Large area heteroepitaxial (11-22)-GaN growth:

What do we learn from in-situ metrology?

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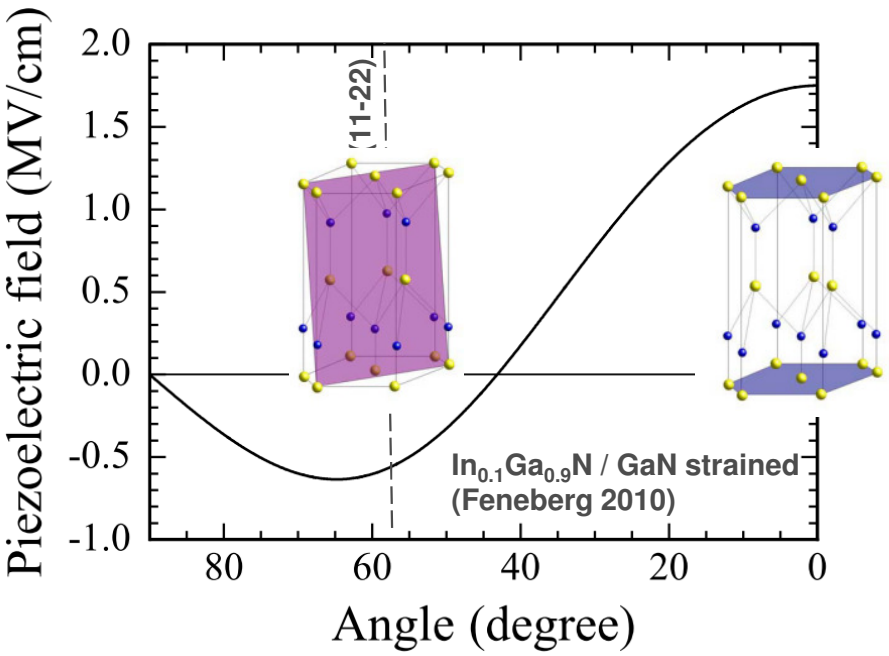
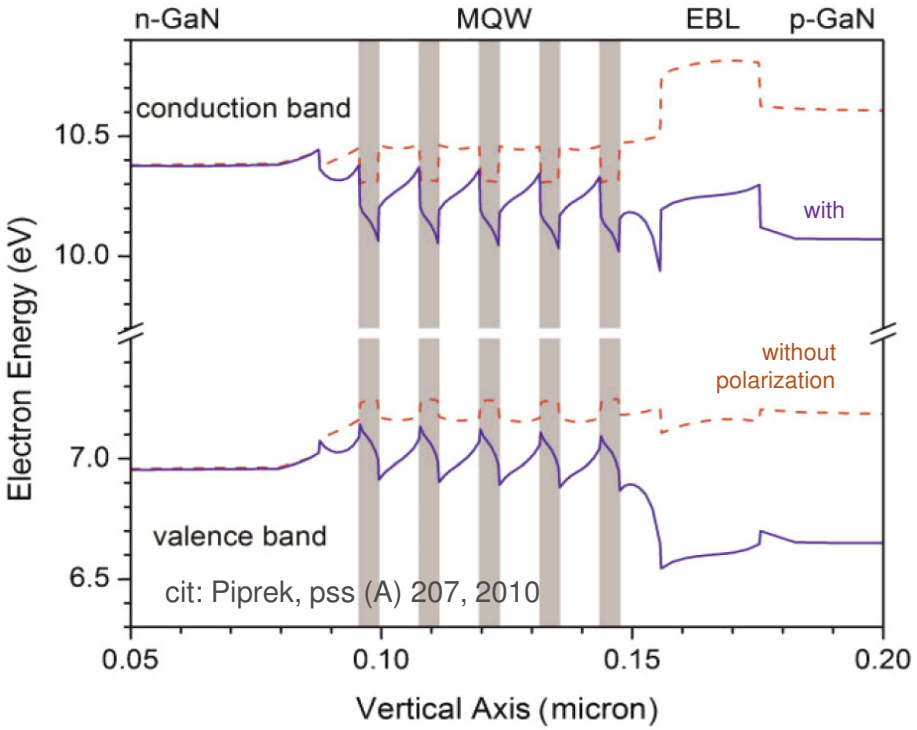
Outline

- Semi-polar GaN: What for use and how to obtain?
- MOVPE of (11-22)-GaN on 4 inch patterned sapphire substrates.
- How to measure temperature on patterned sapphire substrates?
- How does (11-22)-GaN coalescence and layer morphology changes UV reflectance?
- How does strain incorporation differs between semi-polar and polar GaN growth? Is the wafer bow spherical for GaN on stripe-patterned substrates?
- What do we learn about the thermal expansion and thermal conductivity of (11-22)-GaN / r-PSS?

Why non- or semi-polar GaN?

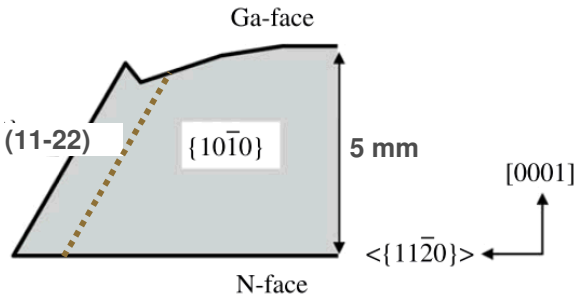




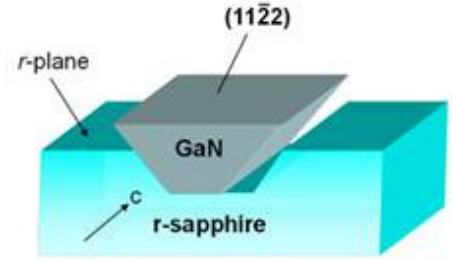
- III-N wurzite structure: spontaneous polarisation along c-direction with additional piezoelectric polaristion due to lattice strain
- polarisation-induced effects in polar c-oriented GaN-LEDs:
  - reduced overlap of electron and hole wave function (due to QCSE)
  - increased leakage currents and Auger recombination
  - emission wavelength shift with current

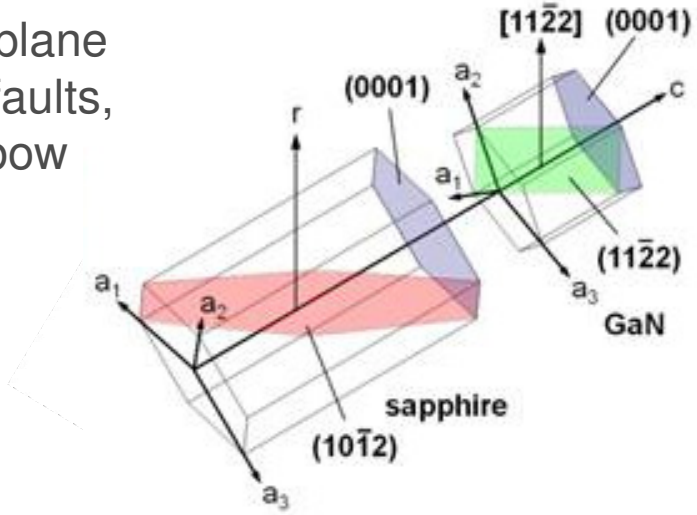
How do produce non-/ semi-polar GaN?

