Growth of Group-III nitrides by MOCVD

Virtual Reactor Nitride Edition

Modeling approach

Input parameters:

- Reactor geometry
- Operating temperature and pressure
- Gas flow rates

Available precursor gases:

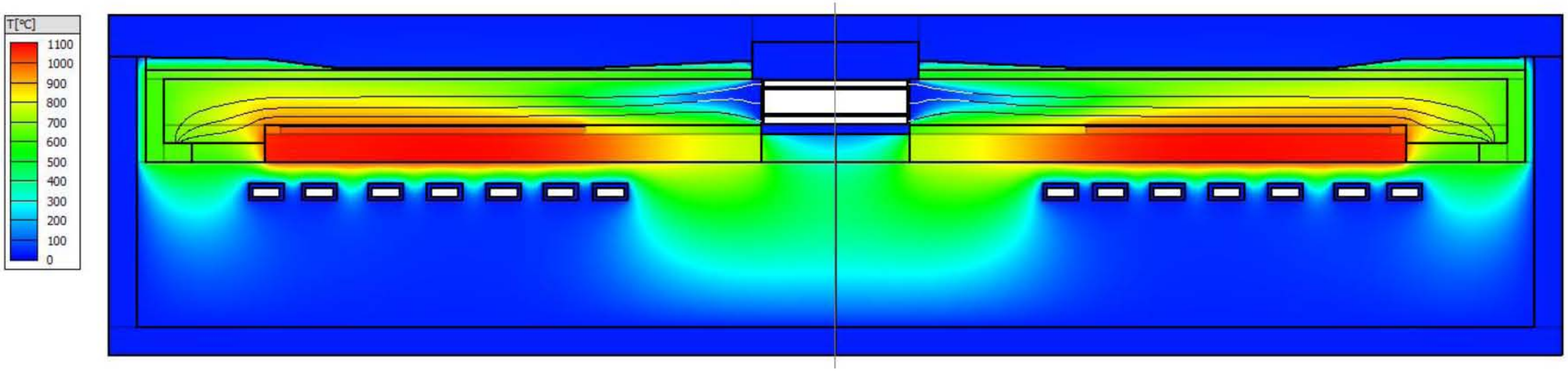
- MO source: TMGa, TEGa, TMAl, TMIn
- Carrier gas: NH_3, N_2, H_2
- Dopant source: SiH_4, $MgCp_2$

Modeling of MOCVD growth of the following materials:

