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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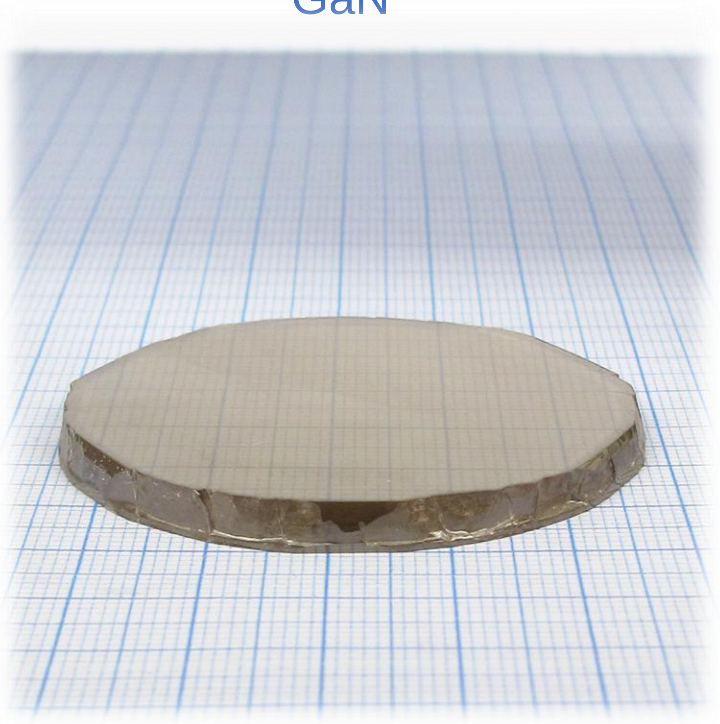
Outline

- **Introduction**
    - $Al_xGa_{1-x}N$ substrates & applications
    - Challenges of growing $Al_xGa_{1-x}N$
- **Experimental setup**
- **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 commercially available free-standing $Al_xGa_{1-x}N$ crystal

AlN

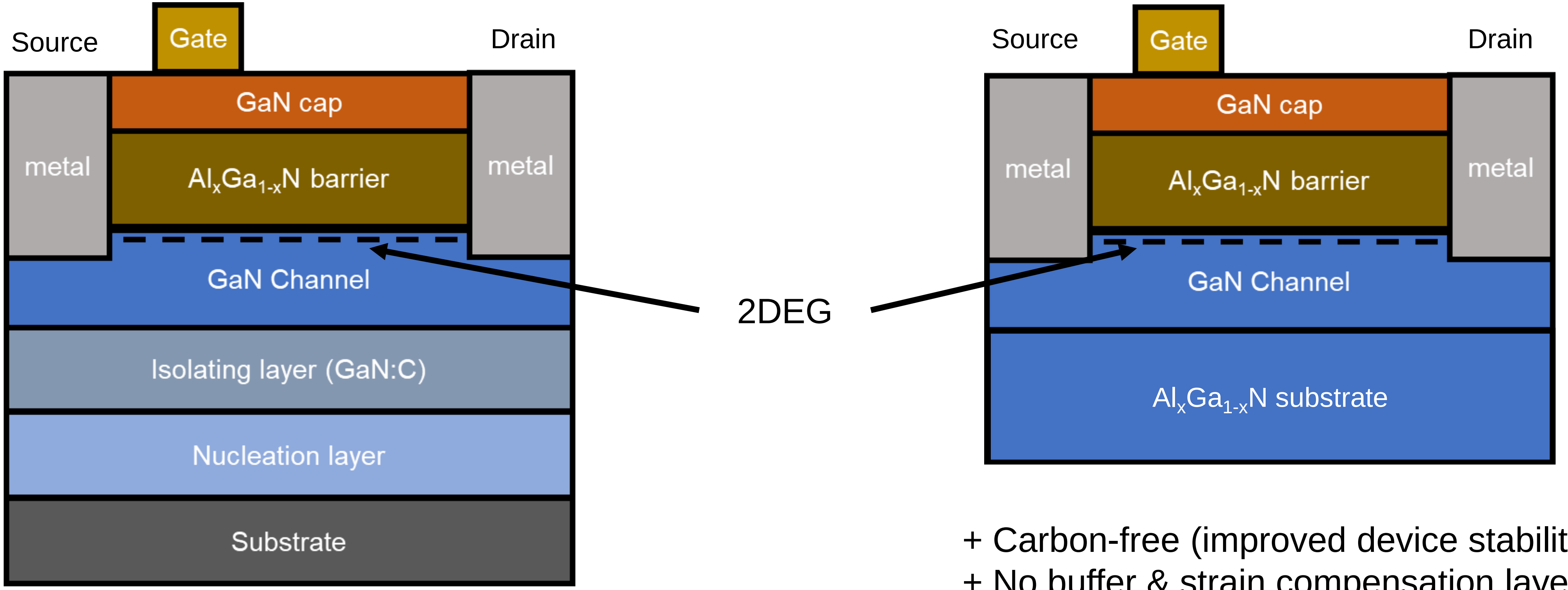
www.hexatechinc.com

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

Physical Vapor Transport

$Al_xGa_{1-x}N$ substrate applications

High Electron Mobility Transistors
(HEMT)



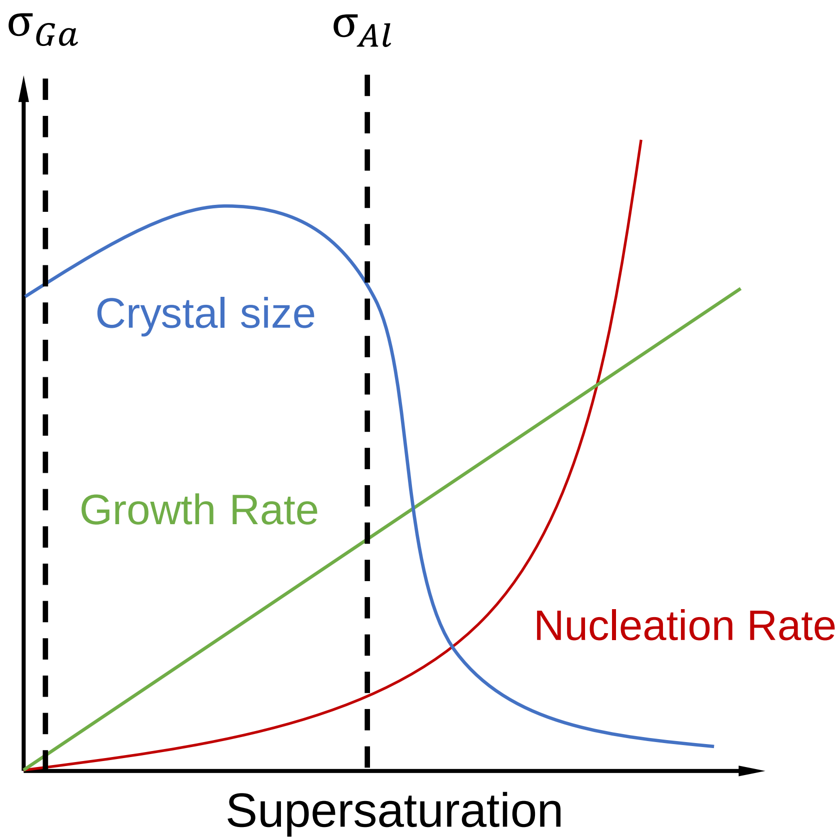
+ Carbon-free (improved device stability)
+ No buffer & strain compensation layers (smaller vertical size)