- **HVPE bulk growth in c- direction + sawing + polishing**
  - low defect density (TDD~10^6 cm^{-2}), but limited in size and quantity



- **Heteroepitaxy (MOVPE)**
  - planar growth, (11-22)-GaN on m-plane sapphire: many defects (stacking faults, TDD~10^9 cm^{-2}), aspherical wafer bow
  - defect-reduced c-oriented growth on tilted sidewalls of r-plane sapphire



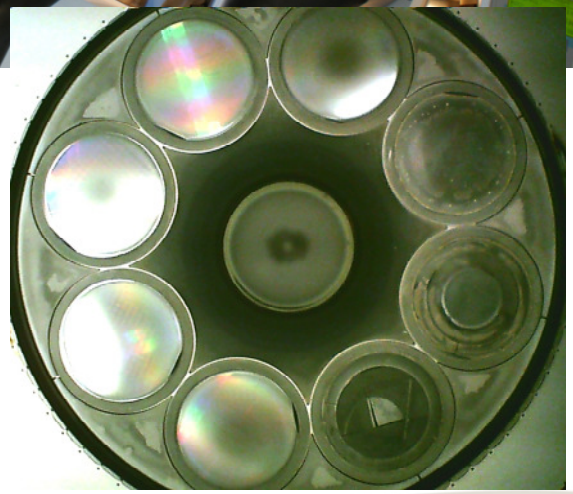


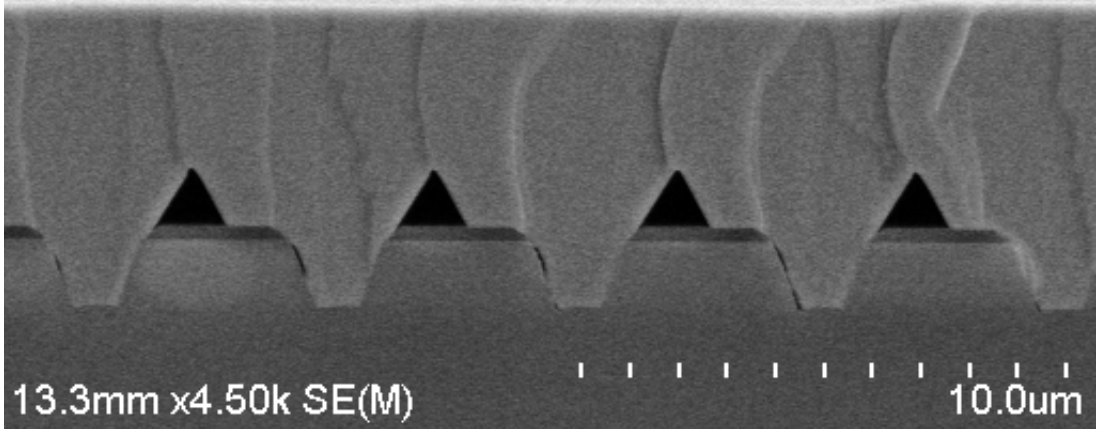
plane	∠ to c
Saphir (10-12)	57.6°
GaN (11-22)	58.4°

pic.: Yamaguchi U

MOVPE of GaN on 100 mm r-PSS

- AIX2600G3-HT in 8x4“ configuration
- r-PSS preparation using stepper litho, SiN_x mask and resist reflow
- multi-step growth sequence (65/150 mbar, 980/1050 °C)
- typically ~ 7 µm (11-22)-GaN with TDD~1x10^{8} cm^{-2} and BSF~1x10^{3} cm^{-1} achieved on 4 inch





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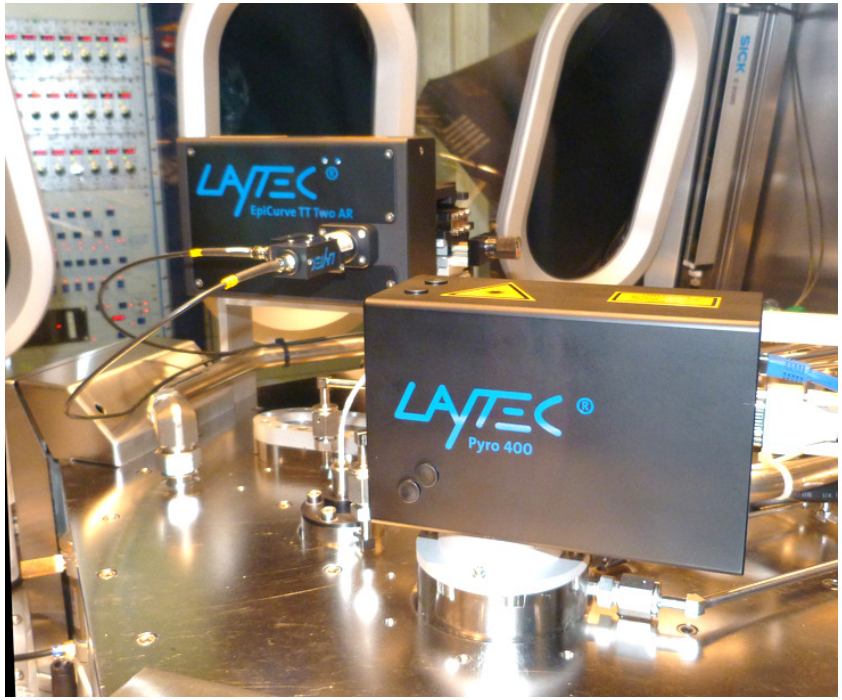
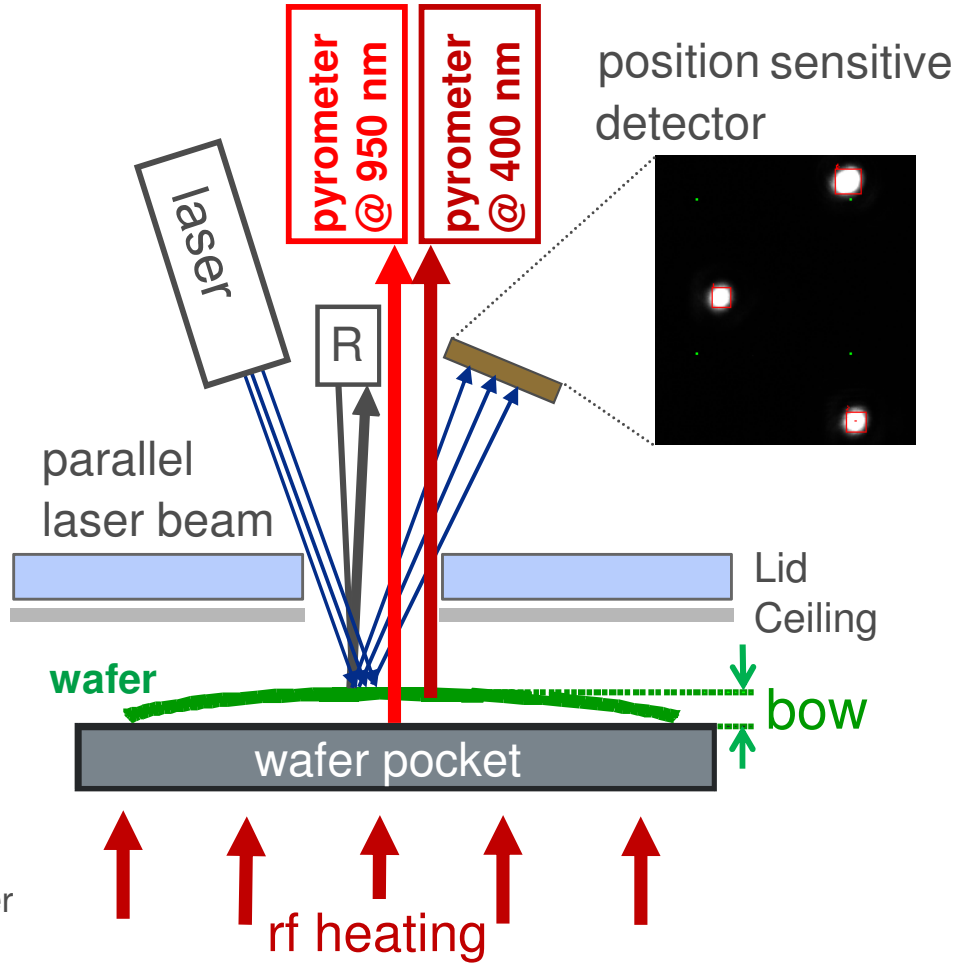
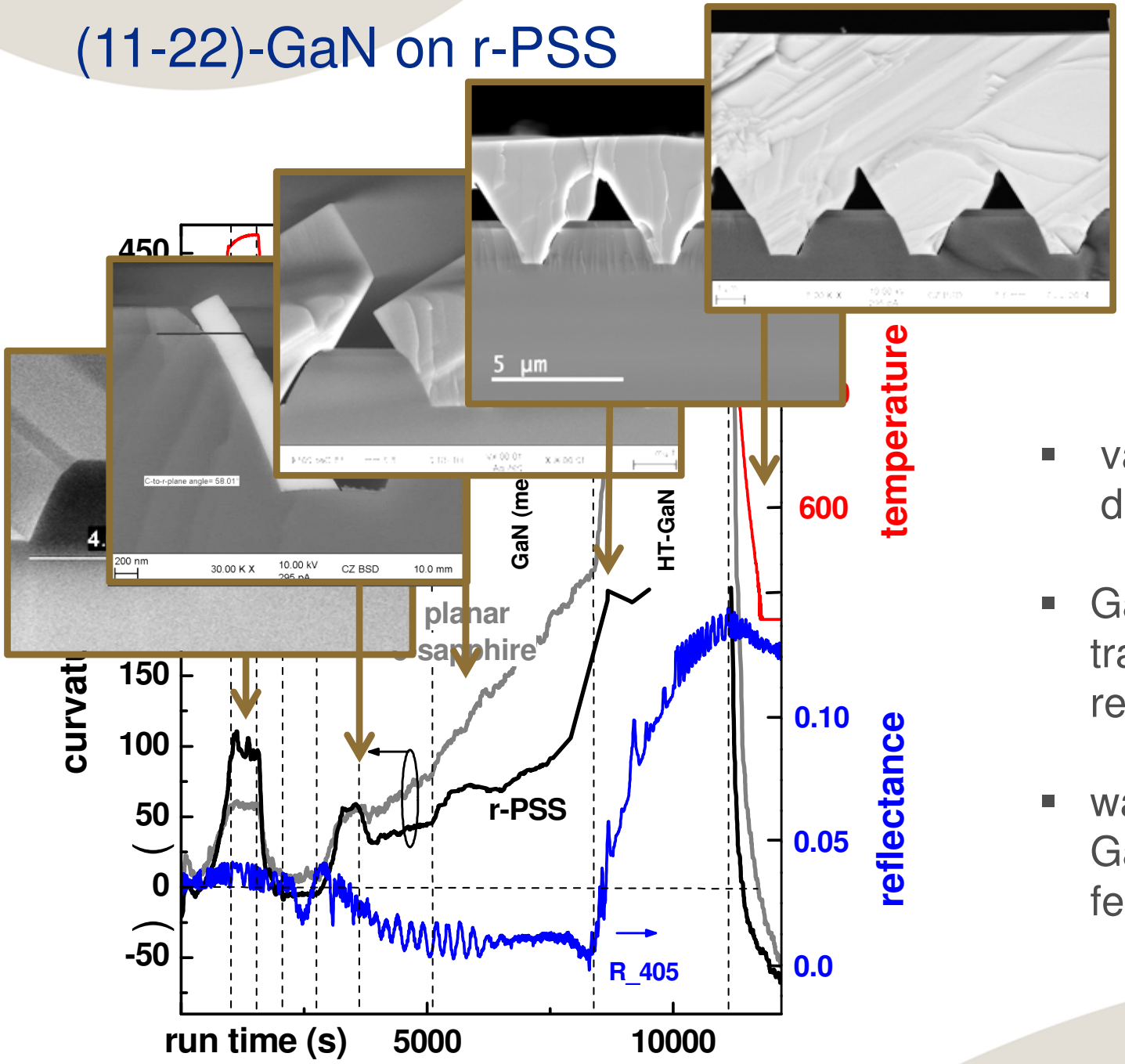
EpiCurve Blue AR / Pyro400





