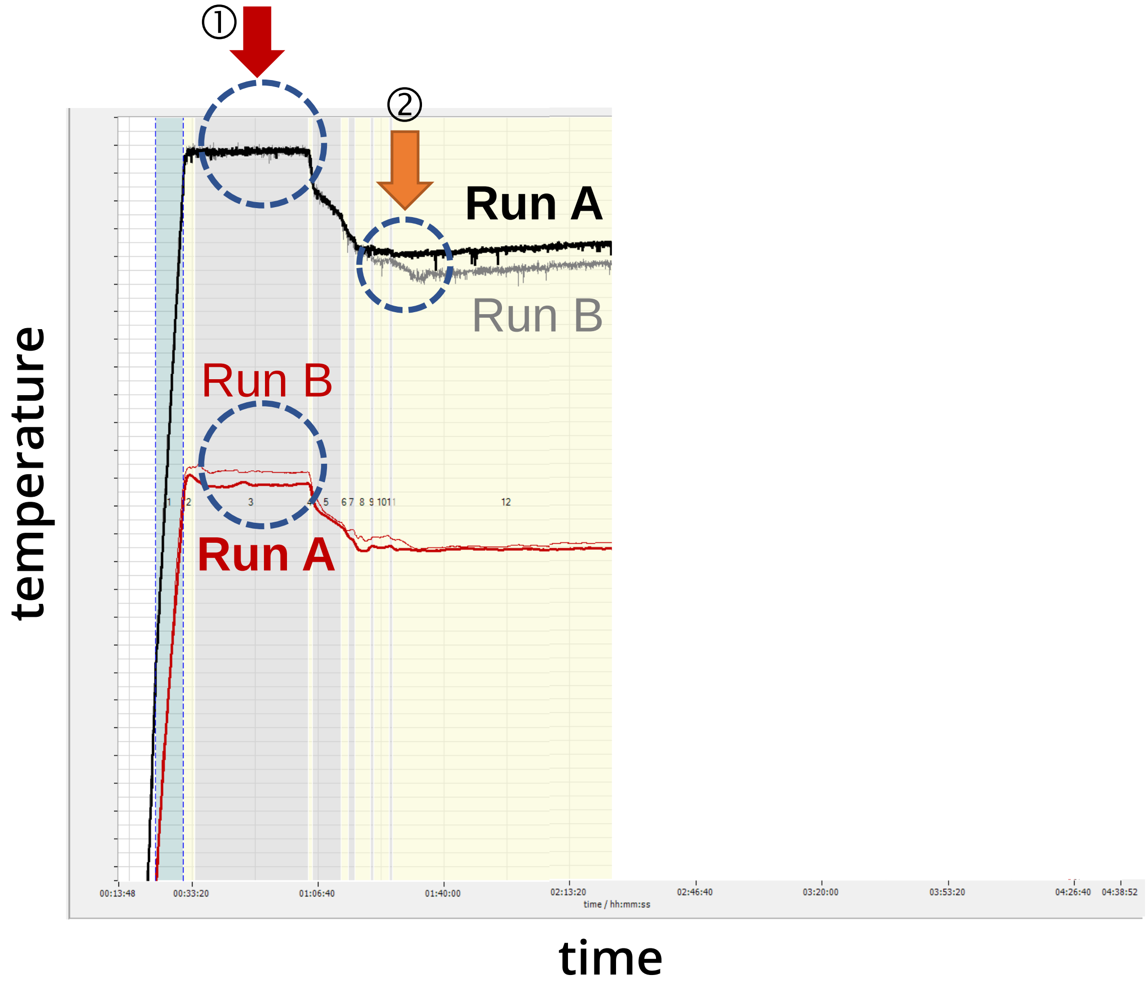
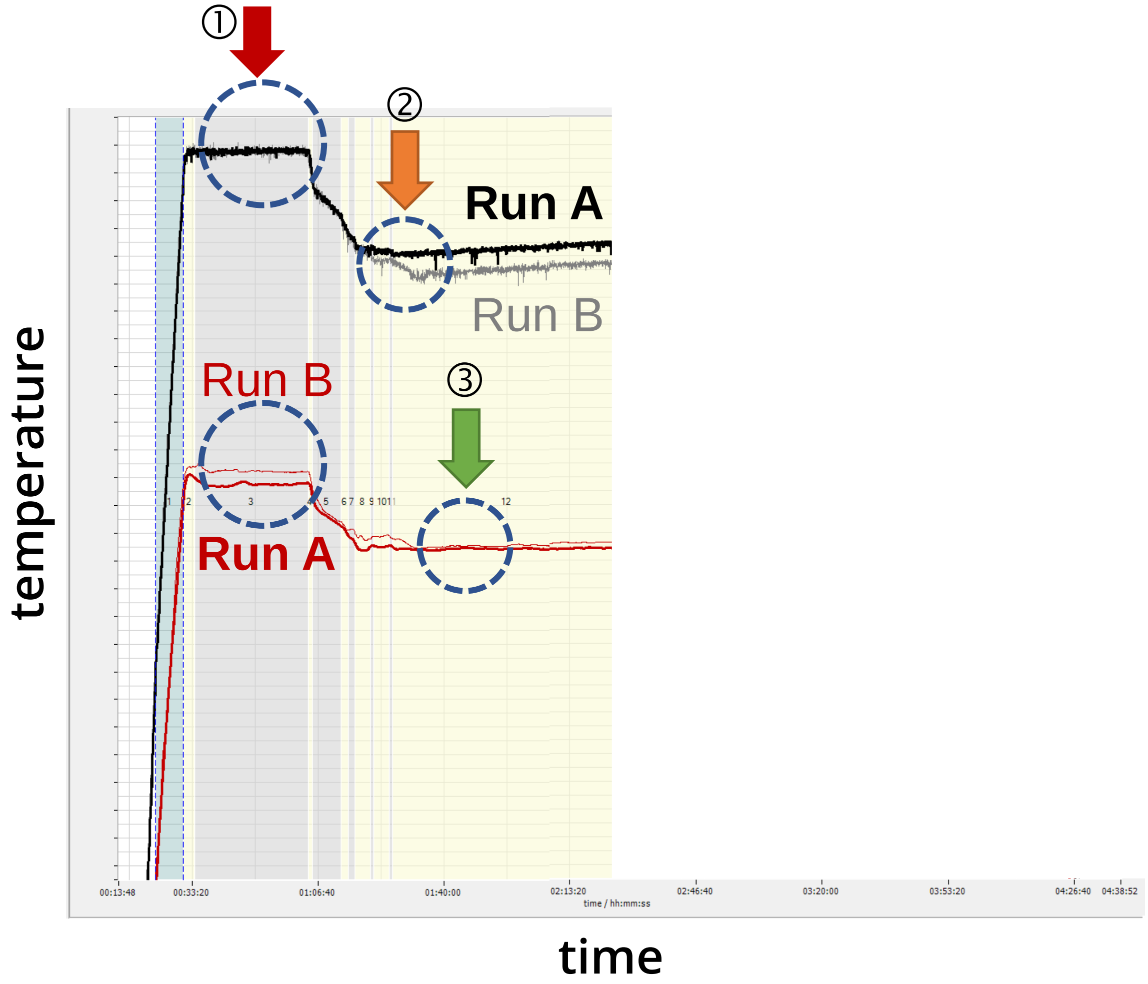
Interactive feed-back control for pocket temperature