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

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

Challenges of growing $Al_xGa_{1-x}N$

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

Experimental setup

Research goals

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

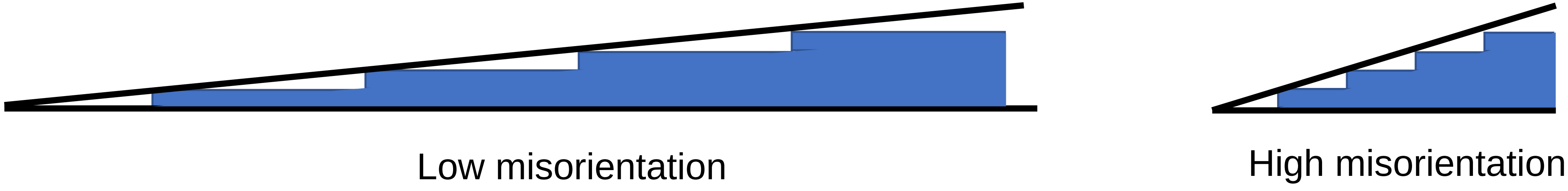
→ 2” Al_2O_3 templates (0.5 μm GaN layer) + final test on 2” Am-GaN

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

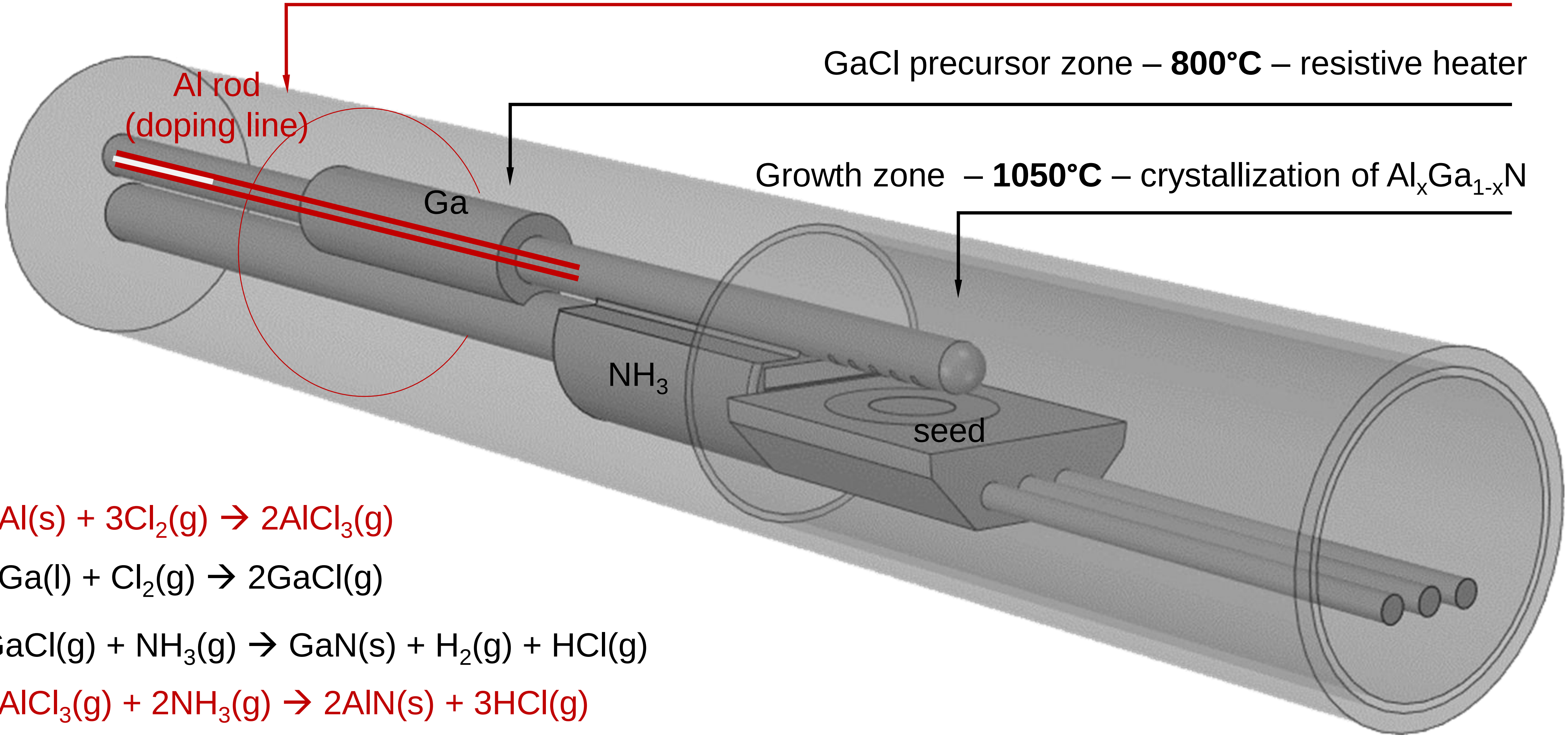
2. Total pressure

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

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



HVPE reactor



$AlCl_3$ precursor zone – **500°C** – passive/resistive heater

GaCl precursor zone – **800°C** – resistive heater

Growth zone – **1050°C** – crystallization of $Al_xGa_{1-x}N$

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

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

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

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

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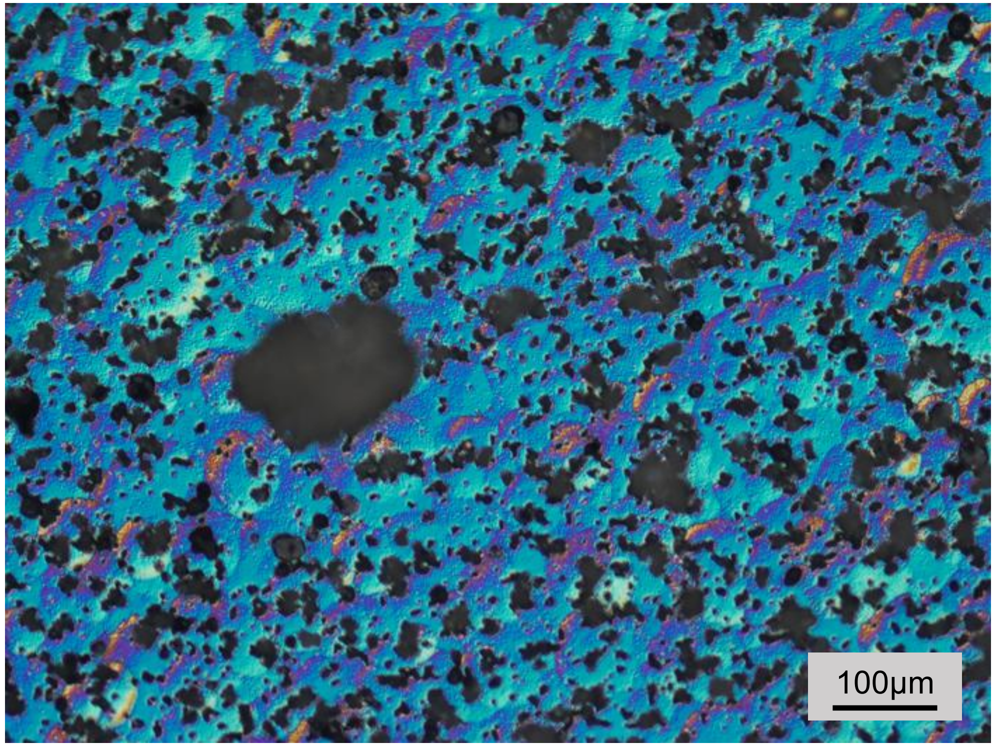
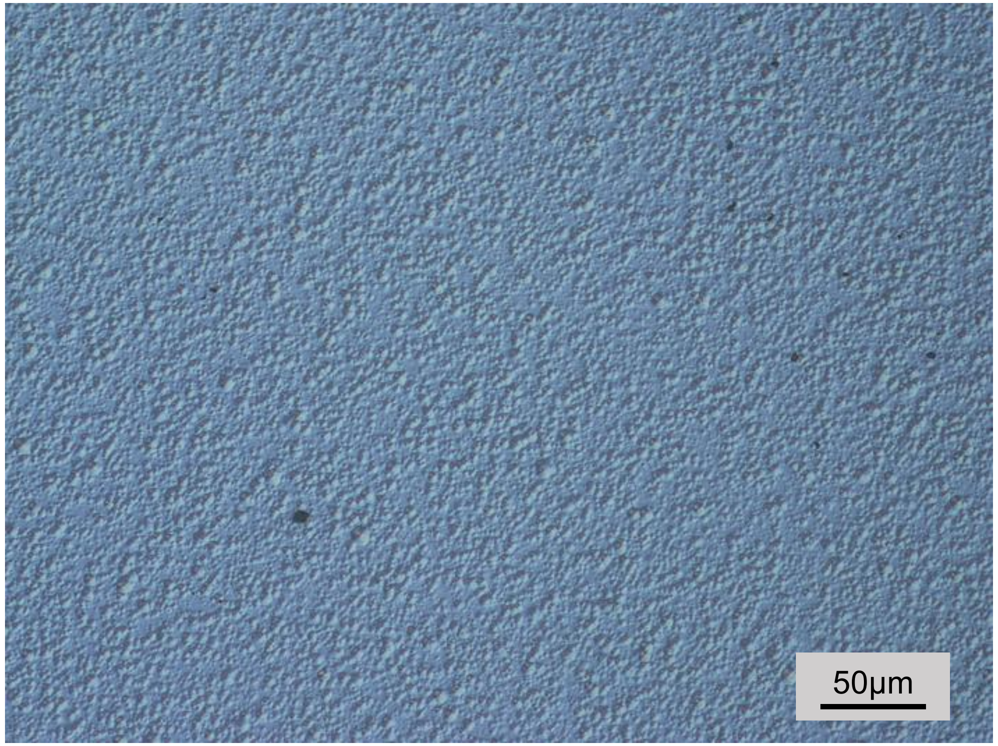
Results:
Parameter optimization