- emissivity-corrected pyrometry (950 nm) to measure T_{pocket}, 400 nm pyrometry to measure T_{wafer}
- multi-wavelength reflectance
- wafer curvature (blue laser, 3-point: aspheric curvature component detectable)

(11-22)-GaN on r-PSS



- various growth steps @ different temperatures
- GaN coalescence traceable by UV reflectance
- wafer curvature of (11-22)-GaN has characteristic features

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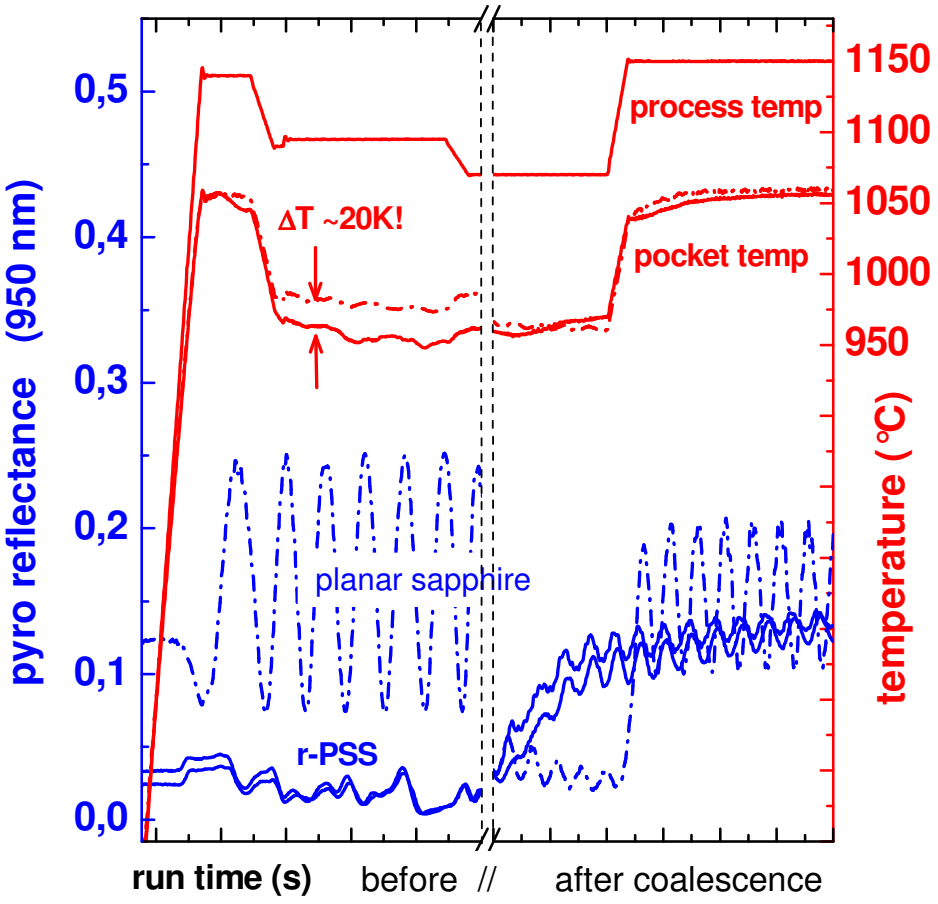
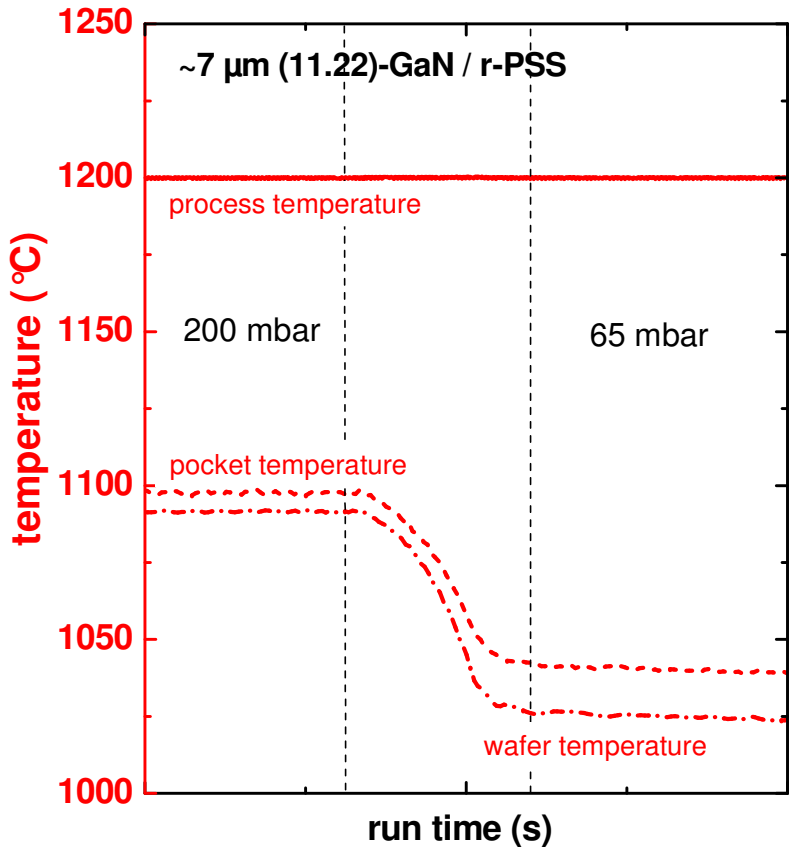
Temperature measurement on PSS wafer

