In-situ metrology during growth of novel nitride-based semiconductor Bragg mirrors

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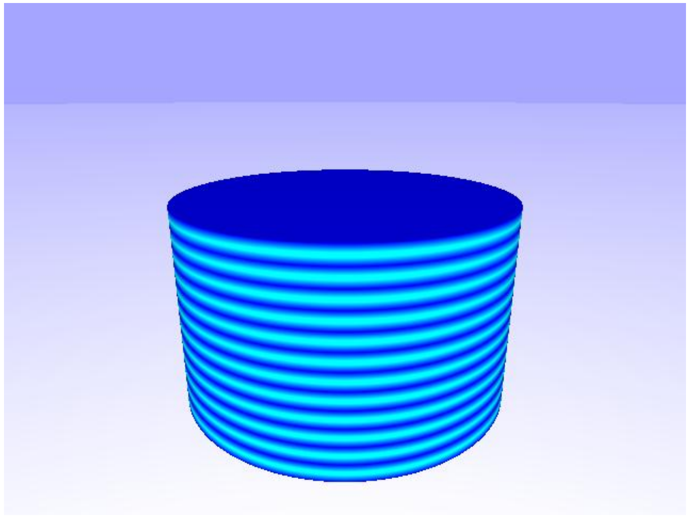
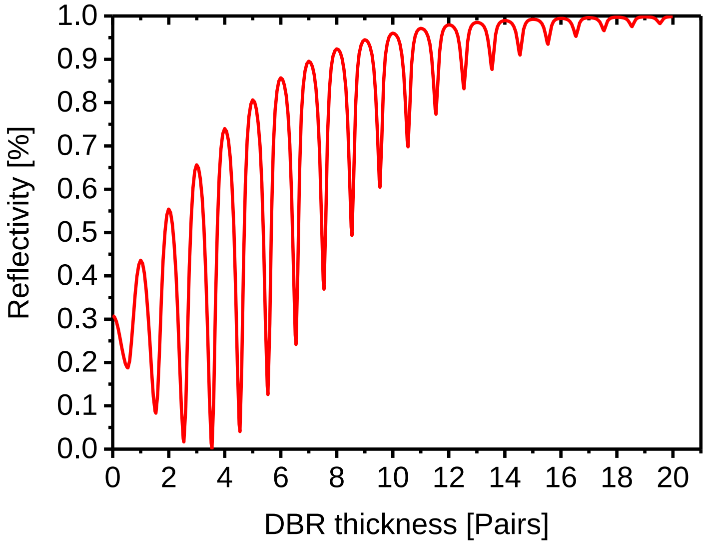
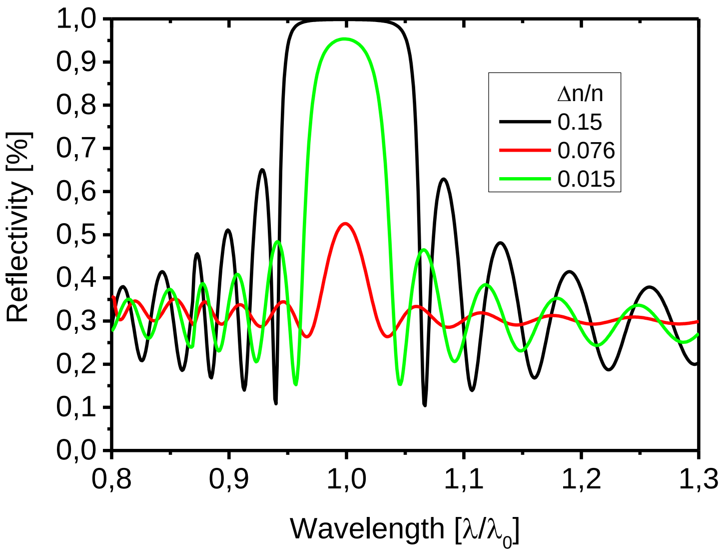
Distributed Bragg mirrors





- Alternating layers of different refractive index
- Tunable reflectivity, central wavelength, and bandwidth
- Key elements in micro-resonators



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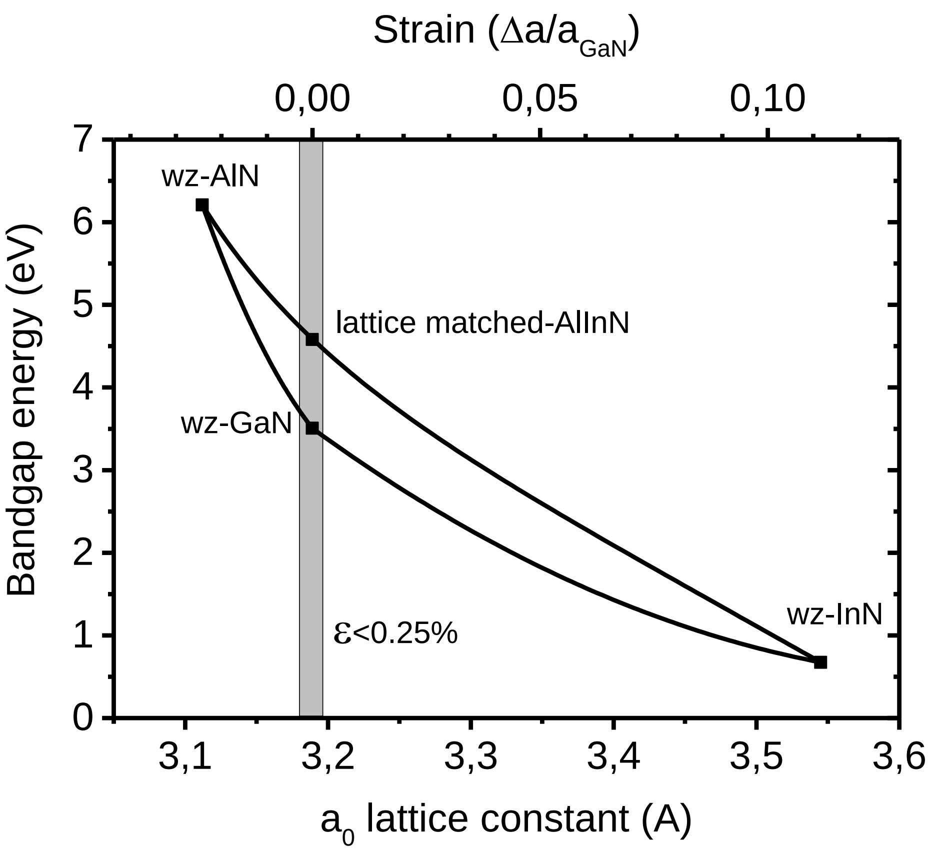
Nitride-based Bragg-reflectors

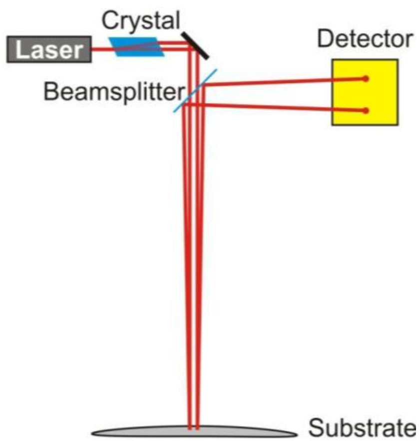


Challenges:

- Mismatch of optimal growth windows
- Lattice mismatch
- Conduction band offsets
- Polarization fields