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

V/III = 59



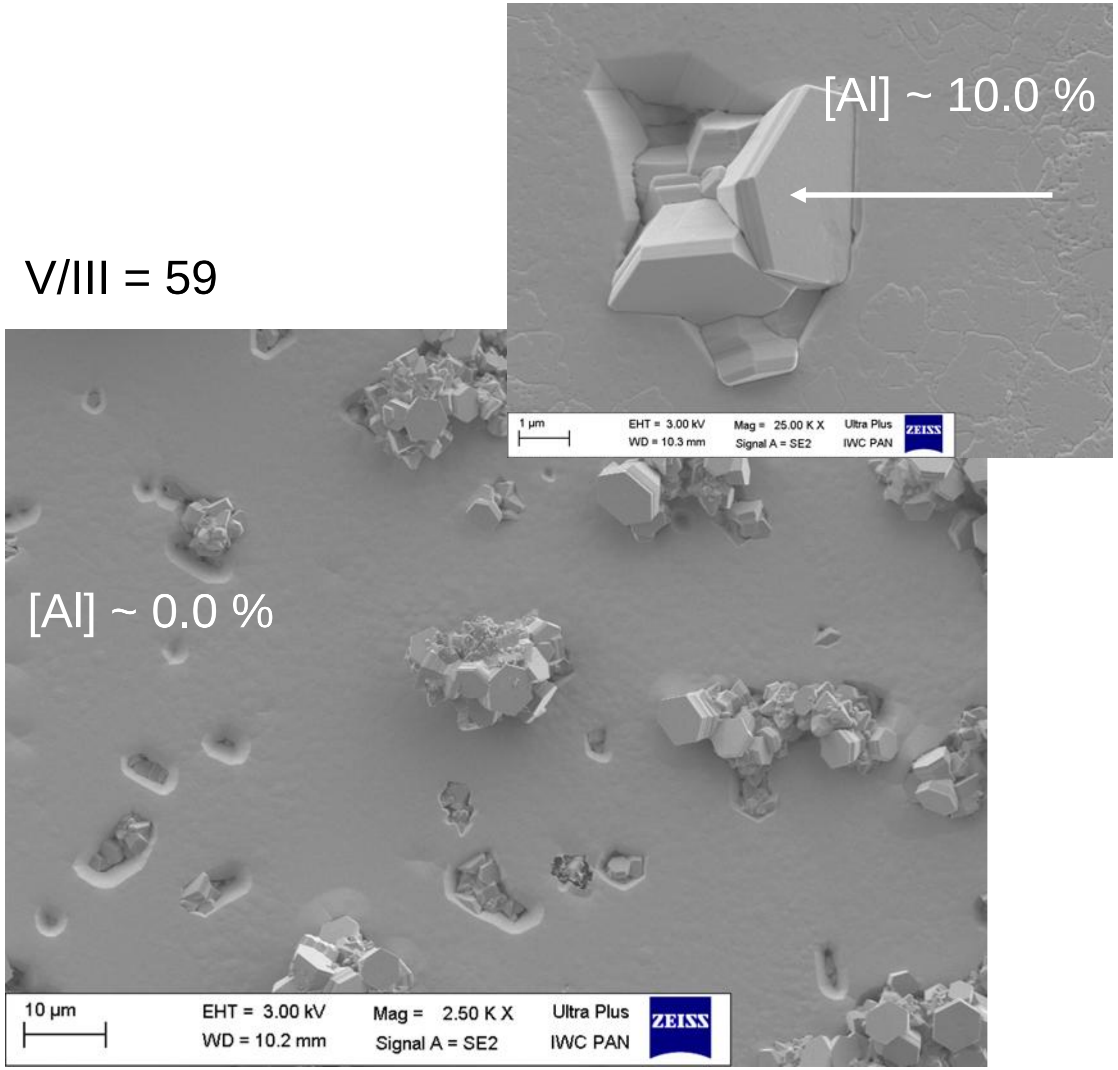
V/III = 21



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

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

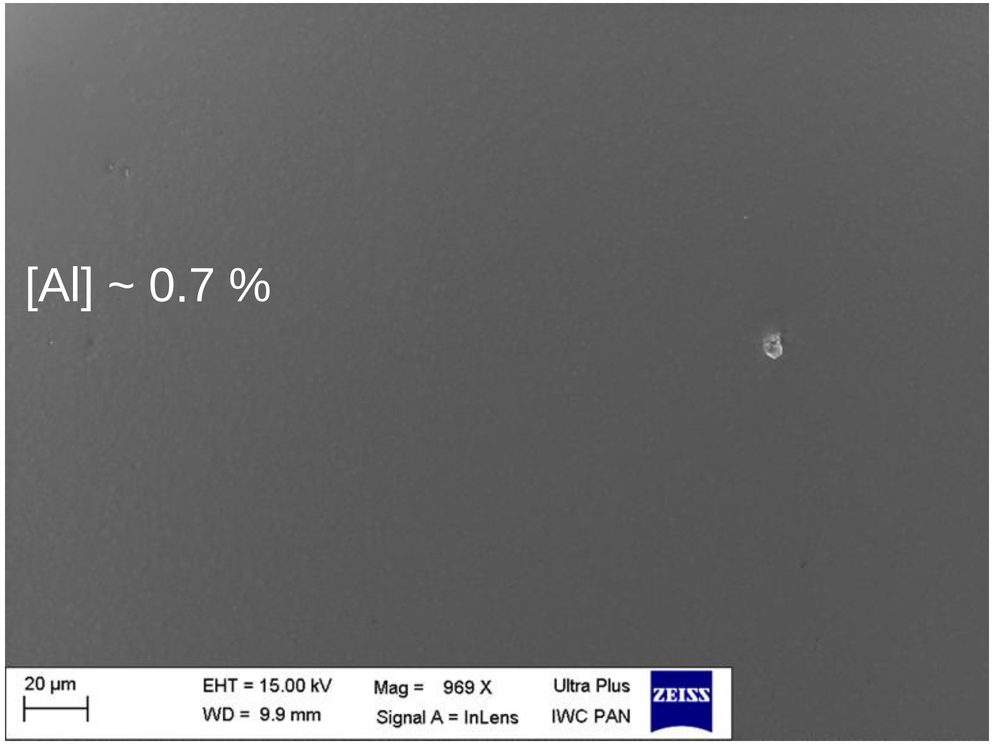
V/III = 59



[Al] ~ 10.0 %

[Al] ~ 0.0 %

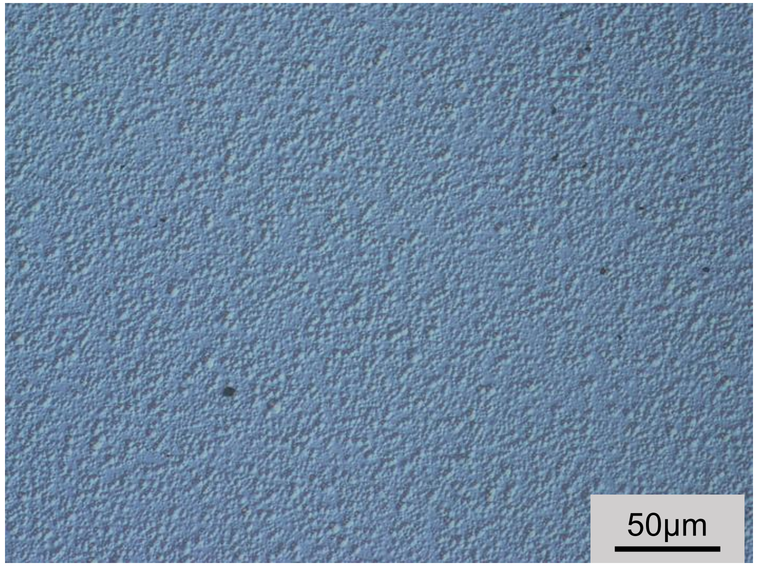
V/III = 21

