



Preliminary studies on halide vapor phase epitaxy of AlGa_N alloy on GaN substrates

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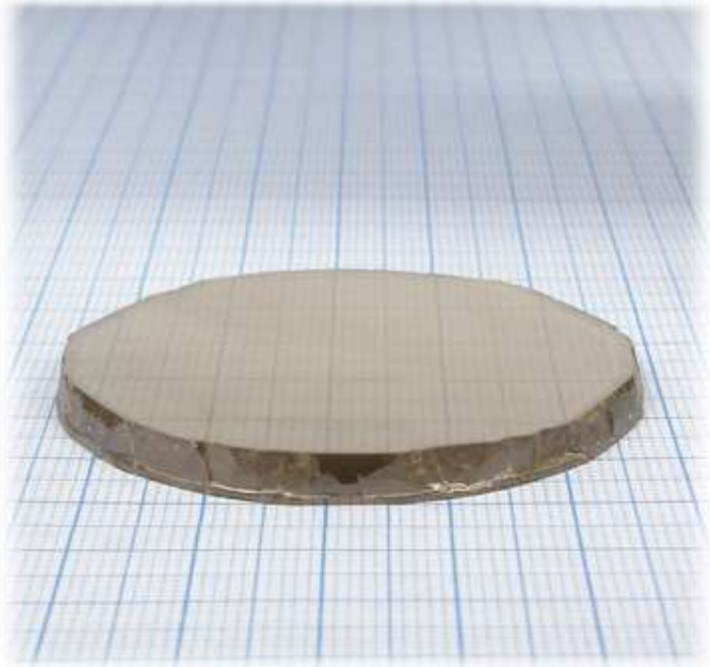
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GaN – AlN – AlGaN

GaN



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Halide Vapor Phase Epitaxy

Ammonothermal (Acidic/Basic)

Na-Flux

AlGaN

lack of
bulk

AlGaN
crystal

AlN

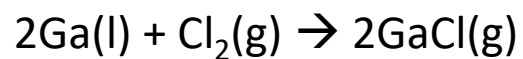
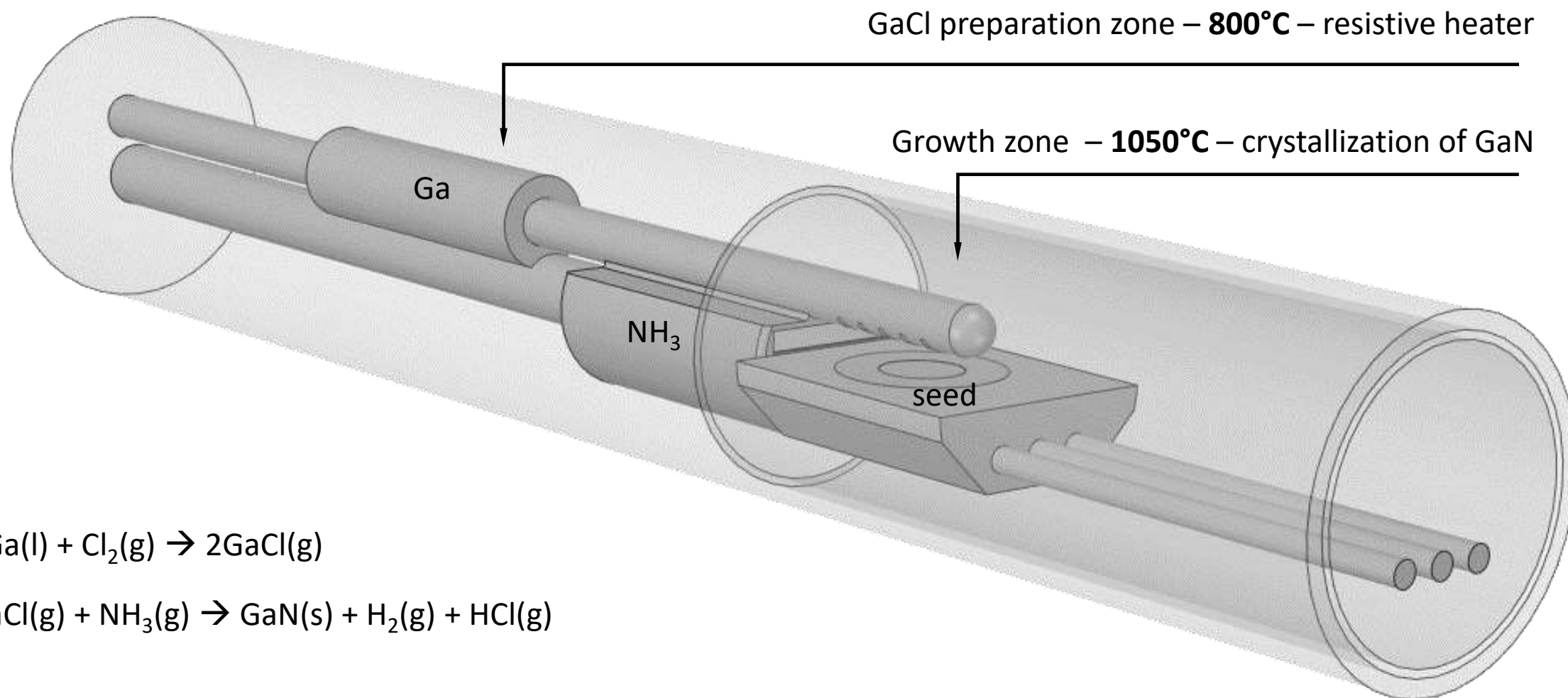


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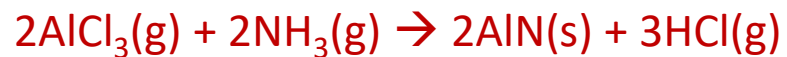
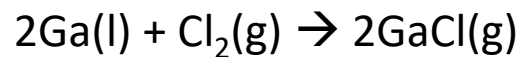
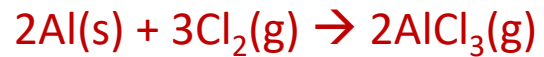
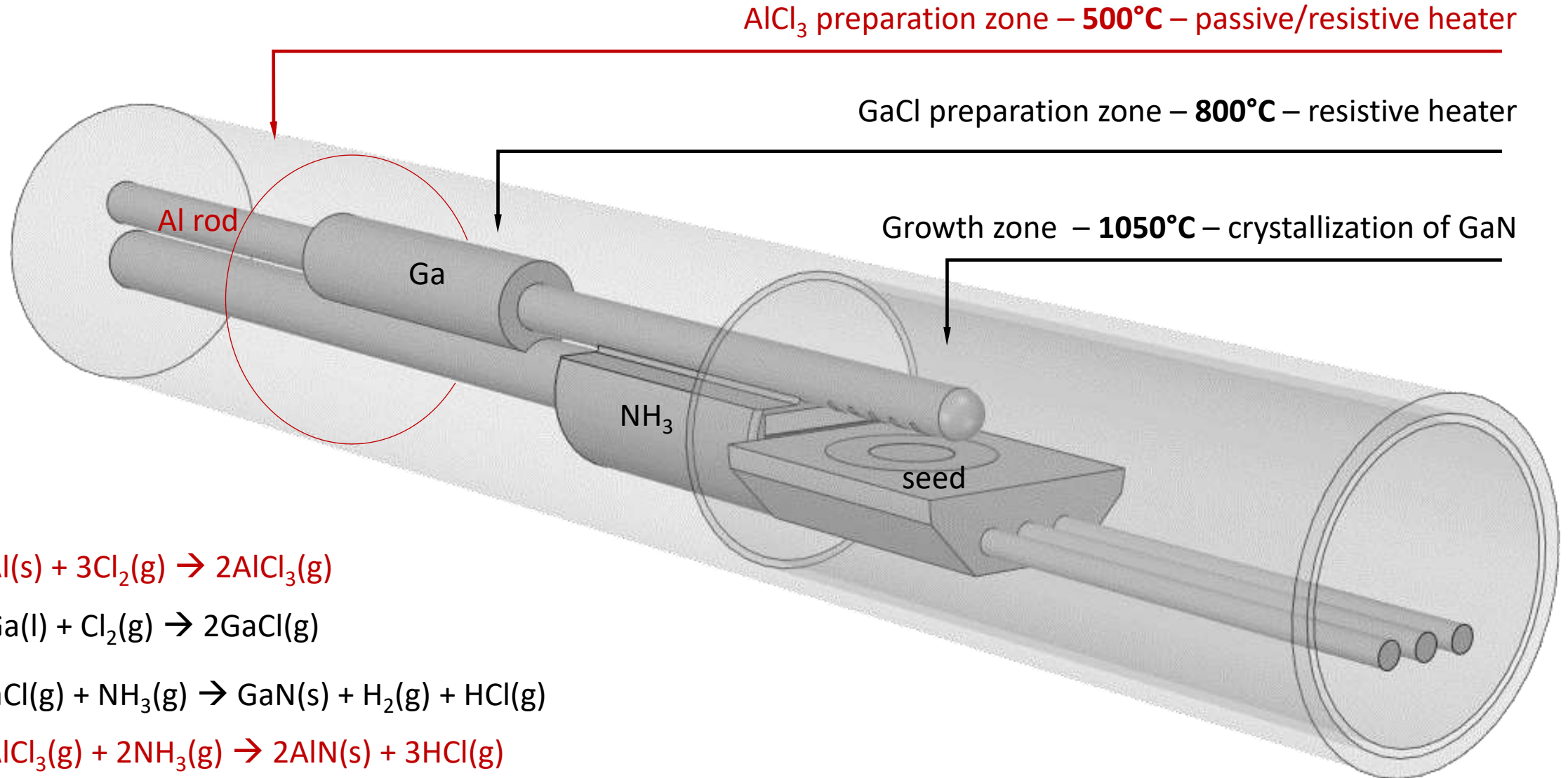
Halide Vapor Phase Epitaxy