- Run A and B (identical recipe):
- ①: Same heater temperature
- Run B shows higher pocket temperature
- ②: Correcting for difference: lowering heater temperature in Run B

Interactive feed-back control for pocket temperature



- Run A and B (identical recipe):
- ①: Same heater temperature
- Run B shows higher pocket temperature
- ②: Correcting for difference: lowering heater temperature in Run B
- ③: Same pocket temperature established as in Run A

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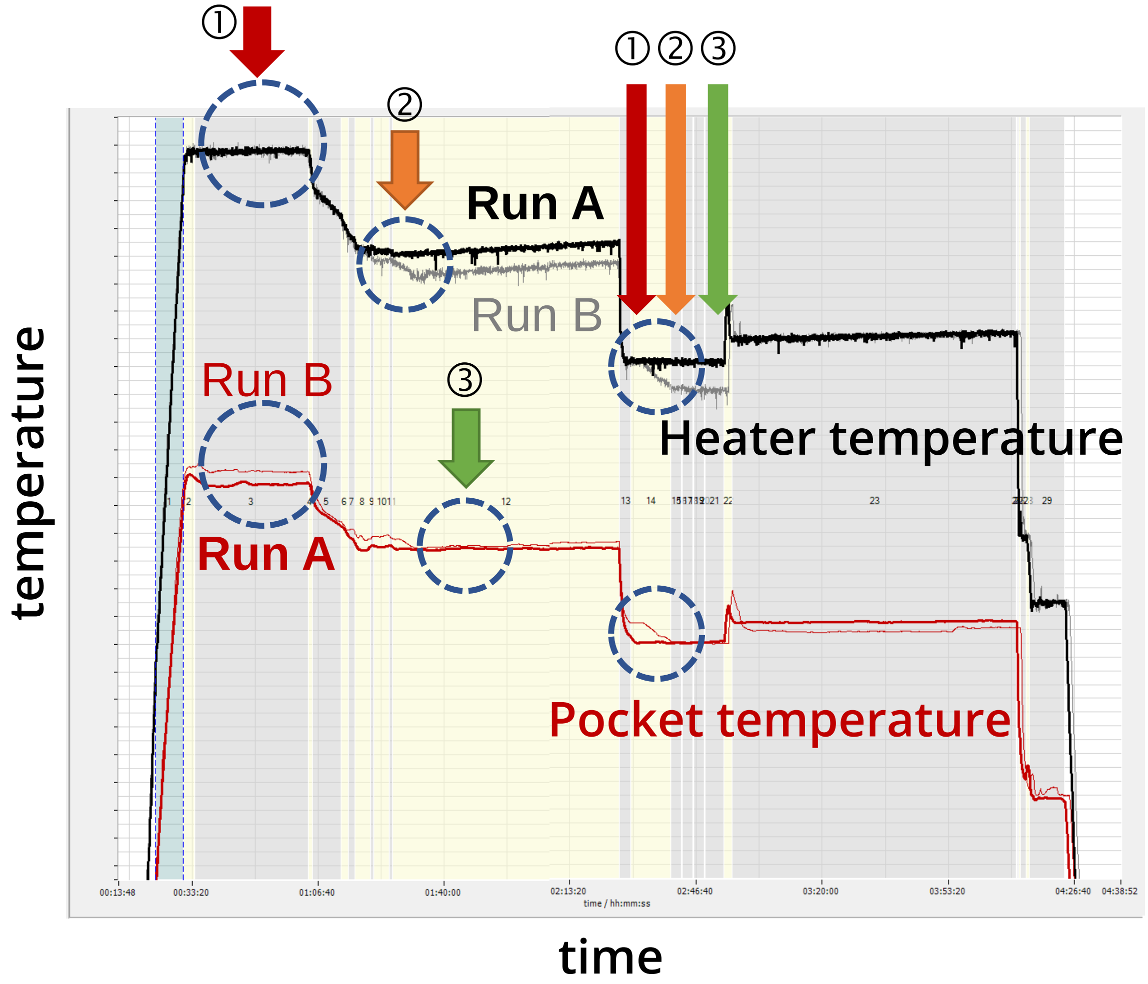
Interactive feed-back control for pocket temperature



- Run A and B (identical recipe):
- ①: Same heater temperature
- Run B shows higher pocket temperature
- ②: Correcting for difference: lowering heater temperature in Run B
- ③: Same pocket temperature established as in Run A
- Same procedure in 2nd half of run