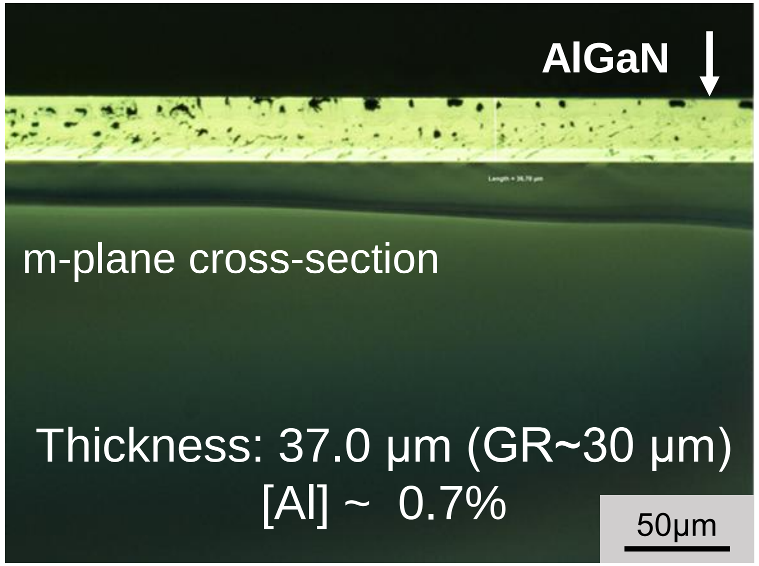


[Al] ~ 0.7 %

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

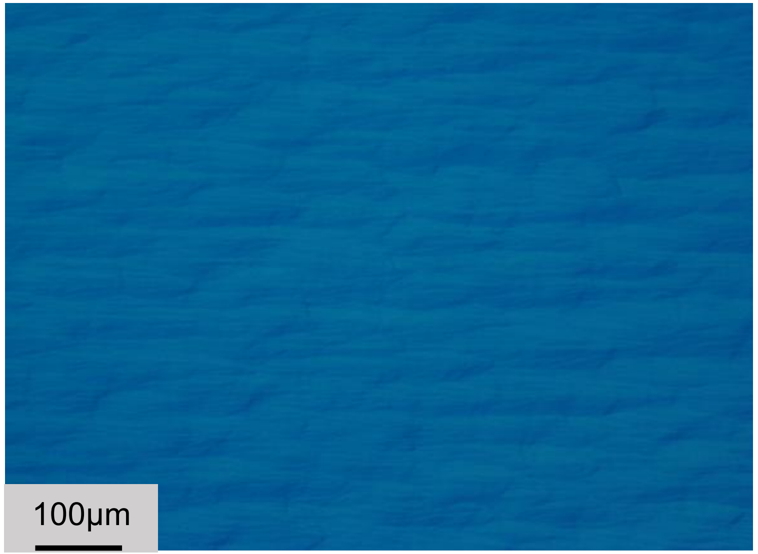
800 mbar

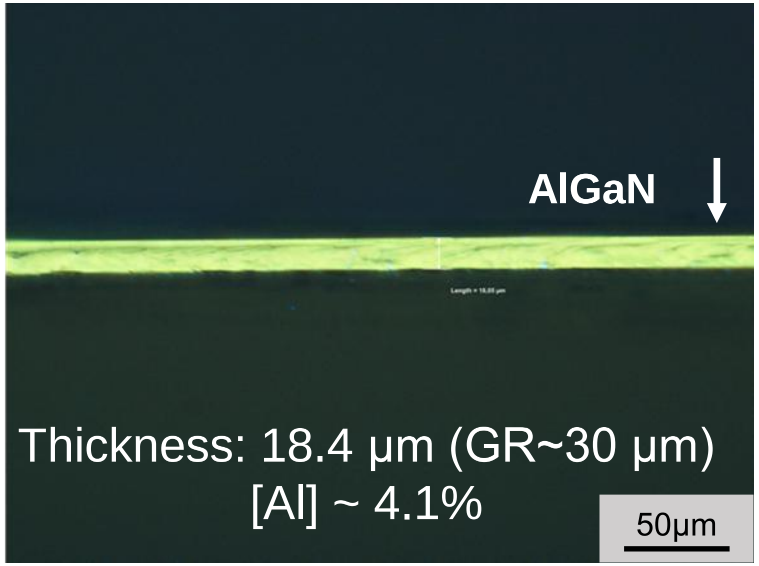




Thickness: 37.0 µm (GR~30 µm)
[Al] ~ 0.7%

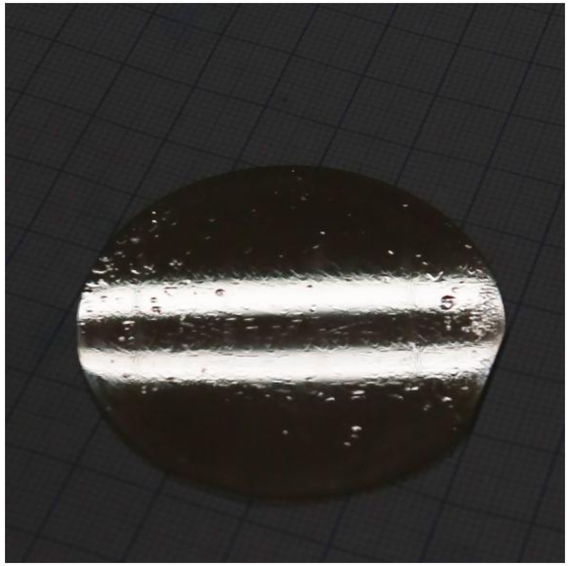
200 mbar

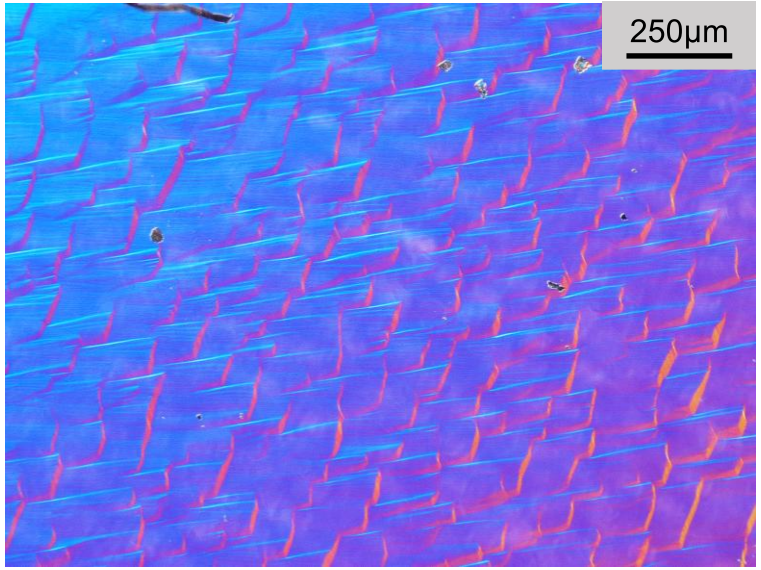


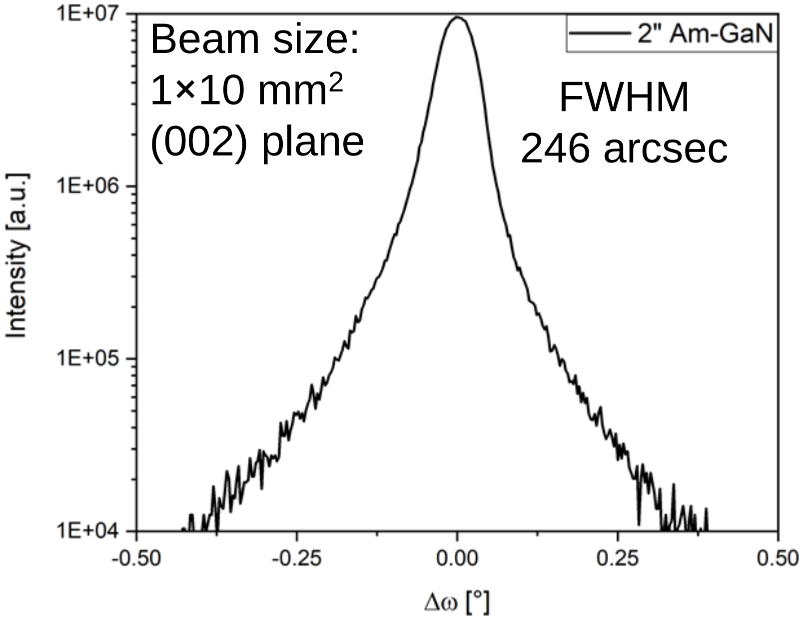