Physical Vapor Transport

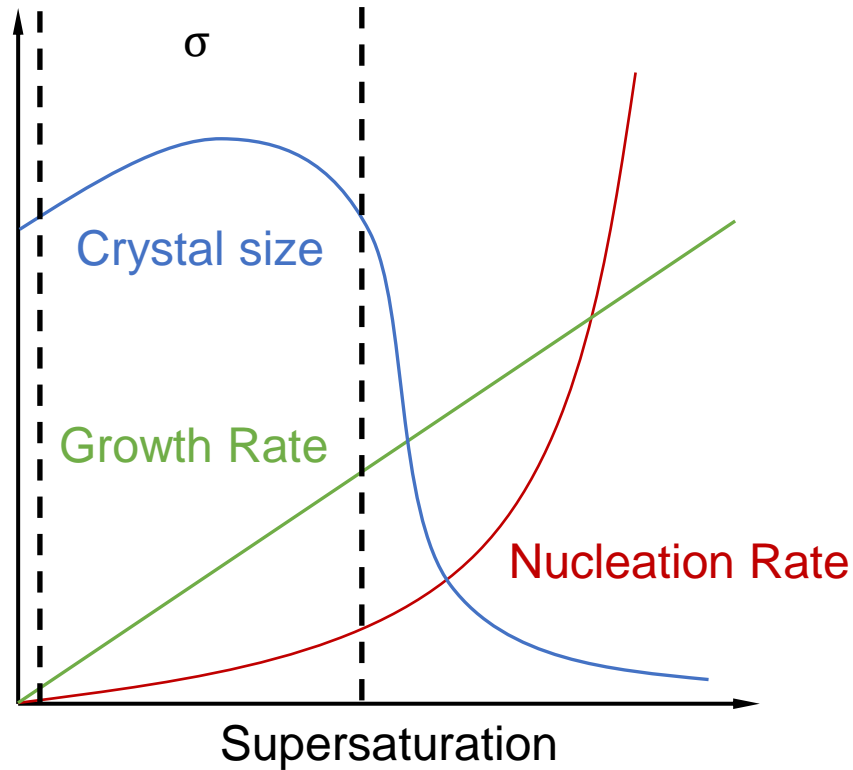
HVPE reactor for GaN growth



HVPE reactor for AlGaN growth



Optimal conditions for HVPE GaN and AlN growth



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

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

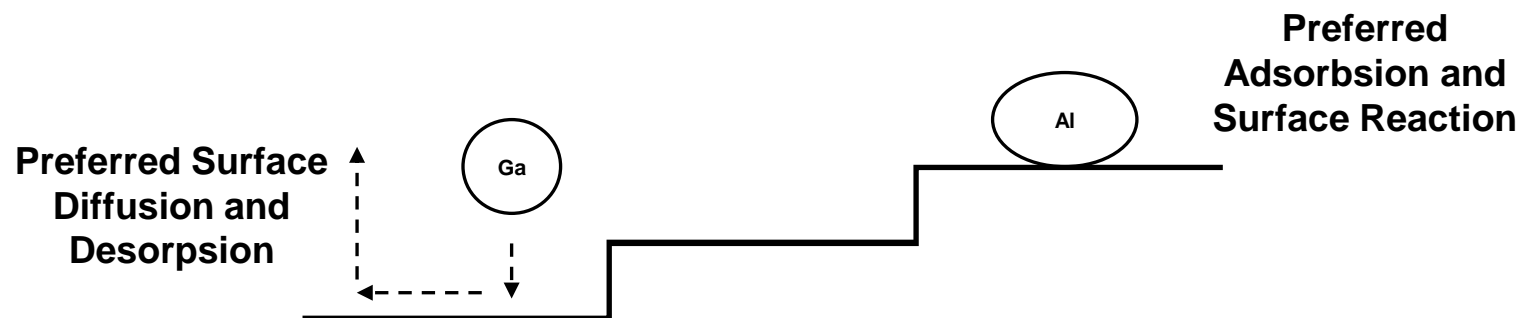
σ - supersaturation

P_i° - input partial pressure

P_i - equilibrium partial pressure

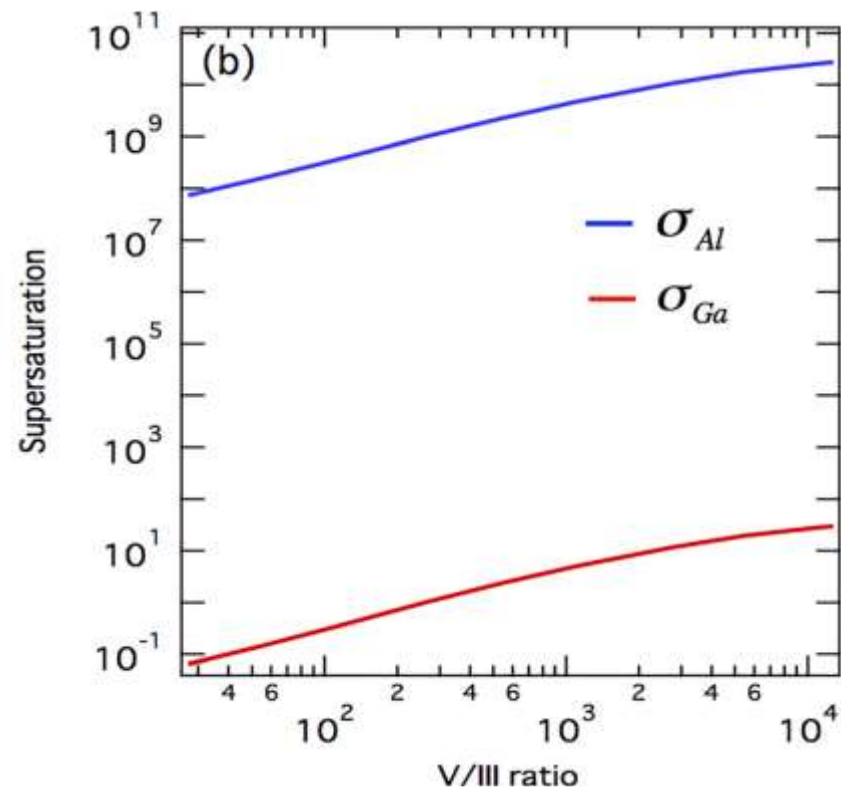
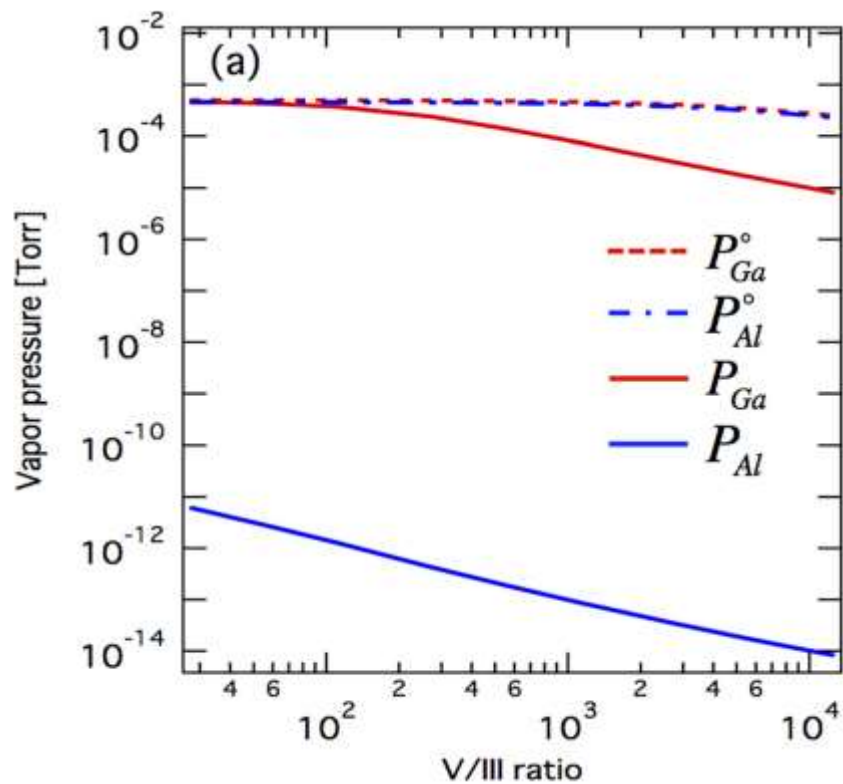
GaN and AlN bulk growth by HVPE method

	GaN	AlN
Growth T [°C]	1050	1450
Source T [°C]	800 – 900	450 – 500
P [atm]	0.8	0.8
NH ₃ [sccm/min]	1000	-
V/III	20	-
Growth rate [μm/h]	240 – 480	150 – 170*



* Y. Kumagai et al. *Appl. Phys. Express* 15 115501 (2022)