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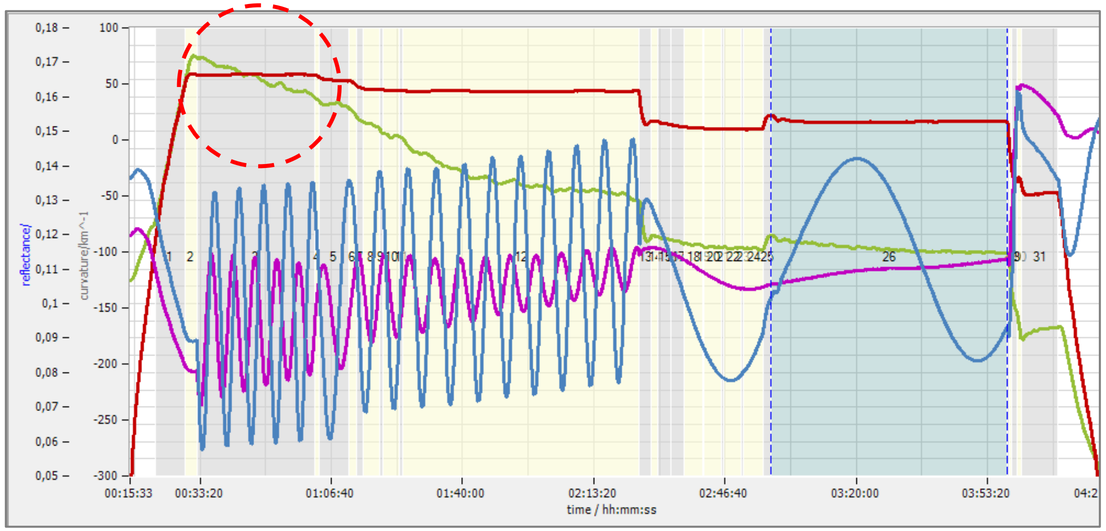
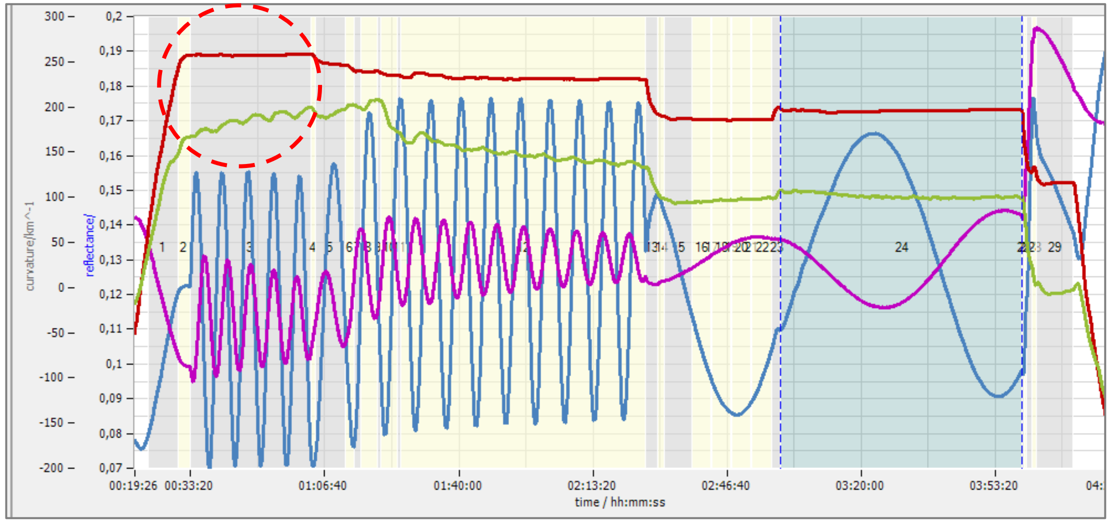
Effect of wafer curvature on 230nm UV-LED emission wavelength