Thickness: 18.4 µm (GR~30 µm)
[Al] ~ 4.1%

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

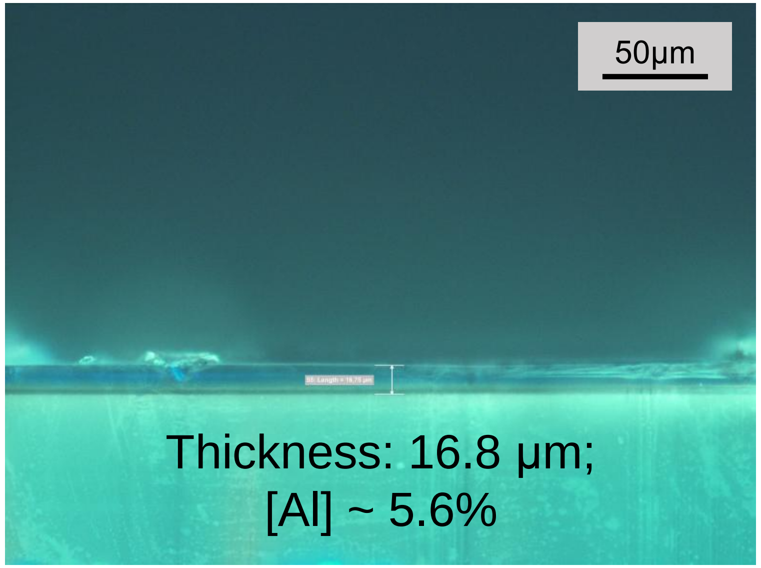






Beam size:
1×10 mm^2
(002) plane

FWHM
246 arcsec

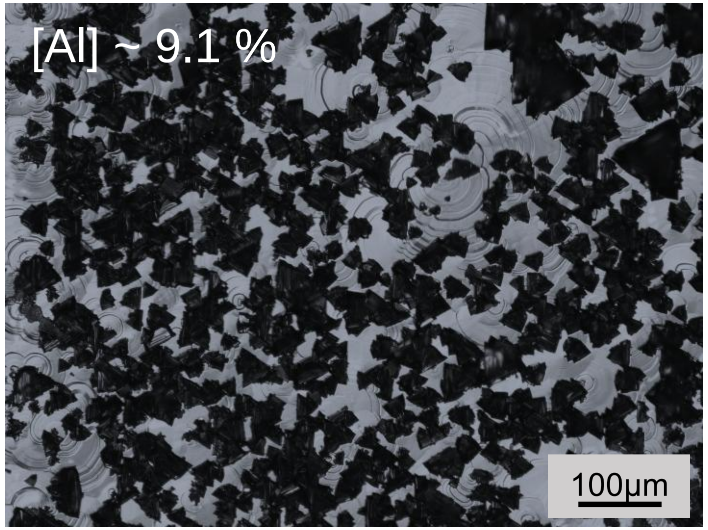


Thickness: 16.8 µm;
[Al] ~ 5.6%

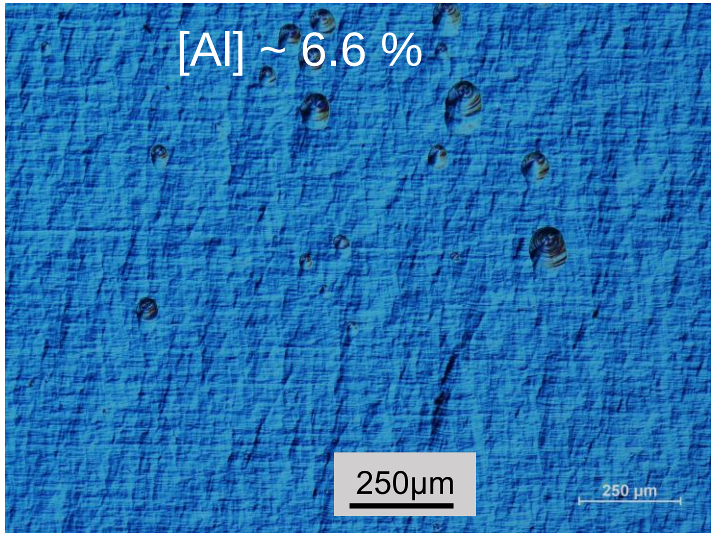
Results:
Influence of misorientation

Misorientation (1” Al$_x$Ga$_{1-x}$N/Am-GaN)