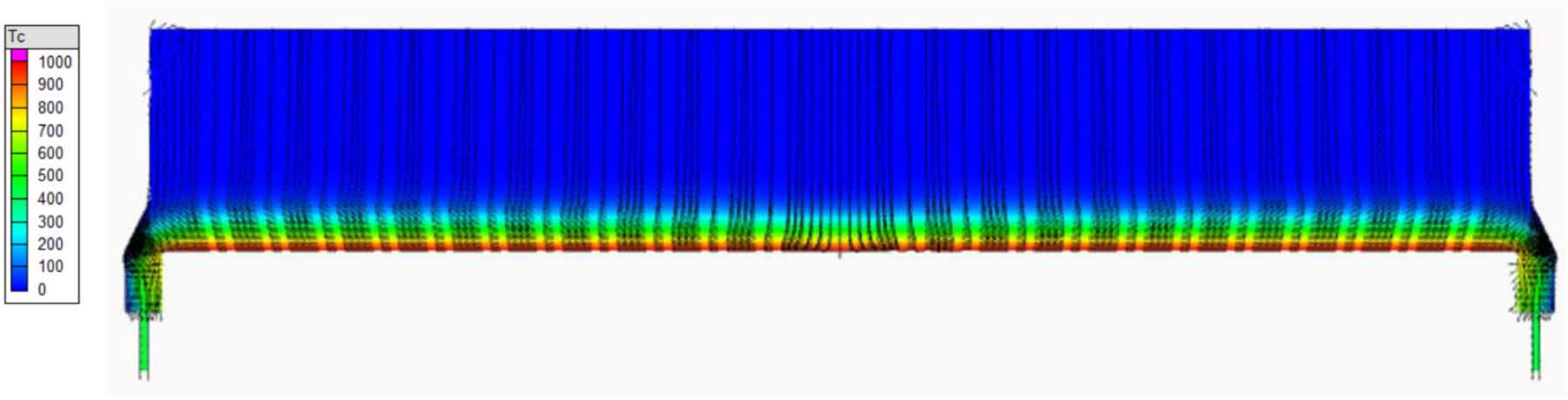
- GaN
- AlN
- AlGaN
- InGaN
- InAlN

Reactor geometry and temperature

Planetary reactor



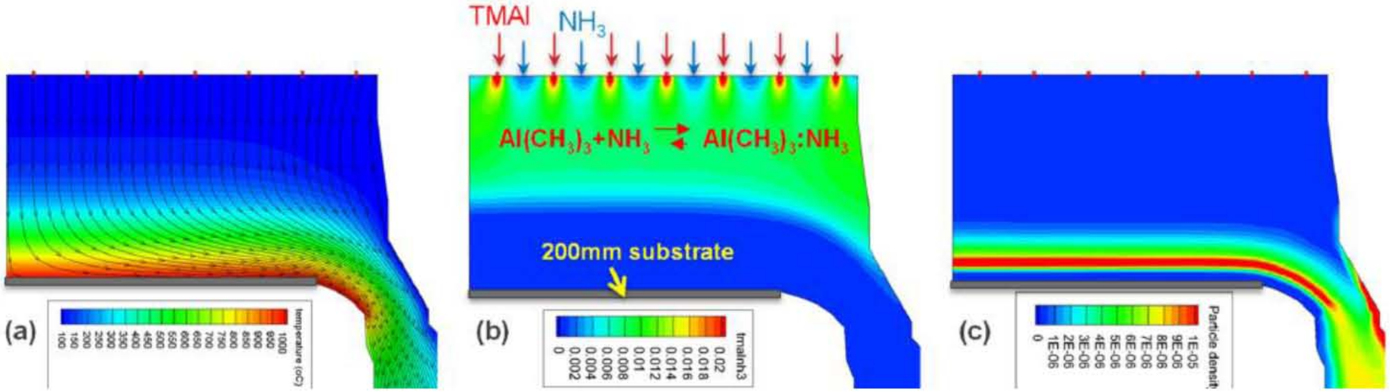
Rotating disk reactor



Growth of the AlGaN/GaN HEMT Structure in Veeco's Propel™ reactor

Process Condition Optimization for High Throughput and High Efficiency Growth of the AlGaN/GaN HEMT Structure in a Single Wafer Rotating Disc MOCVD Reactor

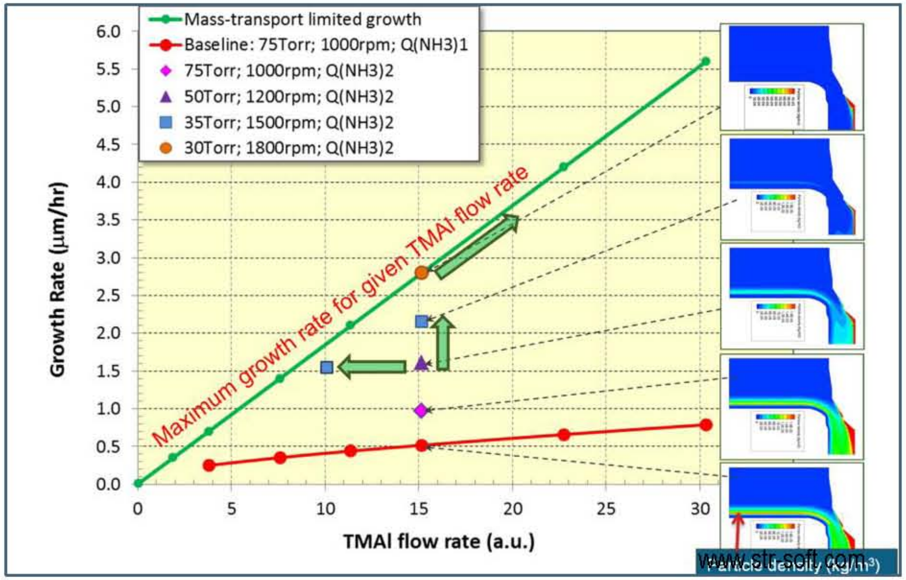
B. Mitrovic*, R Bubber, J. Su, E. Marcelo, M. Deshpande, and A. Paranjpe