Wafer A

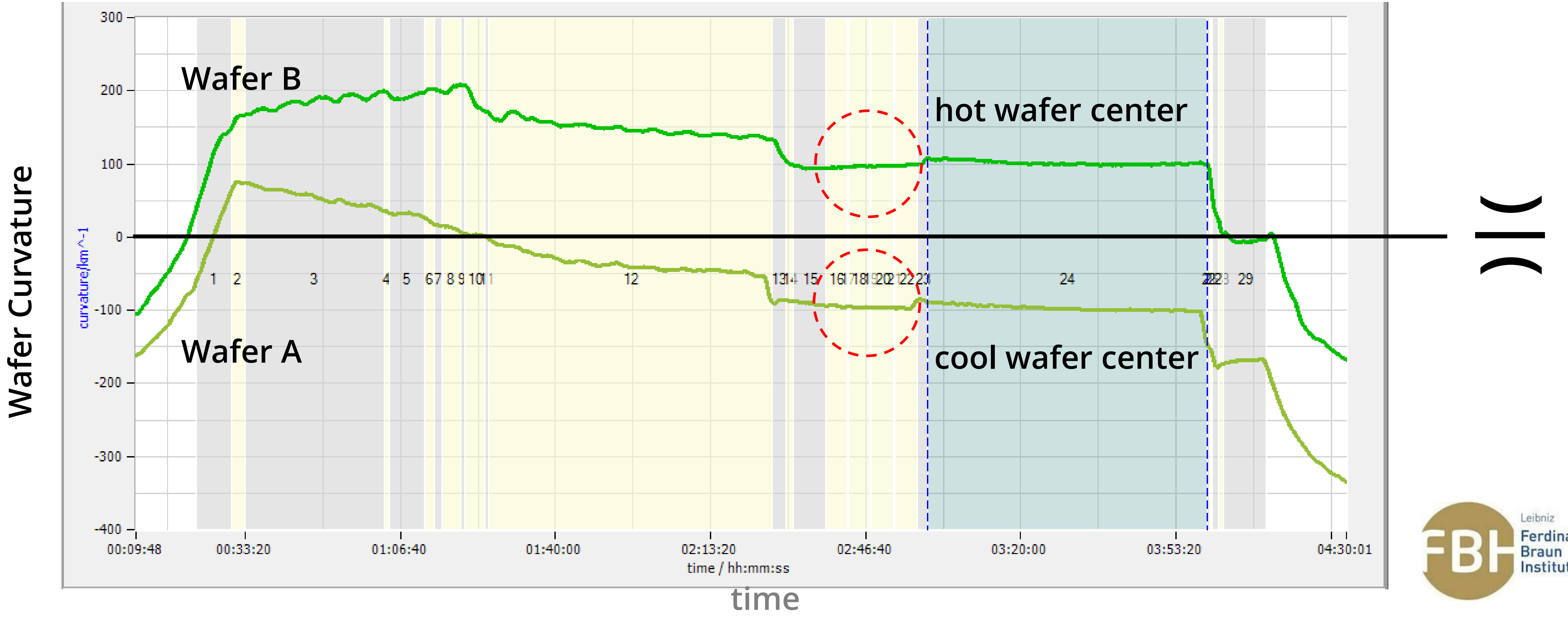


Wafer B



- Two runs with comparable recipe and similar looking in-situ data
- But different template – strain development during AlN growth significantly different
- Result: Strong difference in wafer curvature during growth of MQW

Effect of wafer curvature on 230nm UV-LED emission wavelength

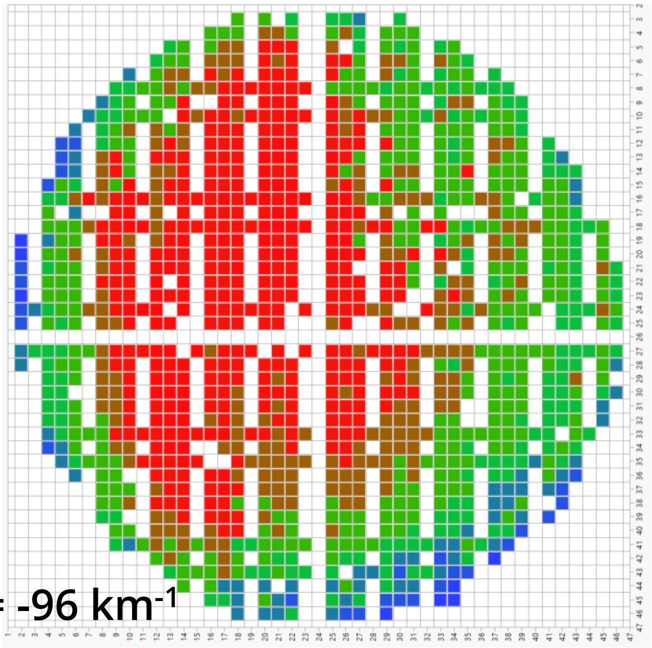


- Uniformity of LED emission can alredy be predicted

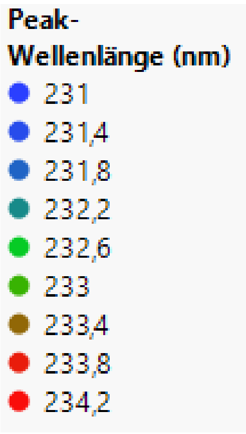
Effect of wafer curvature on 230nm UV-LED emission wavelength