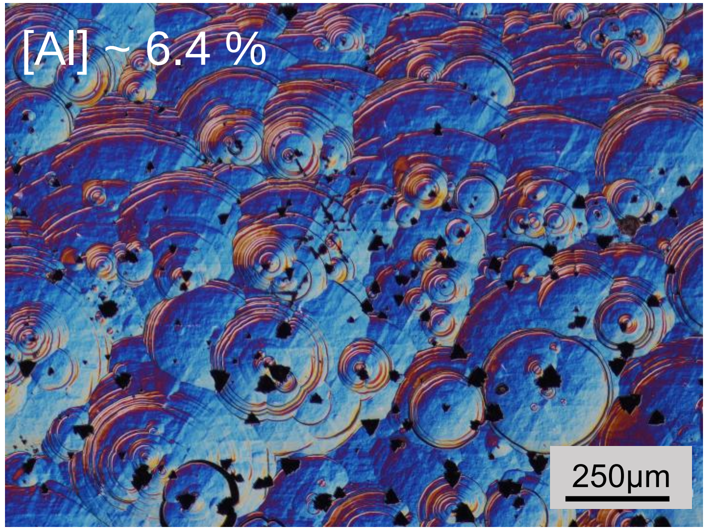
0.5°



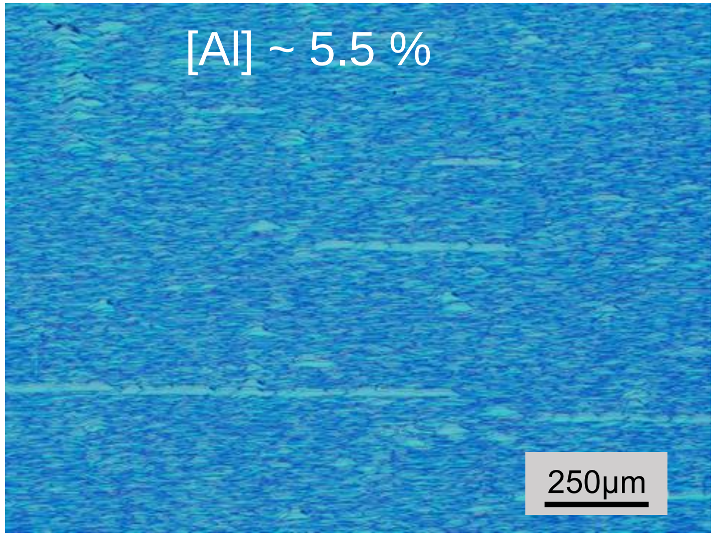
2°



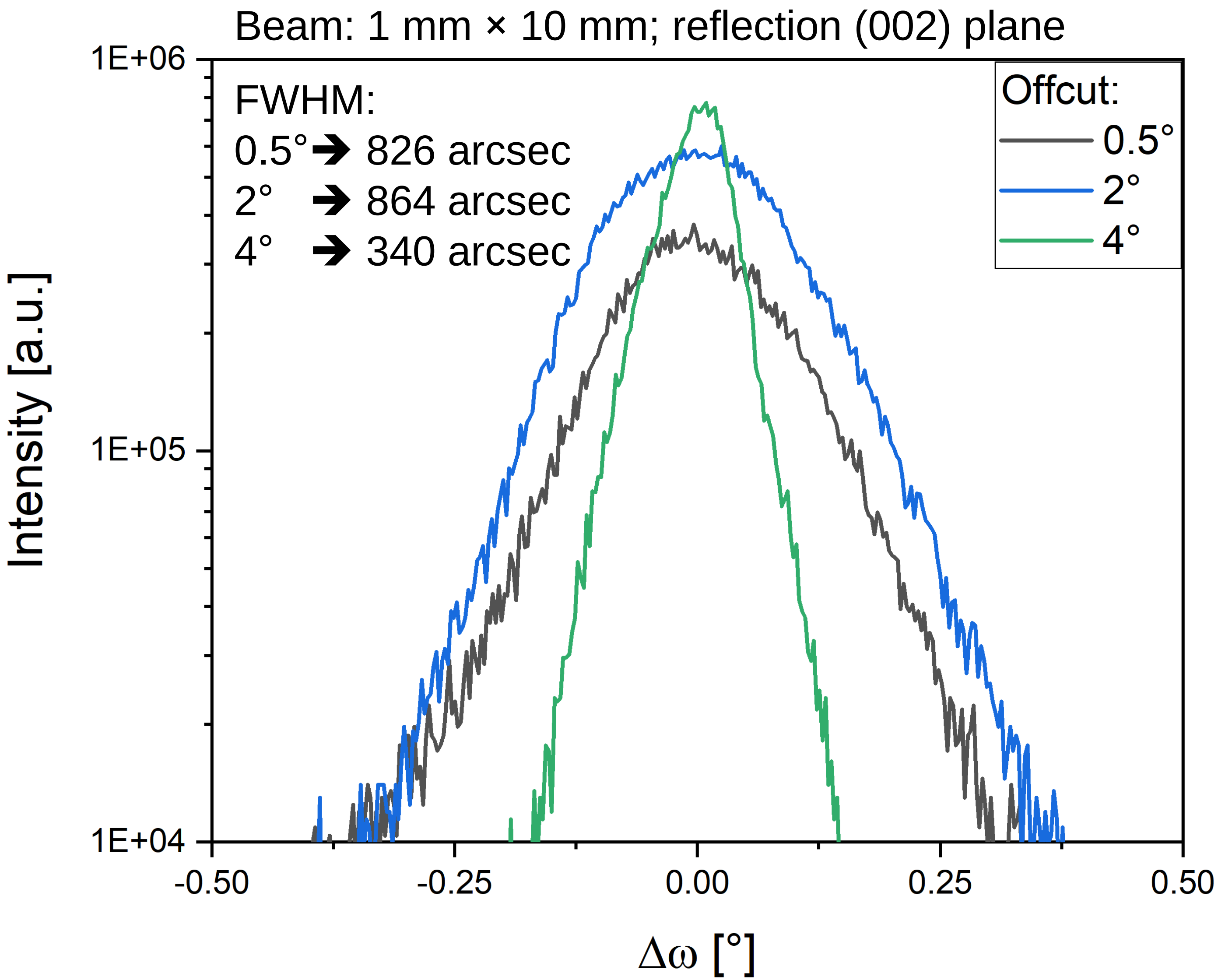
1°



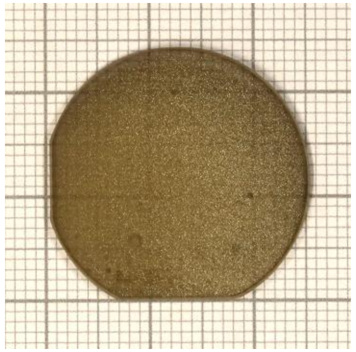
4°

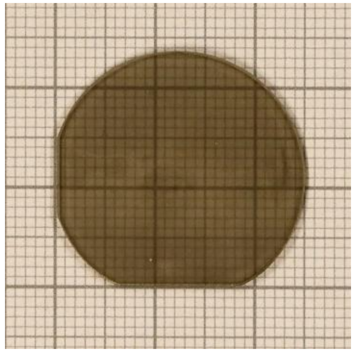


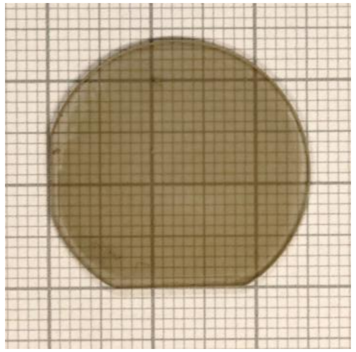