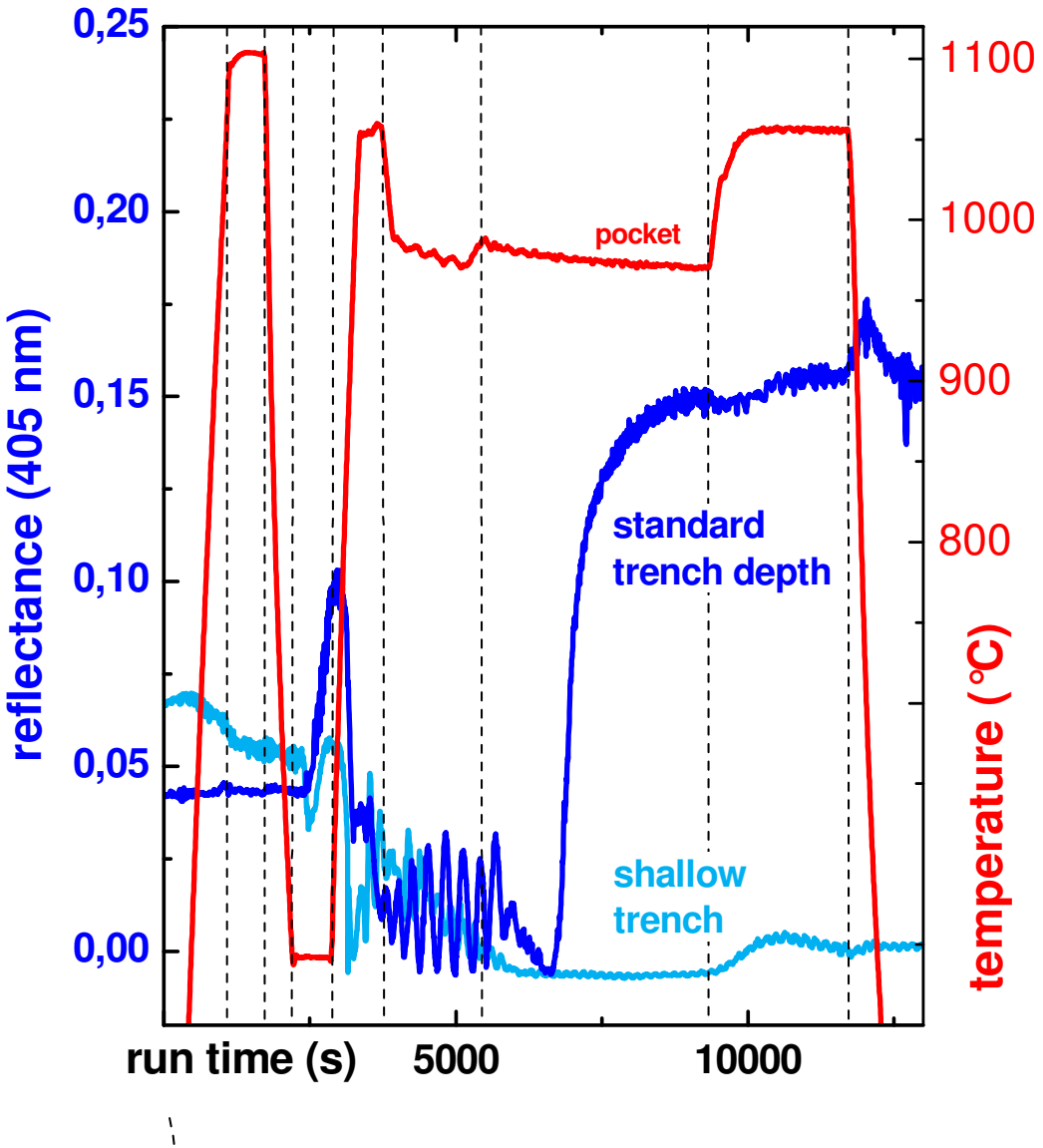


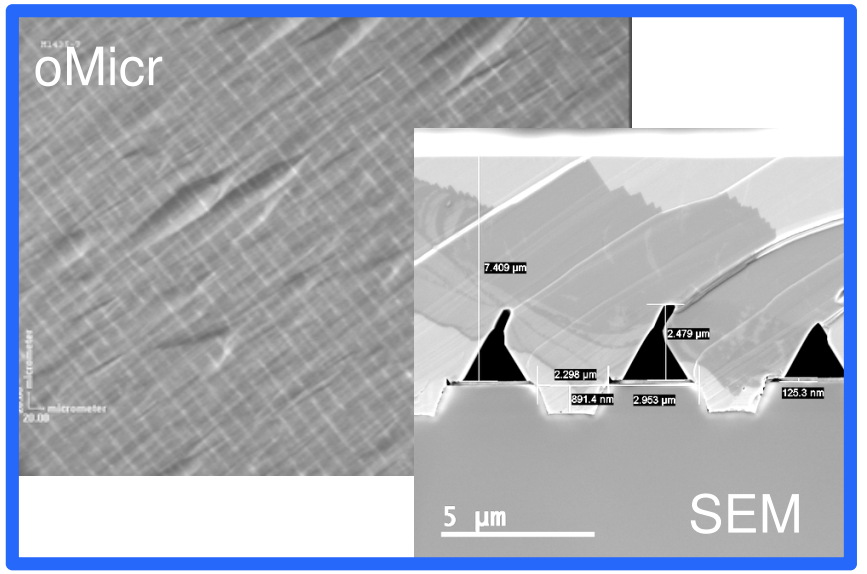


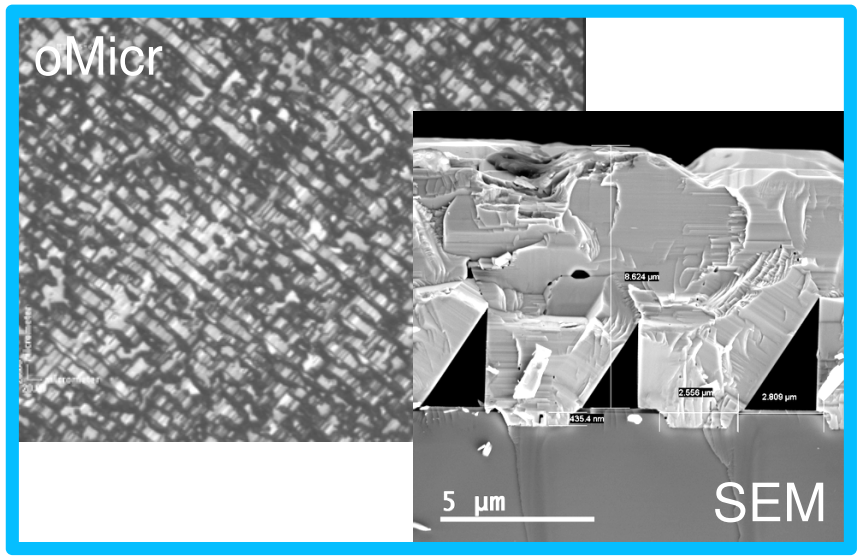
$T_{process} > T_{pocket} > T_{wafer}$
depending on process conditions