Difference of Supersaturation

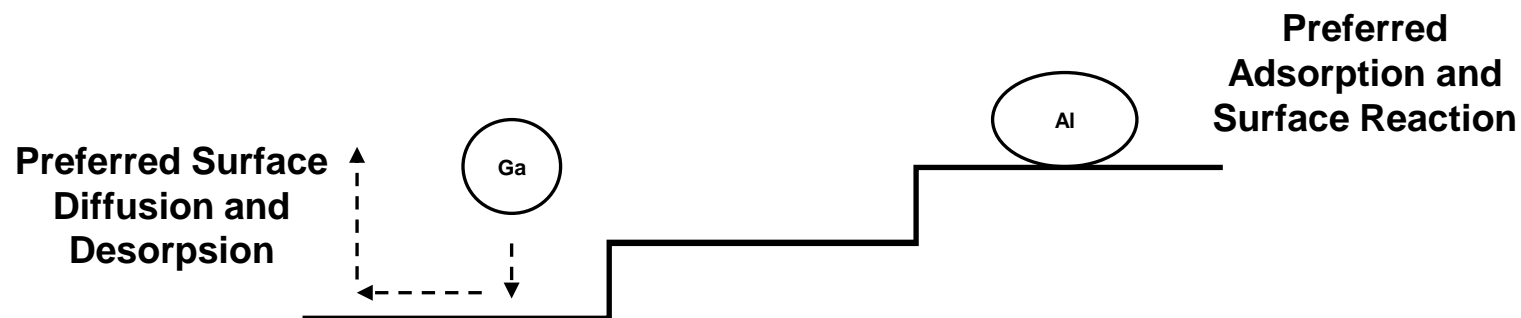


P_i° - input partial pressure
 P_i - equilibrium partial pressure

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

GaN and AlN bulk growth by HVPE method

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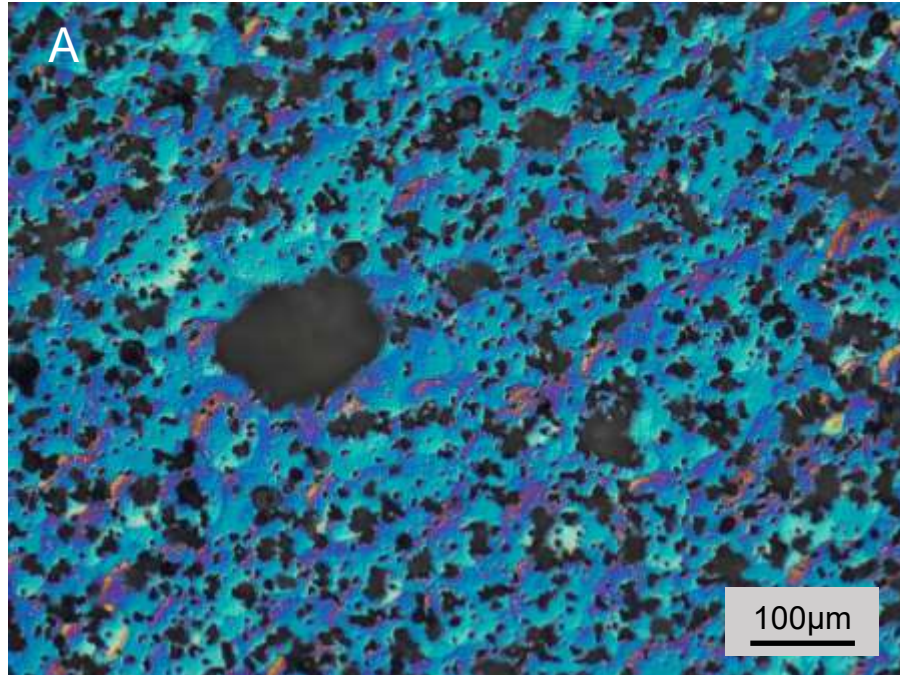
Parameters that affect the saturation

Influence of various parameters on σ

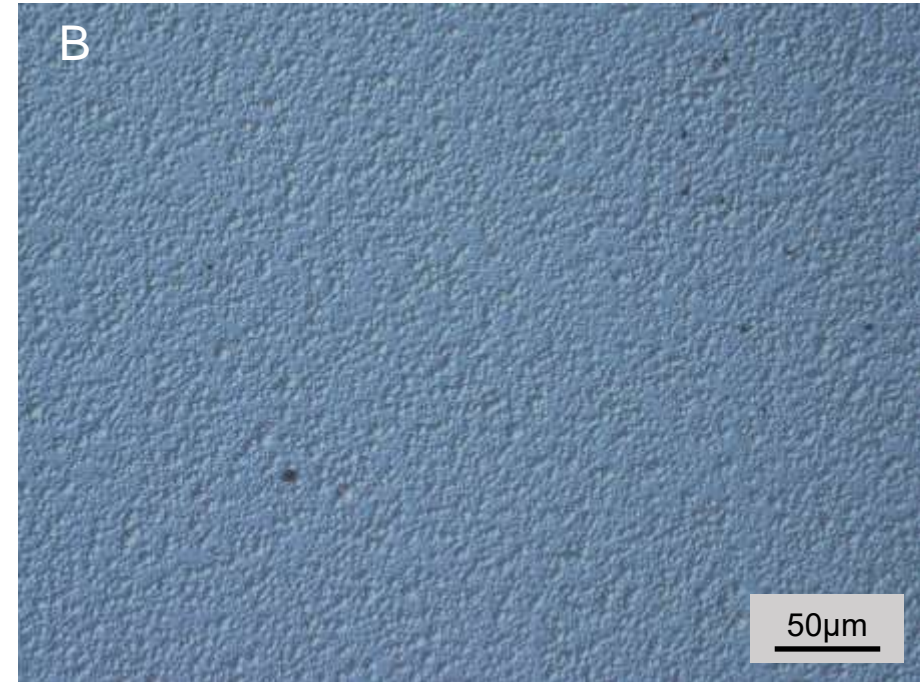
	T ↑	P_{III}° ↑	V/III ratio ↑	$P_{H_2}^\circ$ ↑	α ↑
σ	↓	↑	↑	↓	↓
	Constant	Not too low due to decomposition of GaN		Not too high due to decomposition of GaN	Constant, morphology first