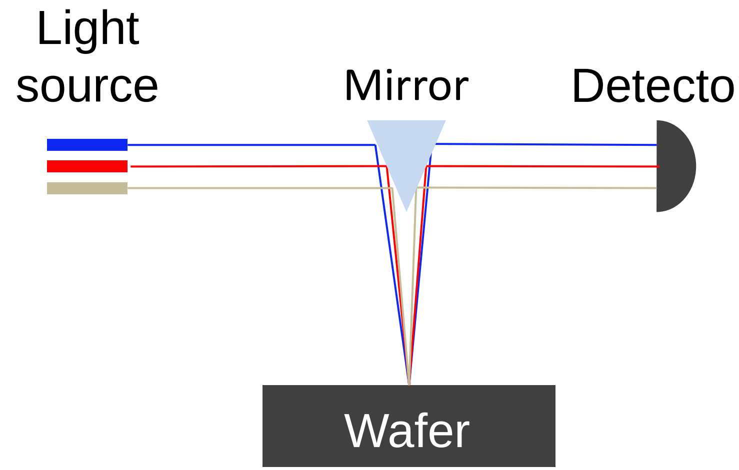
In-situ monitoring of DBR growth

Curvature

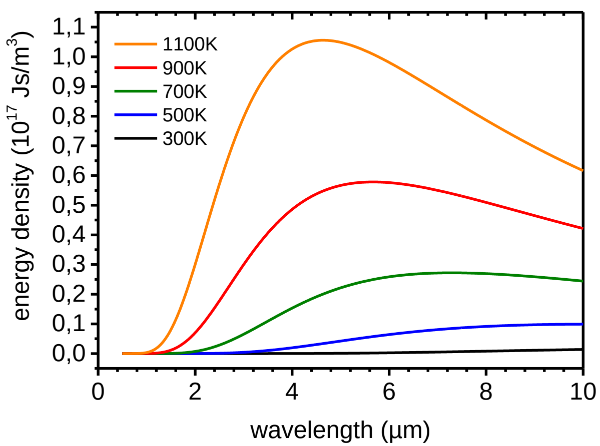


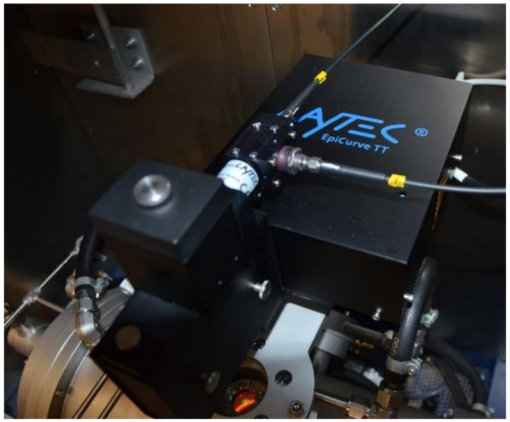
Reflectance at:

- 950 nm
- 633 nm
- 405 nm



True temperature





LayTec EpiCurve®TT AR

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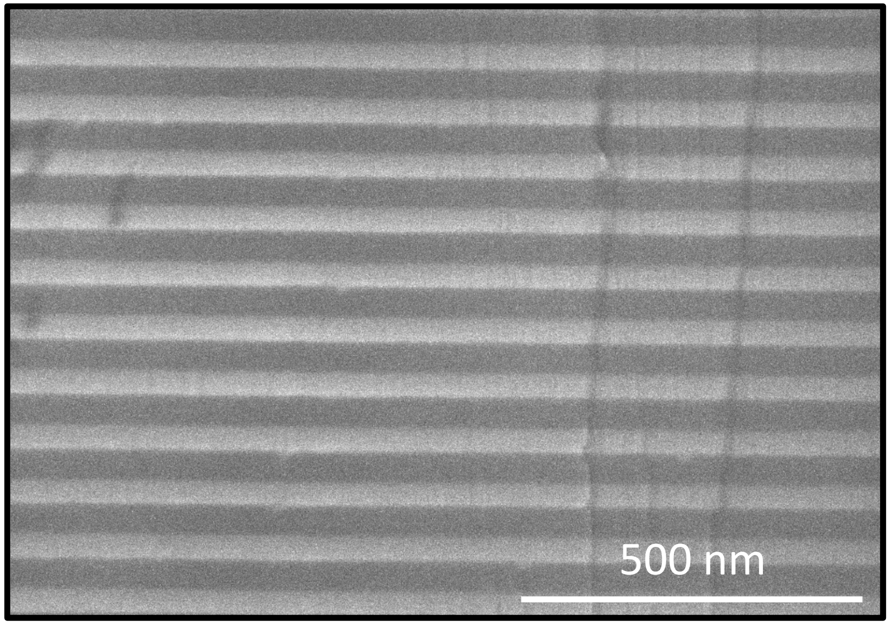
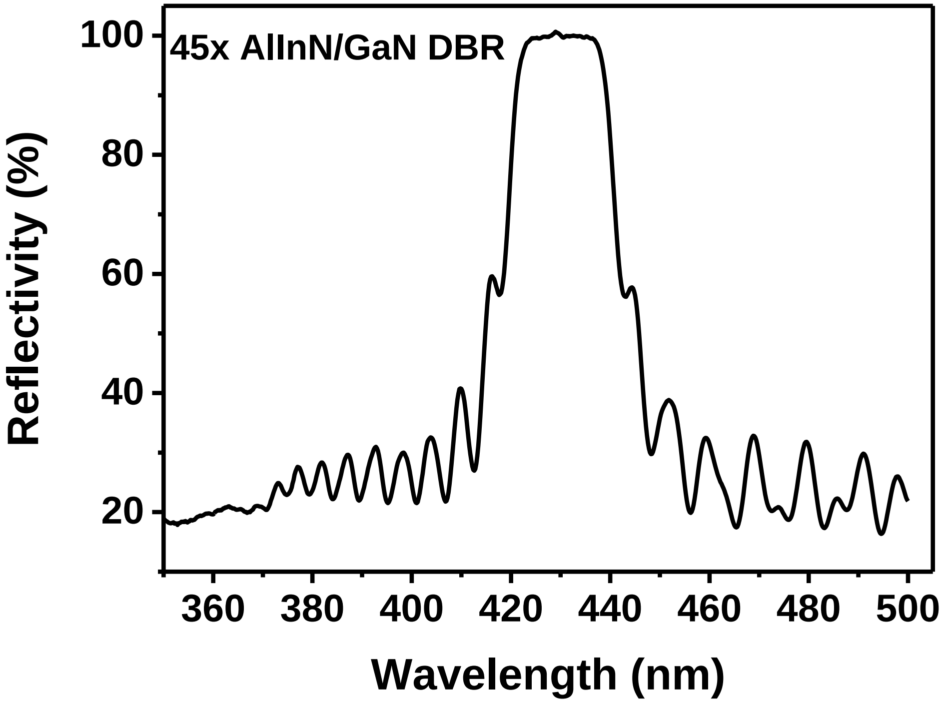
AlInN/GaN DBR

XSEM of AlInN/GaN DBR





- Lattice-matched growth on GaN for x_{In}~17%
- Δn/n~7.5 %, bandwidth > 20 nm
- Maximum reflectivity values above 99 % possible

