Growth of $Al_xGa_{1-x}N$ Layers on GaN Substrates Using Halide Vapor Phase Epitaxy Technology: Road To Novel Nitride Substrates

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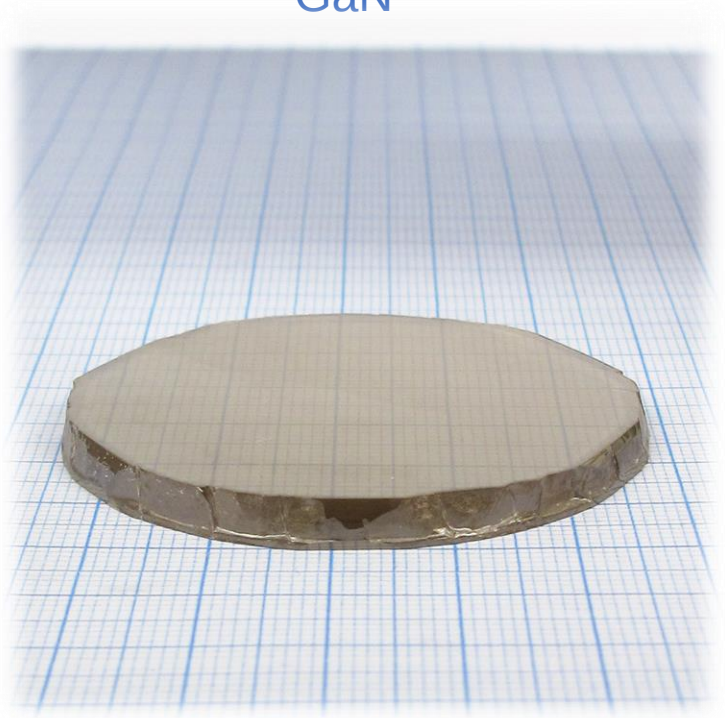
Outline

- **Introduction**
  - $Al_xGa_{1-x}N$ substrates & applications
  - Thermodynamics of $Al_xGa_{1-x}N$ growth
- **Experimental setup**
  - HVPE reactor configuration
- **Results**
  - Optimization of growth process parameters
  - Influence of misorientation
- **Summary**

Introduction

$Al_xGa_{1-x}N$ substrates

GaN



http://unipress.waw.pl/

Halide **V**apor **P**hase **E**pitaxy

Ammonothermal (Acidic/Basic)

Na-Flux

$Al_xGa_{1-x}N$

No free-standing $Al_xGa_{1-x}N$ crystal (yet)

AlN

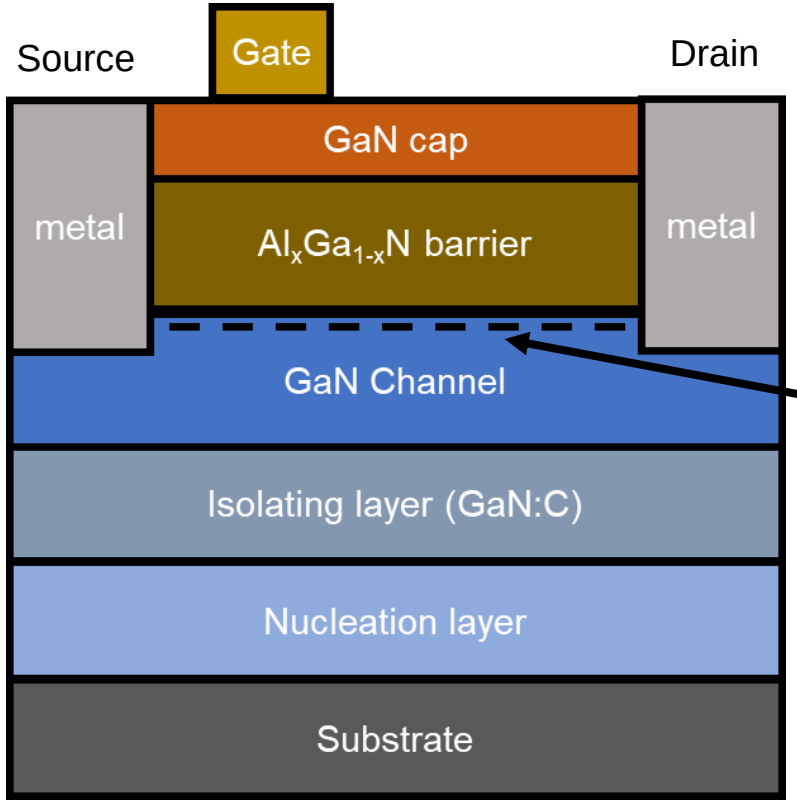
www.hexatechinc.com

Halide **V**apor **P**hase **E**pitaxy

Physical Vapor Transport

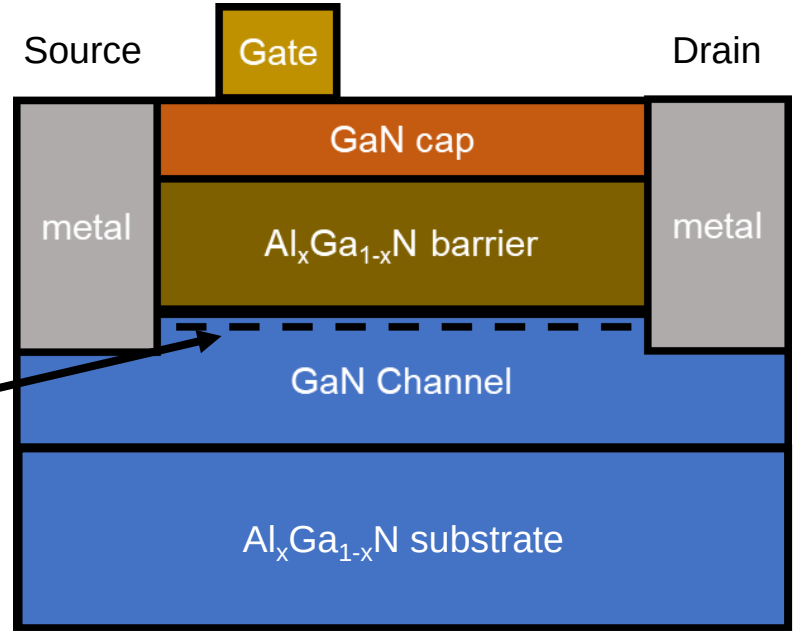
$Al_xGa_{1-x}N$ substrate applications

High Electron Mobility Transistors (HEMT)



Tirado et al., Semiconductor Science and Technology. 20. 864. (2005)