AlGaIn growth – reduction of NH_3

A – high V/III ratio



B – low V/III ratio



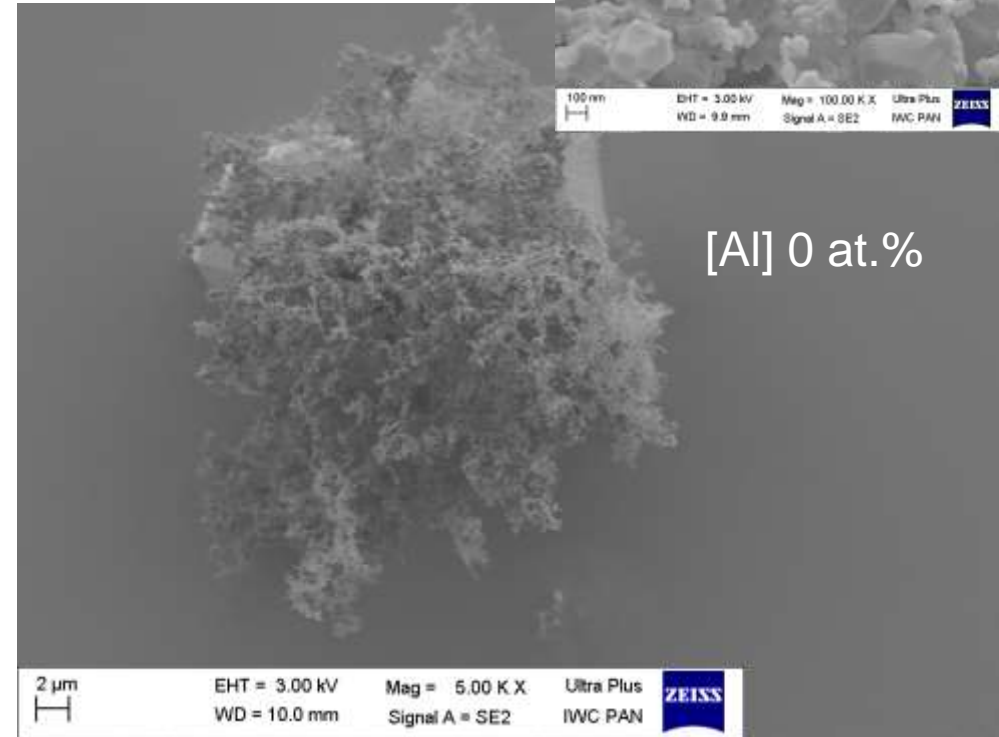
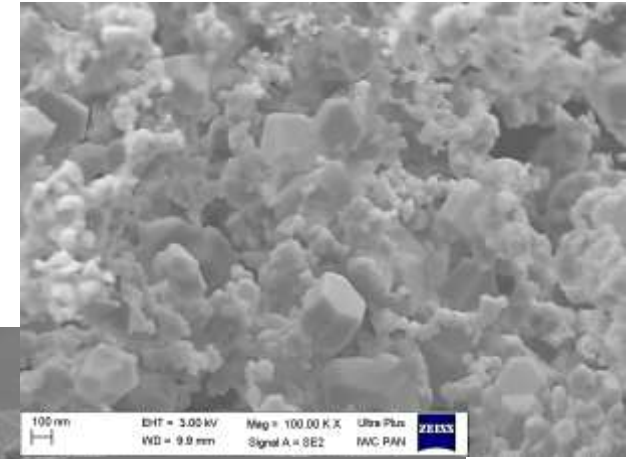
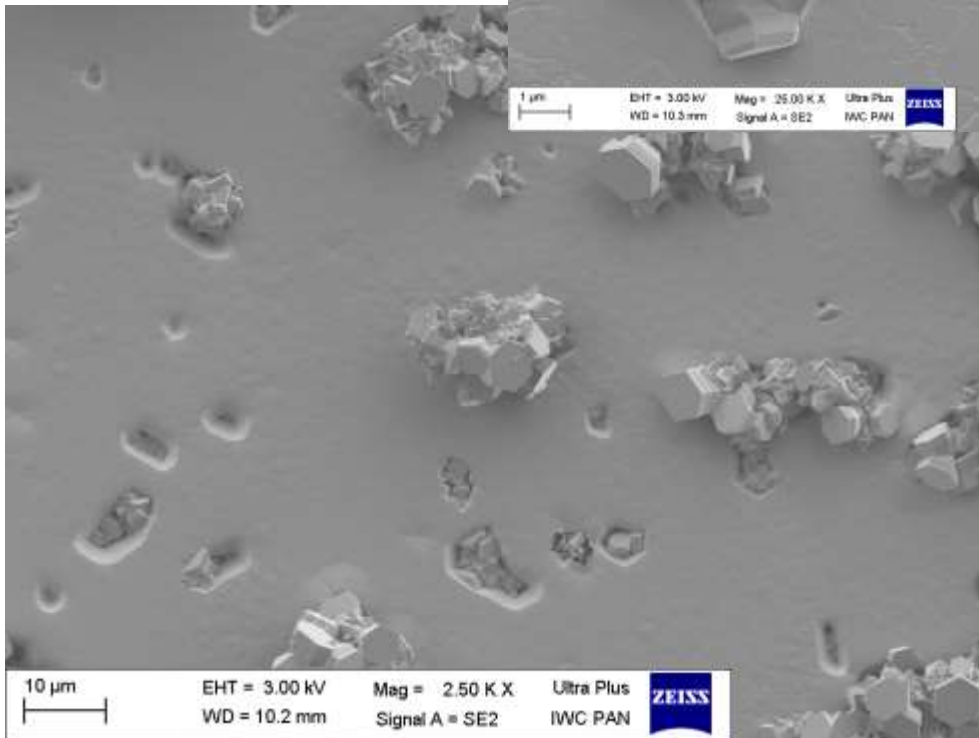
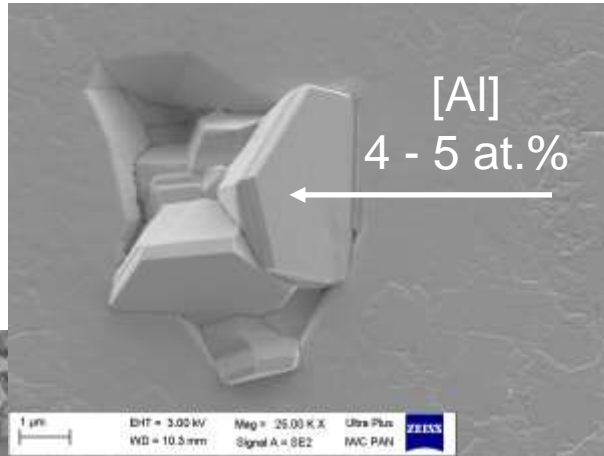
$$V/III = \frac{P_{\text{NH}_3}^\circ}{P_{\text{AlCl}_3}^\circ + P_{\text{GaCl}}^\circ}$$

	A	B
T [°C]	1050	1050
P [atm]	0.8	0.8
NH₃ [sccm/min]	1100	400
V/III	79	21
R	0.31	0.31

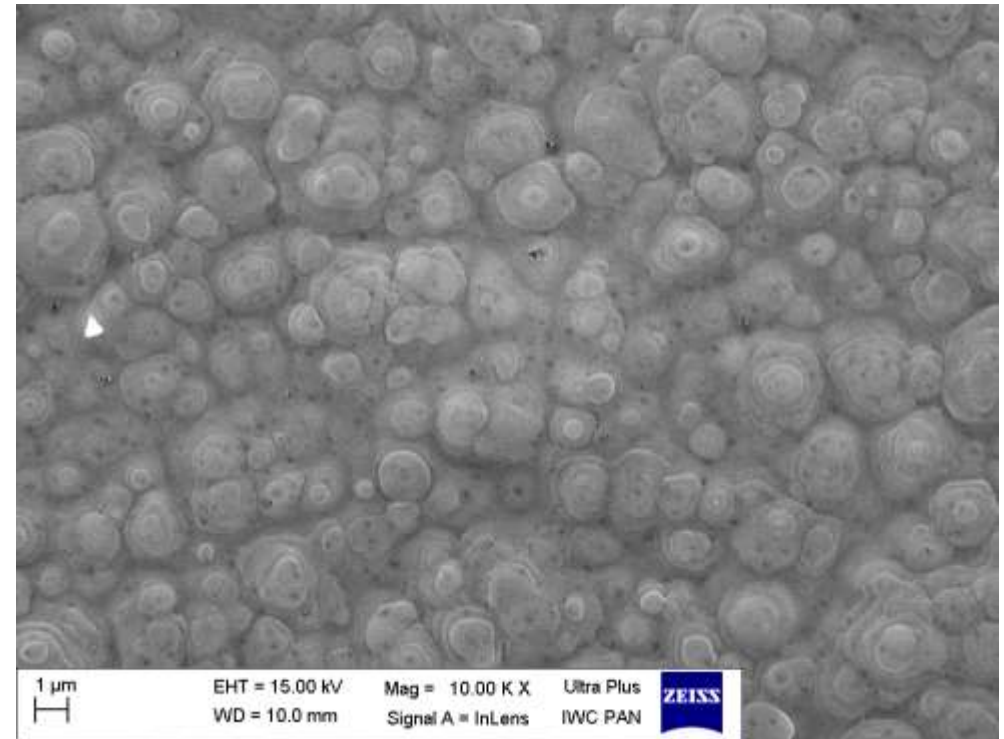
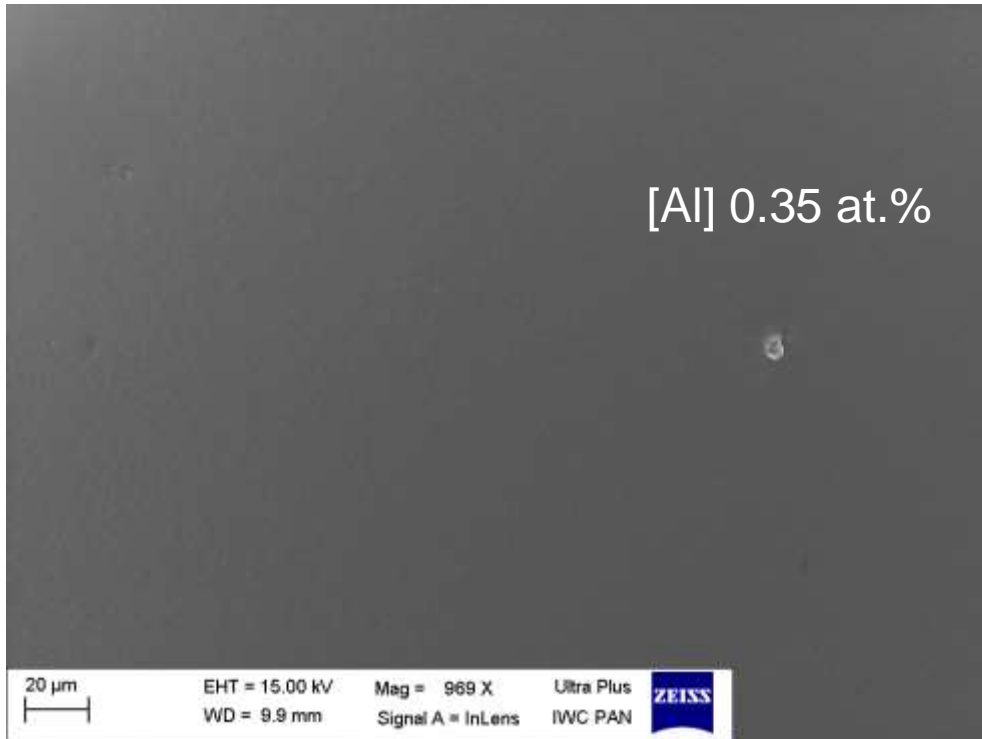
$$R = \frac{P_{\text{AlCl}_3}^\circ}{P_{\text{AlCl}_3}^\circ + P_{\text{GaCl}}^\circ}$$