Electroluminescens maps confirm expectation from in-situ data

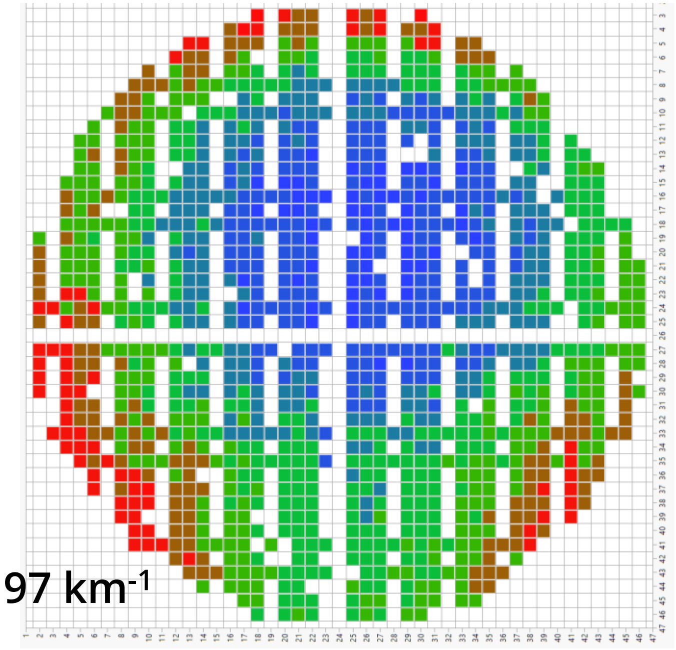
Wafer A



k_{AZ}= -96 km^{-1}



Wafer B



k_{AZ}= 97 km^{-1}

- Far-UVC LED on HTA-AlN/Saphir template
- Longer emission λ in center

- Far-UVC LED on MOVPE-AlN/Saphir template
- Shorter emission λ in center

Outline

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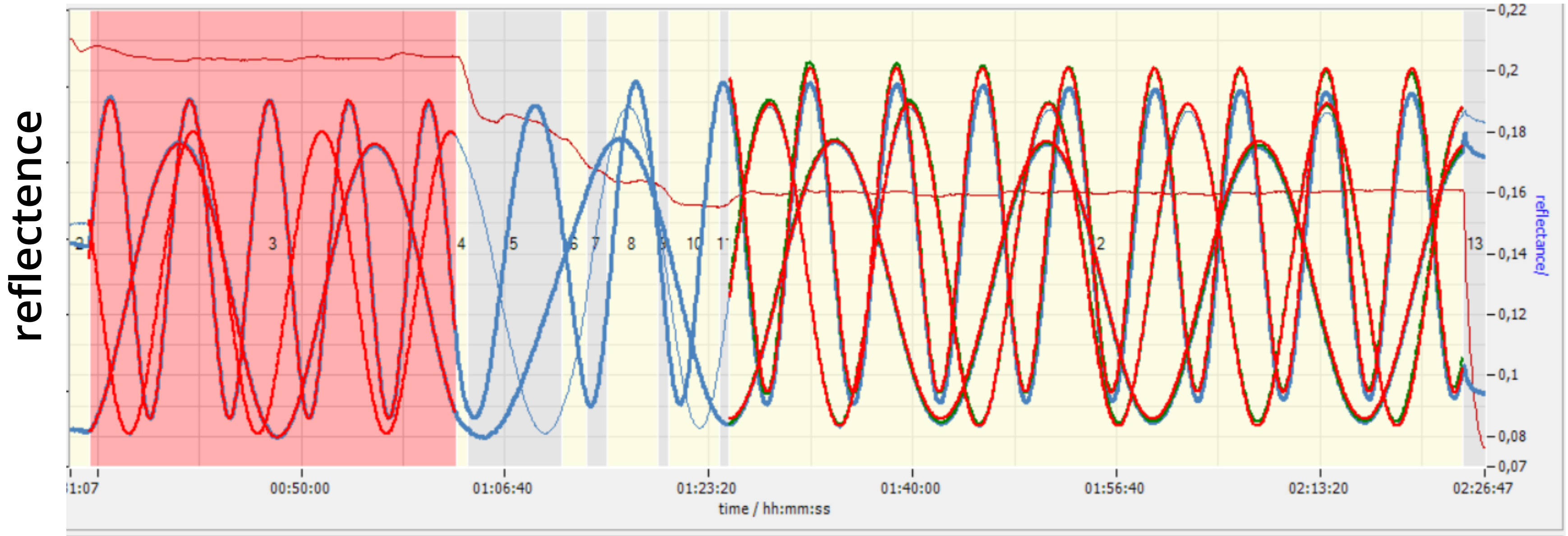
AlGaN composition determination