Optimization of the process conditions allows elimination of parasitic reactions

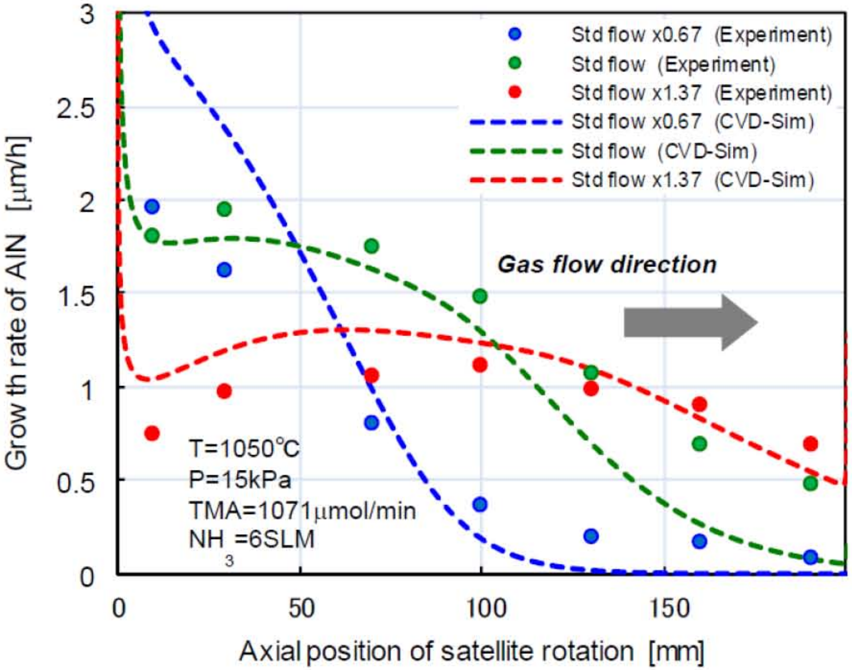
Contours based on CFD and chemistry modeling: (a) Temperature and streamlines, (b) adducts (TMAl:NH3) mass fraction, (c) particle density (kg/m3)

Significant improvement in process time (~50%) and source efficiency is achieved during AlN/AlGaN superlattice HEMT structure growth on 200mm Si substrate while maintaining the desired material quality