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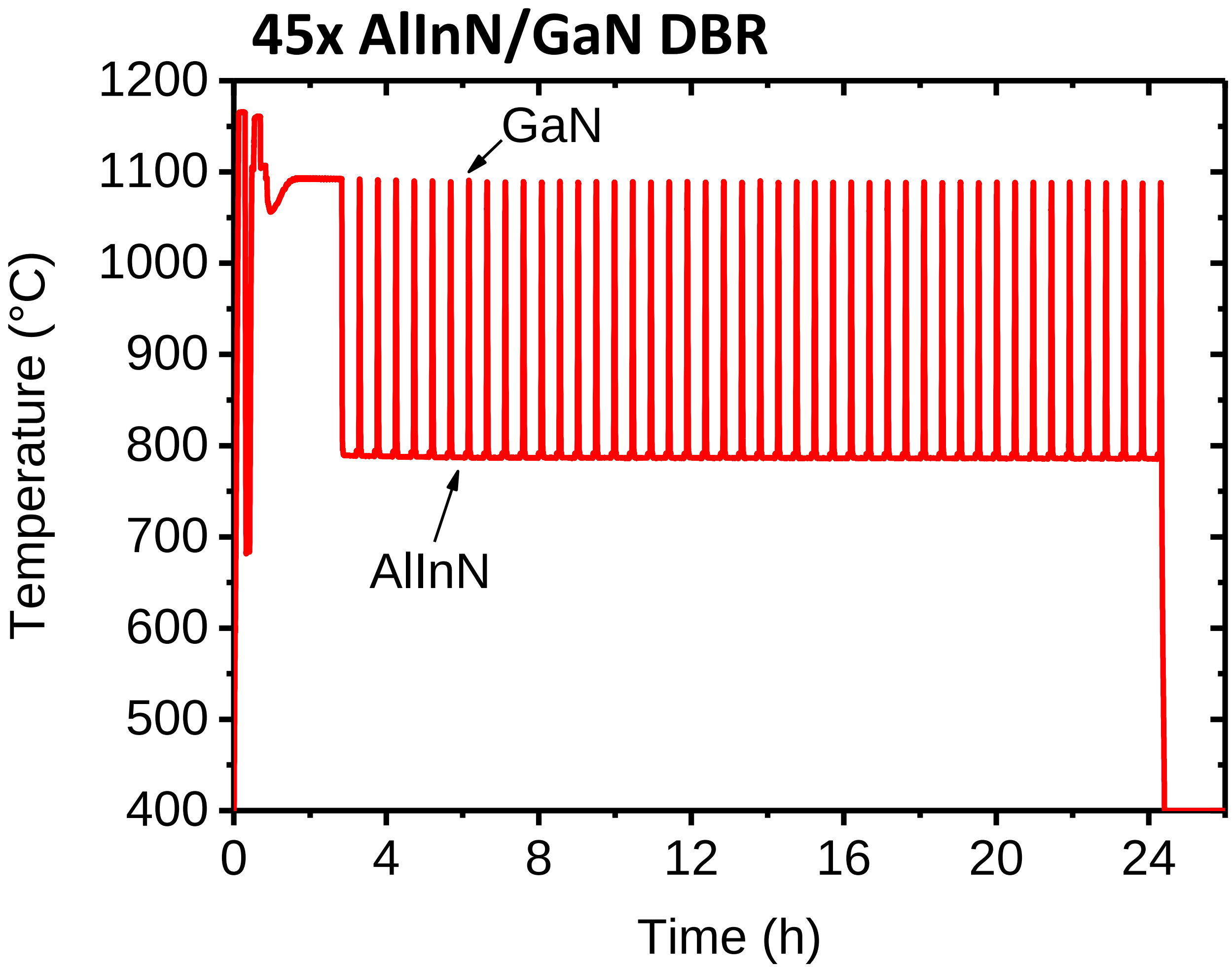
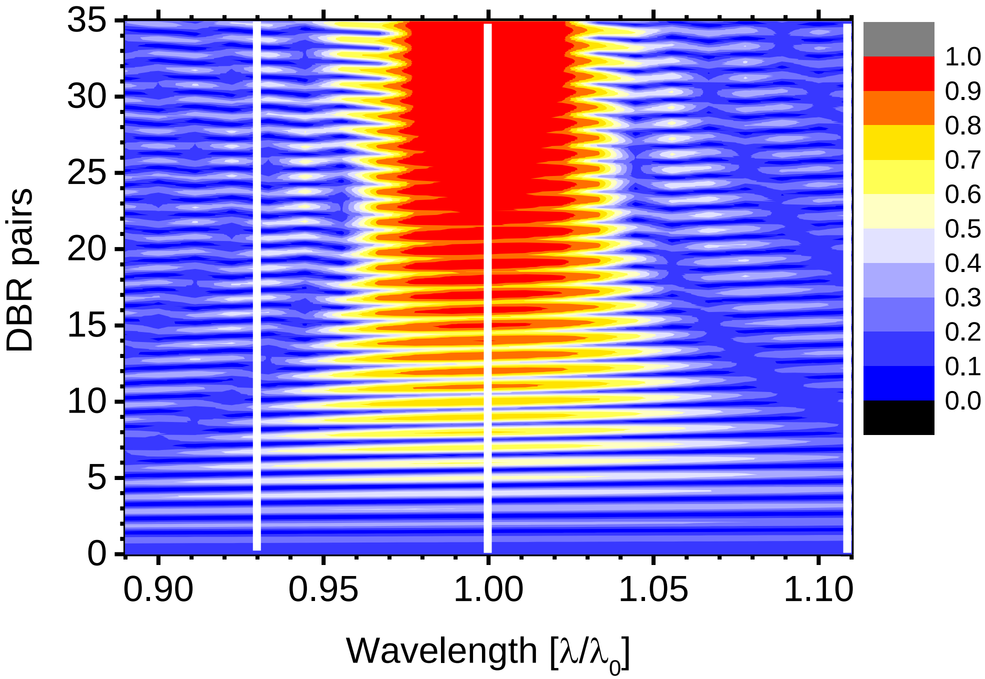
Mismatch of optimum growth window



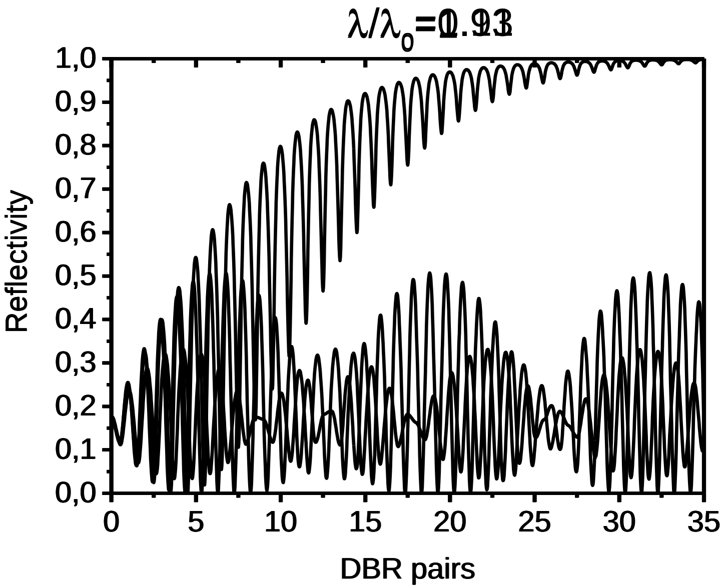
- Steep temperature ramps required
- Very long growth times