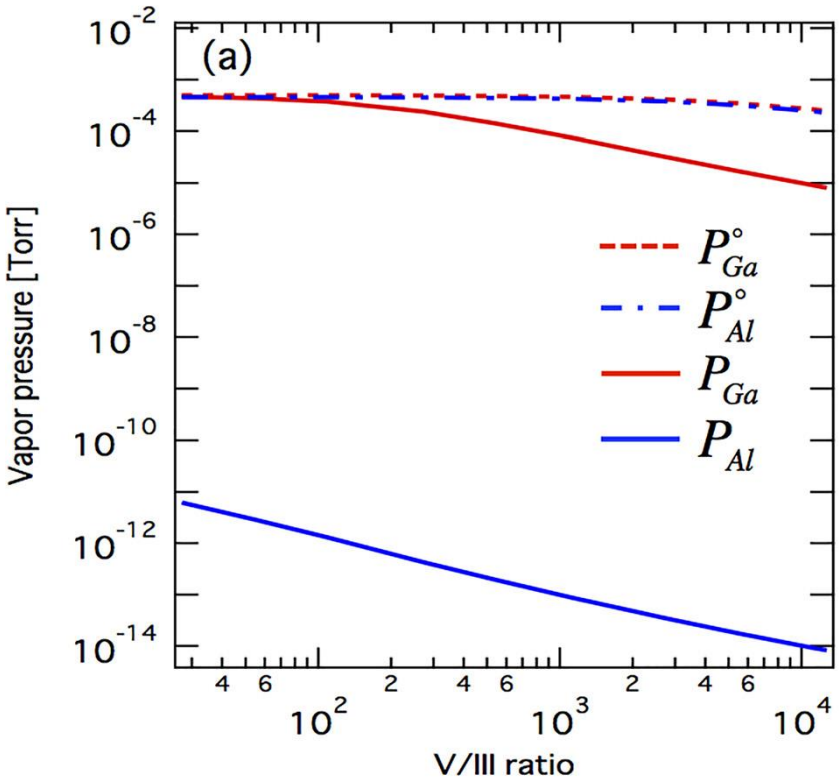
2DEG

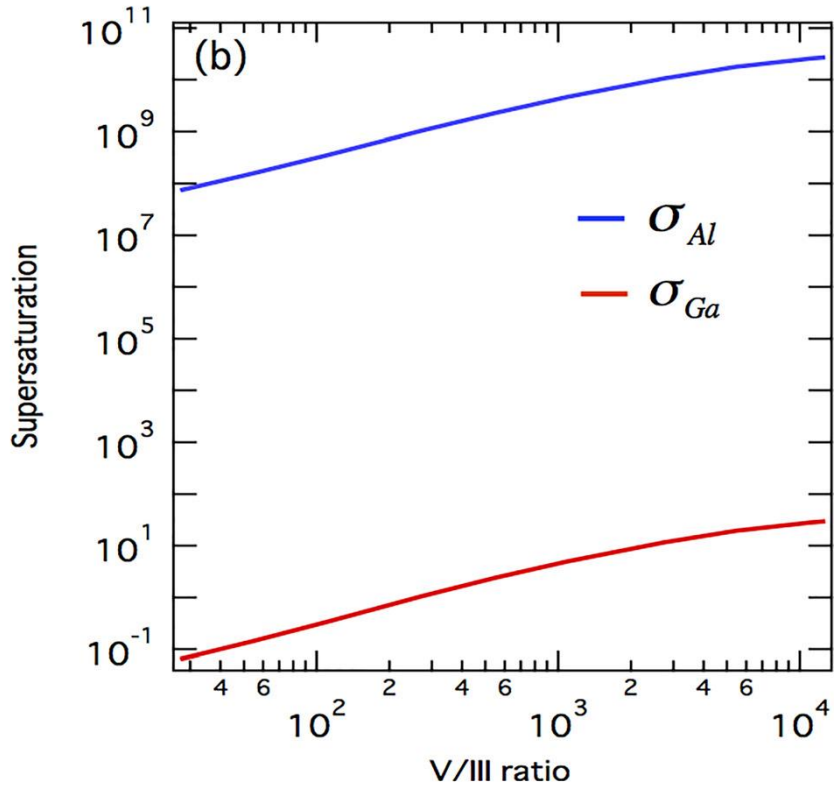


+ Carbon-free (improved device stability)
+ No buffer & strain compensation layers (smaller size)

Zagni et al., *Phys. Stat. Sol. A* **217** 1900762 (2020)

Difference in Al & Ga supersaturations





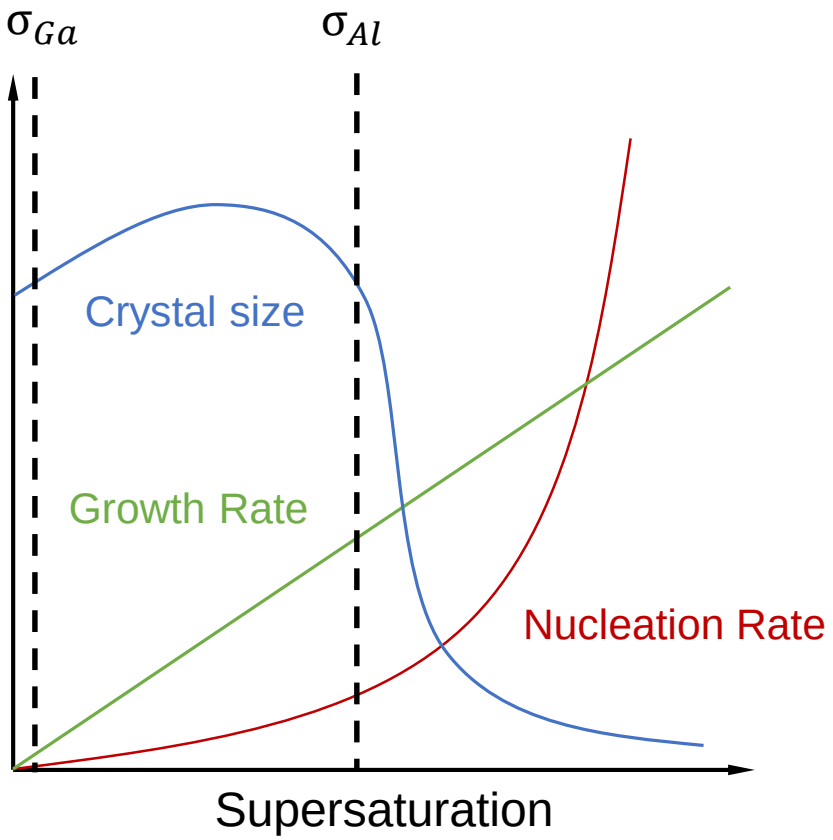
P_i° - input partial pressure
P_i - equilibrium partial pressure
σ - supersaturation

$$\sigma = \frac{P_i^{\circ} - P_i}{P_i}$$

S. Washiyama et al. Journal of Applied Physics 124, 115304 (2018)

Optimal growth conditions

Optimal conditions for HVPE
GaN and AlN growth



$$\sigma_{Ga} = \frac{P^{\circ}_{GaCl} - P_{GaCl}}{P_{GaCl}}$$

$$\sigma_{Al} = \frac{P^{\circ}_{AlCl_3} - P_{AlCl_3}}{P_{AlCl_3}}$$

σ - supersaturation
P_i° - input partial pressure
P_i - equilibrium partial pressure

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Experimental setup

Research goals

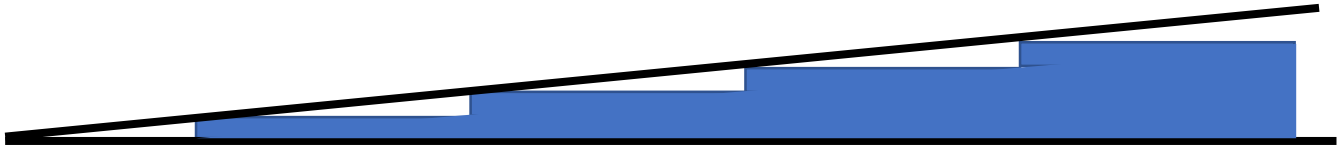
Goal 1: Find optimal parameters for HVPE-$Al_xGa_{1-x}N$ growth (i.e. good morphology)

→ 2” Al_2O_3 templates (0.5 µm GaN layer) + final test on 2” Am-GaN

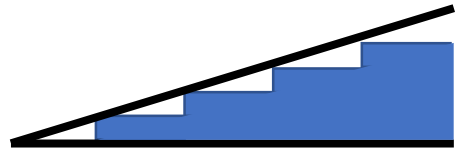
1. $V/III = \frac{P^{\circ}_{NH_3}}{P^{\circ}_{AlCl_3} + P^{\circ}_{GaCl}}$
2. Total pressure