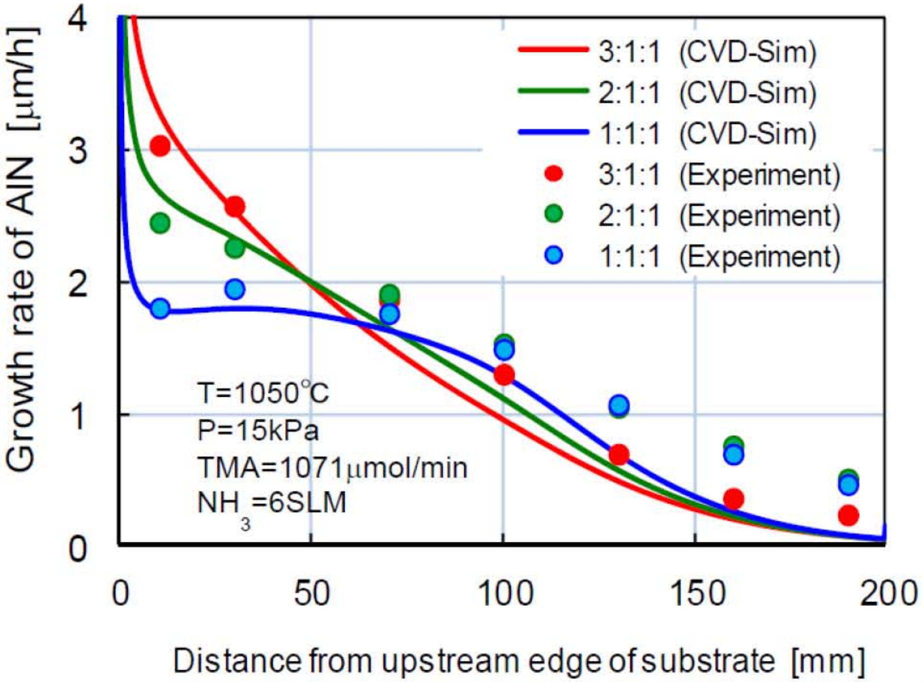


AlN growth in 6x8" Taiyo Nippon Sanso UR 26K reactor

Growth rate vs total flow



Growth rate as a function of the carrier



Modeling allows control of AlN growth rate value and growth rate uniformity over the 8" wafer

TAIYO NIPPON SANSO

Data: A. Ubukata et al., Phys. Status Solidi C 1-4 (2013)

Ioffe Institute

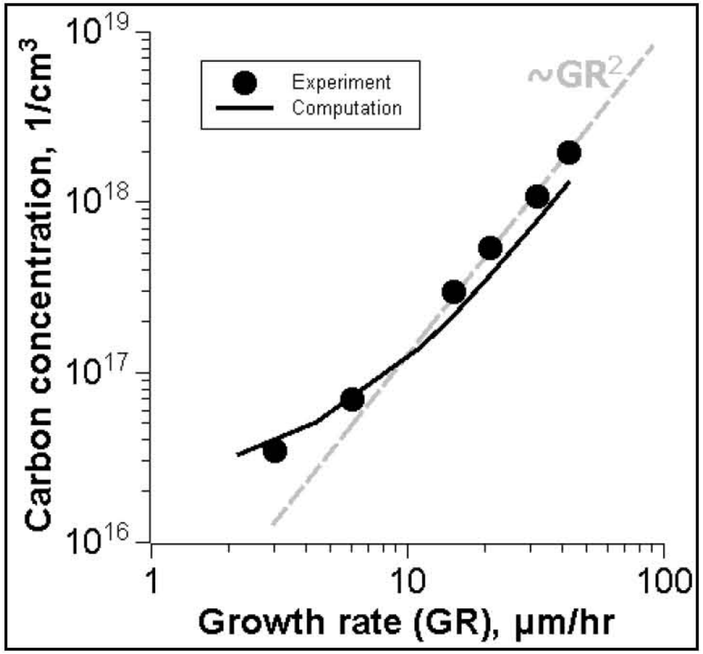
Carbon incorporation in GaN

Carbon is the impurity commonly used for fabrication of high-resistance GaN buffer layers in high power electronic devices. On the other hand, carbon in GaN is undesirable in some applications.