AlGaN growth – NH₃ flow reduction

A – high V/III ratio

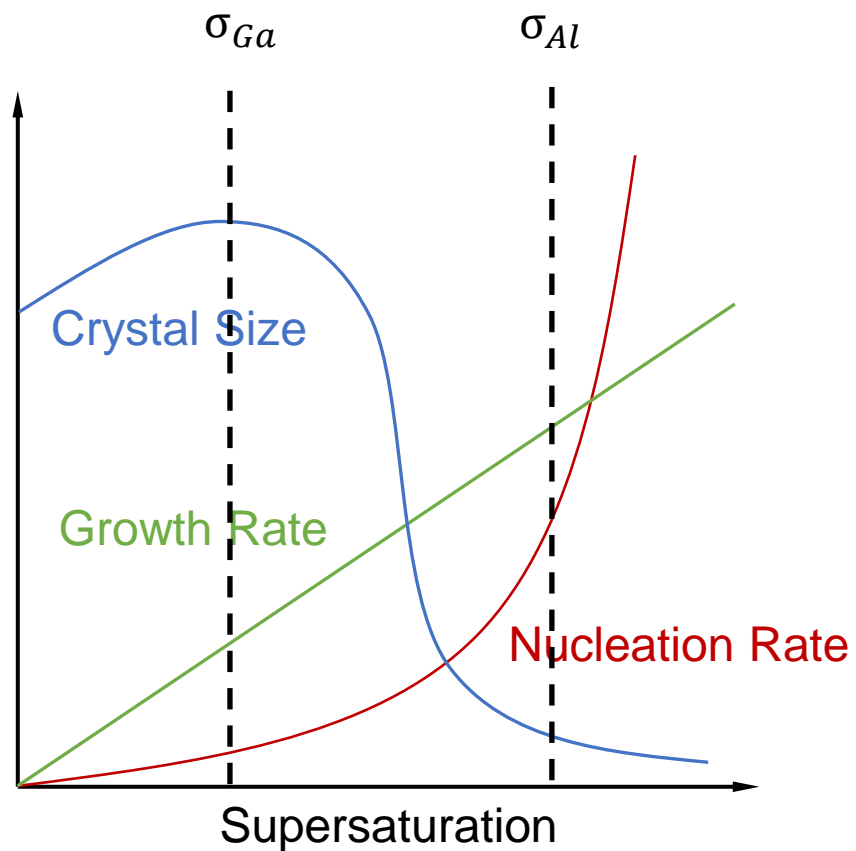


B – low V/III ratio

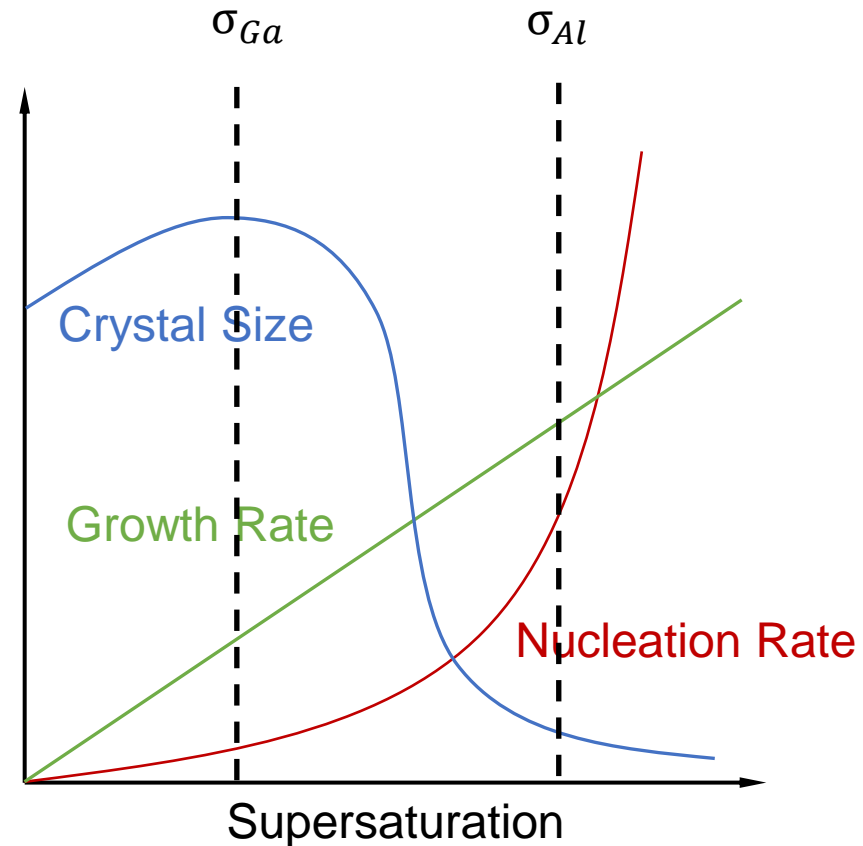


Difference of Supersaturation

A – high V/III ratio

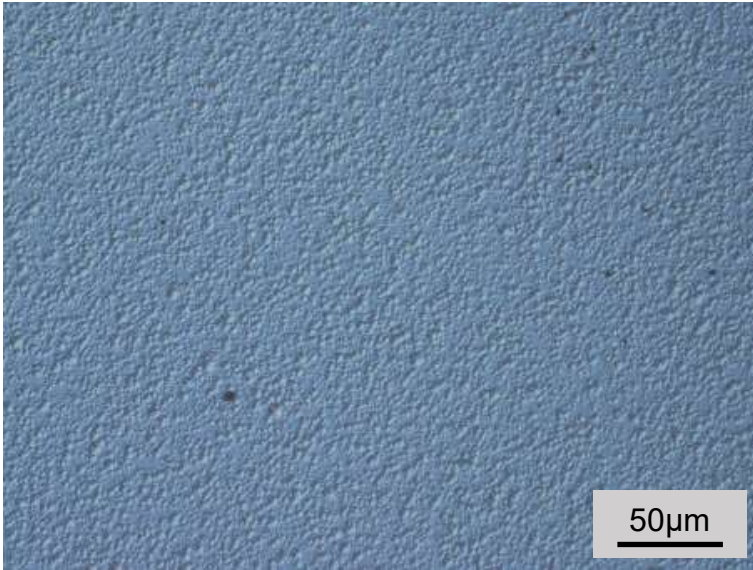


B – low V/III ratio

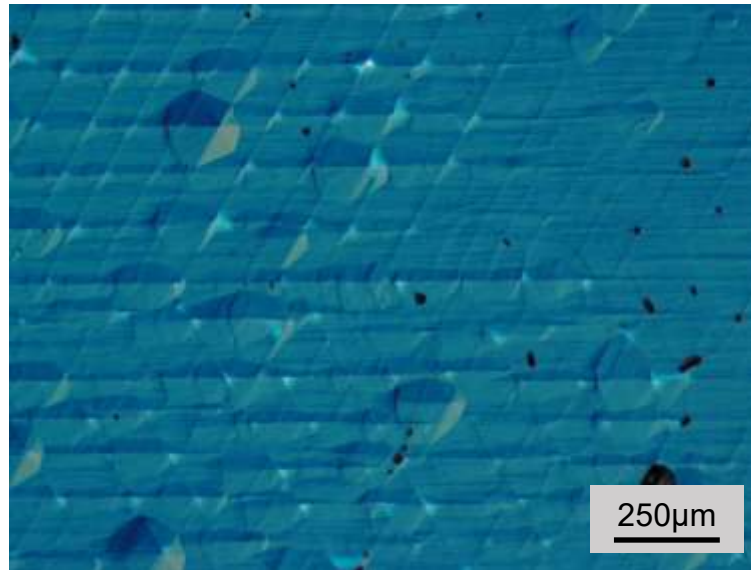


AlGaIn growth – reduction of growth pressure

B. $p = 0.8$ [atm]



C. $p = 0.4$ [atm]



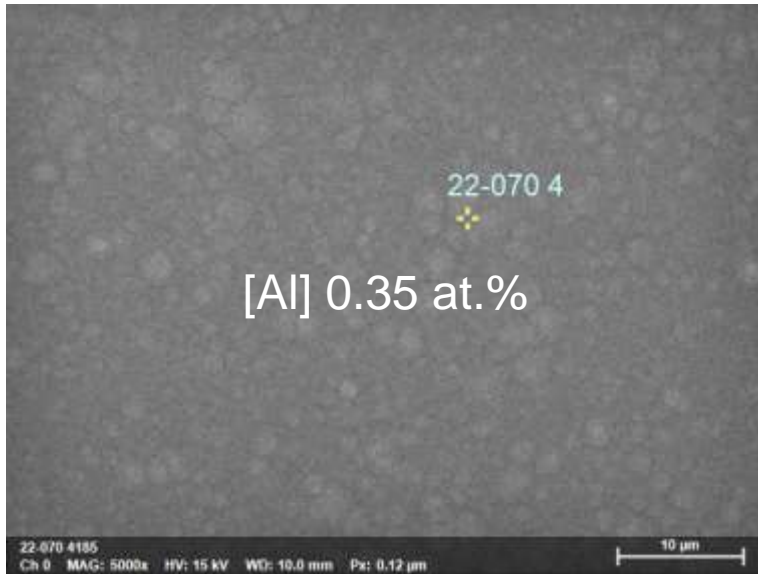
D. $p = 0.2$ [atm]



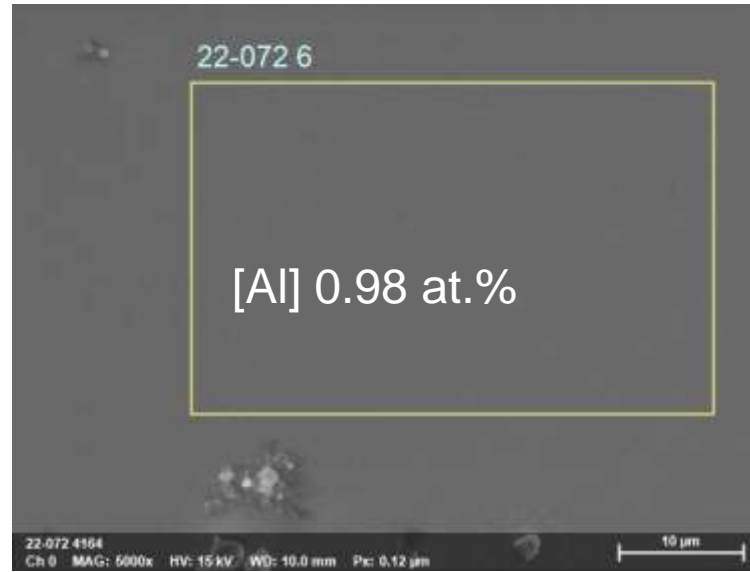
	B	C	D
T [°C]	1050	1050	1050
P [atm]	0.8	0.4	0.2
NH ₃ [sccm/min]	400	400	400
V/III	21	21	21
R	0.31	0.31	0.31