Goal 2: Analyze the influence of misorientation on $Al_xGa_{1-x}N$ growth

→ 4x 1” Am-GaN substrates (0.5°, 1°, 2°, 4° offcut relative to m-plane (10-10))

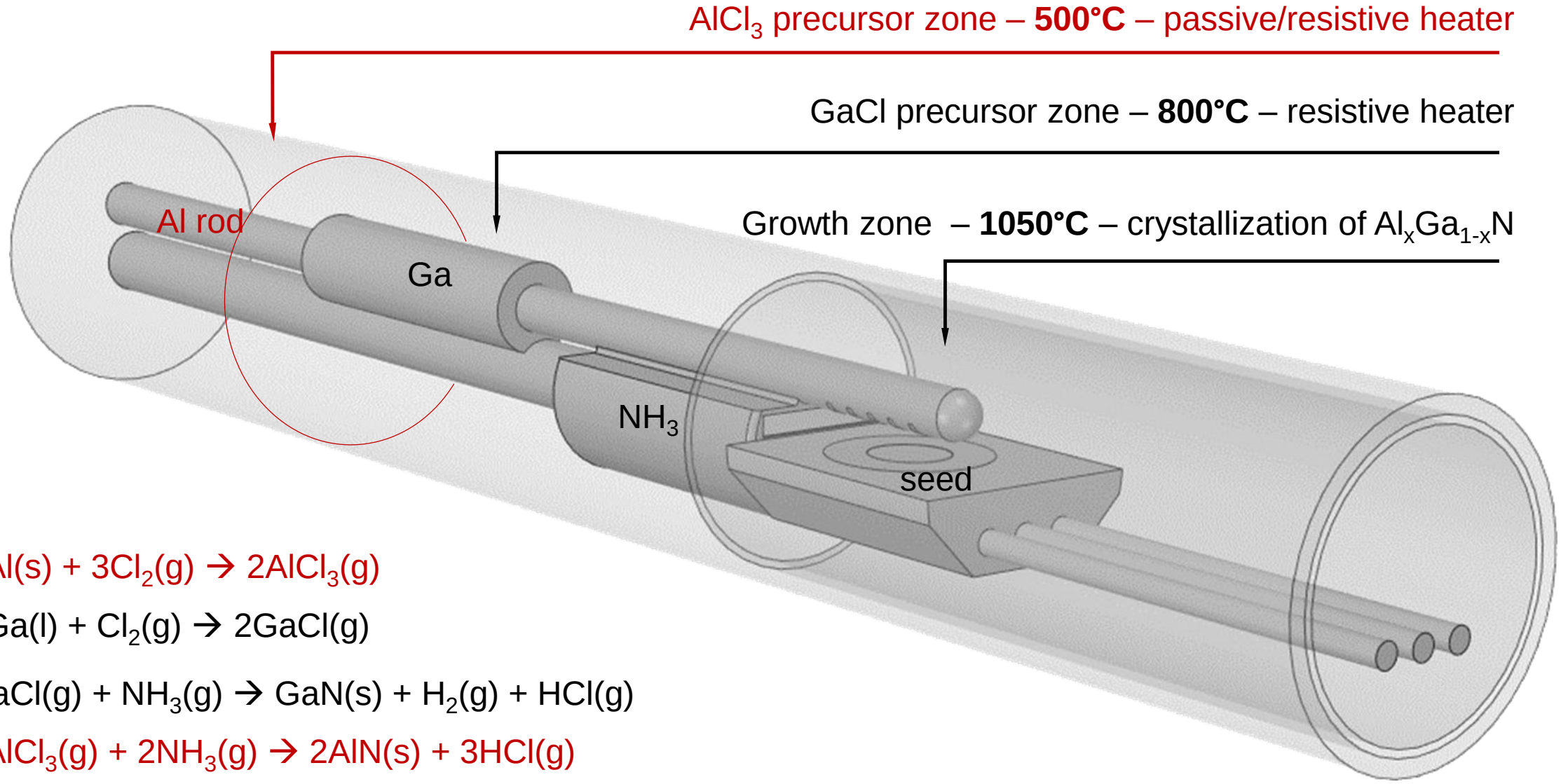


Low misorientation



High misorientation

HVPE reactor



$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(g)$

$2Ga(l) + Cl_2(g) \rightarrow 2GaCl(g)$

$GaCl(g) + NH_3(g) \rightarrow GaN(s) + H_2(g) + HCl(g)$

$2AlCl_3(g) + 2NH_3(g) \rightarrow 2AlN(s) + 3HCl(g)$

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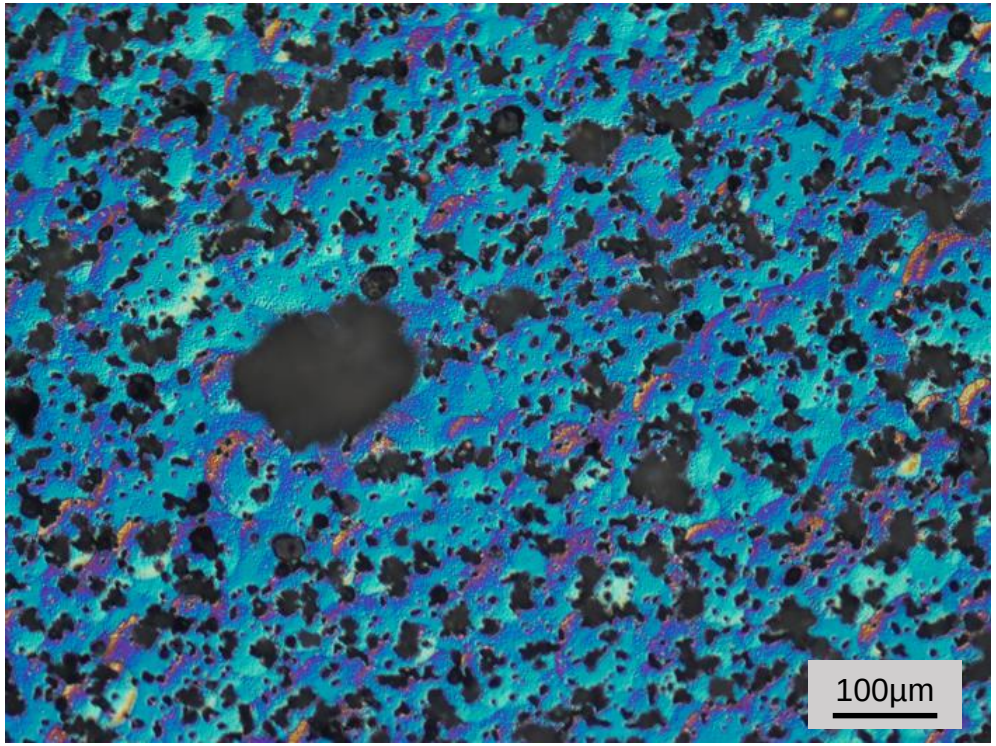
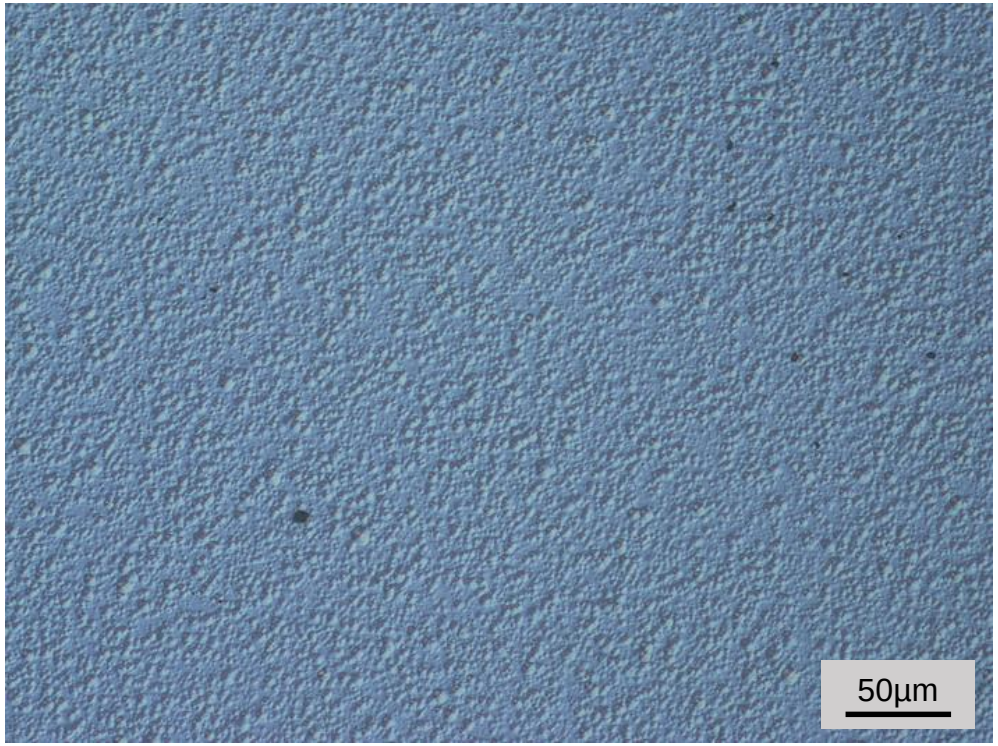
Results:
Parameter optimization