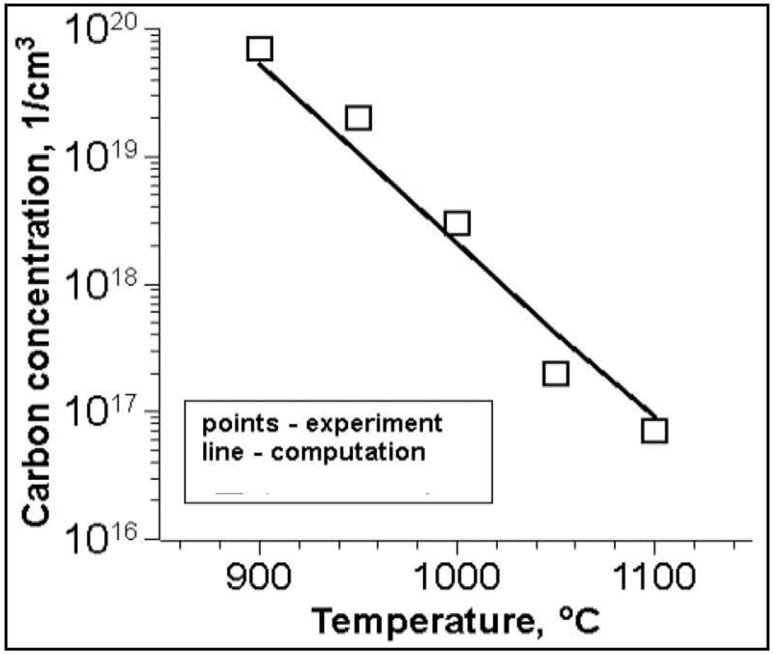
The rate of carbon incorporation depends on many factors and has to be controlled accurately.

Data: W. Lundin et al, ICMOVPE-2018

Effect of growth rate



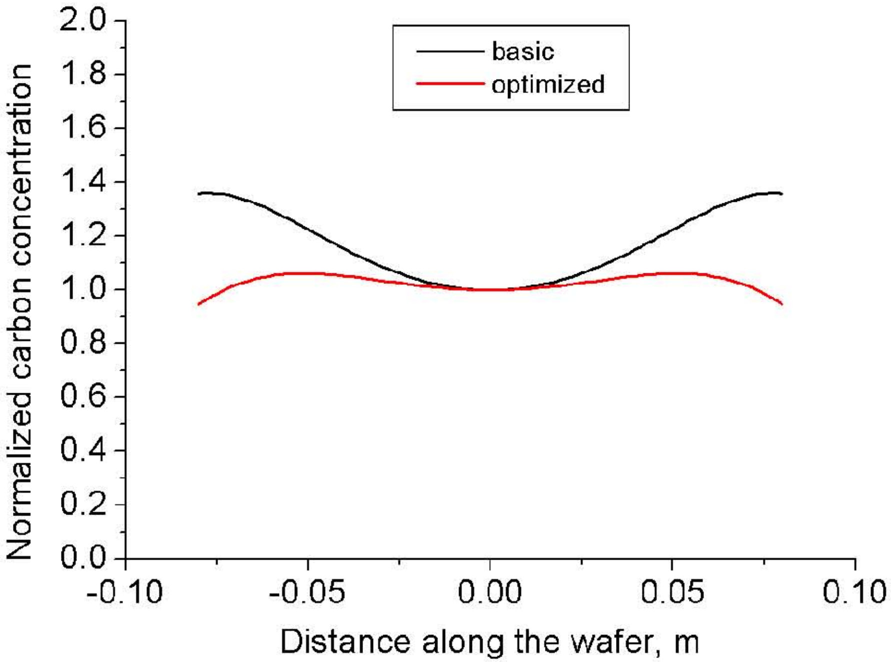
Effect of temperature



Optimization of Carbon in 8” GaN growth

- Carbon incorporation rate depends on many parameters
- It is very difficult to achieve good carbon uniformity for large-diameter wafers
- Advanced optimization of growth recipe is necessary

Carbon concentration



Simulations allows to find the growth conditions providing appropriate carbon concentration in the growing GaN layer and uniform carbon concentration over the surface of 8” wafer