- PSS has low and changing reflectance
- emissivity-correction needs reflectance calibration
- wafer temperature only for coalesced GaN

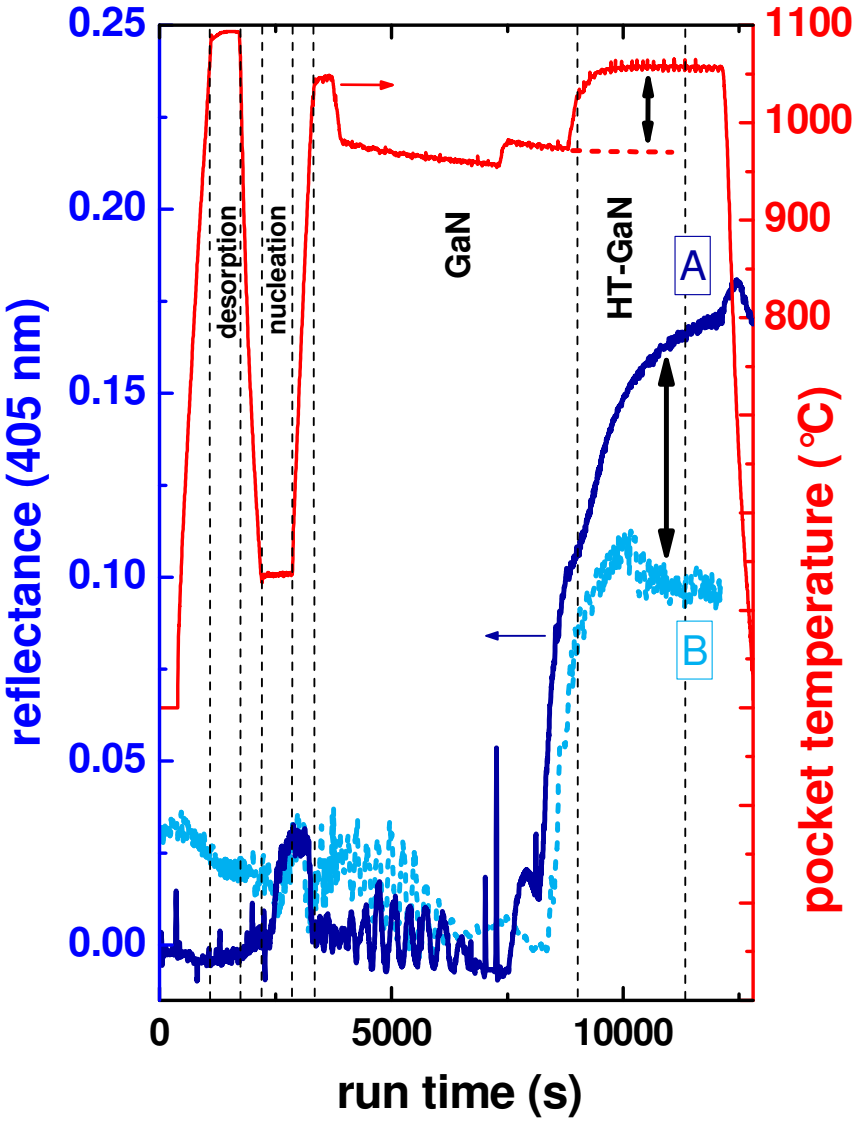
Tracing coalescence

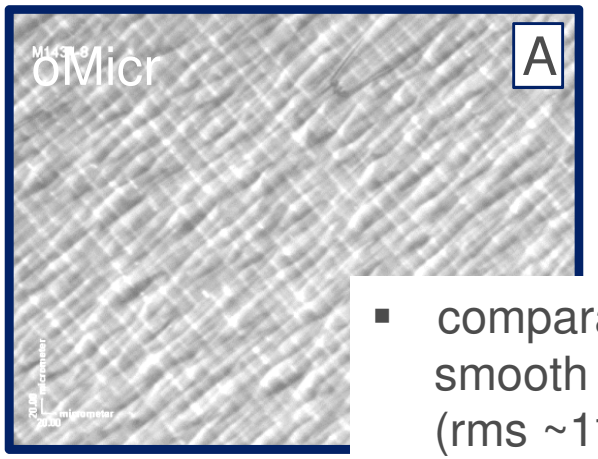




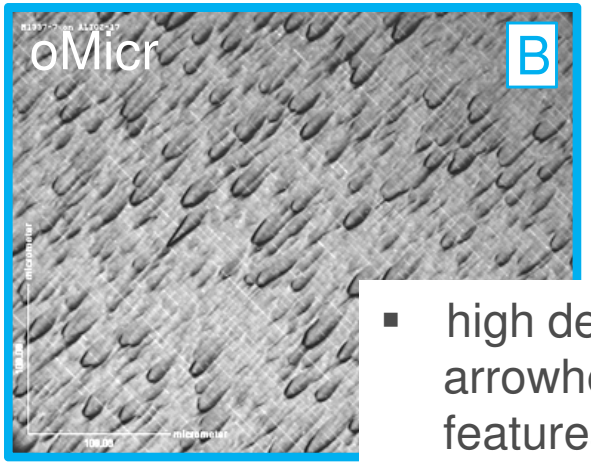


Tracing final layer morphology



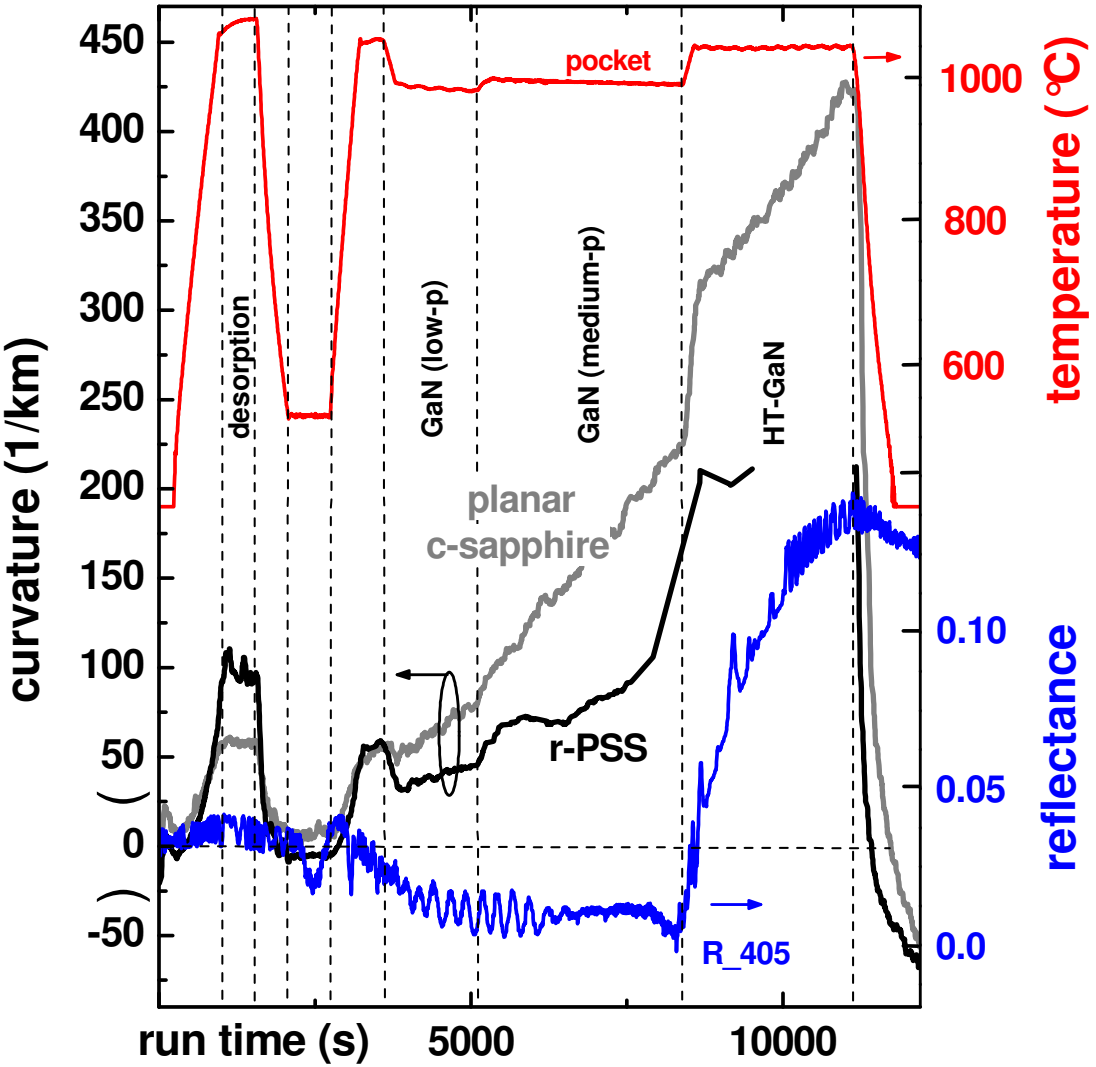


- comparatively smooth morphology (rms ~11 nm)