$Al_xGa_{1-x}N/Al_2O_3$ – V/III ratio (p = 800 mbar)

V/III = 59



V/III = 21



$$V/III = \frac{P^{\circ}_{NH_3}}{P^{\circ}_{AlCl_3} + P^{\circ}_{GaCl}}$$

$Al_xGa_{1-x}N/Al_2O_3$ – V/III ratio (p = 800 mbar)

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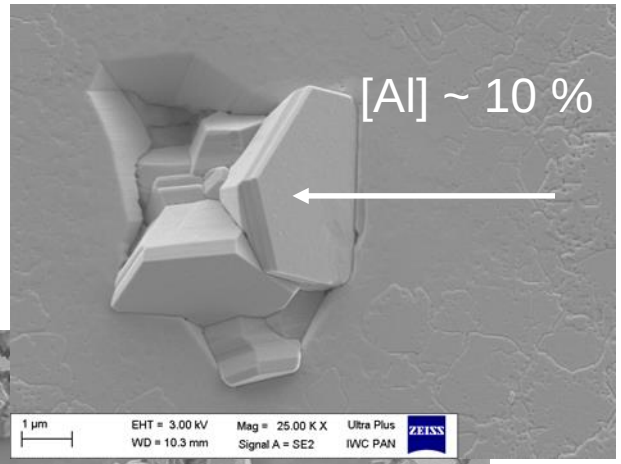
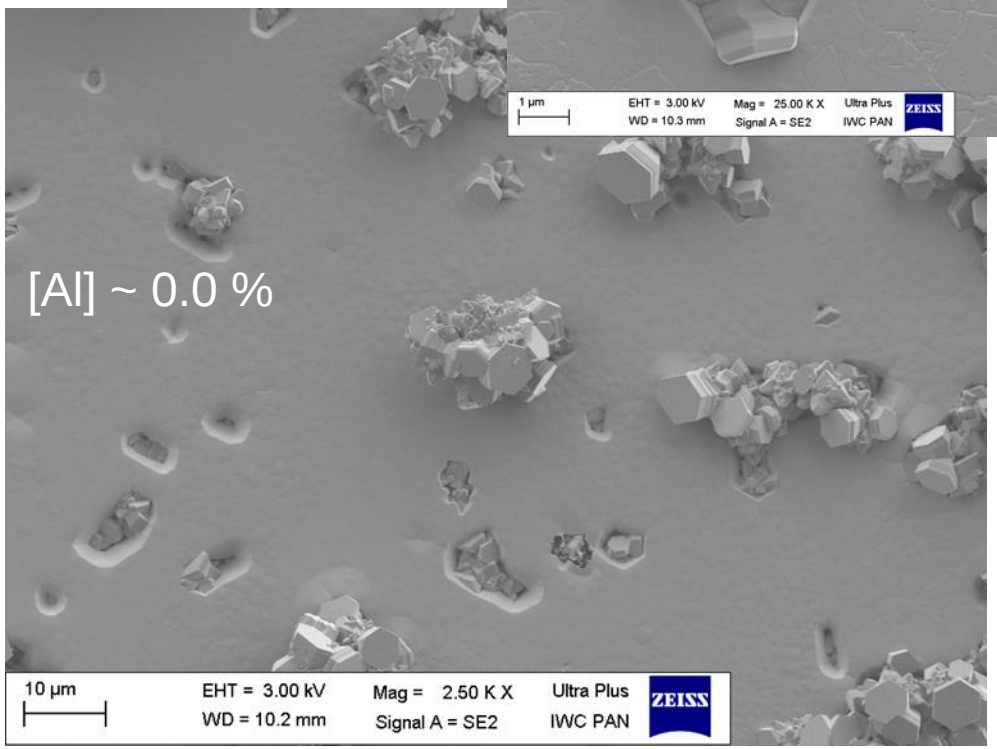
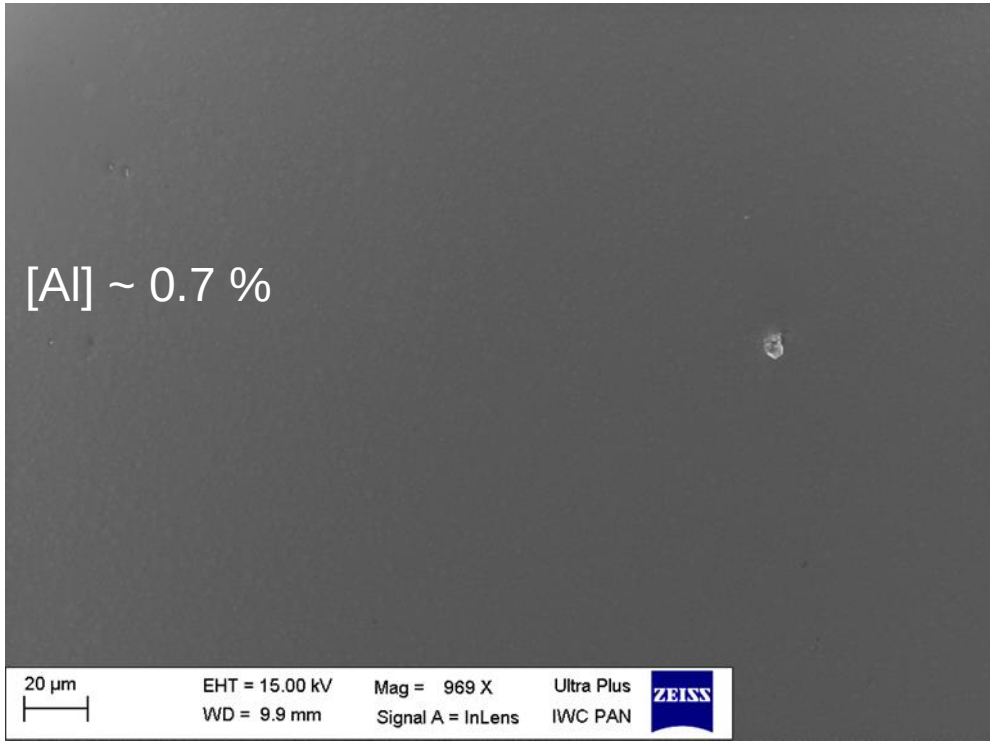