Stress and dislocation behavior and wafer bowing in GaN growth on Silicon

STREEM-AlGaN software

Modeling approach

Input parameters:

- Type of the reactor
- Thickness and diameter od the substrate
- Properties of each layer in the stack: composition, doping, thickness
- Growth conditions

STREEM predictions:

- Curvature evolution of curvature at the stages of heating, growth, and cooling
- Stress relaxation and dislocation dynamics
- Crack formation during the growth and after cooling of the structure
- Influence of the process parameters on the through-wafer temperature drop and its contribution to the structure bow
- Stress state in the particular layers via processing of in-situ curvature data

GaN-on-Si based HEMT epi-wafers with AlN/AlGaN superlattice buffer, grown in production-scale reactor

SiN passivation

AlGaN barrier

u-GaN

C:GaN

SLS AlN/$Al_{0.1}$GaN
103 periods

AlGaN

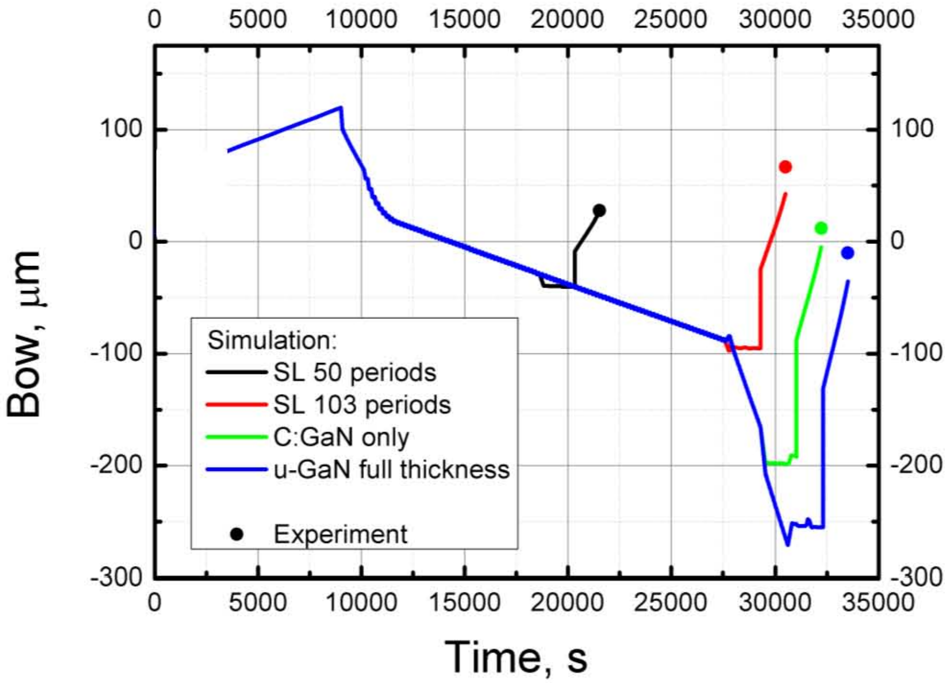
AlN

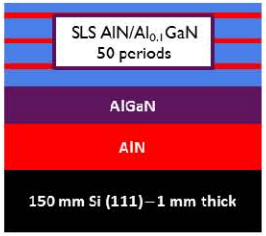
Si (111)

- ✓ GaN-on-Si based HEMT epi-wafers, grown in production-scale reactor
- ✓ AlN/AlGaN superlattice buffer

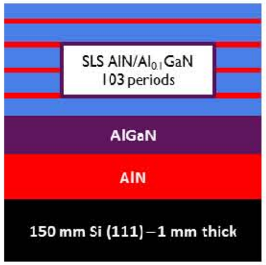
Japanese Journal of Applied Physics 58, SCCD26 (2019)