Evolution of DBR reflectivity

Spectral evolution

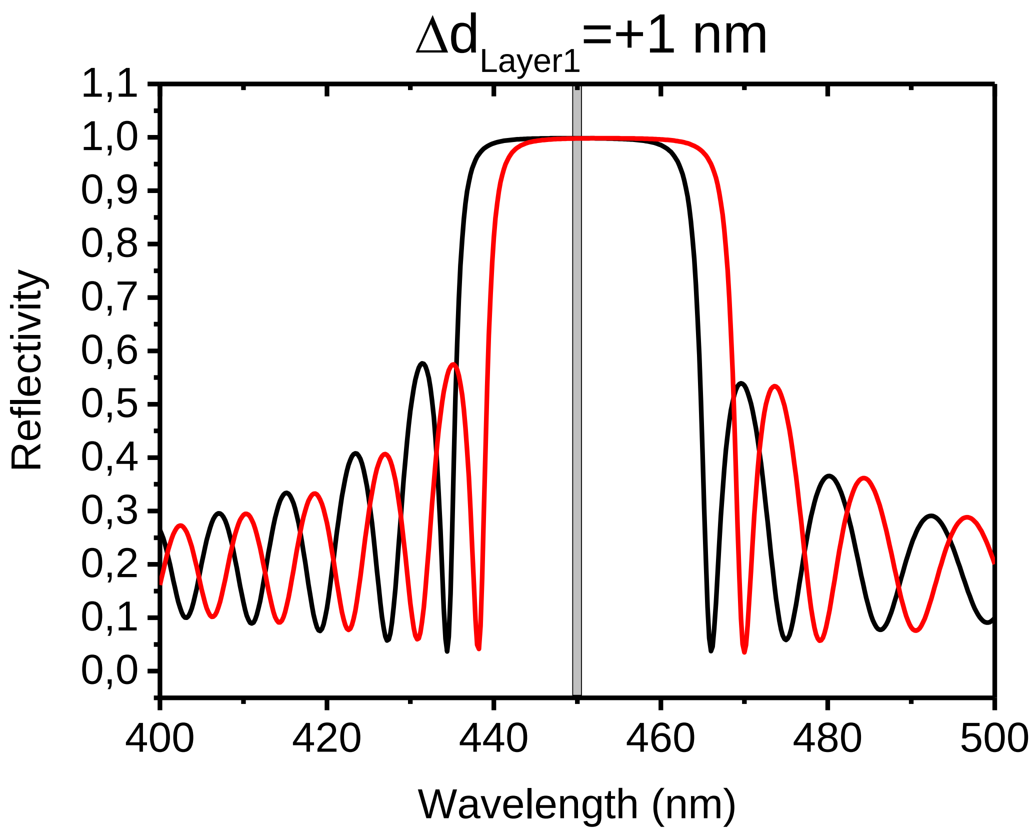


Single transients



- ➢ Characteristic pattern at each wavelength

Prediction of stopband position



Weak sensitivity within stopband

Faster dynamics away from stopband

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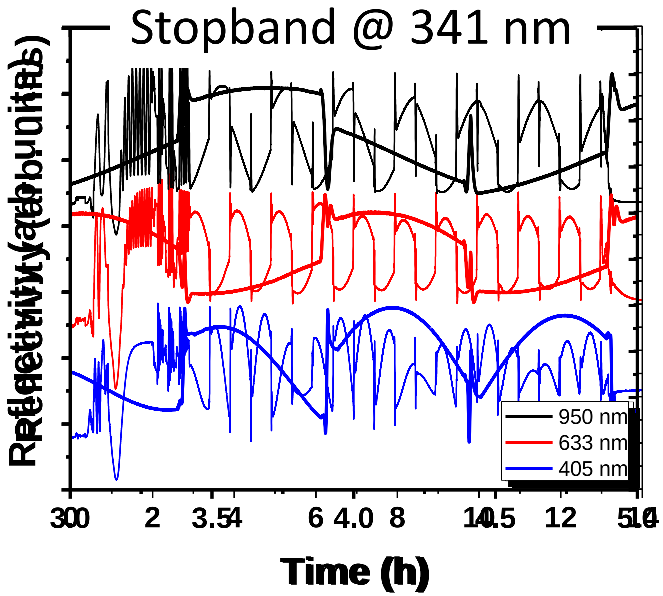
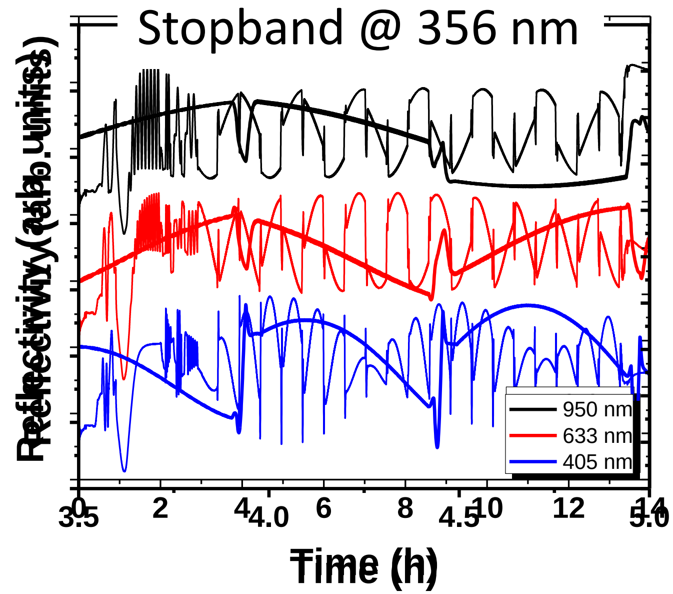
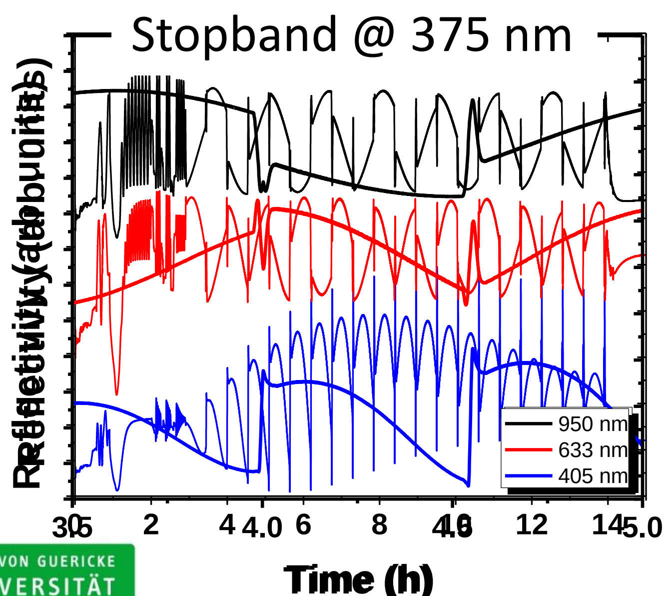
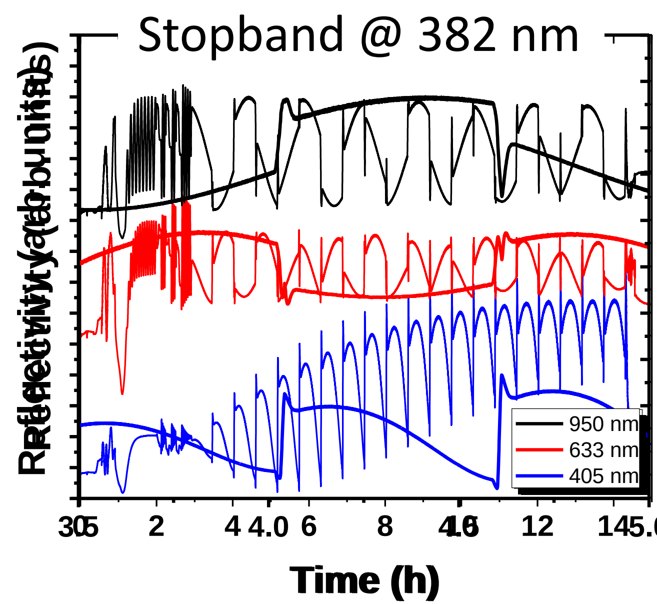
Experimental









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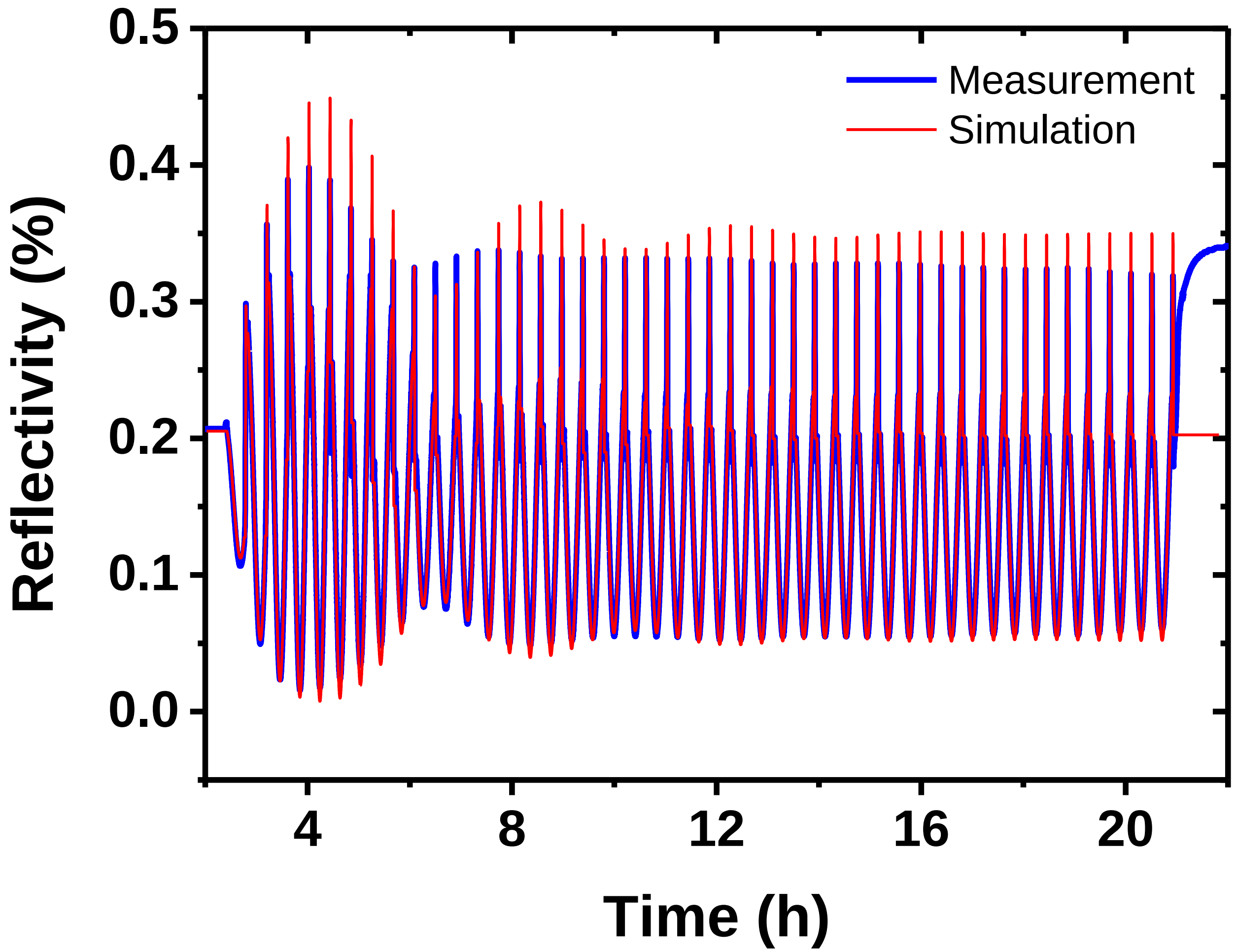
Simulation of full DBR growth