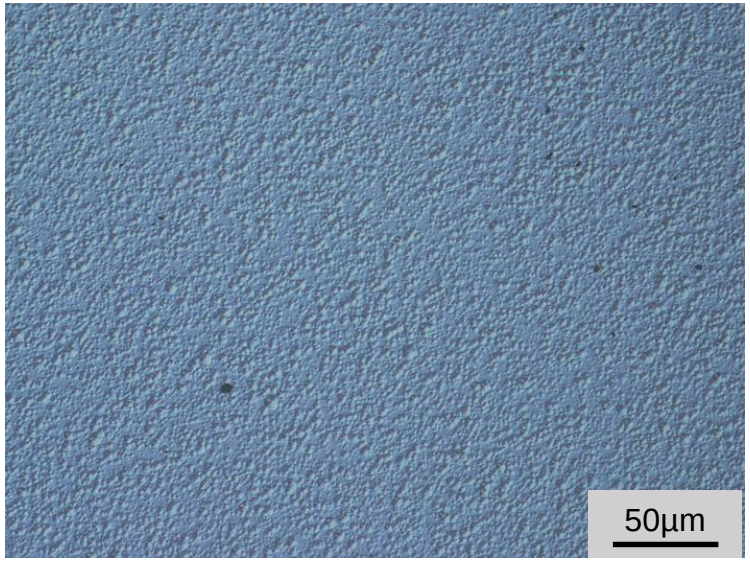


V/III = 21

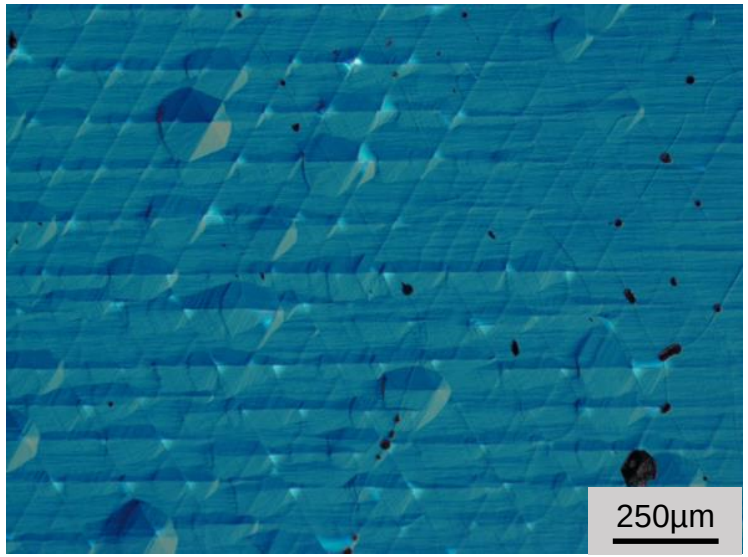


$Al_xGa_{1-x}N/Al_2O_3$ – total pressure (V/III = 21)