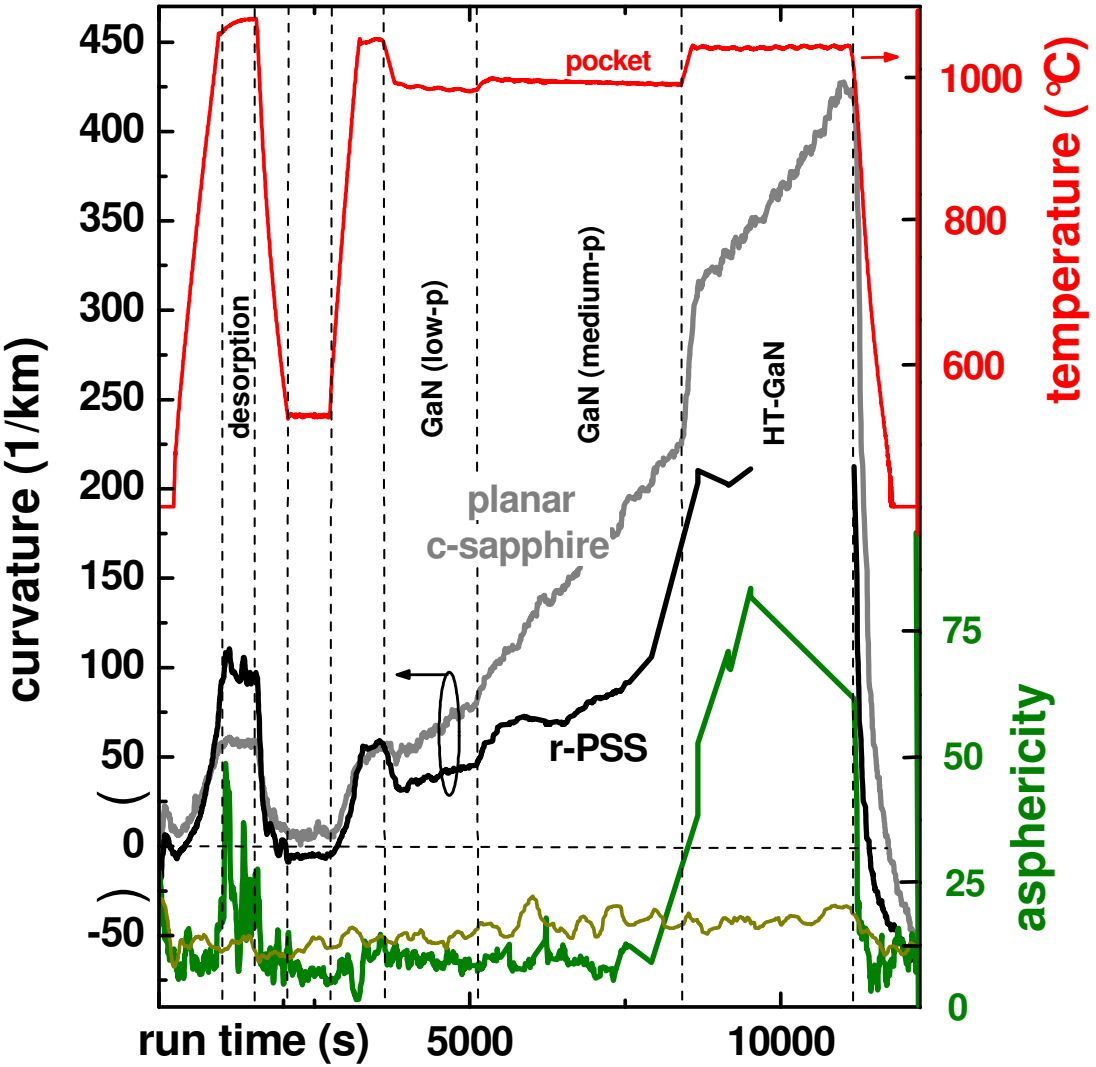
- high density of arrowhead surface features

Wafer curvature

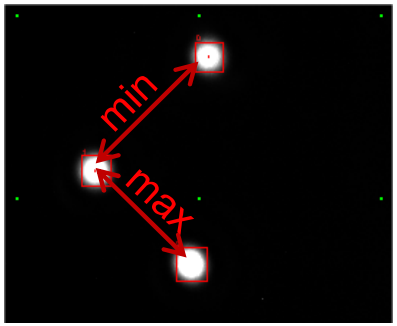


- vertical temperature gradient for PSS larger (frontside cooling)
- tensile strained growth prior coalescence
- HT-GaN growth: large curvature (exceeding measurement limit)
- RT curvature comparable to c-GaN
  (no cracking observed)

Wafer curvature: spherical?