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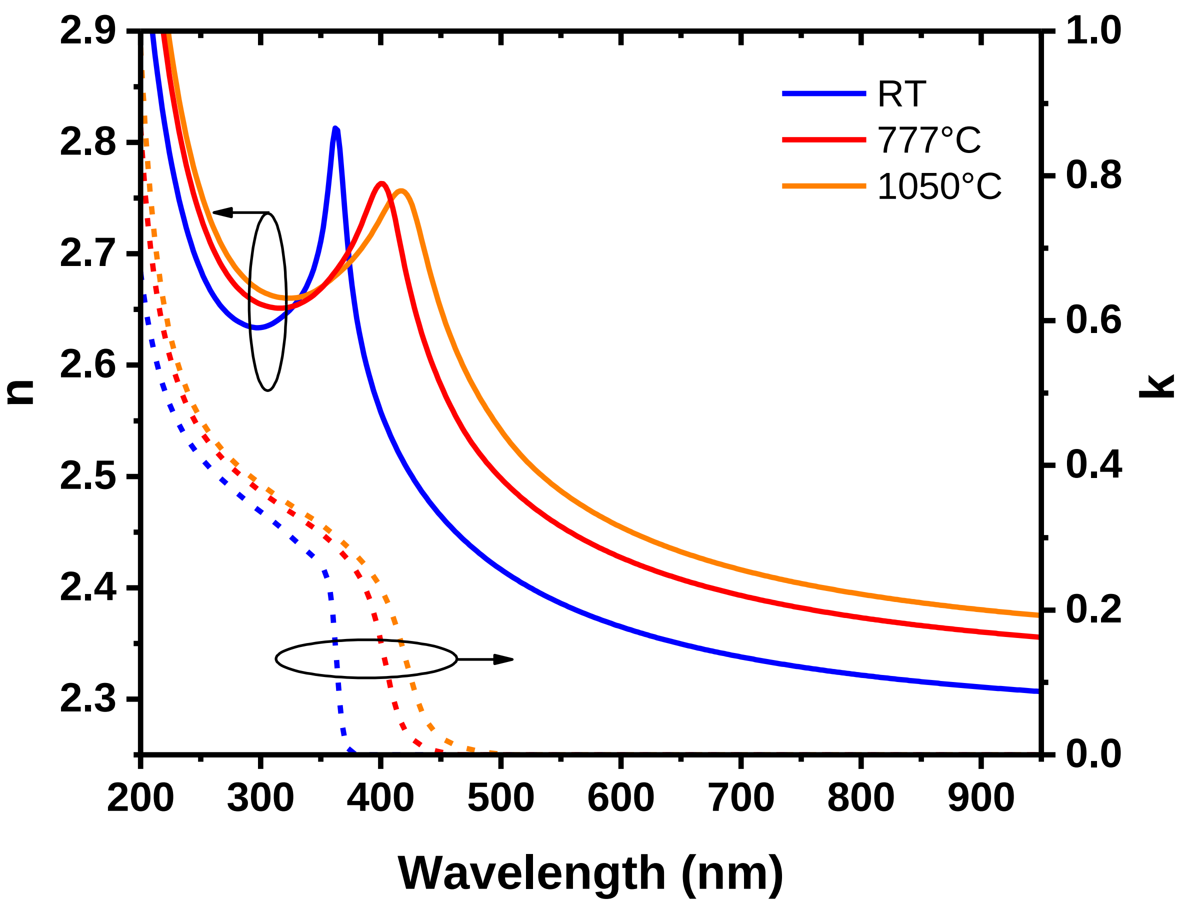
GaN - refractive index at high temperatures



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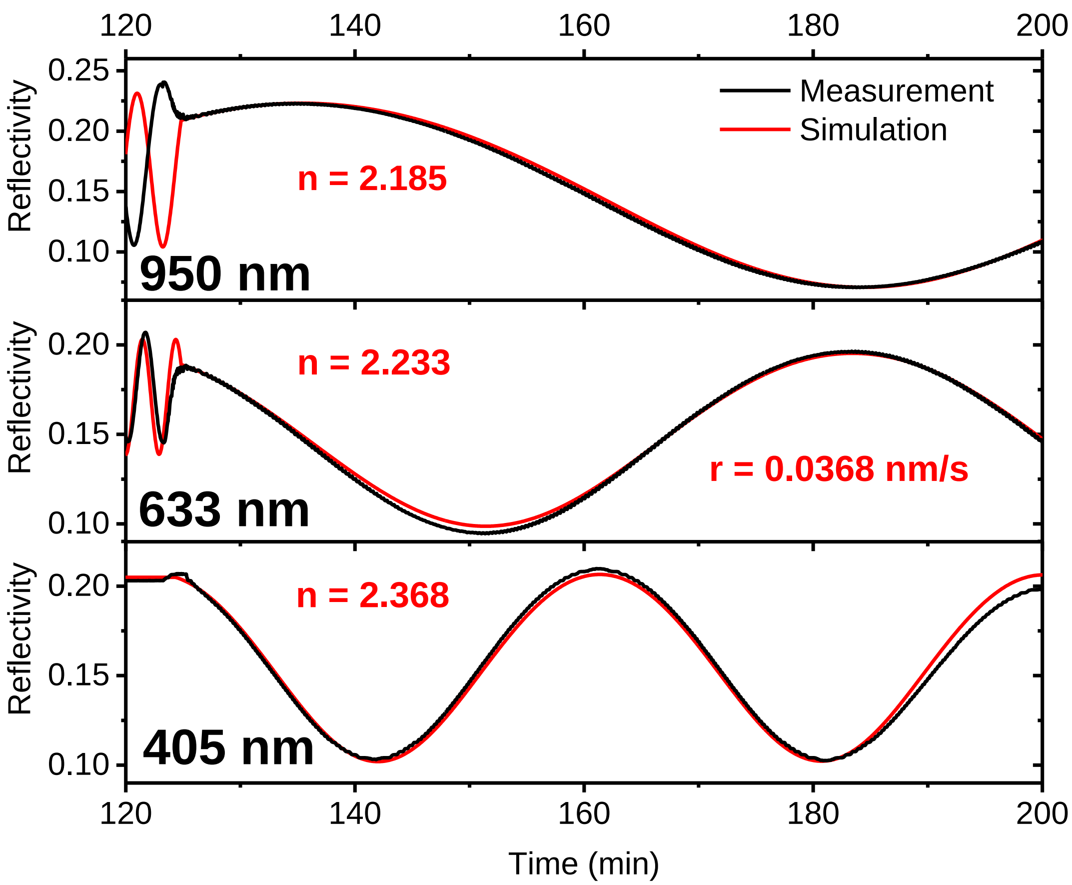
Refractive index of AlInN – in-situ



- ➢ Refractive index fitted using LayTec EpiNet simulation tool.