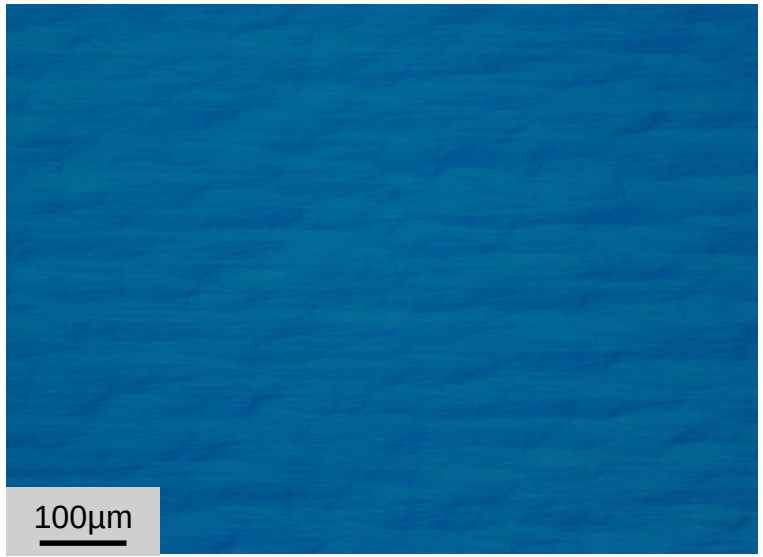
800 mbar

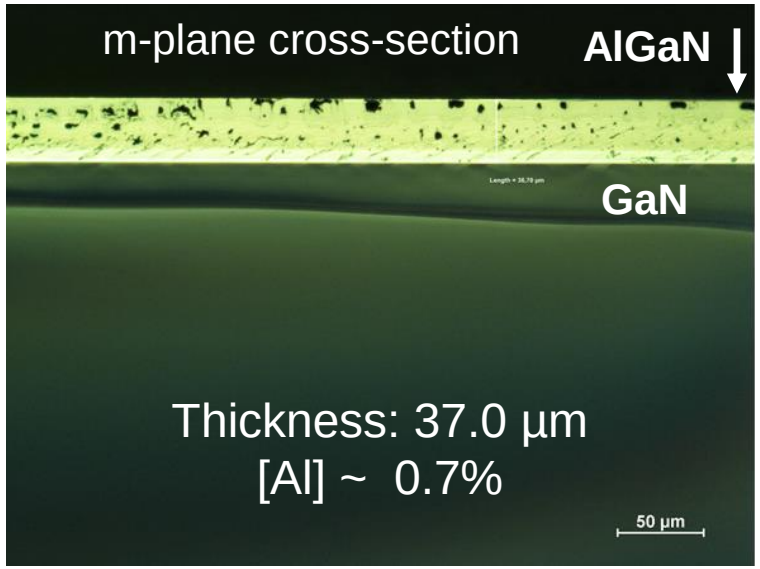


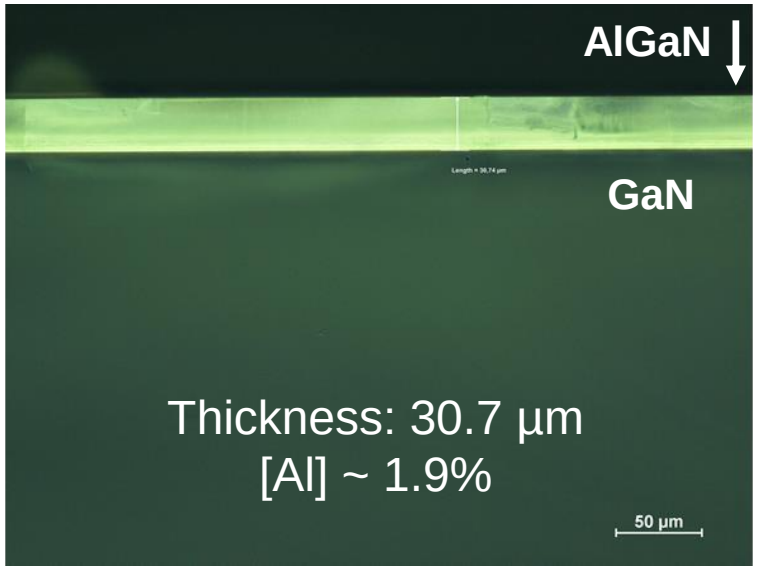
400 mbar

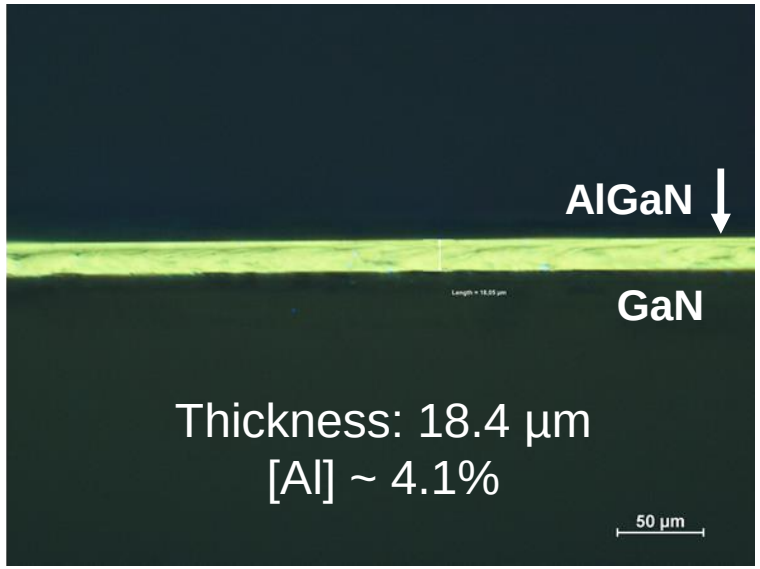


200 mbar

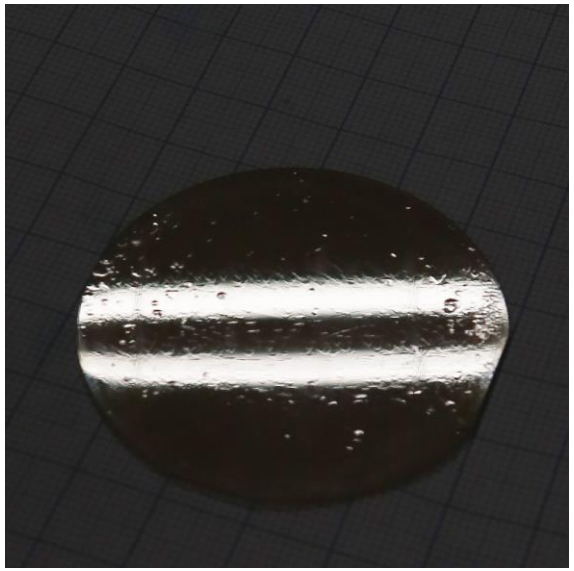


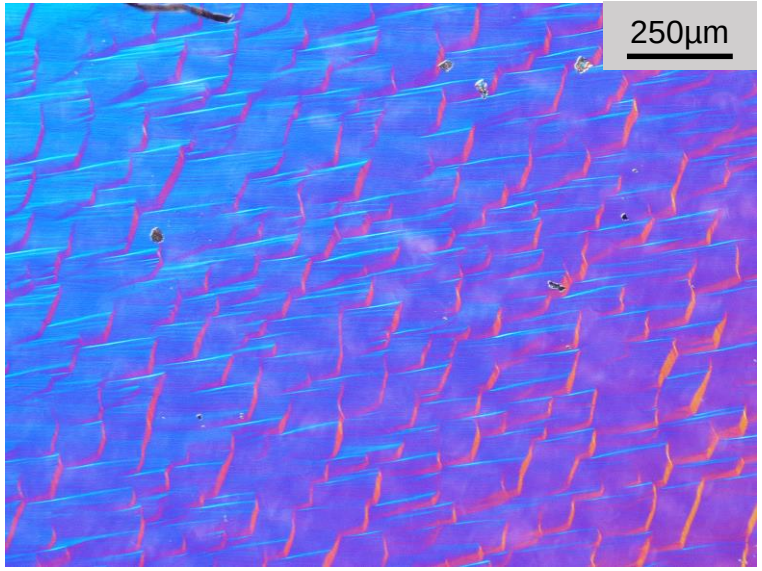


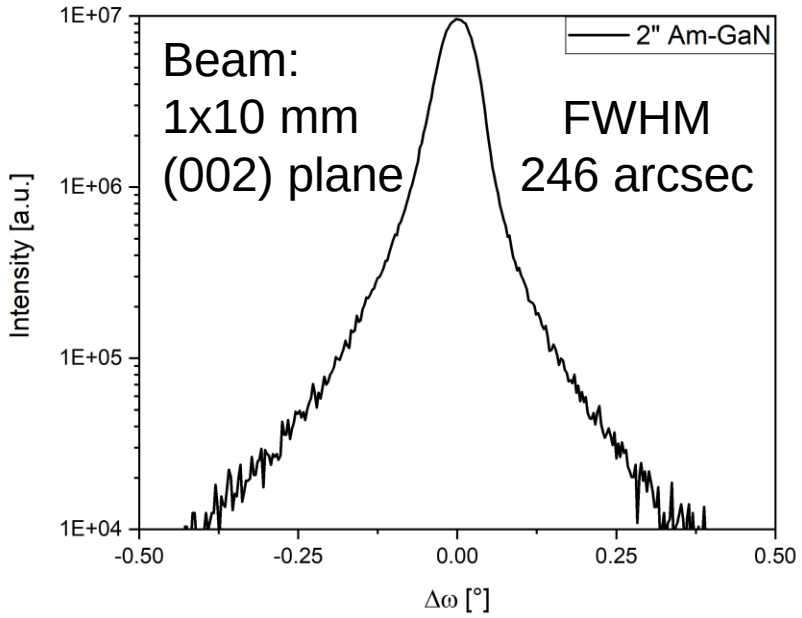


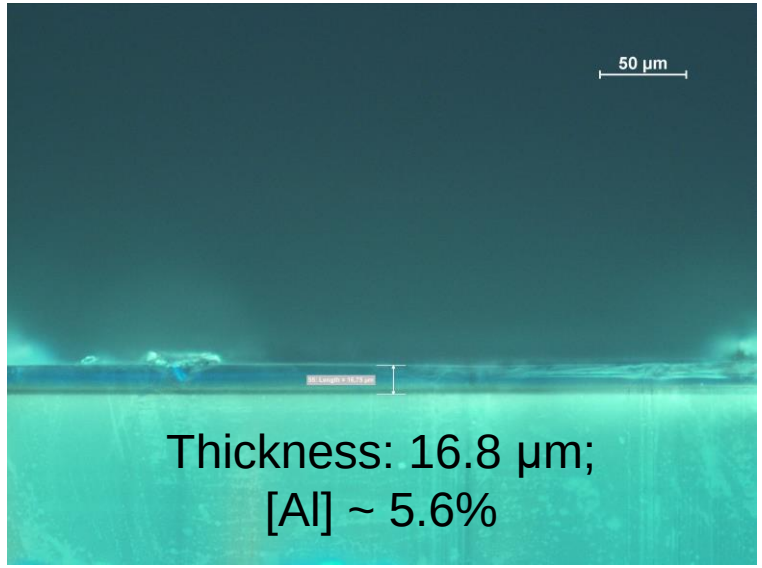


$Al_xGa_{1-x}N$ on 2” Am-GaN (p = 200 mbar, V/III = 21)