Misorientation (1” $Al_xGa_{1-x}N$/Am-GaN)


Beam: 1 mm × 10 mm; reflection (002) plane

FWHM:
0.5° ➔ 826 arcsec
2° ➔ 864 arcsec
4° ➔ 340 arcsec

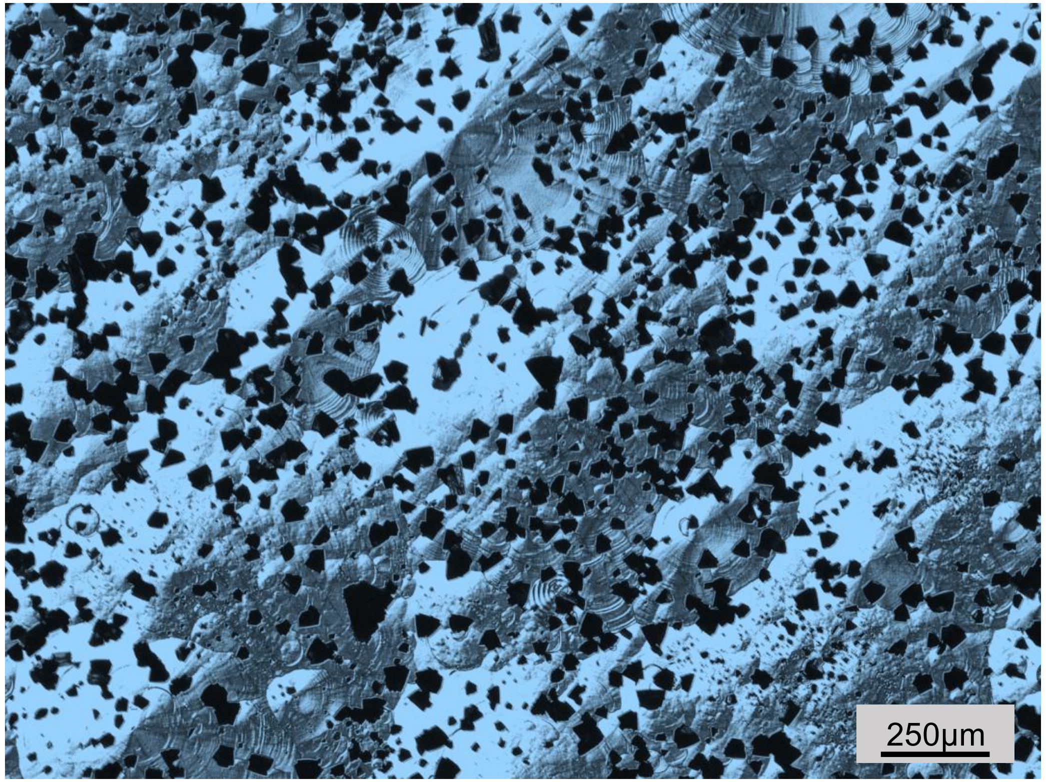

0.5°


2°


4°

Current research: How to increase Al %? (H_2 admixture)