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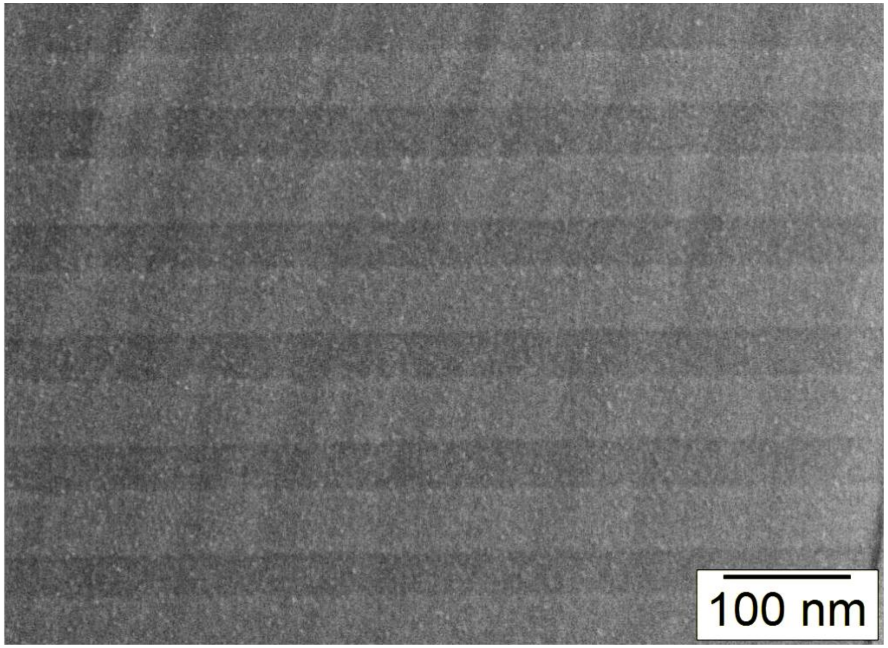
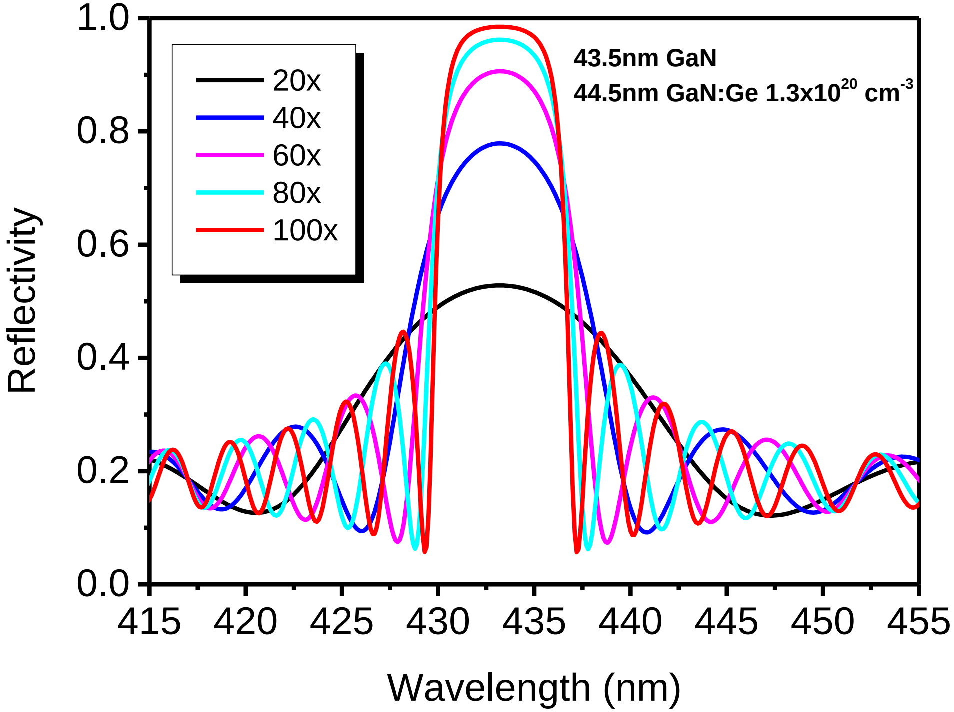
GaN:Ge/GaN DBR

XSEM of GaN:Ge/GaN DBR



Simulation



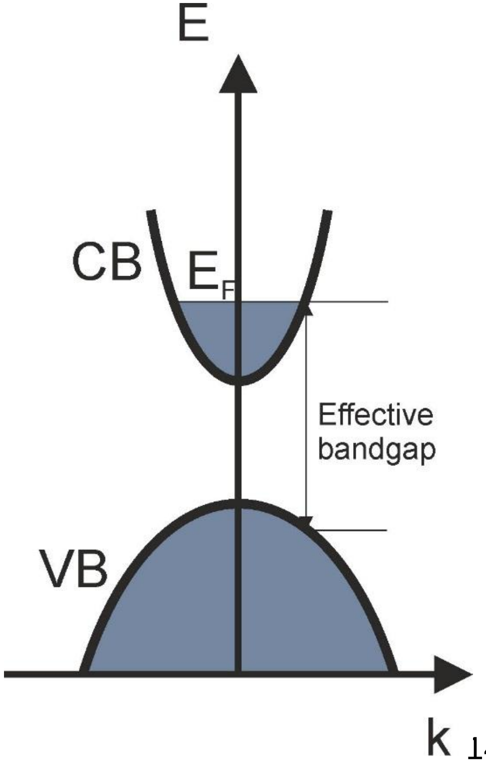
- DBR structure by Ge doping of GaN (strain-free growth)
- $\Delta n/n \sim 2.0$ %, bandwidth ~5 nm
- Narrow-band reflector

Homoepitaxial DBR mirrors

Refractive index change by doping

- Burstein-Moss-effect
  - Blue shift of absorption edge with free carrier concentration
  - Change of refractive index

E. Burstein, Phys. Rev. 93, 632 (1954)
T. S. Moss, Proc. Phys. Soc. B 67, 775 (1954)



- Strain-free, conductive layers
- Similar growth conditions

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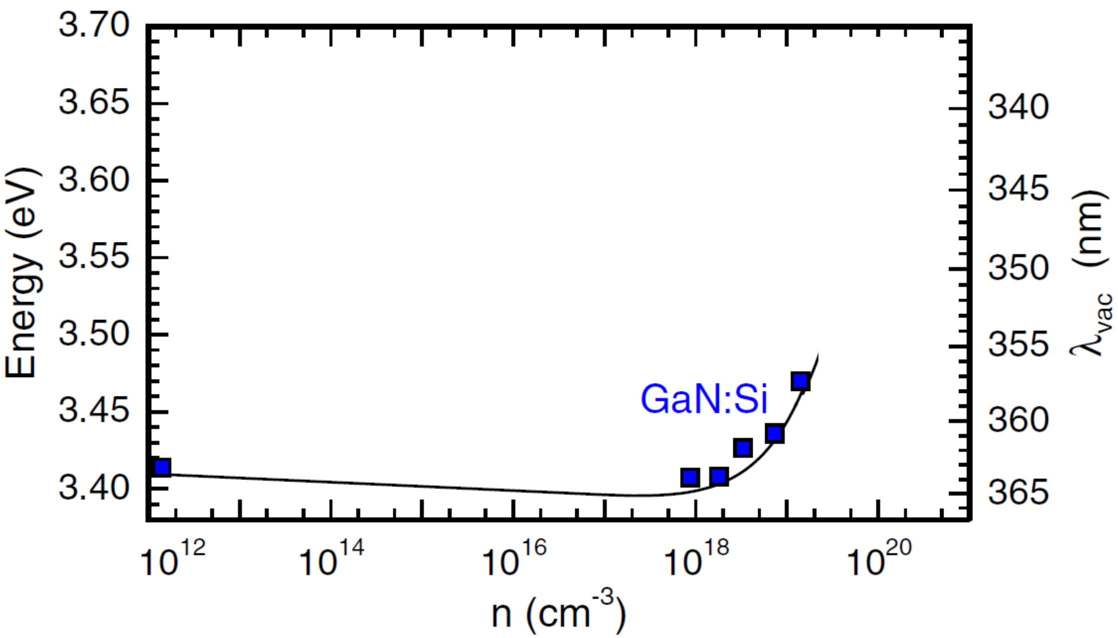
Bandgap shift of n-doped GaN

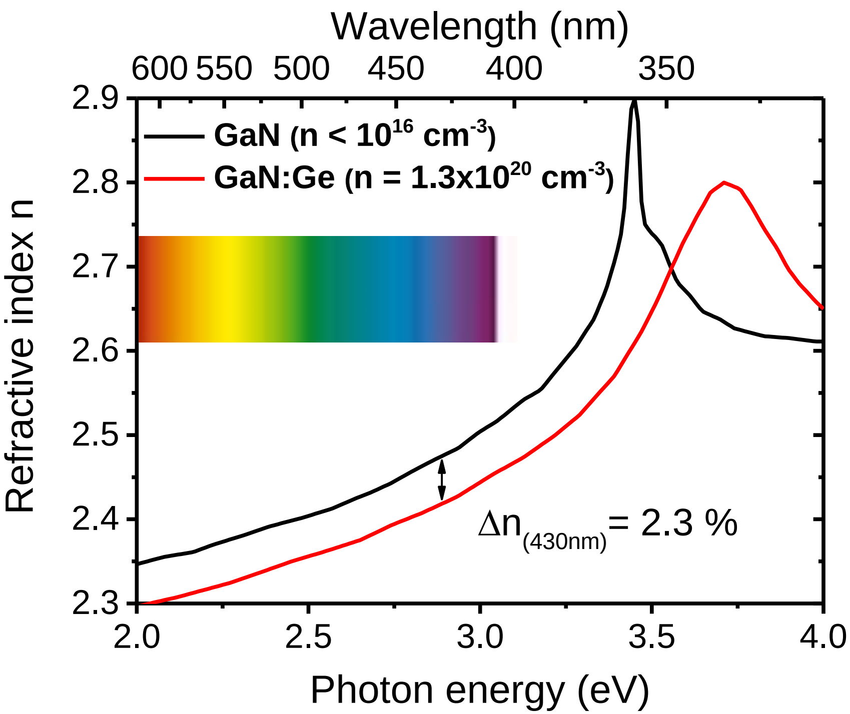
Change of the excitonic transition energy