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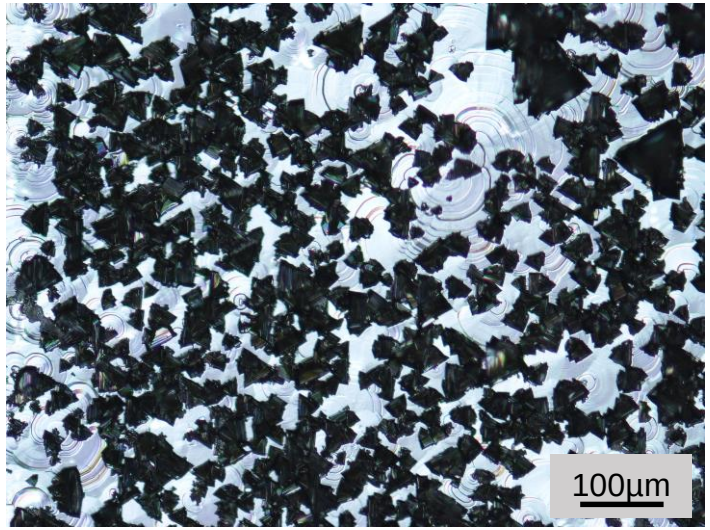
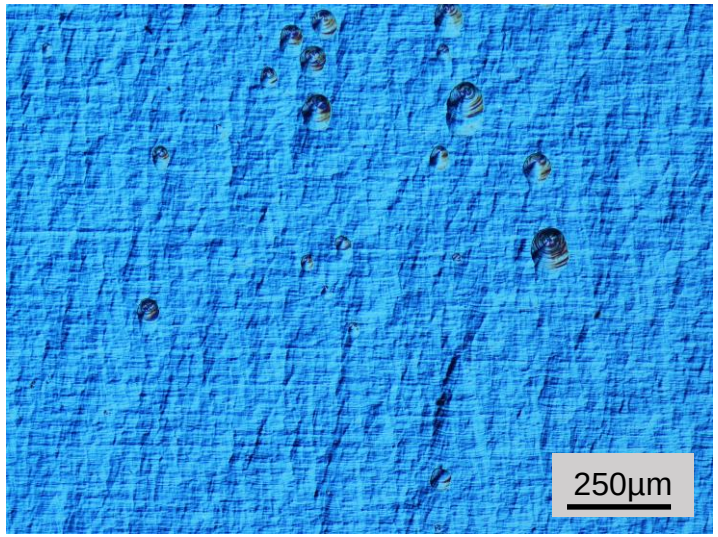
Results:
Influence of misorientation

Misorientation (1” $Al_xGa_{1-x}N$/Am-GaN)

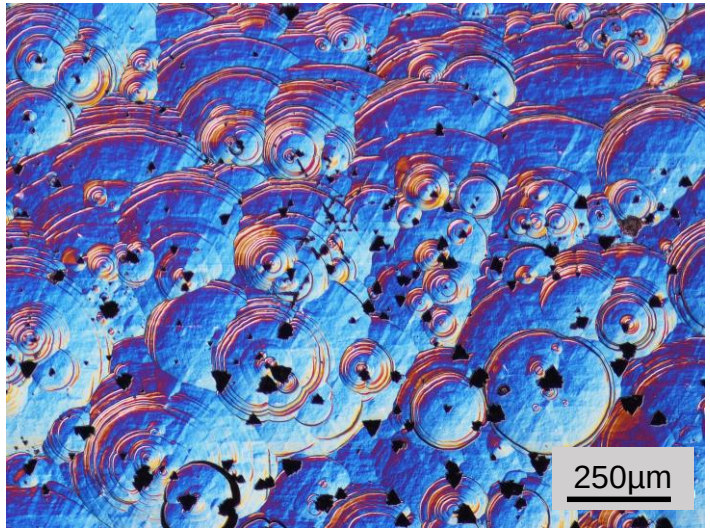


0.5°

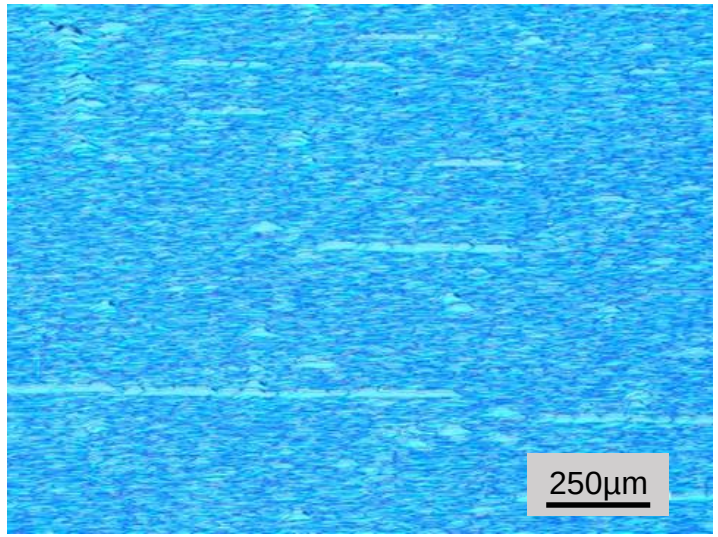


2°

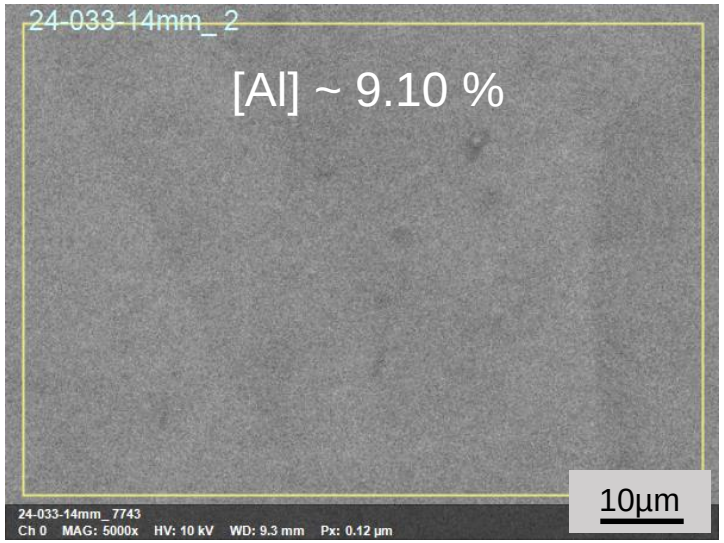
4°



1°



Misorientation (1” $Al_xGa_{1-x}N$/Am-GaN)



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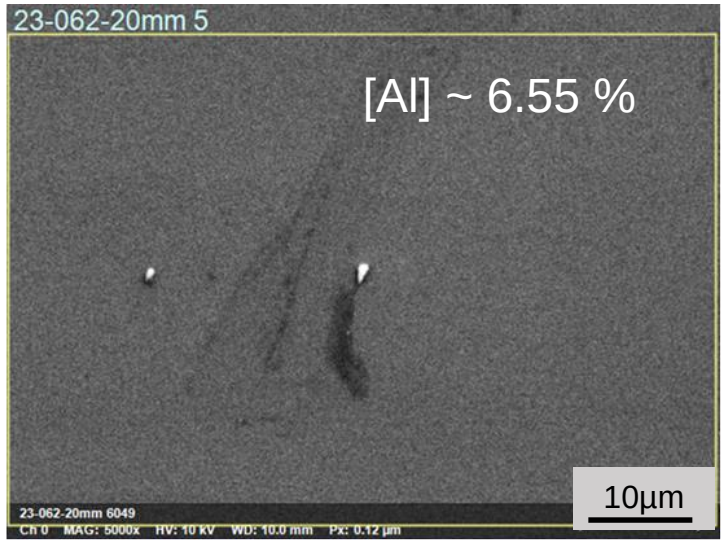
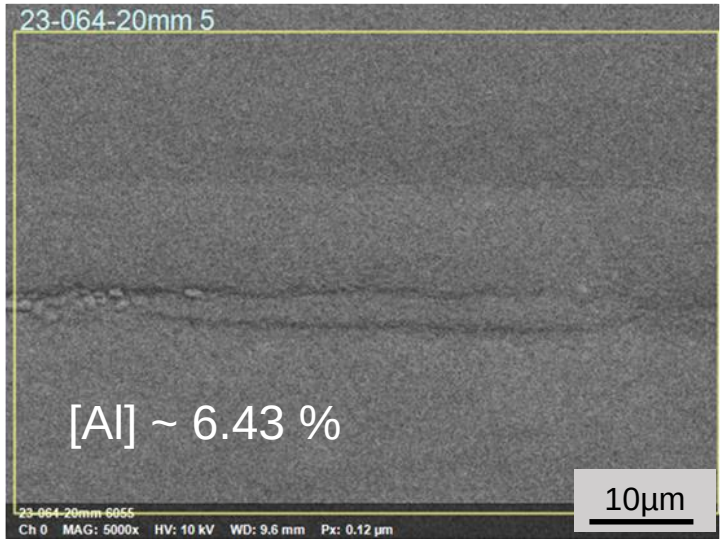
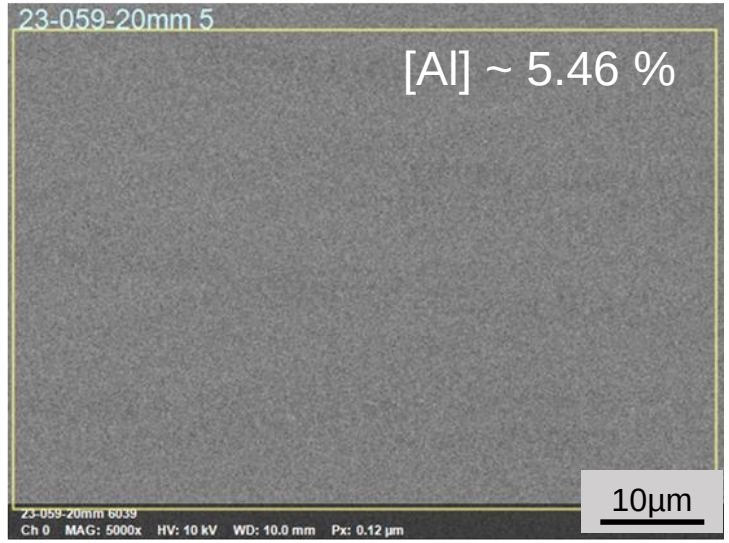