Problem 1: Low [Al] % (only 4%) ➔ Solution 1: Add more Cl_2 over Al



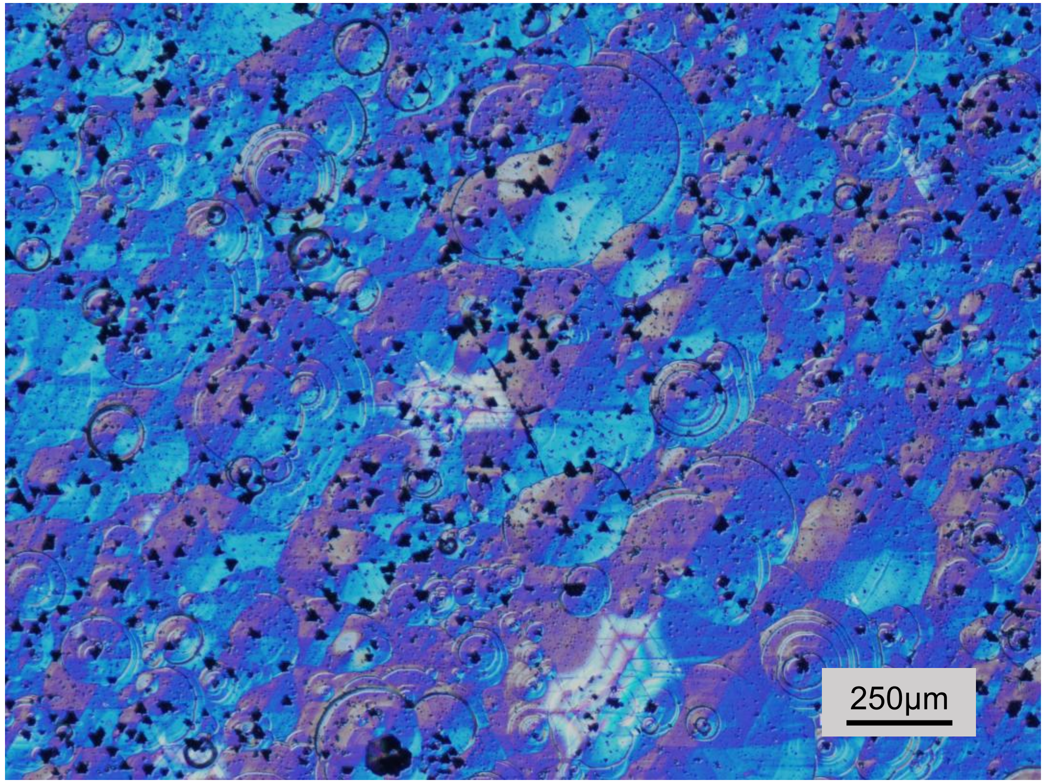
[Al] ~ 5.6 % (✓)

Clear from Crystallites (✗)

Current research: How to increase Al %? (H_2 admixture)

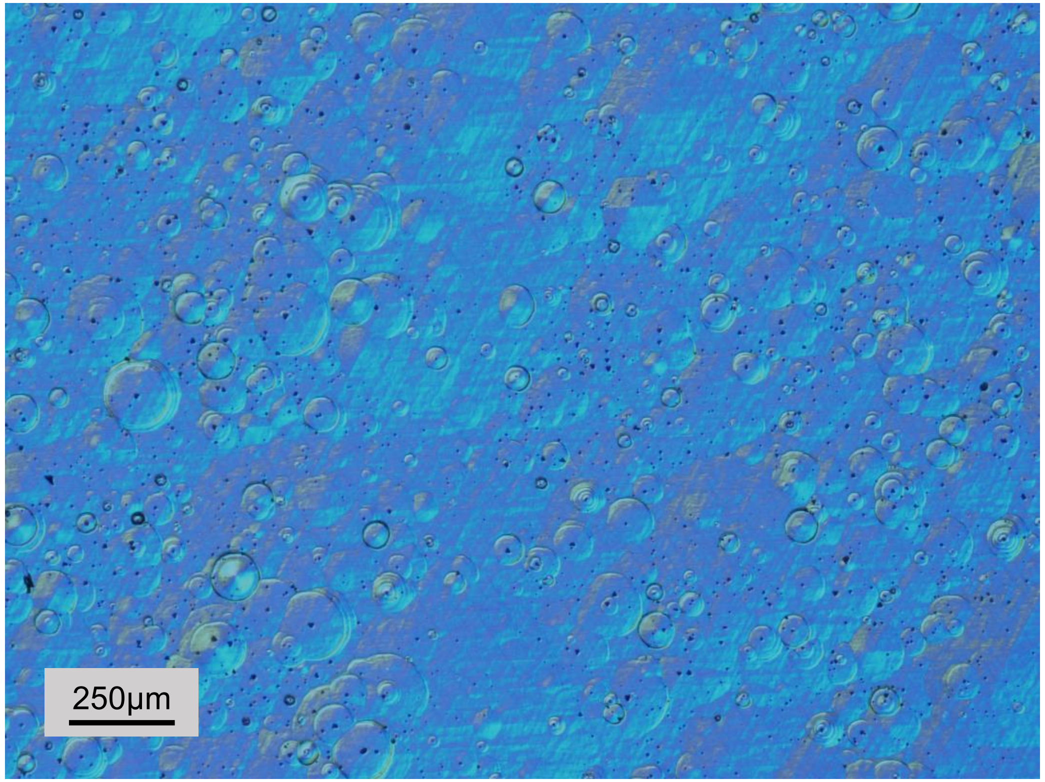
Problem 2: Crystallites ➔ Solution 2: Add H_2

5% H_2 (95% N_2)



[Al] ~ 7.3 % (✓)
Clear from Crystallites (~)

10% H_2 (90% N_2)



[Al] ~ 8.5 % (✓)
Clear from Crystallites (✓)

Summary

Conclusions

- The most optimal $Al_xGa_{1-x}N$ layers morphology was observed for growth in p = 200 mbar & V/III = 21

- Higher misorientation angle ➔ improvement of post-growth morphology & structural quality (XRD)

- The addition of H_2 admixture (5%, 10%) helped stabilize the conditions increased Al incorporation in the grown layers

Next: Strain engineering to obtain a free-standing $Al_xGa_{1-x}N$ crystal

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Acknowledgments

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