AlGaIn growth – reduction of growth pressure

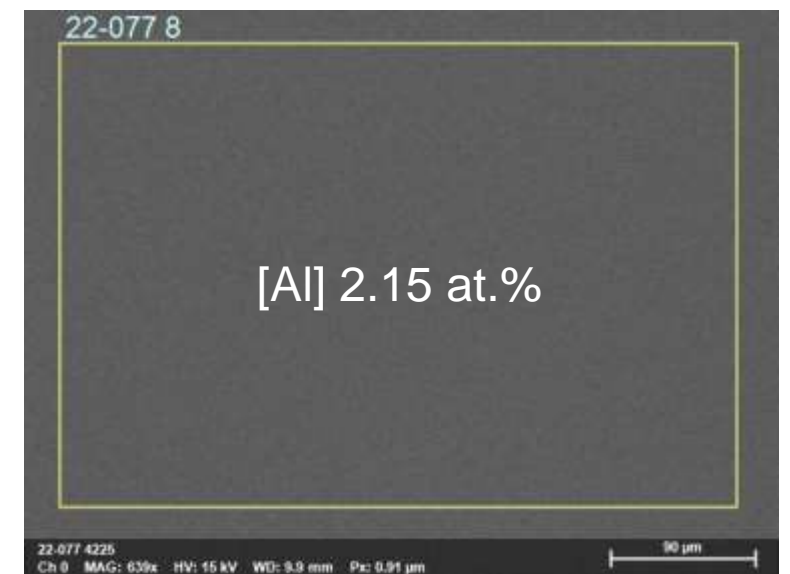
B. $p = 0.8$ [atm]



C. $p = 0.4$ [atm]



D. $p = 0.2$ [atm]



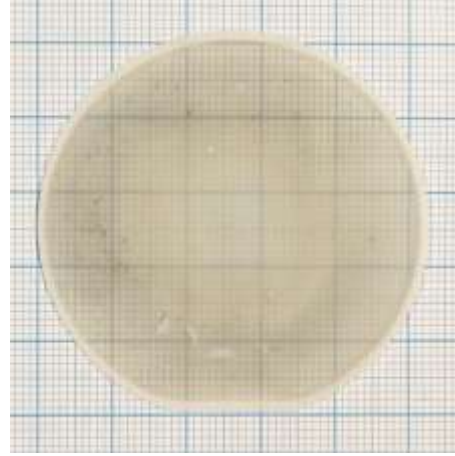
	B	C	D
T [°C]	1050	1050	1050
P [atm]	0.8	0.4	0.2
NH ₃ [sccm/min]	400	400	400
V/III	21	21	21
R	0.31	0.31	0.31

AlGaN growth – reduction of growth pressure

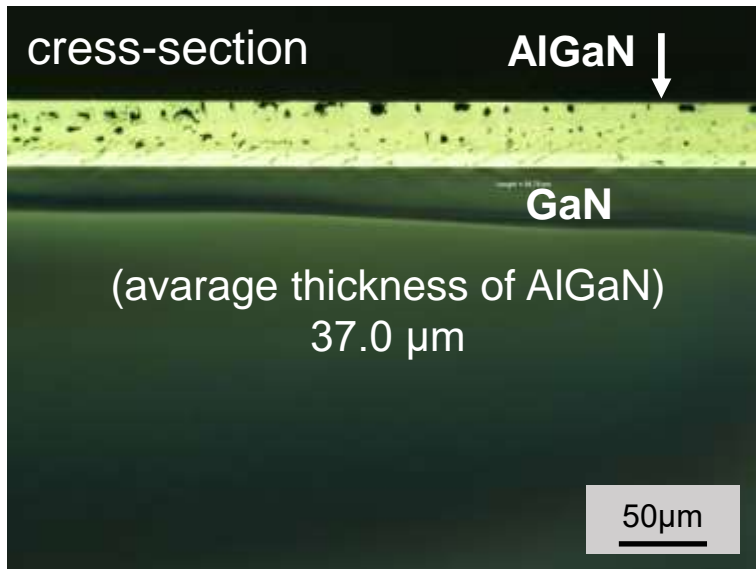
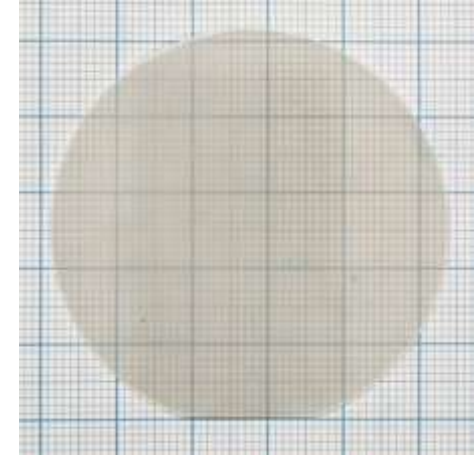
B. $p = 0.8$ [atm]



C. $p = 0.4$ [atm]



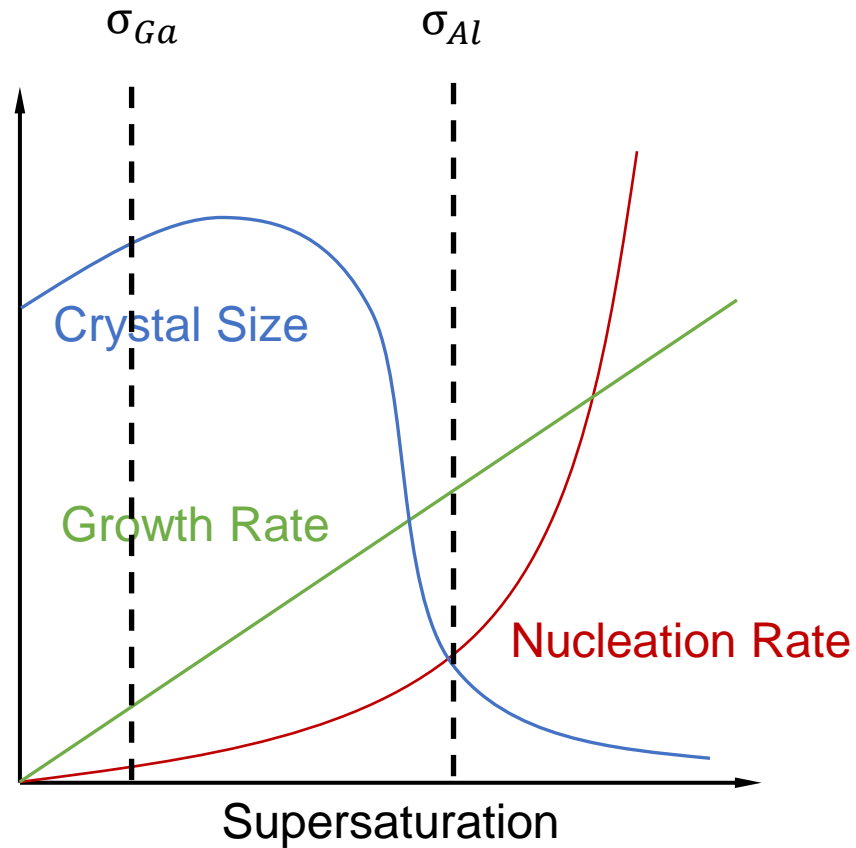
D. $p = 0.2$ [atm]