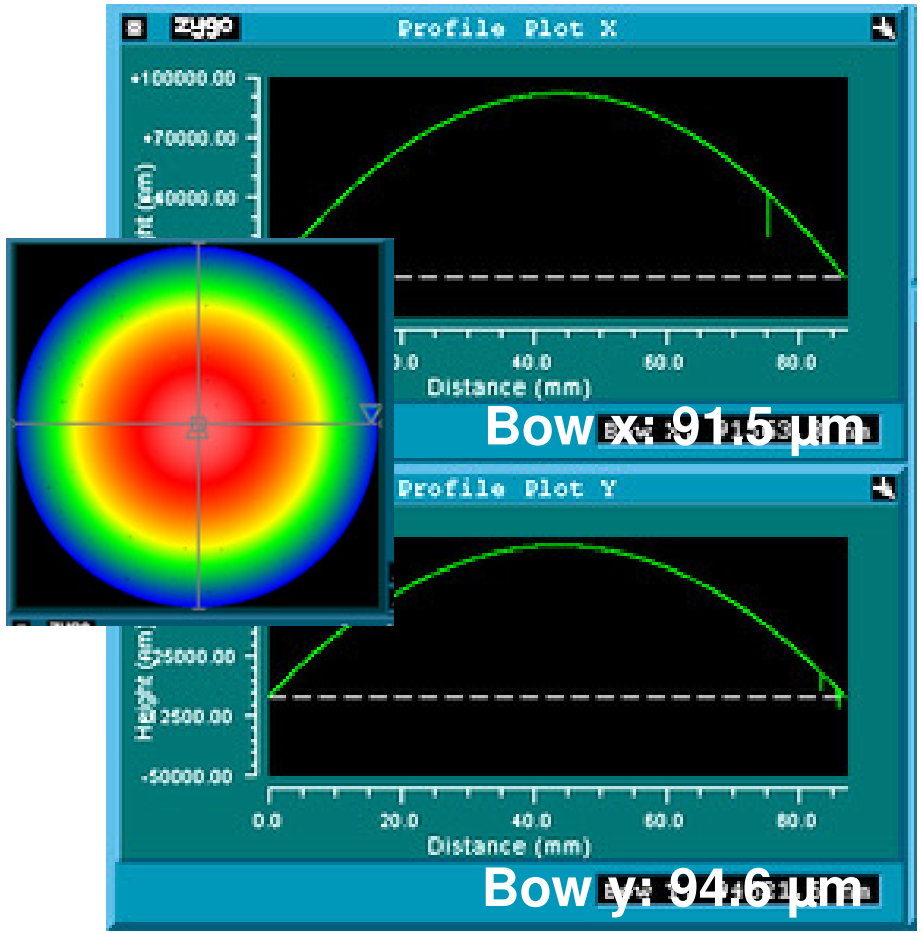


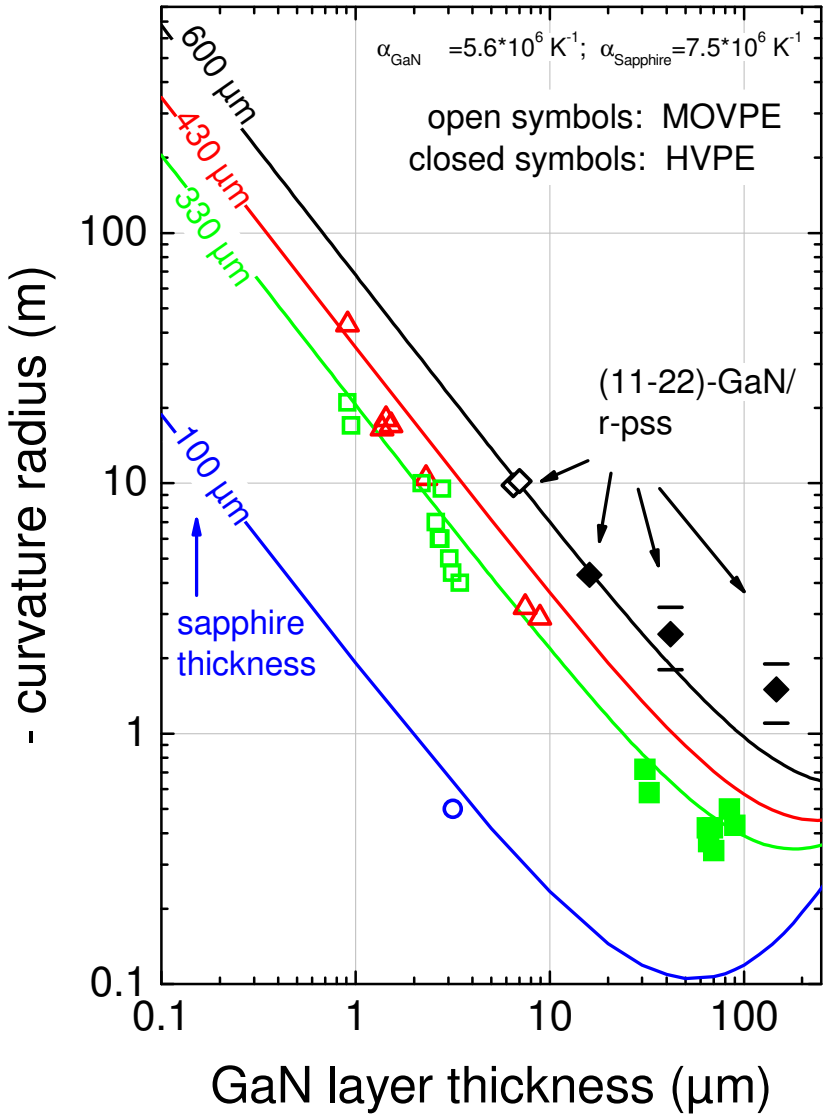
- asphericity: half the difference between maximum and minimum curvature value



- asphericity detectable at high growth temperatures (>1000 °C)
- RT curvature spherical

(11-22)-GaN wafer bow @ RT





- no significant aspheric bow @RT for thickness < 20 µm
- curvature radius vs. layer/substrate thickness similar to planar c-GaN

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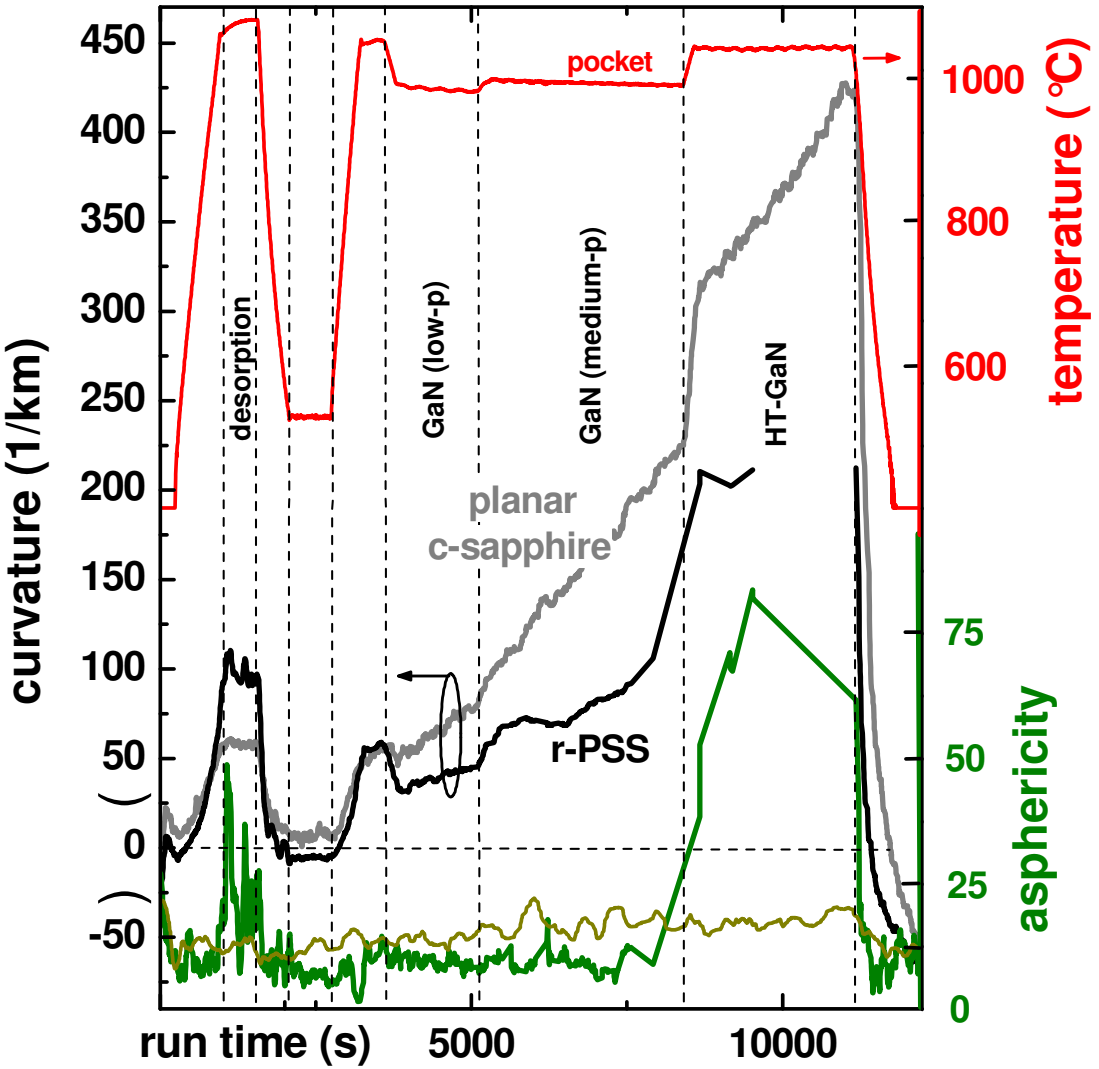
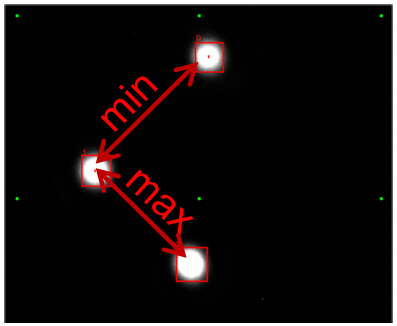
Wafer curvature: spherical?