2°

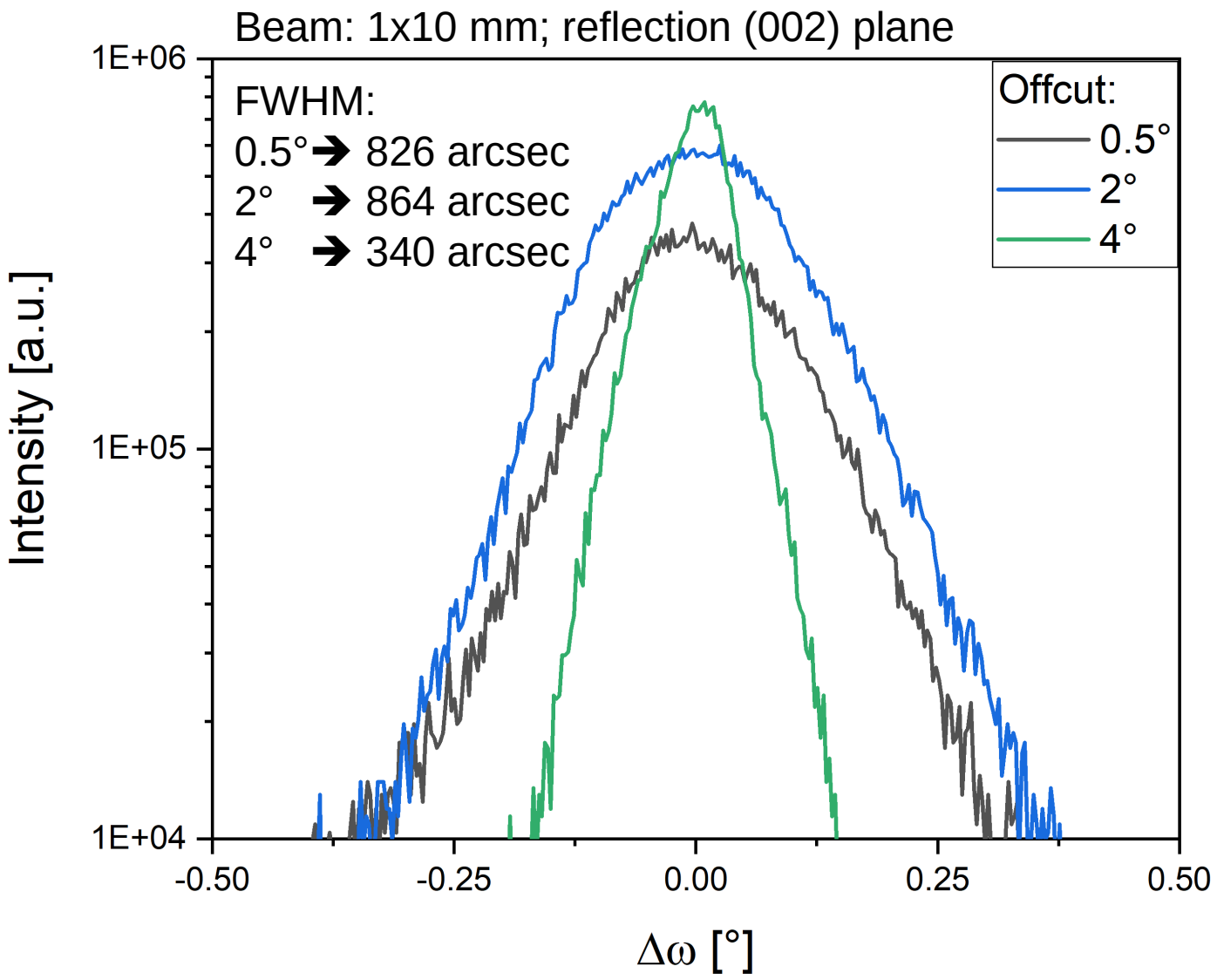
4°

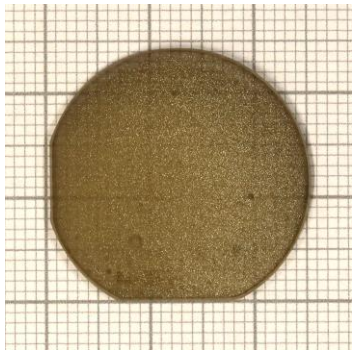


1°



Misorientation (1” $Al_xGa_{1-x}N$/Am-GaN)





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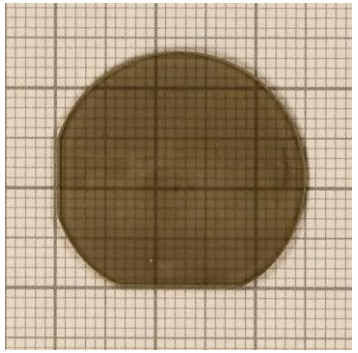

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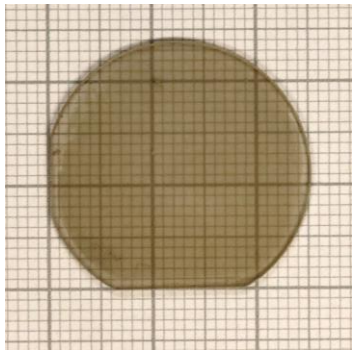

4°

Summary

Conclusions

- $Al_xGa_{1-x}N$ layers have been successfully crystallized on Al_2O_3 templates & Am-GaN substrates
- The most optimal morphology was observed for growth conducted in p = 200 mbar & V/III = 21
- The solid composition of $Al_xGa_{1-x}N$ was in the range of 5-10% on Am-GaN substrates
- Higher misorientation angle ➔ improvement of post-growth morphology & structural quality (XRD)

Next step: Strain engineering for bulk $Al_xGa_{1-x}N$ growth

Acknowledgments

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LIDER/23/0129/L-10/18/NCBR/2019

Thank you for your attention