Stop-growth experiments

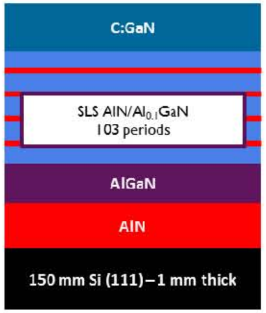




SL 50 periods



SL 103 periods



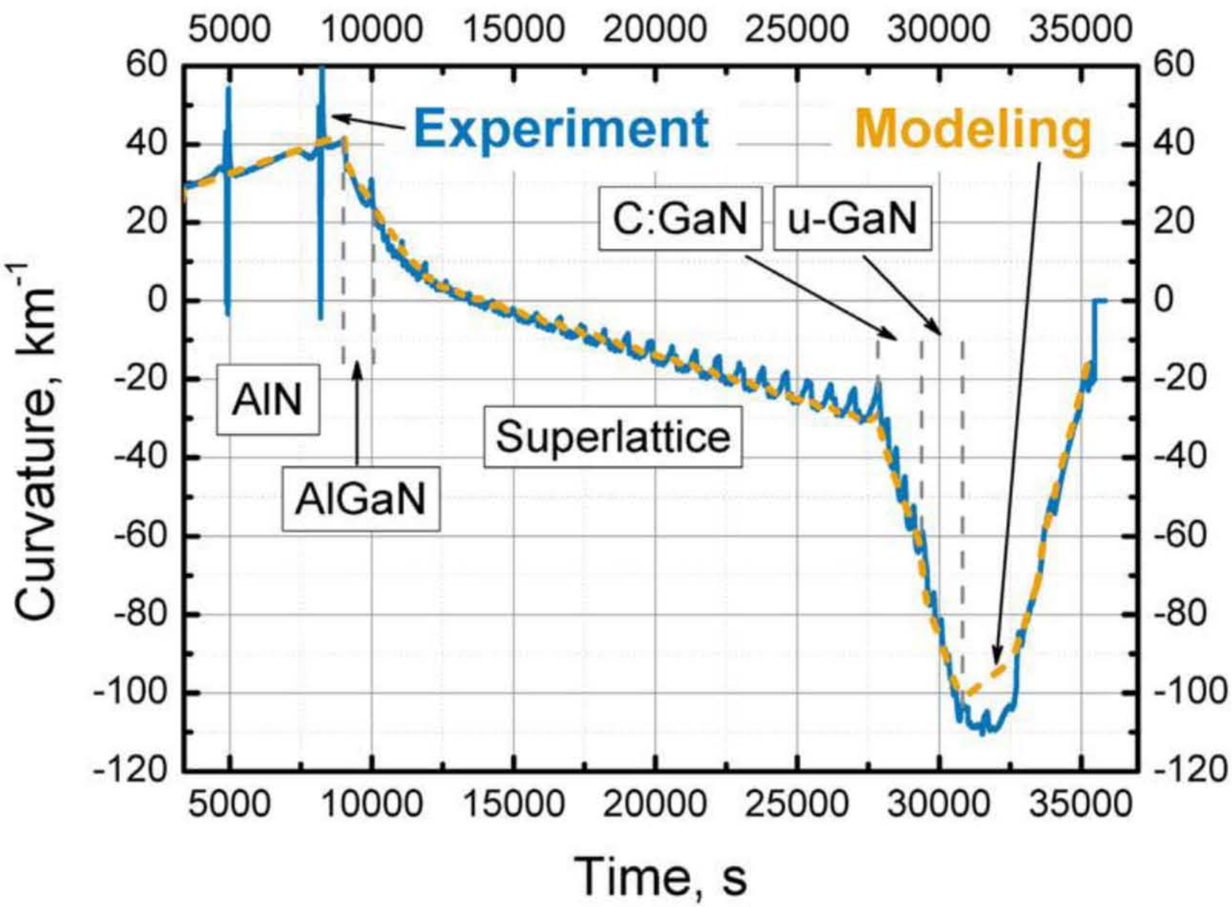
C:GaN only

u-GaN full thickness

Modeling reproduces stop-growth experiments designed to evaluate the effect of individual buffer parts on RT bow:

- **RT bow is predicted for various thickness and composition of the stack**
- **Plastic relaxation in silicon wafer is not expected**

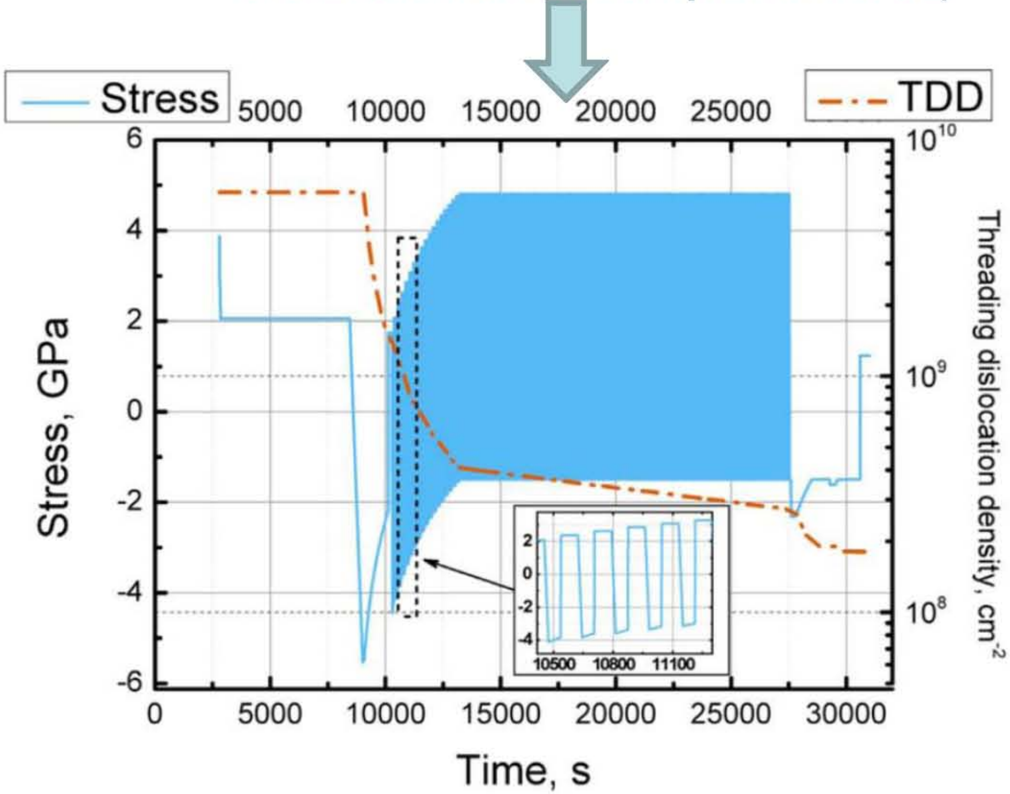
Curvature evolution



- **Adjustment of the recipe provides almost zero curvature after cooling**
- **Linear variation of the curvature for the most part of the SL: weakly changing averaged stress**

Analysis of the stress and TDD evolution in the SL

- Computed temporal variation of the stress and dislocation density (the inset shows the details of the stress evolution in the bottom part of the SL)



✓ AlGaN/AlN superlattice is effective in filtering the dislocations, whose density keeps reducing in the C:GaN and u-GaN layers grown on top of the SL with no nucleation of new dislocations

✓ Unintentional gallium incorporation into nominal AlN layers in the SL has been identified as a factor governing bow and stress evolution

✓ Proper design of the epitaxial structure and optimization of the process parameters provides final reduction of TDD down to about $2 \cdot 10^{8}$ cm^{-2} with the good structural uniformity over 6” wafers and a residual bow below 50 µm