AlN layer (reference) | AlGaN layer (analyzed)



Measured curves

Fitted curves based on physical model and n,k database

Result: x=0,853 (nominal/XRD: 85%)

- In-situ reflectance data can be analyzed to measure growth rate, optical constants (n,k) and ternary composition
- Accuray and precision increases if multiple wavenlegths are used in the analysis
- Shorter wavelengths (405nm and 365nm) further increase sensitivity

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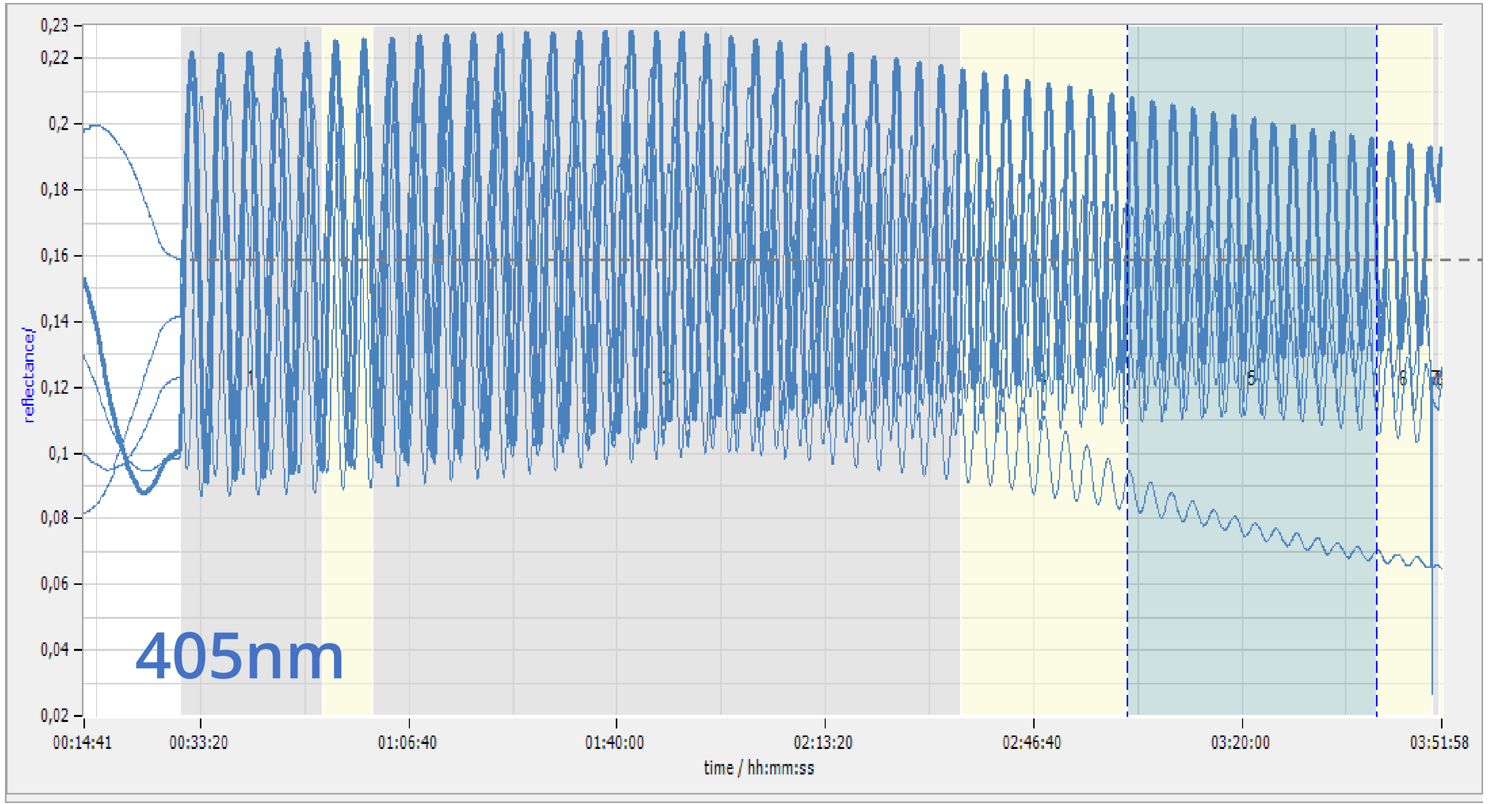
Effect of roughness on in-situ reflectance measurement