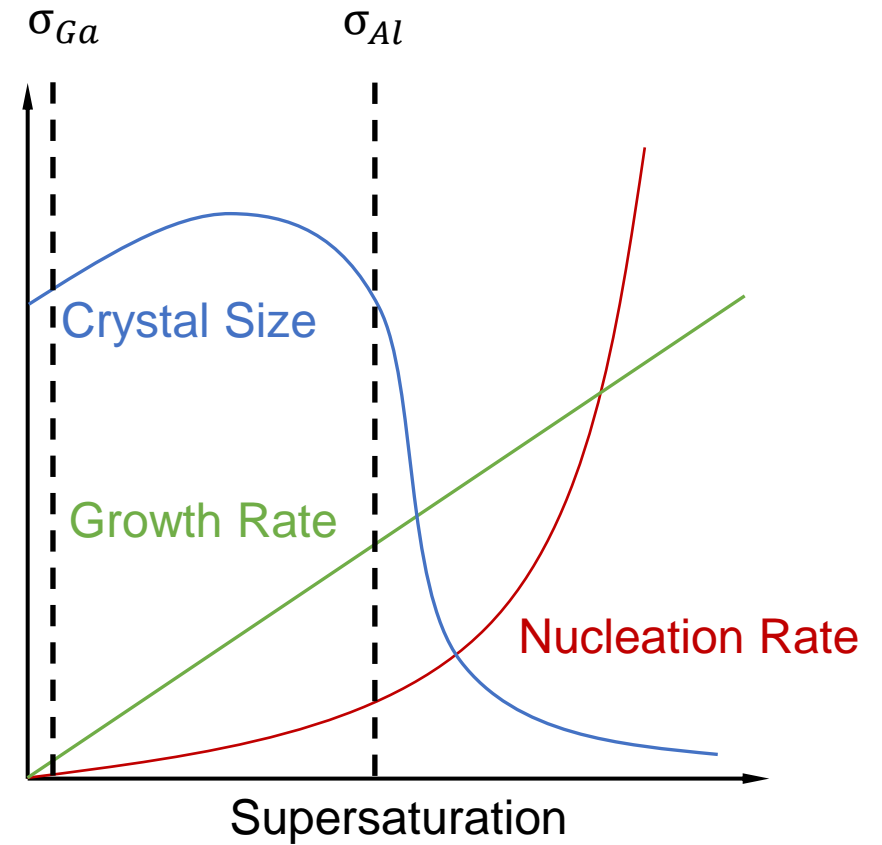
Constant growth time

Difference of Supersaturation

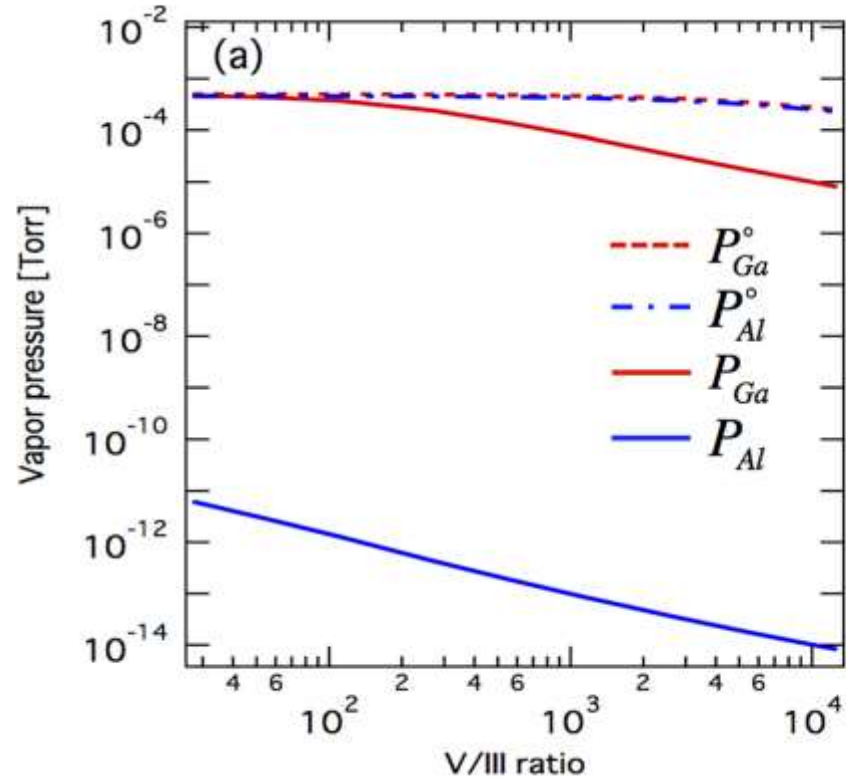
B – $p = 0.8 \text{ atm}$



D – $p = 0.2 \text{ atm}$

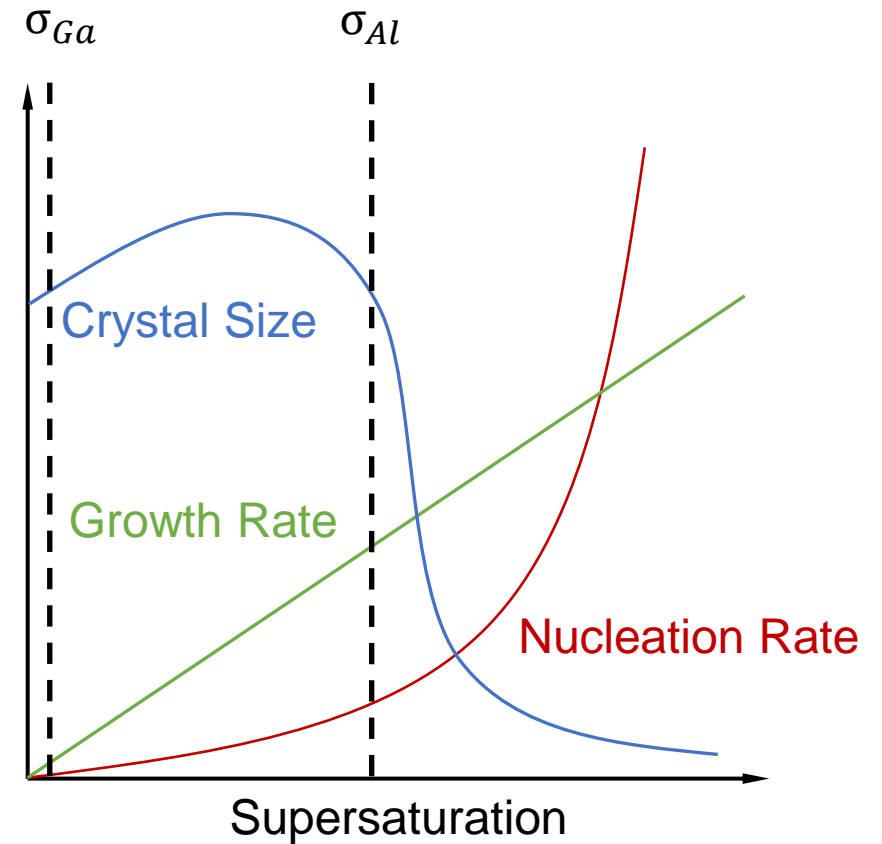


Difference of Supersaturation



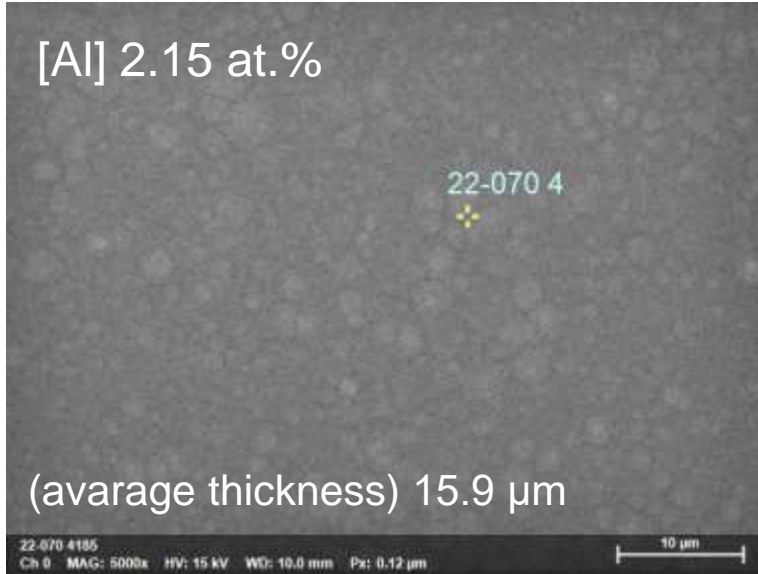
$$\sigma = \frac{P_i^{\circ} - P_i}{P_i}$$