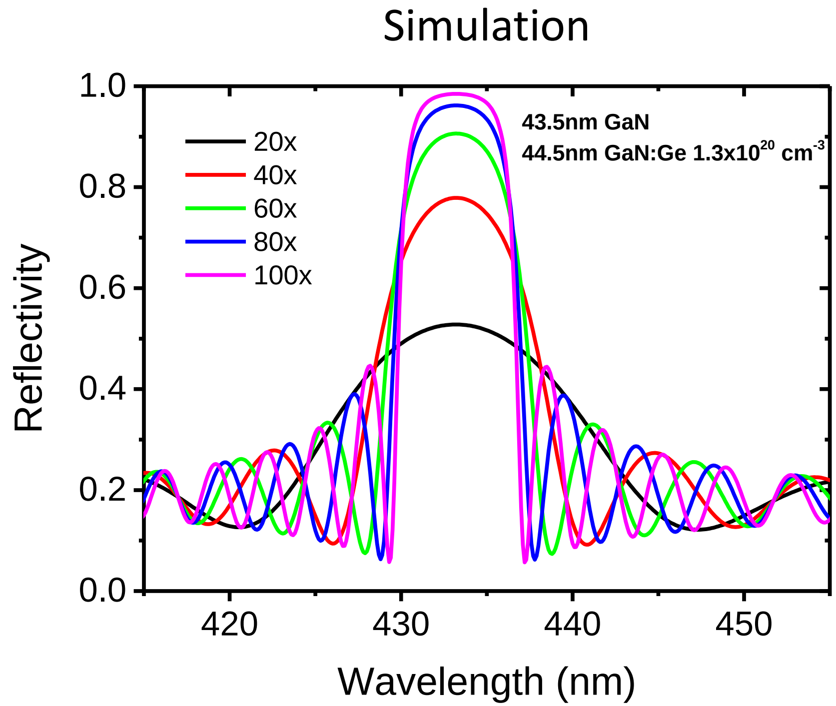
- Bandgap renormalization
- Burstein-Moss-shift



M. Feneberg et al., Phys. Rev. B 90, 075203 (2014)

- Significant (ΔE_g>250 meV) bandgap shift for [n]~10^{20} cm^{-3}.
- Ge-doping superior over Si-doping in MOVPE.





- >2% refractive index change across visible spectrum
- R>90% for 60 layer pairs

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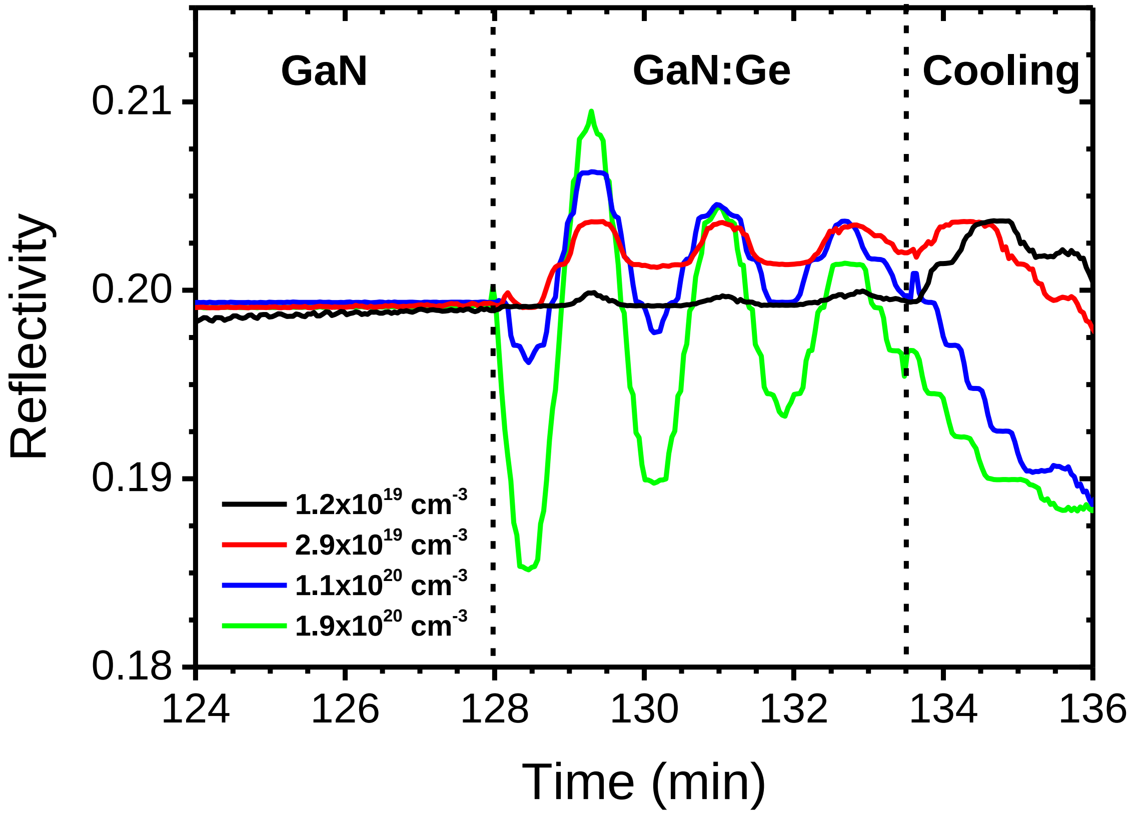
In-situ calibration of doping level

In-situ reflectivity @ λ=405 nm



- Increase of refractive index contrast with doping concentration
- Oscillation amplitude probes free carrier concentration