reflectence



standard template (smoothest)

increasing roughness

highest roughness

- One run – 5 different templates (off cut and roughness varied 2…5nm RMS)
- In-situ reflectance responds clearly on roughness

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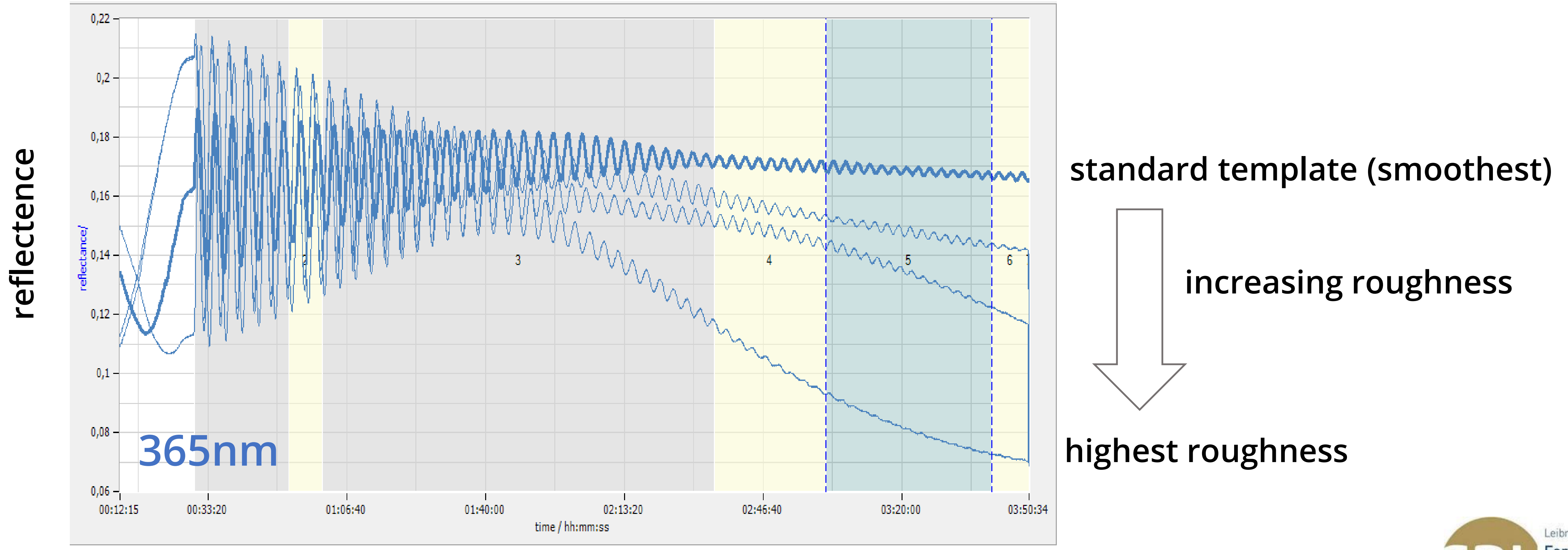
Effect of roughness on in-situ reflectance measurement



- 365nm reflectance has much higher sensitivity for roughness detection

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Summary and Conclusions

- Growth processes for UV-LEDs are challenging and require tight in-situ process monitoring
- Run-to-Run deviations between heater and pocket temperature can be detected and corrected during the growth run
- Wafer curvature measurement allows to predict uniformity of LED emission wavelength across wafer
- In-situ reflectance measurement allow to determine growth rates and AlGaN composition
- UV wavelengths for reflectance measurements increase sensitivity for roughness determination

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Knowledge is key

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