$D - p = 0.2 \text{ atm}$

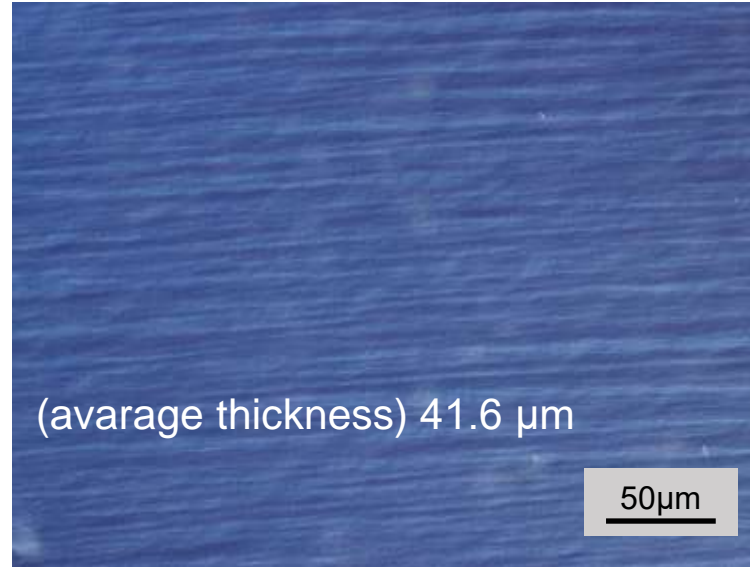


AlGaN growth – reduction of growth pressure

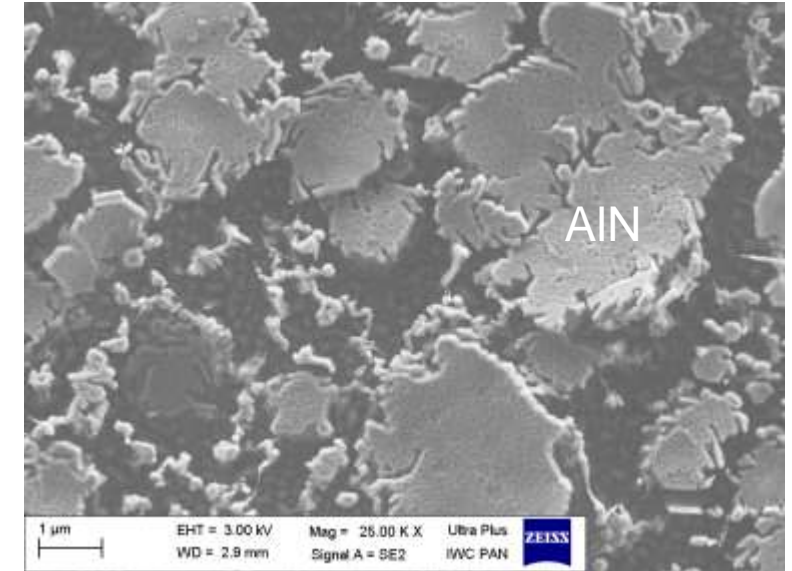
D. GaCl+AlCl₃



E. GaCl

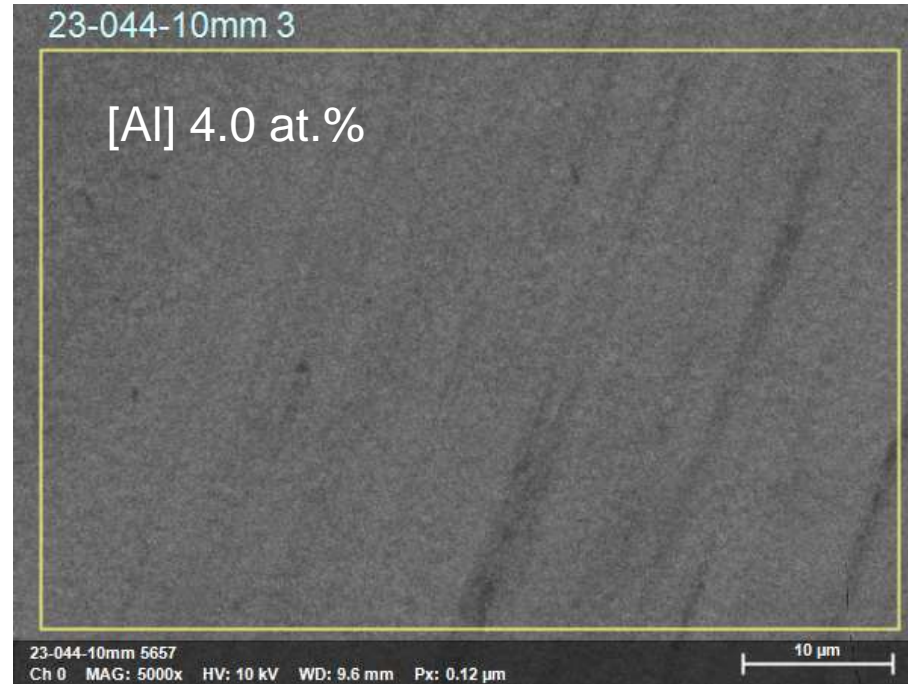


F. AlCl₃

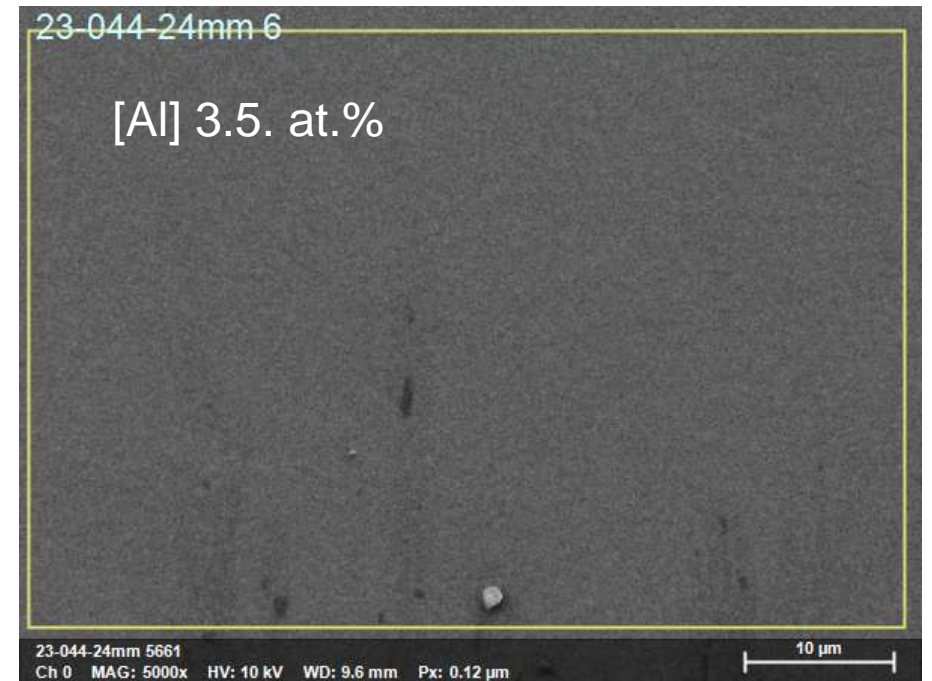


	D	E	F
T [°C]	1050	1050	1050
P [atm]	0.2	0.2	0.2
NH ₃ [sccm/min]	400	400	400
V/III	21	30	68
R	0.31	0 (only GaCl)	1 (only AlCl₃)

Growth of AlGa_N layer on native Am-GaN seed

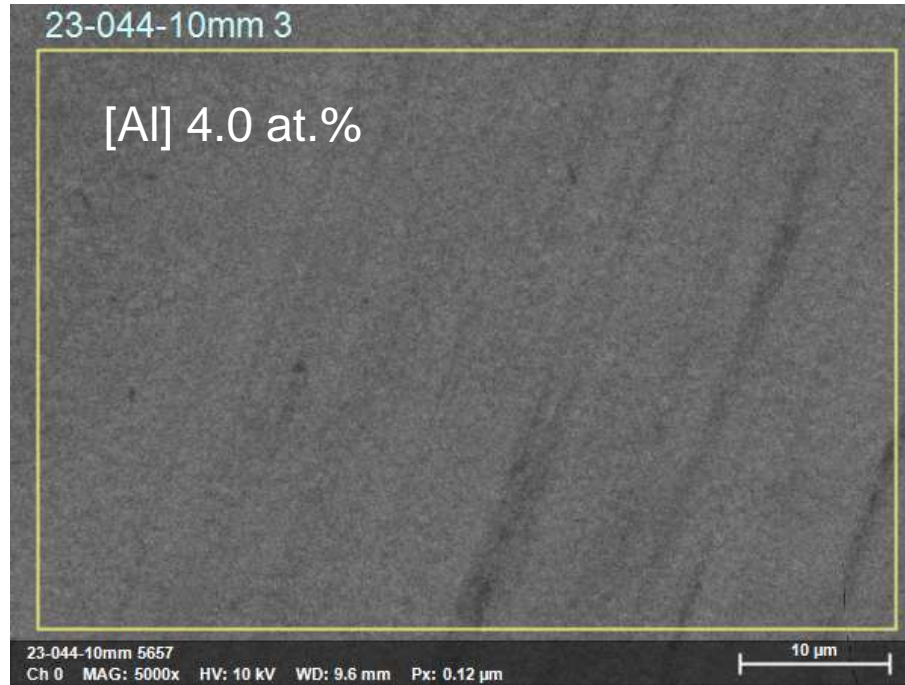


center



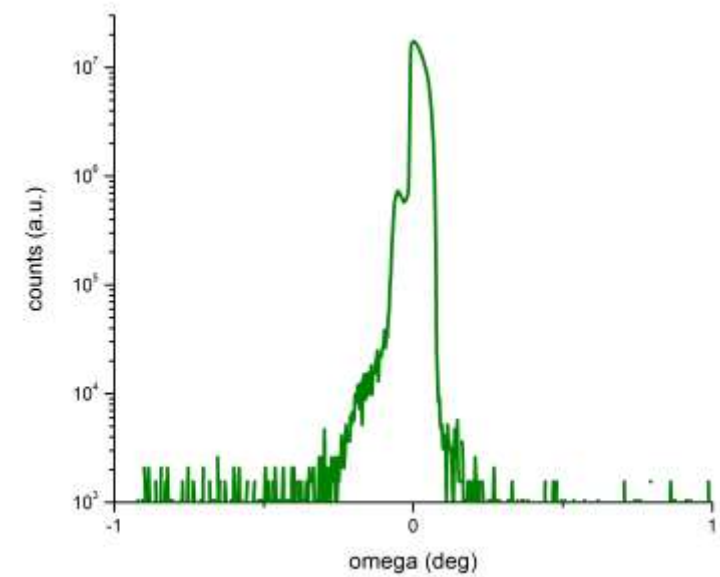
edge

Growth of AlGa_N layer on native Am-GaN seed



center

beam size: 1 mm x 10 mm



XRD for 002 reflection

Summary

- Crystallization of AlGa_N with low concentration of Al is possible at the optimum temperature for GaN growth - 1050°C
- Under such conditions, high supersaturation for Al - favoring nucleation - can be effectively lowered by lowering the ammonia flow without GaN decomposition.
- Reducing the supersaturation for Al is also favored by reducing the pressure in the reactor.
- Reducing the pressure allows shifting the supersaturation for Al from the nucleation region to the crystal growth region.



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Thank you for your attention