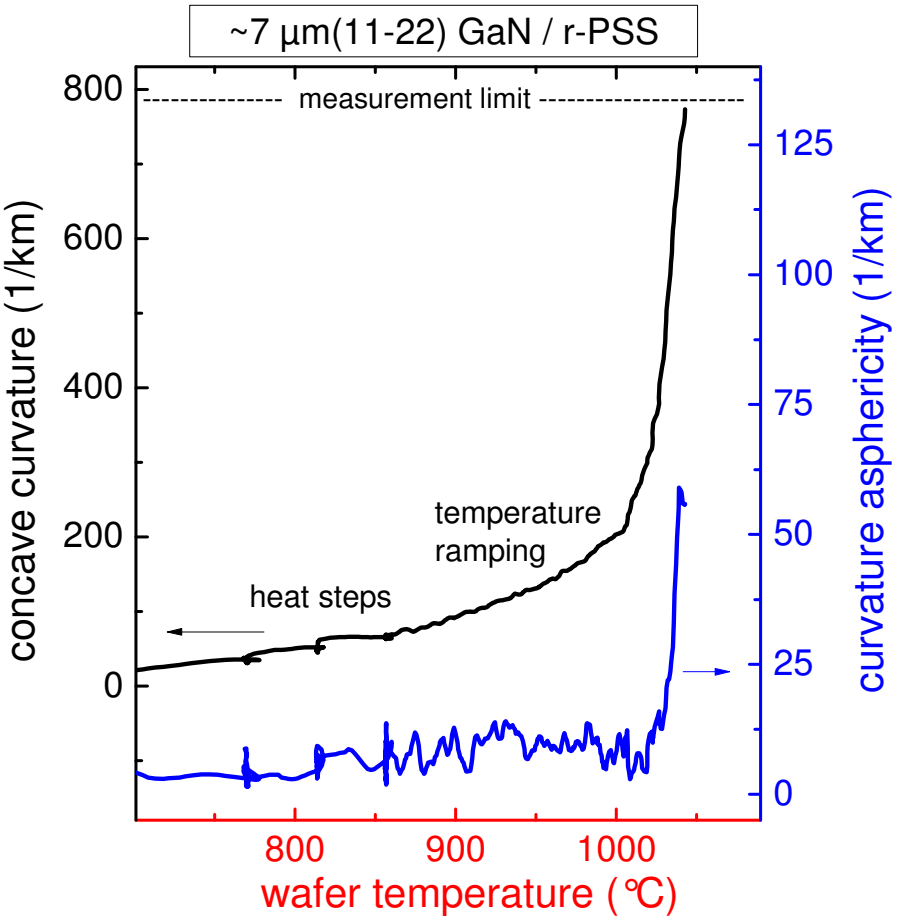


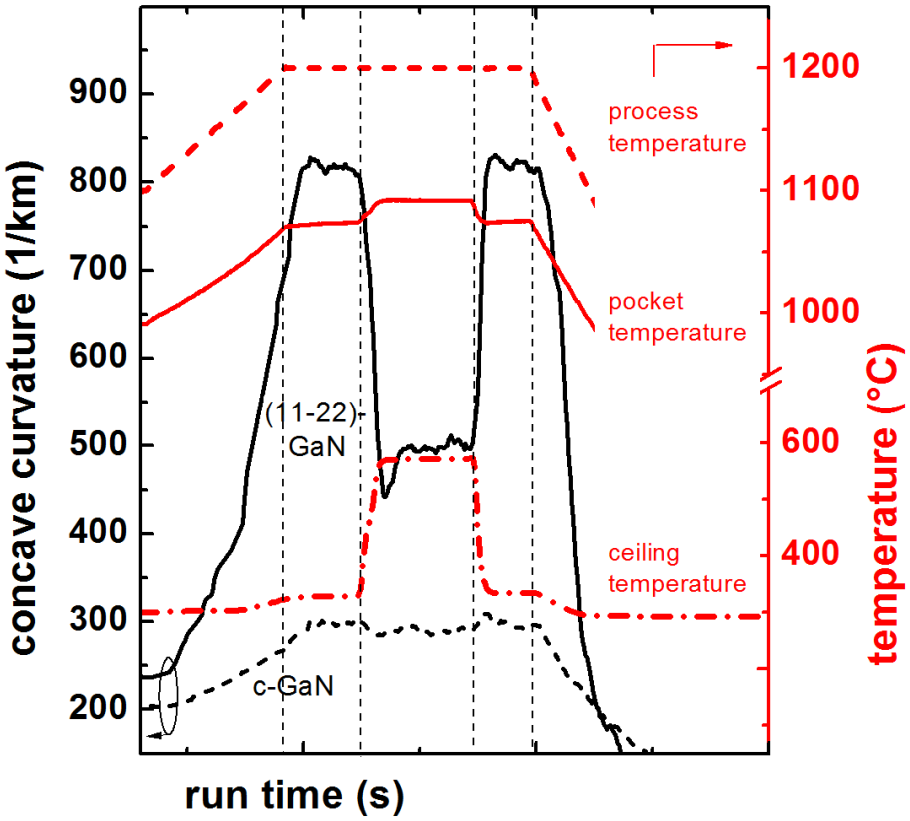
- asphericity: half the difference between maximum and minimum curvature value



- asphericity detectable at high growth temperatures (>1000 °C)

(11-22)-GaN wafer curvature >1000 °C ?





- curvature components: $\kappa_{tot} = \kappa_{initial} + \kappa_{lattice} + \kappa_{\Delta Temp}$ $\left(\kappa_{\Delta Temp} = \frac{\Delta T\, \alpha_S}{d_S}\right)$

  ⇨ take care of T gradient in growth chamber

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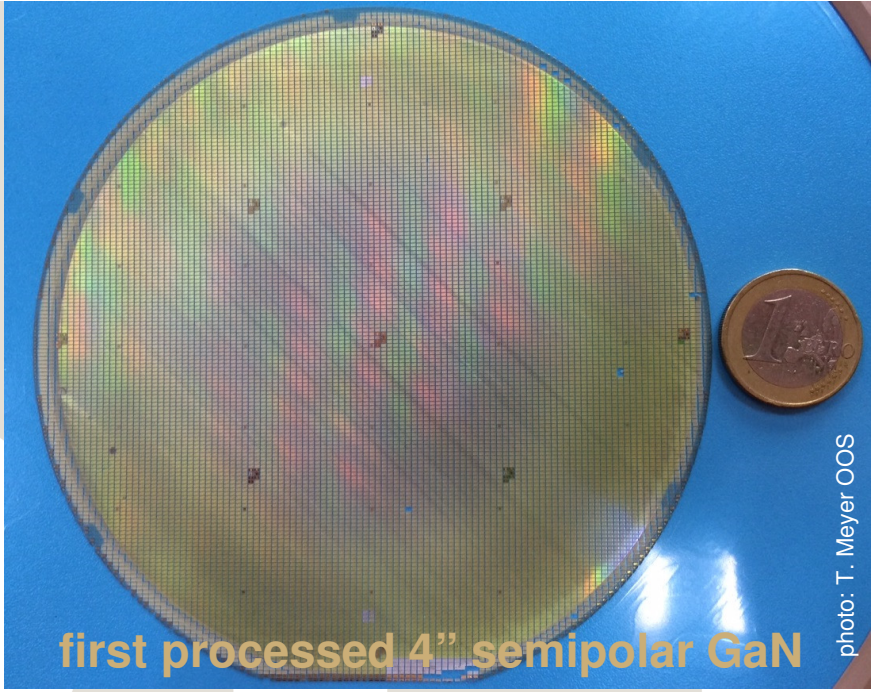
Summary

- **large area semipolar GaN growth on r-PSS optimized with the aid of *in-situ* metrology:**
  - T_{pocket} measurement on PSS not feasable: use planar wafer for calibration, use wafer temperature if possible.
  - reflectance measurements trace coalescence and growth rate, gives fingerprint of final layer morphology
  - tensile strained growth prior coalescence, additional concave curvature component at high growth temperature due to vertical temperature gradient
  - wafer bow is spherical at room temperature and comparable to c-GaN/sapphire



Thank you for your attention!

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SEVENTH FRAMEWORK PROGRAMME

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