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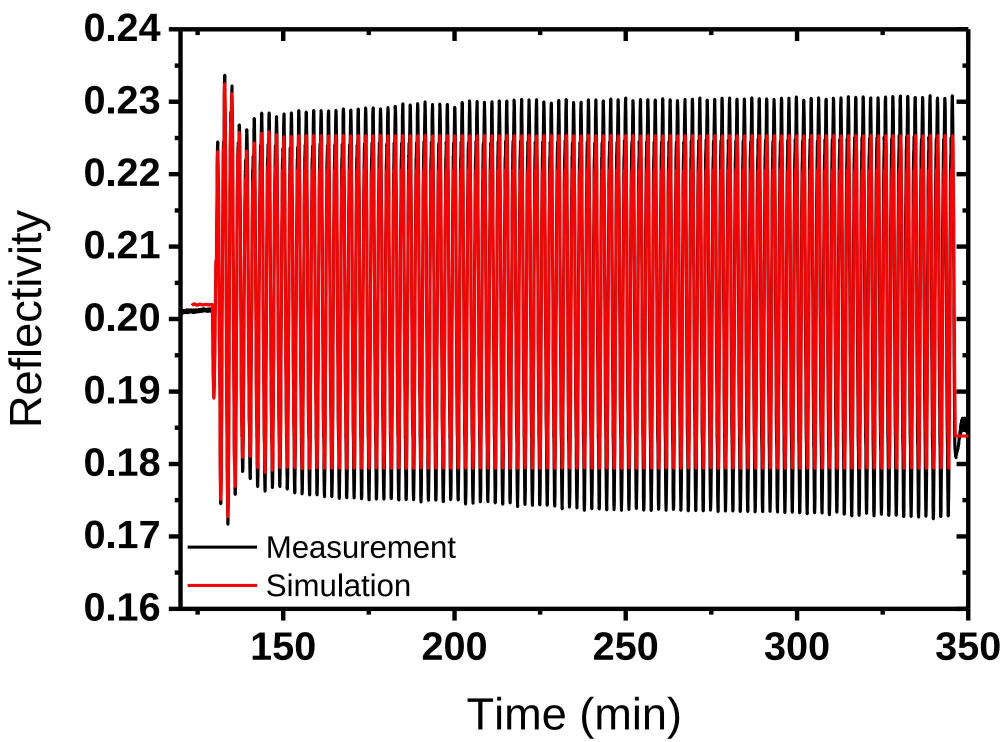
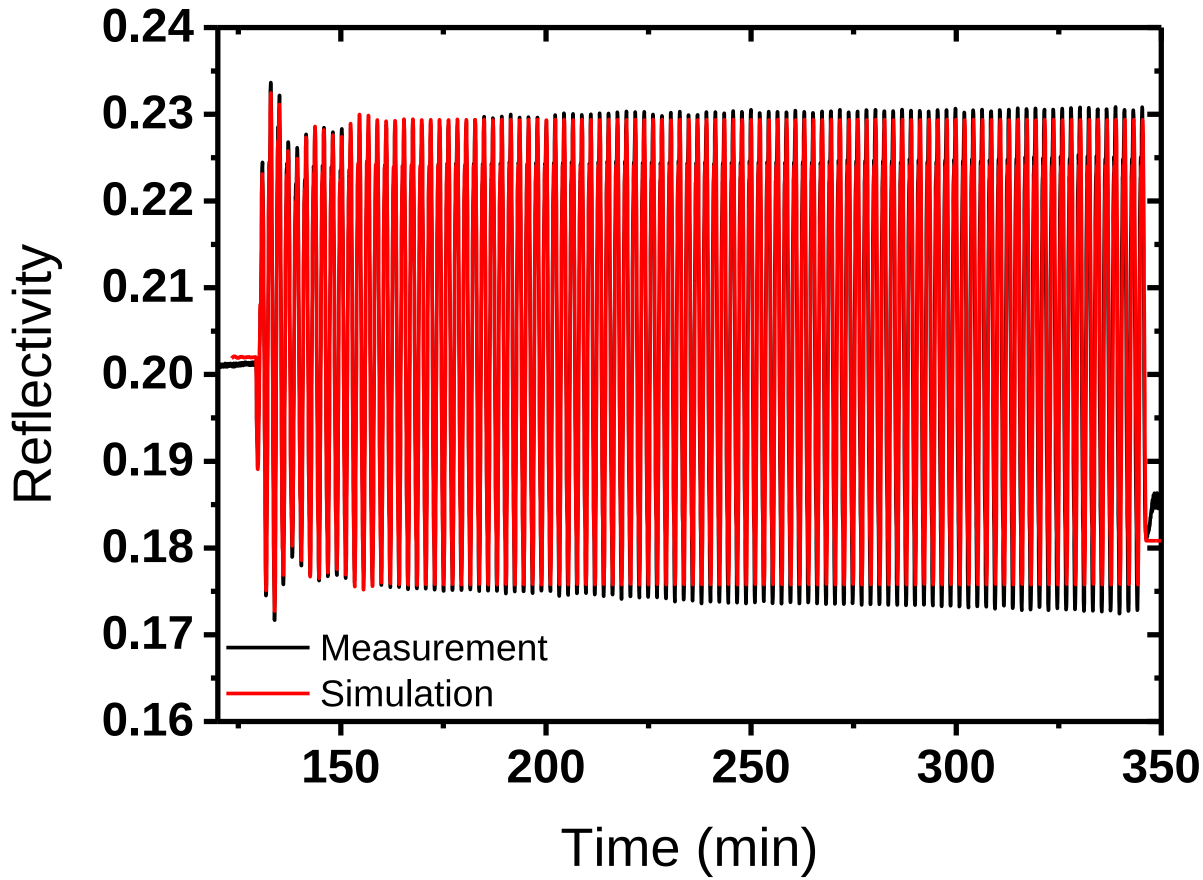
Drift of Ge incorporation



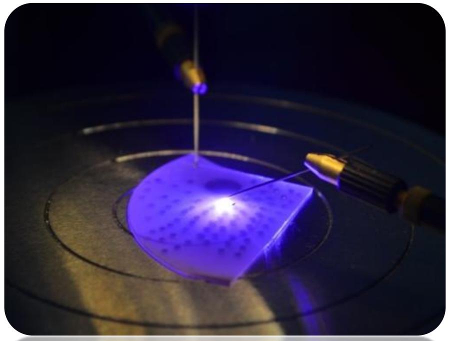
- Strong initial change within 10-15 min
- Long-term drift over hours

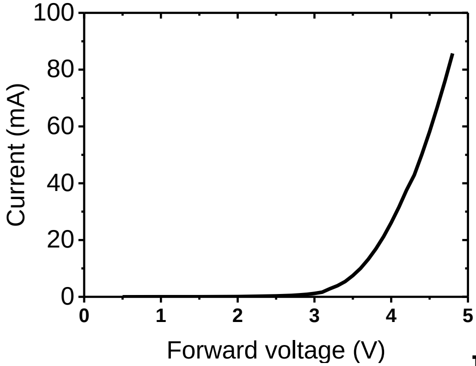
Improved modelling

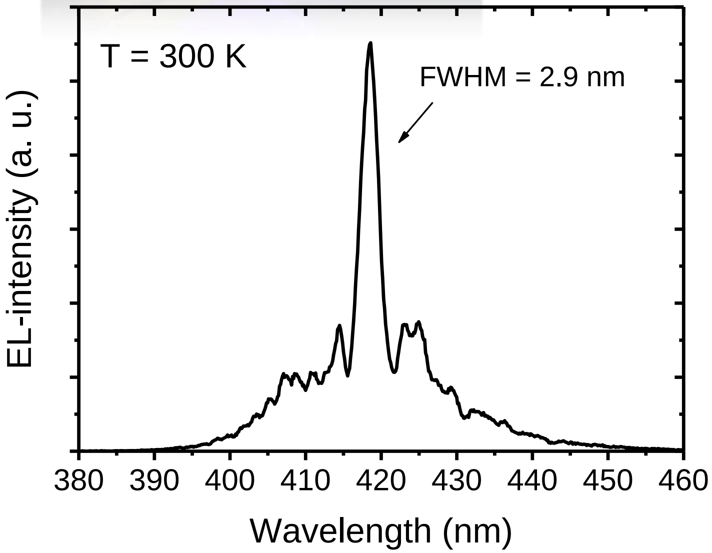


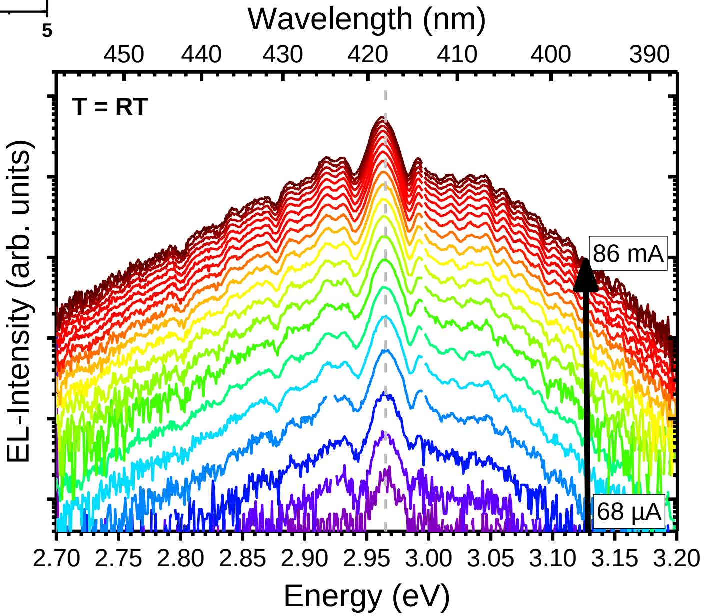
- Adjustment of GaN:Ge n-k values with increasing growth time

LED with GaN/GaN:Ge DBR









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Summary

- In-situ metrology for growth of lattice-matched AlInN/GaN and GaN:Ge/GaN DBRs
- Reflectivity oscillations as sensitive fingerprint of DBR stopband position
- Strength of amplitude oscillations proportional to Ge doping level
- High-temperature n,k-database for GaN as basis for in-situ analysis of AlInN and GaN:Ge

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